Modelling a Global Inclusive Green Economy COVID-19 Recovery Programme

Final report

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Abbreviations

BEV	Battery electric vehicle
CGE	Computable general equilibrium
COVID	Coronavirus Disease
CO_2	Carbon Dioxide
DSGE	Dynamic stochastic general equilibrium
DSSI	Debt Service Suspension Initiative
EC	European Commission
ECLAC	Economic Commission for Latin America and the Caribbean
EIB	European Investment Bank
ENCORE	Exploring Natural Capital Opportunities, Risks and Exposure
ERRP	Economic Reconstruction and Recovery Plan
FCM	Fuzzy Cognitive Mapping
FTE	Full-time equivalent
FTT	Future Technology Transformation
GDP	Gross Domestic Product
GFC	Global financial crisis
GHG	Greenhouse gas
GRP	Green Recovery Program
GTAP	Global Trade Analysis Project
$GtCO_2$	Billion tonnes of carbon dioxide
GW	Gigawatt
IAM	Integrated assessment model
ICE	Internal combustion engine
ICT	Information and Communications Technology
IEA	International Energy Agency
IGEM	Integrated Green Economy Modelling
ILO	International Labour Organization
IMF	International Monetary Fund
IPBES	Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services
IPCC	Intergovernmental Panel on Climate Change
IRENA	International Renewable Energy Agency
Ktoe	Kilotonnes of oil equivalent
LULUCFF	Land Use, Land Use Change, and Forestry
NDC	Nationally Determined Contribution
OECD	Organisation for Economic Co-operation and Development
PAGE	Partnership for Action on Green Economy
PV	Photovoltaic
RCP	Representative concentration pathway
RES	Renewable energy sources
SSP	Shared Socioeconomic Pathway
UNEP	United Nations Environment Programme
VAT	Value-added tax
WHO	World Health Organization
WCMC	World Conservation Monitoring Centre
WWF	World Wildlife Fund
YoY	Year-on-year

Executive Summary

This report documents work to provide a quantified analysis of the impact of alternative (non-green and green) COVID-19 recovery plans on key economic, social and environmental indicators. The main focus is on the global impacts, but two case studies covering South Africa and Latin America and the Caribbean are also presented. The analysis has been carried out using the E3ME energy-economy-environment model which covers the entire global economy in considerable geographical and sectoral detail.

COVID-19 has had an unprecedented impact on economies...

The direct health impacts of COVID-19 and the government measures to contain the virus have plunged economies into the deepest crisis at least since the 1930s Great Depression in per capita terms. Current estimates of the fall in global GDP in 2020 are of the order of 4%. There have been severe consequences for employment and hours worked, especially on jobs that depend on social consumption and interaction.

...and prompted an unprecedented response by governments

Many governments have responded with stimulus measures to counter the impacts. By January 2021, it was estimated that the announced measures amounted to about US$15 trillion globally (O'Callaghan et al. 2020), or some 17% of global GDP in 2019, covering both immediate relief measures (e.g. furlough schemes, income support, tax deferrals or liquidity support among others) and multi-annual / longer-term recovery policies.

Green Recovery measures are needed to prevent a rebound in CO_2 emissions...

There has been an associated fall in CO_2 emissions as fossil fuel energy demand has slumped. But low fossil fuel prices, the fall in investment and the perceived higher risk of lending all act to slow down investment in mitigation measures such as renewable power generation. The nature of recovery packages and the extent of any Green Recovery measures will play an important part in determining whether CO_2 emissions simply bounce back as economic growth recovers.

...but most measures to date are not 'green'

So far the majority of measures introduced have been 'colourless' (no direct impact to improve or harm the environment) while a small proportion have been 'grey' (for example, unconditional tax breaks or bailouts for airlines, expansion of coal mines and gas infrastructure, unconditional bailouts for the oil and gas industry, and relaxation of environmental regulations and standards).

There are a range of green policy candidate measures to include in a recovery package

Green policies that would meet a list of criteria covering timeliness and a range of positive social, economic and environmental benefits include:

- support for investment in renewable electricity generation, and in grid flexibility measures needed to improve energy security as a larger share of generation capacity is made up of intermittent, non-dispatchable renewable sources
- support for investment to improve the energy efficiency of buildings and appliances
- car scrappage schemes and public transport investment to promote uptake of zero emission vehicles
- support for nature-based solutions, such as climate-friendly agriculture or ecosystem restoration and reforestation.

This is not an exhaustive list of green policies that governments can consider. Other green policies that are candidates for inclusion in a Green Recovery package are support for R&D in low-carbon technologies, reform of fossil fuel subsidies (made more acceptable by the fall in world fossil fuel prices), circular economy measures, carbon taxes, targeted rural support policies, etc.

A global Green Recovery Program is estimated to boost GDP and jobs by more than a program that cuts sales taxes...

In a global analysis, two illustrative alternative recovery packages were modelled in E3ME: one ('VAT program') in which recovery was stimulated by cutting consumption sales taxes temporarily by 5 percentage points, and the other ('Green Recovery Program', or GRP) involving a package of measures targeting CO_2 reductions:

- capital subsidies for new renewable power installations
- energy grid investments
- energy efficiency measures, focusing on households
- a car scrappage scheme, focusing on Battery Electric Vehicles (BEV)
- a global reforestation and ecosystem restoration project.

In each country, the two packages were designed to be equal in size in terms of their ex ante impact on government budgets.

At their peak, in 2023, the GRP and the VAT program add 2.3% and 1.7% to global GDP respectively (compared with a baseline projection). Although the programs are temporary, an impact persists in the long term because of the additional private investment that the programs stimulate: we estimate that in 2030 there are positive impacts on GDP of 1.8% in the case of the GRP and 0.4% in the case of the VAT scenario. These boosts to economic activity are also reflected in employment. Global jobs are boosted by 0.8% in 2023 in the GRP and 0.3% in the VAT program, falling to 0.5% and 0.1% respectively by 2030. The GRP results also show the scale of restructuring of economic activity away from fossil fuel extraction and processing and towards the supply chain for decarbonising investments.

... and to cut CO_2 emissions substantially

As expected, the largest difference between the two programs lies in the impact on CO_2 emissions. The extra economic activity stimulated by the VAT program adds slightly to the emissions projected in the baseline. The GRP cuts global net CO_2 emissions by 14% by 2030. While welcome, this is a smaller reduction than required to put emissions on a path that would keep global warming below 1.5-2°C. Analysis, undertaken before the pandemic, of more ambitious decarbonisation policies suggests that stronger action would continue to deliver net GDP and jobs benefits.

An analysis of South Africa's Economic Reconstruction and Recovery Plan showed the benefits of Green Recovery measures and the need to support workers bearing the impact of restructuring

E3ME distinguishes South Africa among its 61 countries/regions and a tailored analysis was carried out, assessing the impact of different components of the Economic Reconstruction and Recovery Plan (ERRP) announced in October 2020. The analysis distinguished 'conventional' (mostly non-green), public works employment schemes and green policies targeting CO_2 reductions.

The package of conventional measures is by far the largest element and it has a correspondingly large impact on GDP. The public works element has a large but temporary impact on jobs and unemployment. The green policies give a further small boost to GDP and, as in the global analysis, involve restructuring within the South Africa economy, which has an important coal sector: there are job losses in coal mining but a slightly larger number created in the renewables supply chain. The boost to economic activity from the conventional and public works elements of the ERRP act to increase CO_2 emissions, while the green measures cut them (by 10% by 2030 compared with a projection with no measures).

A 'Green push' scenario, involving a more ambitious decarbonisation package than included in the ERRP, boosts GDP further, involves a net increase in jobs and a larger scale of restructuring, and cuts CO_2 emissions more strongly (by 20% by 2030).

An analysis of a budget-neutral Green Recovery program that would meet Latin America's NDCs found positive economic and jobs impacts, but a risk that higher energy prices would worsen inequality

ECLAC undertook Green Recovery modelling using E3ME with a focus on Latin American and the Caribbean for a report to its member states, *Building a New Future: Transformative Recovery with Equality and Sustainability* (ECLAC 2020b), published in October 2020.

ECLAC highlighted three long-term crises facing the region: slow economic growth in the decade since the Great Recession, a widening inequality gap over the past 30 years, and widespread environmental degradation, including global warming, as a result of economic development. Among the scenarios modelled, estimates were made of the impact on economic, social and environmental indicators under two Green Recovery programs with different levels of ambition for cutting greenhouse gas emissions: one in which the countries of Latin America and the Caribbean meet their unconditional Nationally Determined Contributions (NDCs) for cutting emissions, and a second in which accompanying action in the rest of the world allows the conditional NDCs to be met.

Policies included subsidies to kick-start take-up of non-conventional renewable energy technologies in power generation and the extension of regulations to promote a higher biofuel blend and adoption of low-emission road transport vehicles. The package included some non-environmental policies to address social inequality: an increase in public spending on health to support better access to medical care among the poor. Unlike the South Africa case study, budget neutrality was assumed compared with the projection with no recovery package: financing was assumed to be provided by the phasing out of fossil fuel subsidies.

As in the global and South Africa analyses summarised above, ECLAC reported large reductions in CO_2 emissions and positive impacts on GDP and employment, in this case arising even with a budget-neutral program. ECLAC also analysed inequality impacts and found that, without compensating measures, higher energy prices under the decarbonisation program would worsen inequality, because energy forms a larger part of the budget of poor households than that of richer households. In the conditional case, this impact of reversed thanks to lower renewable technology costs in a larger global market for those technologies and lower firewood costs due to expanded forests.

Analysis of potential impacts on ecosystem services shows that circular economy measures and nature-based solutions should be included alongside decarbonisation policies in a Green Recovery package

This report also includes a review by the UNEP World Conservation Monitoring Centre of analysis to extend coverage to include impacts on natural capital and the associated ecosystem services. There is a substantial literature documenting the various ways in which higher levels of economic activity result in greater environmental degradation. But work to estimate the scale of feedback from degraded ecosystem services to economic and social impacts is still in its infancy, reflecting considerable uncertainty over the scale of loss of services and the limited empirical support for the extent to which economic dependence on those services can be mitigated by substitution of other production inputs.

For the South Africa case study, WCMC took the detailed sectoral output projections available from E3ME under the various scenarios as inputs to an analysis using the Exploring Natural Capital Opportunities, Risks and Exposure (ENCORE) model of dependences of environmental change on the economy. Without mitigating action, a return to economic growth is likely to degrade many aspects of natural capital in line with historical trends; small differences in GDP between the scenarios have only modest impacts compared with the ongoing trend over time present in all the scenarios. The modelling highlighted the risk that, without compensating action such as improved circular economy measures to reduce the intensity of resource use, the demand for construction materials would put further pressure on natural capital.

1 Introduction

1.1 Context for the project

This report has been prepared by Cambridge Econometrics within the *Inclusive Green Economy response scenario modelling of COVID-19 recovery plans* project, a common initiative of ILO and UNEP. The overall aim of the project was to undertake a credible, quantified analysis of the impact of alternative (non-green and green) COVID-19 recovery plans on key economic, social and environmental indicators globally and in selected PAGE[1] countries. The current report presents the analysis focusing on global opportunities.

The analysis has been carried out using the E3ME energy-economy-environment model which covers the entire global economy in considerable geographical and sectoral detail. As a structural, macroeconometric model, E3ME is well suited to the analysis of the impact of COVID-19 and of stimulus policies to mitigate that impact. E3ME's sectoral and geographic detail supports an analysis of links between economic growth and environmental pressures, including many applications in the field of climate change mitigation. A short description of E3ME is included in Appendix A and further details can be found at www.e3me.com.

As Pollitt et al. (2020), note the pandemic had both supply- and demand-side effects. While lockdowns and restrictions impacted the supply capacity of various industries, demand also fell or restructured, even for industries not directly impacted, as consumer confidence dropped and consumption patterns changed (McKinsey 2020). When modelling the effects of the pandemic and potential recovery programs, it is therefore important to use a modelling framework that can capture restrictions on both the supply and the demand sides of the economy. CGE or New Keynesian DSGE models, which typically assume market clearing, are less suitable choices in this situation. In contrast, E3ME - a simulation model which does not assume optimising behaviour that returns the economy to a market clearing equilibrium - is able to represent the impacts of both demand and supply impacts. Key economic relationships in E3ME are estimated from time series historical data and are based observed behavioural responses rather than strong (in the mathematical sense) assumptions derived from theory.

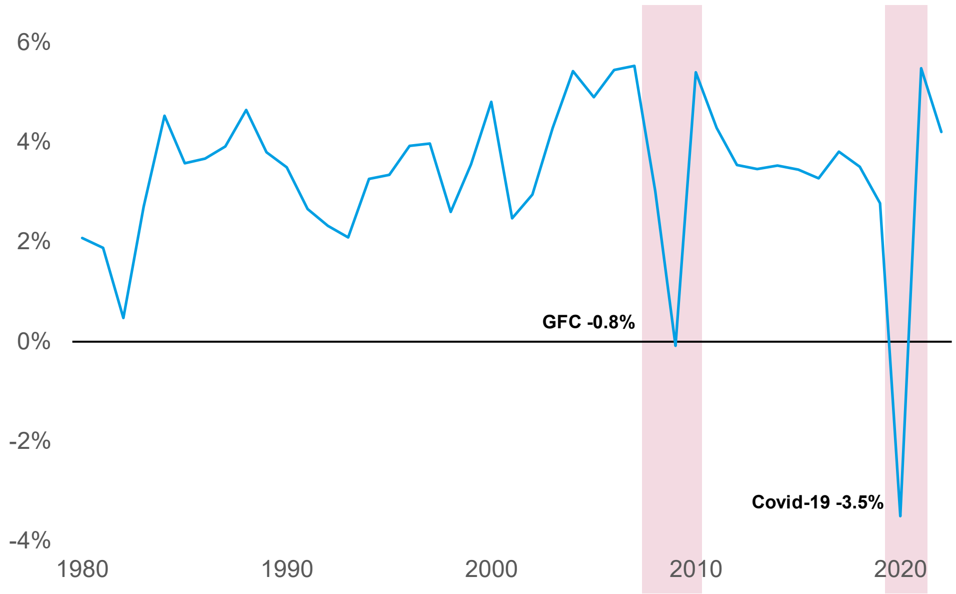
The projections and simulation results presented here should not be considered as predictions, but rather quantified estimates of the scale of the difference that various alternative COVID-19 recovery packages could make to economic, social and environmental indicators.

1.2 The COVID-19 pandemic

The COVID-19 pandemic dominated 2020. Initial reports of an "unknown" pneumonia virus in Wuhan, China were followed by rapid spread of the virus to other parts of the world, and WHO declared a global pandemic in March 2020 (WHO 2020a).

[1] Partnership for Action on Green Economy, www.un-page.org.

Figure 1.1: Year-on-year changes in global GDP: GFC and COVID-19 impacts



Source: IMF (2021, 2020b)

By January 2021, the global number of cases had surpassed 99 million, while deaths attributed to COVID-19 had surpassed 2 million (Our World in Data 2021). There have been several "waves" of the pandemic and peaks in hospitalisations have severely burdened national healthcare systems. A survey conducted by WHO from March to June 2020 of a sample of 105 countries found that 90% of the countries experienced disruptions to their health service, with low- and middle-income countries reporting the greatest difficulties (WHO 2020b).

The economic crisis

The COVID-19 pandemic is first and foremost a healthcare crisis. However, it has had drastic impacts on the global economy. Direct health impacts and government measures to contain the virus have plunged economies into the deepest crisis at least since the 1930s Great Depression, with a reduction in economic activity and employment that dwarfs the 2008 Global Financial Crisis (GFC) (see Figure 1.1).

Governments around the world responded to the rapid spread of the virus by introducing lockdown regimes in the period March-June 2020 and then again in October 2020, when the second wave of the pandemic emerged worldwide (Financial Times 2021). These entailed (to varying degrees depending on the country): restrictions on internal and external travel, restrictions on public gatherings, closure of schools, and closure of 'non-essential' activities such as restaurants, bars and hotels. The measures helped to contain the pandemic, but at a huge cost in terms of lost production and employment.

The January 2021 IMF *World Economic Outlook Update* estimates that global GDP contracted by 3.5% in 2020 (IMF 2021), while the OECD's December 2020 *Economic Outlook* puts the figure at 4.2% (OECD 2020). The magnitude of this recession is unprecedented on a global scale (the 2008-09 GFC produced a 2% fall in 2009). Nevertheless, these estimates and corresponding forecasts for 2021-22 paint a picture that is somewhat brighter than what was initially estimated during 2020 (e.g. the IMF estimated a 4.4% decrease for 2020 in October). The IMF attributes this change in outlook to stronger economic activity in the second half of 2020. However, given that most countries were hit by a second wave of the virus and reintroduced restrictions, it remains to be seen whether a renewed downturn in 2020 Q4 will lead to a downward revision.

Labour market impacts

In January 2021, ILO (2021) estimated that at the height of the pandemic about 18% of working hours were lost (2020Q2 compared to 2019Q2), equivalent to 525 million FTEs[2]. According to the same report, annual working hours lost in 2020 amounted to 8.8%, 255 million FTEs or approximately four times as much as during the GFC of 2008-09.

The impact has been particularly severe on those whose work depends on social consumption and interaction, notably in the hospitality and leisure economy, where jobs are low-skilled, low-paid and are often occupied by young people (ILO 2021). The loss of incomes and restrictions on social interaction have had major impacts on wellbeing, including mental and physical health conditions.

Government responses

Governments around the world have initiated various relief packages to limit the adverse economic effect of restrictive measures. These include sizeable stimulus packages, often including furlough schemes, income support, credit guarantees, liquidity support and tax deferrals (IMF 2020a; O'Callaghan et al. 2020). Together these measures often account to several percentage points of the country's GDP (Bruegel 2020; IMF 2020a).

Environmental impacts

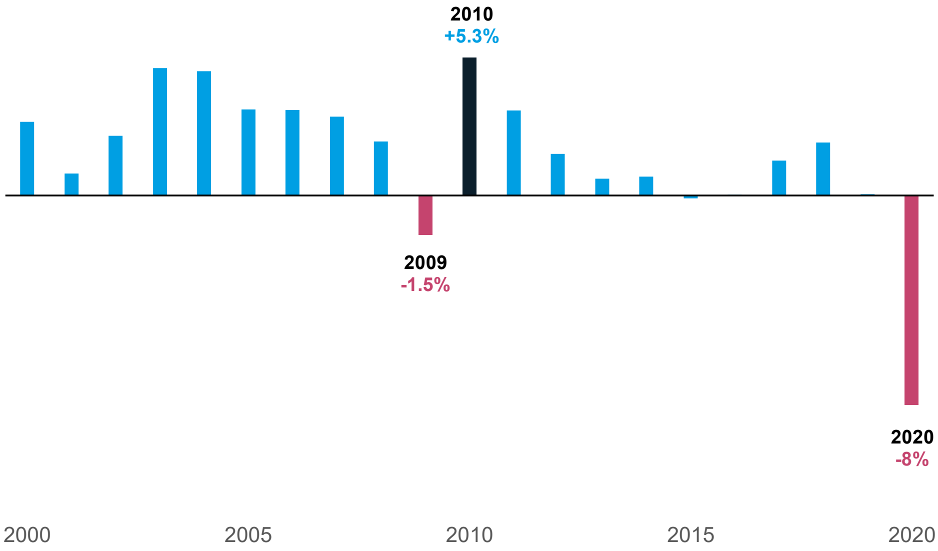
As a positive side-effect of the restricted economic activity and particularly global travel, environmental harm decreased in 2020. For example, GHG emissions have declined by almost 9% in the first half of the year (Evans 2020; Liu et al. 2020). The IEA estimates that annual CO_2 emissions in 2020 were 8% lower than in 2019 (IEA 2020a), a reduction "twice as large as the combined total of all previous reductions since the end of World War II" (IEA 2020a, 4). This decline has been driven by an unprecedented drop in energy demand, particularly affecting coal and oil demand and thus substantially reducing emissions (IEA 2020a). However, energy demand, and therefore emissions, are expected to rebound once economies re-open. The annual increase in CO_2 emissions after the 2008-09 financial crisis was the largest increase on record (IEA 2020d), as shown in Figure 1.2.

The pandemic and the economic downturn may themselves undermine efforts to decouple environmental degradation from economic growth. The IEA (IEA 2020d) notes the following concerns:

- the sharp fall in oil and gas prices may deter uptake of RES technologies
- the slump in output and investment could prolong the operation of inefficient / carbon-intensive capital stock
- especially in developing countries, the perceived risks of lending have increased, raising questions about the cost and availability of debt finance for new energy technologies.

[2] Assuming a 48-hour working week.

Figure 1.2: Year-on-year changes in global CO_2 emissions, GFC and COVID-19 impacts



Data sources: Friedlingstein et al. (2020); Ritchie and Roser (2020); IEA (2020a)

However, the IEA also notes some positive aspects. Lower fossil fuel prices may give governments room to reform fossil fuel subsidies (IEA 2020d). While global energy investments are estimated to have dropped by about 20% in 2020, much of this decline has been attributed to the oil and gas sector (-32%), while investment in utility-scale RES has proved more resilient (IEA 2020c). Finally, while debt finance is a pressing issue, there have been some initiatives to relieve the burden on developing countries. For example, under the Debt Service Suspension Initiative (DSSI) it has been proposed to defer debt service payments, while guaranteeing no excess losses to creditors (Lang, Mihalyi, and Presbitero 2020).

The case for Green Recovery policies

Therefore, the net effect of the crisis and recovery on environmental outcomes is ambiguous. Given this background, the content of recovery programmes could be decisive. As the IEA highlights (IEA 2020d), economic recovery programs, if they include green policies, could provide a substantial boost to clean energy technologies, while creating new jobs and economic activity. Whereas a different set of policies can set back the cause of climate change mitigation. As the Climate Action Tracker outlines (Climate Action Tracker 2020a), there are several recovery policies that can work *against* environmental targets, potentially pushing emissions above what would have happened in the absence of the pandemic. Initial modelling has supported this (Climate Action Tracker 2020a; Pollitt et al. 2020).

2 Recovery Plans

2.1 Introduction

The goal of this chapter is to introduce some of the key concepts related to a green economic recovery. Section 2.1 provides a brief discussion of the differences between relief and recovery and then continues to explain the differences between Green Recovery policies and other types of policies. Section 2.3 provides a more detailed description of the key policies being put forward in the literature to form part of a Green Recovery package. The concepts and recommendations introduced in this chapter have informed the design of the scenarios for the modelling results presented in this report.

2.2 Designing economic recovery

Stimulus measures to combat the economic impact of COVID-19 announced by September 2020 by governments around the world amounted to around US$12 trillion or 12% of global GDP (UNEP 2020, 36). It was estimated that by January 2021 this total had increased to about US$15 trillion (based on O'Callaghan et al., 2020). For comparison, McKinsey reported in June 2020 that the US$10 trillion announced by then was already about three times what was spent in response to the GFC (Cassim et al. 2020). However, importantly, the timescale of these measures is not defined and spans over several years.

Rescue vs. recovery

Much of this amount represents ***'relief' or rescue measures***. These are designed to provide immediate support to people and firms who are in a dire financial / liquidity situation as a result of the pandemic (Hepburn et al. 2020). These measures include furlough schemes, income support, tax deferrals or liquidity support among others (IMF 2020a; O'Callaghan et al. 2020). By the end of December 2020, most announced policies belonged to this group, focusing on short-term interventions (UNEP 2020).

However, governments are also considering policies with longer-term goals and time-frames, intended to help the economy recover once restrictions are lifted (Hepburn et al. 2020; UNEP 2020). We call these measures ***recovery policies***, to distinguish them from the short-term interventions.

It is expected that post-COVID-19 recovery policies will, first and foremost, aim to boost employment and economic activity. For example, the announced main goal of the European Union's large-scale recovery plan *'is to mitigate the economic and social impact of the coronavirus pandemic'* (European Commission 2020b)[3]. In another example, South Africa's president has communicated the following goals: job creation, reindustrialisation of the economy, acceleration of economic reforms, fighting crime and corruption and improving the capability of the state (South African Government 2020a).

As Hepburn et al. (2020, p. S364) state, *'A key objective of any recovery package is to stabilize expectations, restore confidence, and to channel surplus desired saving into productive investment'*. Since a recovery of private

[3] The full goal statement reads: "The aim *is to mitigate the economic and social impact of the coronavirus pandemic* and make European economies and societies more sustainable, resilient and better prepared for the challenges and opportunities of the green and digital transitions."

consumption and investment spending is needed to bring about a restoration of economic activity, restored confidence and expectations are critical.

What policies have proved effective before?

Designing efficient and effective policy packages is going to be a primary task for governments and policy-makers. While the crisis itself was different in its nature, experiences from the response to the 2008-09 GFC can give some insights.

Hepburn et al. (2020) argue that, in the case of the GFC, the economic success of recovery packages was strongly affected by two factors*:* the *speed of impact* and the *magnitude of economic multipliers*. From a review of the literature they conclude that: government spending on investment delivered higher multipliers than tax deductions and that direct cash transfers have performed well (Hepburn et al. 2020).

Various IEA publications comment on observed policy impacts from an energy perspective (IEA 2020b; Varro et al. 2020). Taking again the GFC experience as a starting point, these papers argue that scaling up successful existing policies proved to be the most efficient measure, providing high economic and employment returns. These programs usually have existing policy and administrative structures and so they can be implemented quickly (IEA 2020b; Pérez-Cirera and Lieuw-Kie-Song 2020; Varro et al. 2020). The IEA also emphasises the need for *technology readiness*, citing examples of funding for advanced biofuels and hydrogen, which due to the lack of mature technology, have not brought about the expected outcomes (IEA 2020b). Finally*, human capital readiness* is just as important if recovery policies are targeting certain technologies (IEA 2020b): if the necessary skills are lacking in the workforce, investments may fall short of expectations.

Defining Green Recovery policies

Support and advocacy for an environmentally sustainable recovery, led by green policies, appears to be gaining ground in policy and government circles. Public support also appears to be building. A survey, conducted for the European Investment Bank in October 2020, showed that 57% of EU, 49% of US and 73% of Chinese respondents would support their governments taking environmental concerns into account when designing economic recovery, even if that means a slower economic recovery (EIB 2020).

But what does ‘Green Recovery’ mean? After the 2008-09 GFC, authors at the World Bank proposed the following definition for ‘green stimulus’: ‘*Green stimulus is the application of policies and measures 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, p.5). The fundamental idea underlying this definition is that there can be a “decoupling” of environmental harm and economic growth (Strand and Toman 2010), at least in the case of the recovery.

While it has been suggested that a relative decoupling[4] of GHG emissions and economic growth has been under way in developed countries in the last decade (Mikayilov, Hasanov, and Galeotti 2018), this might be not be the case in developing countries. As Cohen et al. (2017) shows, the overall picture might be substantially biased due to international trade. Emissions from developed countries are often outsourced to developing countries (where

[4] Meaning that GHG emission *grow* with a lower rate than economic production. *Absolute decoupling* would be achieving economic grow, while decreasing GHG emissions.

environmental regulations are more permissive) through global value chains. Hence, while viewed from the perspective of national production there may seem to be evidence of decoupling, from the viewpoint of consumption the extent of decoupling is much less.

Therefore, Green Recovery policies need to find a way to facilitate economic growth and job creation, while having a net-negative impact on global environmental harm, including reducing GHG emissions. Since Green Recovery policies are intended to improve social wellbeing as well as curb environmental degradation, their impact on income distribution and inequality is also of interest.

Grey and colourless

'Green' recovery is also defined in opposition to 'grey' and 'colourless' recovery policies. Colourless policies are defined as having a neutral effect on the *status quo* of environmental harm (meaning that they do not *worsen* the environmental harm linked to economic growth) (Dafnomilis et al. 2020; Hepburn et al. 2020). Dafnomilis et al. (2020) note that this category might be particularly relevant in the case of economy-wide measures. For example, an economy-wide VAT reduction can be considered a colourless policy as its environmental impact is ambiguous and *dependent on the existing economic structure*. However, due to the lack of decoupling, these policies are still likely to have *negative impacts* on the environment (e.g. increasing carbon emissions in line with economic growth).

On the other hand, grey[5] measures are defined as those that can directly contribute to *excess* environmental harm (Dafnomilis et al. 2020), for example because they are likely to increase GHG emissions (Hepburn et al. 2020). These policies include unconditional tax breaks or bailouts for airlines (Hepburn et al. 2020; UNEP 2020), expansion of coal mines and gas infrastructure, unconditional bailouts for the oil and gas industry (Climate Action Tracker 2020a) and relaxation of environmental regulations and standards (UNEP 2020).

Table 2.1: Overview of rescue & recovery policies, based on their environmental impact, with policy examples (not exhaustive)

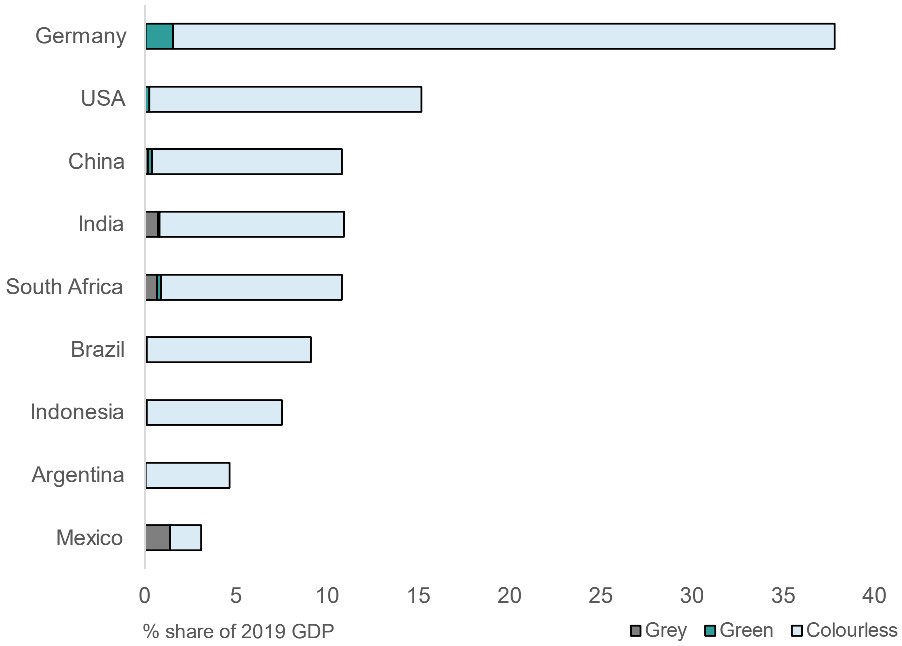
	Colourless no *direct* environmental effects, often economy-wide, keeping the *status quo* of economic structure	**Grey** direct contribution to environmental harm, creating excess carbon emissions	**Green** direct contribution to reducing environmental harm, climate change mitigation, sustainable growth
Rescue / relief instant, short-term, keeping businesses and people afloat	Temporary waiver for interest payments; liquidity support for corporations; tax deferrals; direct provision of based needs; direct cash transfers	Unconditional bailouts for airlines, oil and gas, automotive manufacturing companies	Bailouts, support for train operators, public transport companies
Recovery long-term, rebuild, reshape the economy, create new jobs replacing lost ones	General R&D spending; healthcare investment; education investment; income tax cuts; reduction in VAT or other consumption taxes	Establishing / increasing oil and coal reserves, new investments into coal and gas infrastructure; unconditional support for refurbishment and upgrade of buildings; reduction of car sales taxes without conditions	Support for renewable deployments, incentivising electric vehicles, energy efficiency investments, afforestation and reforestation, R&D boost for carbon-free technologies, ecosystem regeneration

Policy examples are based on: Climate Action Tracker, 2020a; Hepburn et al., 2020; O'Callaghan et al., 2020; UNEP, 2020

[5] Following PBL authors' approach "to accommodate different cultural contexts and avoid racial connotations" (Dafnomilis et al. 2020, 2) we choose to refer to carbon-intensive, environmentally harmful policies as 'grey' rather than 'brown' (which was previously used by others).

In April 2020, Hepburn et al. (2020) reported that 4% of the then announced rescue policies were green, while 4% were grey and the rest (92%) colourless.

Figure 2.1: Scale of fiscal rescue and recovery in selected economies categorised by carbon emission effects



Based on UNEP, 2020, p. 39
Oxford University Recovery Project (O'Callaghan et al., 2020)

The UNEP reported (UNEP 2020) that by October 2020 most recovery policies were primarily supporting the current *status quo*. From the G20 group of countries, only about a quarter have dedicated parts of their recovery packages explicitly to low-carbon measures, while some of them have even initiated new high-carbon investments (UNEP 2020). Figure 2.1 provides an illustrative overview of the share of different types of policies in selected countries.

Confirming this, according to January 2021 data from the Oxford Economic Stimulus Observatory, only about 20% (by value) of the policies included there have a climate neutral effect and just 4% will contribute to lowering GHG emissions; the rest (76%) will induce a net increase in emissions (O'Callaghan et al. 2020).

UNEP's Emission Gap Report draws together the recommendations that various authors have made to assess the likely effectiveness of recovery policies (UNEP 2020, 42), summarised in Figure 2.2. In addition to timeliness and environmental, economic and jobs benefits, the list includes the question of government budget capacity and social benefits. Others (IRENA 2020; Pérez-Cirera and Lieuw-Kie-Song 2020) echo these criteria, but add further points: a push for system transformation is emphasised both by IRENA and WWF-ILO authors. Reflecting on government budget constraints, IRENA also highlights the role of private finance and calls for policies that have the potential to trigger investments with market financing (IRENA 2020).

Concerning employment impacts, the IEA notes the need for policies that target workers displaced by the pandemic (IEA 2020b). If recovery policies create jobs in different sectors and require different skills compared with where the jobs have been lost, the resulting skills mismatch could lead to inflationary pressures rather than lower unemployment (ILO 2020).

Figure 2.2: Non-exhaustive, simplified overview of recently published literature that proposes indicators to assess and design low-carbon, sustainable and socially inclusive economic recovery measures

Indicators	IEA (2020)	World Bank (2020d)	Hepburn *et al.* (2020)	Jotzo *et al.* (2020)	O'Callaghan *et al.* (2020)	Vivid Economics (2020b)
Timeliness (including speed of implementation and timing of effects)	✓	✓	✓	✓	✓	✓
Employment (including scale, quality, location and their distribution over time)	✓	✓		✓		✓
Economic activity (including short- and long-term impact and multiplier effects)		✓	✓	✓	✓	✓
Government budget capacity (including the impact on fiscal space, e.g. producing future fiscal revenues or savings to the government)				✓		✓
GHG emissions (including short- and long-term and potential lock-in)	✓	✓	✓	✓	✓	✓
Other environmental benefits (including air quality and water)		✓		✓	✓	
Social benefits (including access to public resources, health, gender equity, cost-of-living reductions for low-income earners or improved public health)	✓	✓		✓	✓	

Adopted from UNEP, 2020, p. 42
IEA (2020) refers to IEA (2020d), Hepburn et al. (2020), O'Callaghan et al. (2020) are cited in this paper as well. For the other sources please refer to the Emissions Gap Report 2020.

These kinds of criteria have been used previously for evaluating Green Recovery policies. In 2011, using the E3ME macroeconometric model, Cambridge Econometrics conducted an *ex post* analysis of recovery policies in Europe after the GFC (Cambridge Econometrics 2011). The criteria in that evaluation included: timeliness, job creation impact, targeting vulnerable groups, environmental impact, fiscal deficits and productivity and innovation.

2.3 Policies for Green Recovery

Since most policies in the current set of rescue and recovery plans are expected to increase GHG emissions, there is substantial scope to increase green content in the plans. We list below the main elements from a number of recent publications (Climate Action Tracker 2020a; Hepburn et al. 2020; IEA 2020b; IRENA 2020; Pérez-Cirera and Lieuw-Kie-Song 2020; Pollitt 2020; UNEP 2020). IEA's Sustainable Recovery report (IEA 2020b) provides a more detailed analysis of many of these policies.

Support for investment in renewable energy

While energy demand is estimated to have fallen by about 6% in 2020, largely due to the COVID-19 pandemic, the generation of electricity based on renewable sources has proven to be resilient, with an estimated increase of 0.8% (IEA 2020a). However, investment in the expansion of capacity based on renewable technologies is estimated to have fallen by about US$10 bn (3%) to US$301 bn or (IEA 2020e). This level is some US$223 bn below the average annual investment amount needed over 2019-2030 to realise the IEA's Sustainable Development Scenario, a scenario consistent with achieving key energy-related sustainable development goals (IEA 2019). Further, it is expected that the pandemic will have an even worse effect on investment in developing countries as increased risk aversion and the decline of foreign capital flows are expected to hinder the deployment of renewables there (IRENA 2020).

Incentivising renewables meets the test of various effectiveness criteria discussed above: there are existing incentive programs, with established administrative structures, and these are likely to attract private finance. In the EU, ‘green’ measures following the GFC are estimated to have cost about 0.3% of GDP on average and produced a 0.6-1.1% boost to GDP (Cambridge Econometrics 2011). Similarly, in the US, almost one million new ‘green’ jobs are estimated to have been created by the *American Recovery Act of 2009* (Climate Action Tracker 2020a).

IEA authors also note that investment in renewables would be most effective when coupled with training (IEA 2020b). A recent example is the partnership between the Danish energy group Ørsted and a union in the US, to develop a skilled labour force to build an offshore-wind connector (Volcovici 2020). Policies may also need to provide incentives for training and hence address the potential problem of skills mismatch.

Increasing grid flexibility

Electrification of demand and an increasing share of intermittent needs to be accompanied by investment in energy flexibility to mitigate energy security risks. Improvement and modernisation of energy grids mitigates the risk of high-cost disruptions and improves the integration of variable energy sources, and supports access to electricity in countries where this is still lacking (IEA 2020b). Grid improvement can also support cross-border electricity trading (IEA 2020b; IRENA 2020) with benefits for resilience and energy security.

IRENA considers flexibility investments alongside with renewable installation as an area with high employment benefits: an estimated 25 jobs could be created per US$1m of investment (IRENA 2020). The IEA further emphasises that grid investments create jobs across a variety of roles during construction, including manufacturing jobs (IEA 2020b). The IEA estimates that grid modernisation could create about 8 jobs per US$ 1m of investment.

Investment in storage capacity is another way of increasing the flexibility of the energy system (IRENA 2020), but in this case the readiness of the technology and the market needs to be investigated more closely.

Energy efficiency in buildings and appliances

Buildings account for 30% of global emissions (IEA 2020b) and are one of the most difficult sectors to decarbonise; the success of energy efficiency measures targeting the buildings sectors has been limited (Pollitt 2020). Nevertheless, retrofitting and energy efficiency improvements in buildings provide an opportunity for economic recovery.

The IEA estimates that 9-30 jobs could be created for every US$1m of energy efficiency investment in the sector (IEA 2020b). Many of these jobs are relatively low-skilled, and low-skilled jobs were generally hit harder by the pandemic (ILO 2021). Building improvements are also typically labour-intensive (Climate Action Tracker 2020a), therefore providing a further direct boost to the economy through higher wage incomes.

Timeliness is also an important advantage of measures in this field. New projects can be started quickly and construction and renovation work, subject to necessary safety regulations, is permitted in most countries even if COVID-19 restrictions are in place. Governments can direct policy towards the retrofitting of public buildings and social housing, therefore creating a pipeline of work for the industry (Climate Action Tracker 2020a; IEA 2020b).

Further measures, focusing on household appliances and, especially in developing countries, access to clean cooking have the potential to create new jobs and reduce the time spent on household maintainance, predominantly by women (IEA 2020b).

Incentives for zero emission vehicles

Car scrappage schemes were introduced by several countries after the GFC to boost consumption and in the same time increase the energy efficency of the vehicle fleet (Cambridge Econometrics 2011; Climate Action Tracker 2020a; Pollitt 2020). Policies now could target uptake of electric vehicles, which would provide a stimulus to the car industry, reduce carbon (and local air) emissions, and promote a more rapid reduction in technology costs (IEA 2020b).

An uptake in Battery Electric Vehicles (BEVs) would also ramp up industries in the supply chain. Battery manufacturing still needs to grow substantially (IRENA 2020), but this kind of commitment could push car manufacturers, suppliers and other players to invest in manufacturing capacity.

An important consideration, however, is the equity aspect of such measures. As Linn (2020, p. 10) writes: '*subsidizing scrappage reduces the supply of older used vehicles, raising prices of used vehicles. This effect [...] would likely be regressive because low-income households are more likely to buy used vehicles than are high-income households. Subsidizing new electric vehicles is probably regressive because most consumers of those vehicles have incomes higher than a typical US household.*' Hence, auxiliary measures, such as providing low-cost loans for low-income groups or discounted public transport could be considered as complements. The precise design of the policy also matters: Miller et al. (2020) showed that, for example, different subsidy amounts can lead to substantially different allocation outcomes.

Governments also have opportunities for important direct interventions to accompany uptake incentives. These include investments in public transport infrastructure, such as the electrification of public road transport vehicles (Climate Action Tracker 2020a) or investments into rail infrastructure (IEA 2020b). These measures would complement the rescue measures introduced by some governments to bail out or support public transport operators.

Ecosystem restoration and reforestation

Natural capital investments or nature-based solutions, such as climate-friendly agriculture or ecosystem restoration and reforestation, represent 'fast-acting climate-friendly policies' (Hepburn et al. 2020). They are among the most important and effective policies for reducing environmental harm and creating sustainable jobs. While these efforts can contribute to the protection of natural carbon sinks (Climate Action Tracker 2020a), they also touch upon areas where other carbon mitigation policies cannot provide relief. Nature-based solutions can contribute to biodiversity and wildlife protection (Climate Action Tracker 2020a), and provide jobs and improve human wellbeing (Pérez-Cirera and Lieuw-Kie-Song 2020).

A framework for deploying such programs, including measures such as reforestation, ecosystem rehabilitation, management of invasive species and the use agroecological approaches to food production has been developed following the GFC (Pérez-Cirera and Lieuw-Kie-Song 2020). Many of these measures can also be implemented within a short timeframe, under government control, leading to large-scale public employment opportunities. There is relevant experience of implementing these programs, historically in countries such as the US, but more recently in developing countries like India, Ethiopia or South Africa (Pérez-Cirera and Lieuw-Kie-Song 2020).

According to Pérez-Cirera and Lieuw-Kie-Song (2020) these policies can also deliver impressive employment benefits. Afforestation and reforestation works could create as much as 275-625 FTE per million dollars of investment (Pérez-Cirera and Lieuw-Kie-Song 2020, 24–25).

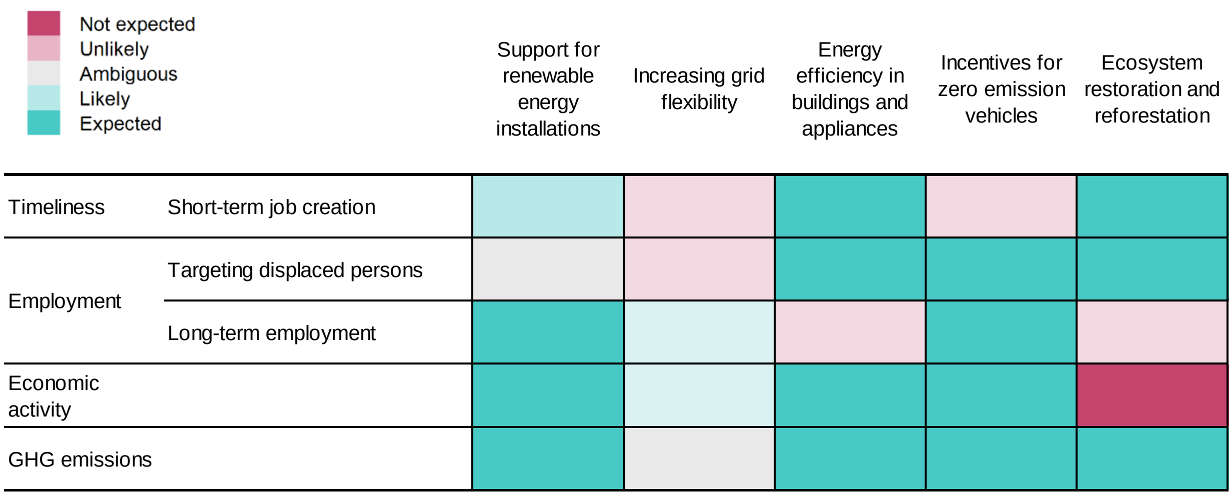
Further policy areas

Other policy recommendations in the literature include:

- clean R&D spending and, mostly in developing countries, targeted rural support policies in developing countries (Hepburn et al. 2020)
- low-carbon R&D in industry and aviation (Climate Action Tracker 2020a)
- specific technologies in R&D (hydrogen, batteries, small modular nuclear reactors and carbon capture, utilisation and storage) (IEA 2020b)
- reform of fossil fuel subsidies (Climate Action Tracker 2020a; IEA 2020b; UNEP 2020), particularly given the opportunity afforded by the sharp fall in fossil fuel prices during the pandemic to cut subsidies without increasing end-user prices (IEA 2020b).

Figure 2.3 provides a qualitative assessment of the policy options based on (IEA 2020b; IRENA 2020; Pérez-Cirera and Lieuw-Kie-Song 2020).

Figure 2.3: Assessment of the policy archetypes based against key effectiveness criteria



Based on IEA (2020d); IRENA (2020); Pérez-Cirera and Lieuw-Kie-Song (2020)

3 Modelling a Global Green Recovery

3.1 Introduction

Chapter 2 noted that recovery programs can be evaluated against a number of criteria, such as:

- timeliness and hence the timeframe for the impacts to come through
- economic multipliers or the efficiency of the interventions with respect to their budgetary cost
- job creation potential
- avoiding harming nature, or even reducing harmful pollutants and pressures, building natural capital.

Models that explicitly incorporate economy-energy-environment linkages, such as E3ME (Cambridge Econometrics 2019), can produce quantified estimates of prospective policy impacts for indicators relevant for assessing performance under these criteria, enabling comparison between the expected ex ante effectiveness of different policy options. Modelling exercises can focus on particular countries or regions, as in the case studies summarised in Chapter 4 (see also Kiss-Dobronyi, Pollitt, and Fazekas (2020) for the Visegrad group of European countries), simulating the effects of detailed policies that are under discussion. Modelling can also be carried out at the global level, to shed light on how the same set of policies implemented in parallel across the world has different effects in different regions. It can also highlight important global interlinkages such as learning effects (Mercure 2012) that reach beyond borders.

In this chapter, we take stock of the existing literature, focusing on studies that have carried out Green Recovery modelling scenarios, including both previous applications of the E3ME model and studies that use other models. We discuss studies that include *global* recovery scenarios and report them in the order in which they were published. This provides context for the new modelling presented in this report and allows us to identify the added value of our analysis. Following discussion of the literature, we set out the policies that we include in our scenario modelling, and the main assumptions made.

3.2 Existing literature on global Green Recovery modelling

Following the initial outbreak of the pandemic, by 2020 Q3, it seemed that social distancing restrictions were achieving their desired effect and many governments were starting to relax them (Financial Times 2021). At the same time, various studies began to report model-based assessments of the effectiveness of potential Green Recovery policies and recovery packages (Climate Action Tracker 2020a; IEA 2020b; IRENA 2020; Pollitt et al. 2020).

In April 2020, Climate Action Tracker's policy brief included a calculation of the potential carbon emission impacts of four different kinds of recoveries (Climate Action Tracker 2020a). This developed assumptions about the relationship between decarbonising investments and carbon intensity, drawing on results from McCollum et al. (2018). The brief reported that a scenario involving renewed investment in fossil fuels (+0.1% investment in fossil sources, -0.4%

in renewables) could add an additional 5 $GtCO_2$ to annual emissions. In contrast, a weak green stimulus (-0.1% investment in fossil sources, +0.4% in renewables) could decrease annual emissions by 10-12 $GtCO_2$ (Climate Action Tracker 2020a, 13). But the study did not incorporate modelling that could estimate economy or labour impacts or analyse policy effects other than a shift in the composition of investment.

In June 2020 two comprehensive studies looking at sustainable recovery, in the context of energy, were published by the IEA (2020b) and IRENA (2020). These include global policy scenarios, with estimated quantified impacts on employment, economic growth and emissions (in the case of the IEA study).

IRENA's Transforming Energy Scenario, covering the period 2021-23, proposes an average US$2 trillion investment into clean energy. Just over half of this amount is allocated towards energy efficiency, 25% towards renewables and about 22% for electrification and infrastructure investments (IRENA 2020, 118). While the scenario was not designed specifically to model a Green Recovery, IRENA reviewed the suitability of the various instruments it proposed for inclusion in sustainable short-term recovery programs (IRENA 2020, 121–26). Estimates of labour market and economic growth (using E3ME) were also provided, to inform assessment of the potential contribution to economic recovery. IRENA reported that recovery investment linked to the scenario could boost GDP by 1% on average in 2021-23. Additional employment could amount to 2 million extra jobs in the first year and 5.5 million jobs by 2023 (IRENA 2020, 128–29). IRENA did not explicitly discuss how much of this investment would be financed from public or private sources, but the report did discuss certain public financing solutions, such as conditional bailouts and reform of fossil fuel subsidies (IRENA 2020).

IEA's Sustainable Recovery special report (IEA 2020b) represents the most comprehensive recent study on the effects of a sustainable recovery in the energy sector to date. The study assessed a number of energy policies against the effectiveness criteria described in Chapter 2, and included a modelling exercise, carried out with the IMF, on the macroeconomic impacts of the proposed policies (IEA 2020b). Measures were proposed in six areas: electricity generation, buildings, transport, fuels, industry and innovation. The plan was intended to be implemented over 2021-23, and proposed an average US$1 trillion investment per year collectively across the six areas (IEA 2020b, 108). The study expected that about 30% of the financing would come directly from governments, and that this would trigger the remaining 70% from the private sector (IEA 2020b, p. 114).

The plan is estimated to lead to a 3.5% increase in real global GDP in 2023 compared with the outturn without the plan (IEA 2020b, 120). Global employment is projected to be 9 million jobs higher in each year 2021-23 as a result of the measures (IEA 2020b, 117). Just over 35% of these jobs are connected to the buildings sector (to carry out the energy efficiency measures), and a further 25% by 2023 are manufacturing and construction jobs stimulated by the increased energy sector investments.

The study estimates that by 2025 annual emissions would be 3.5 $GtCO_2$ lower than they would have been without the recovery plan (IEA 2020b, 123). To put this in context, this is about the same size as the total emissions of the European Union in 2019.

In June 2020, Cambridge Econometrics published initial estimates of the economic and emission impacts of the pandemic and of two recovery scenarios: one focused on stimulating household consumption, the other focusing on measures to target CO_2 reductions. Results were published in the C-EENERG working paper series[6] (Pollitt et al. 2020). This working paper was the forerunner of the present report's modelling exercise, described in the next section. A subsequent report, published in October 2020 (Pollitt 2020), drew on this initial modelling and incorporated later information about the impact of the pandemic.

Both studies developed two stylised recovery scenarios focusing on 2021-2023: one based solely on a policy designed to stimulate household consumption (through a reduction in consumption taxes) and one with green elements (Pollitt 2020; Pollitt et al. 2020). The ex ante value of the fiscal package is the same in both scenarios. Green measures included capital subsidies for renewables, tree planting, public investment in energy efficiency and grid modernisation, and a car scrappage scheme directed towards BEVs (Pollitt 2020; Pollitt et al. 2020). Total public spending for the green measures amounted to around 1% of global consumption tax revenues (Pollitt et al. 2020, 17).

The studies conclude that global GDP would be boosted by up to 4% by 2023 by the recovery packages, although GDP would remain below what it would have been in the absence of the pandemic (Pollitt et al. 2020, 19). The scenario with green policies produced a stronger boost, especially for employment. The consumption tax scenario boosts jobs while the policy is in place but, when the temporary tax cut comes to an end, about half of additional jobs are lost. The green policies scenario generates more jobs than the consumption tax scenario in the initial years and the higher level (Pollitt 2020).

Unsurprisingly, CO_2 emissions rise in the consumption tax case, reflecting the indirect environmental impacts of 'colourless' recovery policies. The green policies scenario achieved a long-term reduction in emissions by 2030 of 9% or 3.2 $GtCO_2$ compared with a baseline with no recovery measures (Pollitt et al. 2020).

In December 2020, Shan et al. (2020) published an article modelling a series of scenarios in which they varied the size and composition of fiscal stimuli and also the carbon intensity of investment spending, using an adaptive multiregional input-output model[7]. They report that, without a reduction in the carbon intensity of investment, recovery spending amounting to 10% of GDP would boost GDP by just over 1% and emissions by about 1.5% by 2024 (2.04 $GtCO_2$) (Shan et al. 2020, 4). While '*changes in the structure of fiscal stimuli will not have significant impacts on economy recovery and emissions*' (Shan et al. 2020, 4), the carbon emissions intensity of investment does. If the share of investment going into carbon-intensive technologies and fields remains the same as it was in 2017, then cumulated emissions through a five-year period will increase by 15.6% (22 $GtCO_2$), while if the share of clean energy

[6] The original working paper, published in June 2020 can be found here: https://www.camecon.com/wp-content/uploads/2020/06/The-economic-effects-of-COVID-19.pdf
[7] The adaptive nature of the model means that it incorporates certain production capacity constraints and consumption behaviour changes resulting from the economic shock.

technologies were increased it would cut emissions by 4.7% (6.6 $GtCO_2$) (Shan et al. 2020, 4).

The present study builds on these findings, drawing where relevant on their assumptions and the kinds of policy impacts they have represented. We extend the existing literature in the following ways. First, we compare a “colourless” recovery package, with a Green Recovery program and hence highlight the extent to which the impacts of the Green Recovery program match up to or improve on the “colourless” package. Second, our baseline (pandemic impact) projection has been updated to include latest available estimates on the short-term economic and energy impacts of the COVID-19 pandemic. Finally, we explore differences in impacts across sectors and geographical regions.

3.3 A Global Green Recovery scenario

The modelling exercise presented in this report builds on earlier work by Cambridge Econometrics (Pollitt et al. 2020; Pollitt 2020), but differs in important aspects. We keep the original approach in the aspect of comparing two recovery scenarios – one solely focusing on cutting consumption taxes to boost household spending (‘VAT scenario’) and one also incorporating green elements. Ex ante, the size of the two recovery programs in terms of their impact on government budgets are of the same size. The VAT scenario is modelled with the same assumptions as in the earlier studies: a global, 5% reduction of consumption taxes maintained for 2021-23, followed by a gradual phase-out by 2027. This provides a consistent scale and benchmark for the design of alternative recovery scenarios.

Updates and revisions have been introduced to other parts of the modelling, the baseline projections and the Green Recovery scenario assumptions in particular.

Baseline

The baseline used for this study draws on the latest IMF (IMF 2021; 2020c), World Bank (World Bank 2021) and European Commission (European Commission 2020a) economic estimates. It also includes updated energy figures for 2020 based on IEA (IEA 2020a) and improved employment and labour estimates based on the latest ILO projections (ILO 2021). The estimated employment impacts of the pandemic have been updated based on ILO estimates 2020 Q2 and Q3 (ILO 2021). The estimated effects of the pandemic on the structure of household consumption have been updated based on Office for National Statistics (2020) data and adjusted for global regional differences based on spending category level survey results conducted in 11 countries by McKinsey (2020).

The baseline projection includes recovery and relief policies insofar as they have influenced the data and forecasts from the above-mentioned sources. The goal of the baseline is to provide a projection of the future without policy action that goes beyond what is already known, to serve as a counterfactual projection. By comparing alternative policy scenario results with the baseline projection, we show the impact of the alternative policy package.

Green Recovery scenario policies

The Green Recovery scenario continues to build on five main policies, largely in line with the discussion in Section 2.3 above:

- subsidised renewable energy installations

- energy grid investments
- energy efficiency measures, focusing on households
- a car scrappage scheme, focusing on BEVs
- a global reforestation and ecosystem restoration project.

The following paragraphs discuss the detail of each of these policy assumptions.

Subsidised renewables installation

Renewable deployment is modelled in the scenario through capital subsidy to RES installations. A 50% capital subsidy is assumed, following Pollitt (2020), accepting that higher subsidy rates will not necessarily lead to a higher take-up and could put excessive pressure on existing grid infrastructure. Sensitivity analysis was carried out to check the impact of alternative subsidy rates (25% and 75%) and this confirmed the choice of 50% as the preferred rate[8].

The subsidy program is assumed to run for three years (2021-23) and to provide support to all wind and solar PV investments globally. We model the impact on private (electricity utility) investment in E3ME using the FTT:Power (Mercure 2012) submodule. Hence, we calculate the scale of public subsidy implied by the 50% subsidy rate and the scale of private finance that this triggers from the estimated investment response to the subsidy.

BEV car scrappage scheme

While there are potential concerns about the equity aspects of a car scrappage scheme, we include the measure because the automotive sector was heavily affected by the pandemic (IHS Markit 2020) and there are already plans for unconditional bailouts for the industry (Climate Action Tracker 2020a). A car scrappage scheme that is conditional on purchasing a BEV, has the potential to bring in private spending (Green et al. 2020).

Following Pollitt (2020) and Pollitt et al. (2020), we assume a 20% government subsidy for new BEVs if they are purchased as part of the scrappage scheme (i.e. they are replacing less energy efficient, ICE vehicles) and a 4.5% rate of car fleet turnover between 2021 and 2023. While this is a sizeable target, we calculate that similar programs with subsidy amounts around this were successful in some cases (see IHS 2010; Cambridge Econometrics 2011; International Transport Forum 2011).

In line with Cambridge Econometrics (2011), we assume that initially much of the spending is additional. It is likely that much of this spending is bringing forward purchases that would otherwise have occurred in later years (Green et al. 2020), which is what the policy is attempting to bring about. We assume that, as the recovery picks up, the degree of additionality decreases, with one third of spending on vehicles not additional in 2022 and two thirds in 2023.

Grid investment, modernisation

Faster deployment of renewables and electrification of road transport will put pressure on existing electricity infrastructure. Additional investment in the grid is necessary to reduce the chance of high-cost disruptions (IEA 2020b) and to unlock energy storage potential coming from a wider adoption of BEVs.

[8] The 75% subsidy leads to high levels of early scrapping of power equipment for technologies like coal, CCGT and even for solar PV as onshore wind becomes really inexpensive in certain periods / regions. The 25% subsidy produces better multiplier outcomes than the 50% subsidy, as in private investment induced to government spending ratio is better. Nevertheless, the overall amount of investment and thus employment gains are lower. We choose the 50% subsidy, because in the case of a recovery program we preferred having a stronger impact from this policy, even if it is somewhat less efficient financially.

In the modelling we assume that grid investments rise in line with the take-up of renewable energy. Investment in the grid of about US$800 million per 1 GW[9] of new installed renewable capacity is assumed through 2021-23. We assume that this is entirely public financed. Hence, the scale of investment in both renewables capacity and the grid follow from the assumption of the rate of subsidy for renewables capacity and the estimated market response.

Energy efficiency

Energy efficiency measures could be the policies with a short lead-in time and with a vast impact on labour markets. Following Pollitt (2020) we consider publicly financed energy efficiency improvements, which lead to a 6% reduction in energy use by households by 2023. This represents a small acceleration compared to IEA's Sustainable Development Scenario, where energy consumption in buildings falls 28% by 2040 (IEA 2019). We estimate the cost of the country-level programs using IEA's estimate of energy intensity improvement cost (IEA 2020d, 207), assuming that US$ 10 million investment is needed to reduce consumption by 1 ktoe.

Global reforestation

Ecosystem restoration and nature-based solutions in general can be an important part of the recovery, offering both environmental advantages and high labour intensity (Pérez-Cirera and Lieuw-Kie-Song 2020). In the scenario we model a global reforestation project with two parts. First, using data from (TrillionTree Campaign 2021), we assume that governments finance the completion of ongoing reforestation projects in 2021-22. The estimated cost of this is US$ 4.2 bn[10]. Second, through 2022-23, we assume that reforestation efforts continue in areas where there is a high reforestation potential (subtracting what has been already done in the TrillionTree project) based on (Bastin et al. 2019). We assume that in 2022-23 a further annual US$ 8.4 bn is allocated towards these programs, financed by national governments or international donors. The labour potential of these programs is also explicitly modelled: based on figures reported by Pérez-Cirera and Lieuw-Kie-Song (2020) we assume that reforestation efforts can create 0.4 FTE[11] jobs per hectare.

Beyond green recovery – low-carbon transition

The recovery policy scenarios assessed are limited in scale to match the ex ante budgetary cost of the "colourless" recovery package, so that comparison between their impacts can be made. Hence, the recovery policy scenarios have not been designed to curb greenhouse gas emissions to the extent required to meet a 1.5°C or 2.0°C climate warming target. Rather, we specify policies consistent with a given ex ante budget cost and examine to what extent these contribute to meeting emissions targets, as well as stimulating GDP and jobs growth. The case studies reported in Chapter 5 took a different approach, testing the economic and social impact of more ambitious decarbonisation policies.

However, we can infer what the global impact of more ambitious decarbonisation policies might be on the basis of earlier E3ME modelling exercises, completed before the pandemic. Typically, these have found that a full-scale system transition, aiming for substantially reduced emissions or even

[9] In the IEA Sustainable Recovery (IEA 2020b, 108, 123) scenario annual grid investment is assumed to be US$110 bn, in the same time additional RES deployment is assumed to be about 130-150 GW.
[10] Estimated based on the planned number of tree plantings in the individual projects, subtracting current progress and multiplying with average planting costs per region. Data was collected from the TrillionTree Campaign (2021) website.
[11] This is the lower bound of their estimate.

carbon neutrality, can yield net positive global economic and labour outcomes (IRENA 2019; New Climate Economy and World Resources Institute 2018; Eurofund 2019; Mercure et al. 2018). We expect these conclusions to hold in a pandemic-affected global economy. Indeed, since economies across the globe are currently functioning below capacity, more productive resources are available to undertake the large-scale investment required to bring about decarbonisation. The ‘net’ positive global impact is important to note: our findings for differential impacts by geographical macroregion in this report (Section 4.2) suggest that the stronger restructuring implied by stronger decarbonisation measures would have similar differential effects, even if the low-carbon transition would lead to positive outcomes for the global economy overall (Eurofund 2019; Mercure et al. 2018).

4 Modelling Results

4.1 Introduction

This chapter presents the results of the modelling exercise, focusing first on the global results for economic, labour and environmental indicators. A subsequent section presents regional results to highlight the differences between regions, reflecting their different economic and energy structures. This is followed by a section that reviews the cost and financing of the programs.

Three scenarios were modelled up to 2030, in line with the description provided in Section 3.2:

- Baseline: a projection based on long-term growth prospects as well as the most recent economic projections, including the estimated impacts of COVID-19, by IMF, the World Bank, EC and energy projections by EC and IEA
- VAT scenario: the scenario assumes a consumption-boosting economic recovery, introducing a 5% VAT reduction globally through 2021-2023, gradually phased out
- GRP scenario: this scenario assumes the global implementation of the previously described green policies through 2021-2023, and a limited VAT reduction, again gradually phased out.

We refer to the scenario with a 5% reduction in consumption taxes, but no green measures, as the *consumption-boosting scenario* or simply *VAT scenario.* We refer to the scenario with green policy measures as the *Green Recovery Program* or *GRP* for short. Note that the *GRP* scenario implements some VAT reduction as well, to make the ex ante budgetary cost of the two programs equivalent in scale.[12].

By design, we do not vary the scale of the recovery program between countries in an attempt to reflect the political plausibility of what action might actually be undertaken in each country, because this would obscure the extent to which cross-country impacts differ due to countries' economic and energy structures.

4.2 Global results

GDP

Figure 4.1 shows summary global GDP results for the two scenarios. The results show (left panel) that both the VAT scenario and the GRP deliver a boost to the global economy. The impacts grow during the policy implementation period (2021-23, highlighted) and they decrease after the active intervention ends. However, their effects do not fade away completely. At their peak, in 2023, the GRP and the VAT program add 2.4% and 1.8% to GDP respectively (compared to the baseline), but some effect continues to 2030. We estimate that in 2030 the long-term effects of the GRP could amount

[12] The public cost of the *GRP* measures is supplemented by a VAT reduction to ensure that, together, the ex ante cost to the government budget equals that of the full *VAT* scenario.

to a net positive effect of 1.9% for GDP, compared to 0.4% in the case of the VAT scenario.

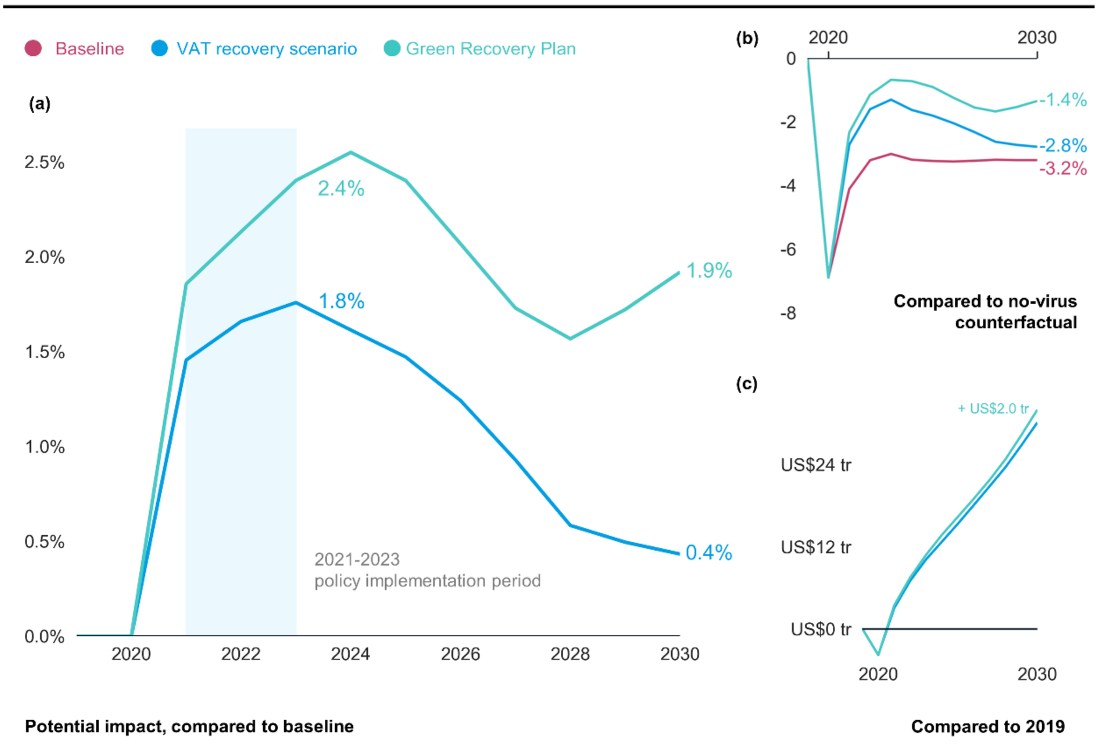
These results, both the magnitude and the stronger long-term effect of the Green Recovery, are consistent with Cambridge Econometrics' previous work (Pollitt 2020). For comparison, IEA estimates that global GDP could be 3-3.5% higher by 2025 if policies proposed in their report are implemented (IEA 2020b, 121).

The upper-right panel of Figure 4.1 presents the current results compared to our pre-COVID baseline (what would have happened in the absence of the pandemic). Even with the implementation of these recovery programs, global GDP does not recover to the level it is projected to have reached if there had been no pandemic, suggesting that even further policy action and spending is required.

The bottom-right panel of Figure 4.1 shows the level of global GDP relative to its 2019 level. After a strong dip in 2020, the economy recovers in both scenarios, showing an overall increase of about US$30 trillion (current prices) by 2030 in the VAT scenario and about US$32 trillion in the GRP scenario.

It is also worthwhile to look into how this overall effect is made up of impacts in different GDP final expenditure components. In the GRP scenario during the policy implementation period, much of the GDP gain is a direct consequence of government spending. Consumption gains during 2021-2023 are lower here as the VAT reduction is smaller and the boost to incomes from other measures has yet to take full effect. However, the boost to investment is much larger, due to subsidised RES investment and grid modernisation.

Figure 4.1: Impacts on global GDP, % difference from baseline



Source: E3ME modelling

After 2023, consumption picks up in the GRP scenario as well. This is partly the effect of higher incomes, and partly because of the constraint that the ex ante fiscal cost matches that of the VAT scenario, so that VAT cuts appear in the GRP scenario in 2024 when the direct green fiscal measures are stopped.

Employment

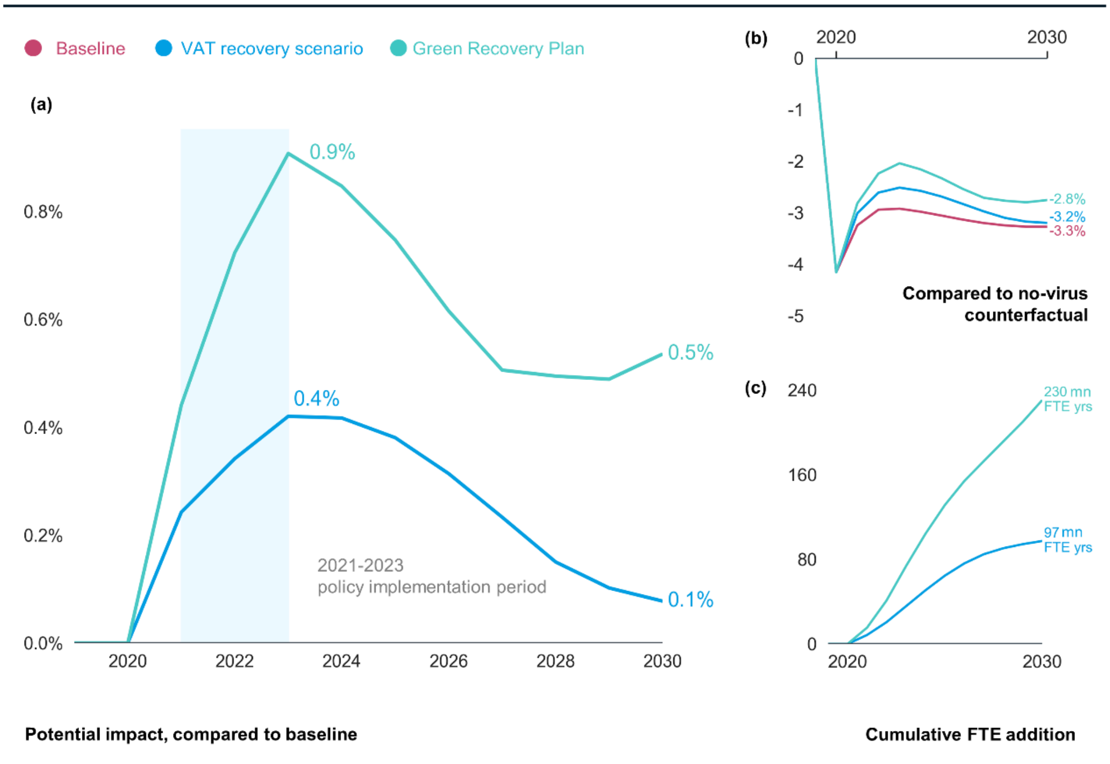
Employment increases by 0.9% by 2023 in the GRP (about 32 million jobs) and 0.4% in the VAT scenario (about 15 million jobs), compared with the COVID-19 baseline, as shown in Figure 4.2 (left panel). As the policy implementation period comes to an end, employment increases more sharply in the GRP scenario than in the VAT scenario because many of the additional jobs in the GRP scenario are temporary by design (e.g. reforestation efforts, energy efficiency projects). Nevertheless, in the current situation creating short-term employment can be important for supporting livelihoods, especially for those who lost their jobs. While not all the employment gains are permanent, it is important to note that the GRP can add about 230 million FTE years of employment cumulatively over the 2021-30 period.

Although employment falls back more sharply in the GRP scenario, the level of jobs remains higher than in the VAT scenario. Increased incomes in the implementation period led to higher consumption in the later years which supports higher economic activity and more jobs. But, as with GDP, employment remains lower than projected under the counterfactual no-COVID-19 case, as shown in the upper-right panel of Figure 4.2.

CO_2 emissions

The impact of the scenarios on CO_2 emissions is presented in Figure 4.3.

Figure 4.2: Impacts on global employment, % difference from baseline



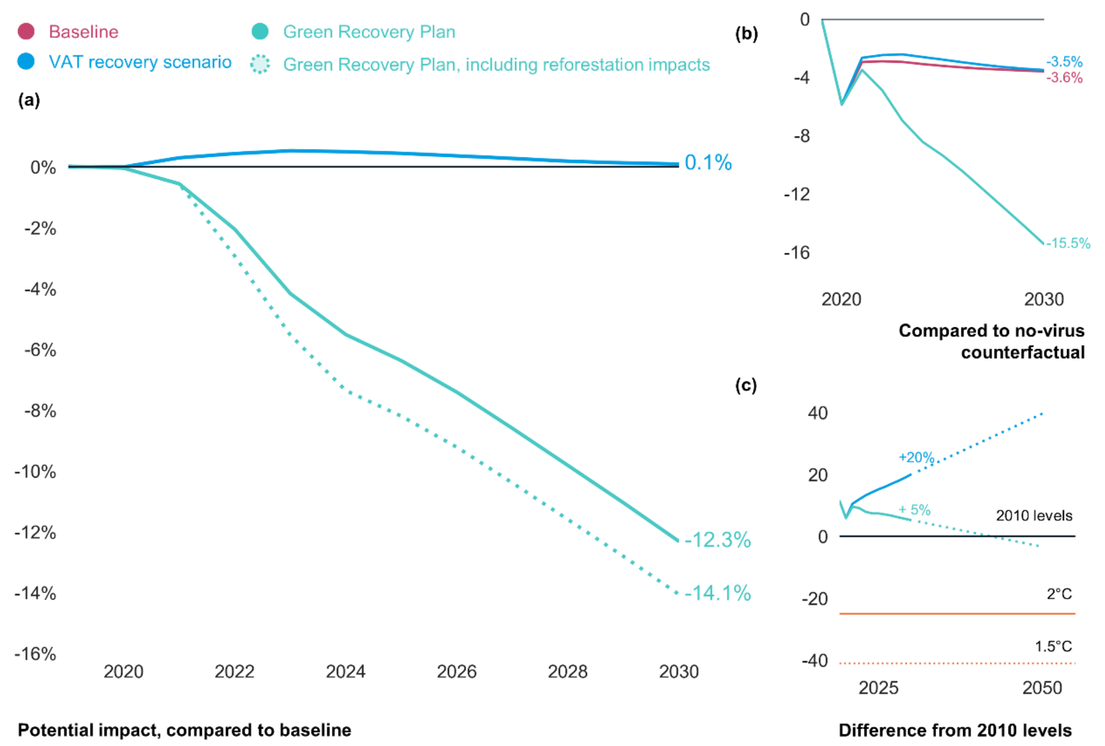
Source: E3ME modelling

E3ME estimates CO_2 emissions on the basis of its projections of energy consumption of different fuels and the carbon intensity of those fuels. The CO_2 emissions embodied in other products (e.g. the emissions associated with the production of the steel used to make electric cars or wind turbines) are also incorporated, because energy use is represented for every sector. The carbon intensity data are derived from historical time series for emissions in the EDGAR database and for fuel use in IEA's energy balances (Cambridge Econometrics 2019).

The VAT scenario raises emissions slightly compared to the COVID-19 baseline. The GRP scenario produces substantial reductions: global emissions are 12% lower than in the COVID-19 baseline by 2030.

E3ME does not include emissions for the LULUCF sector and so we have calculated the contribution of the reforestation program to emissions reductions outside the model. We take the scale of reforestation in each climatic region and use an average CO_2 removal rate based on Bernal et al. (2018). On this basis, reforestation would cut net emissions further, to 14% below the baseline by 2030. For comparison with IEA, which reports figures for 2025, we estimate a reduction of about 1.8 $GtCO_2$ by 2025, excluding the impacts of reforestation and 2.4 $GtCO_2$ including it. IEA's Sustainable Recovery scenario estimates a somewhat larger reduction (3.5 $GtCO_2$) (IEA 2020b, 123). CO_2 emissions are lower than the no-COVID-19 baseline projection (upper-right panel) even in the VAT scenarios because GDP (and hence energy demand) is lower.

Figure 4.3: Impacts on global CO_2 emissions, % difference from baseline



Source: E3ME modelling

The bottom-right panel shows the emission pathways from the scenarios compared to 2010 levels, the benchmark used by IPCC (Edenhofer et al. 2014). Both scenarios show emission levels above 2010 figures by 2030. In the case of the *VAT* scenario this is more than 20%, while in the *GRP* it is reduced to 5% over 2010 levels. In the figure we extrapolated simulated trends to 2050 and also indicated the level of emission reduction that would need to be reached in order to have a chance to limit global warming to 1.5°C or 2.0°C (Edenhofer et al. 2014, TS 54). While the GRP-like recovery can certainly be a good step in the right direction, there is still much to be done.

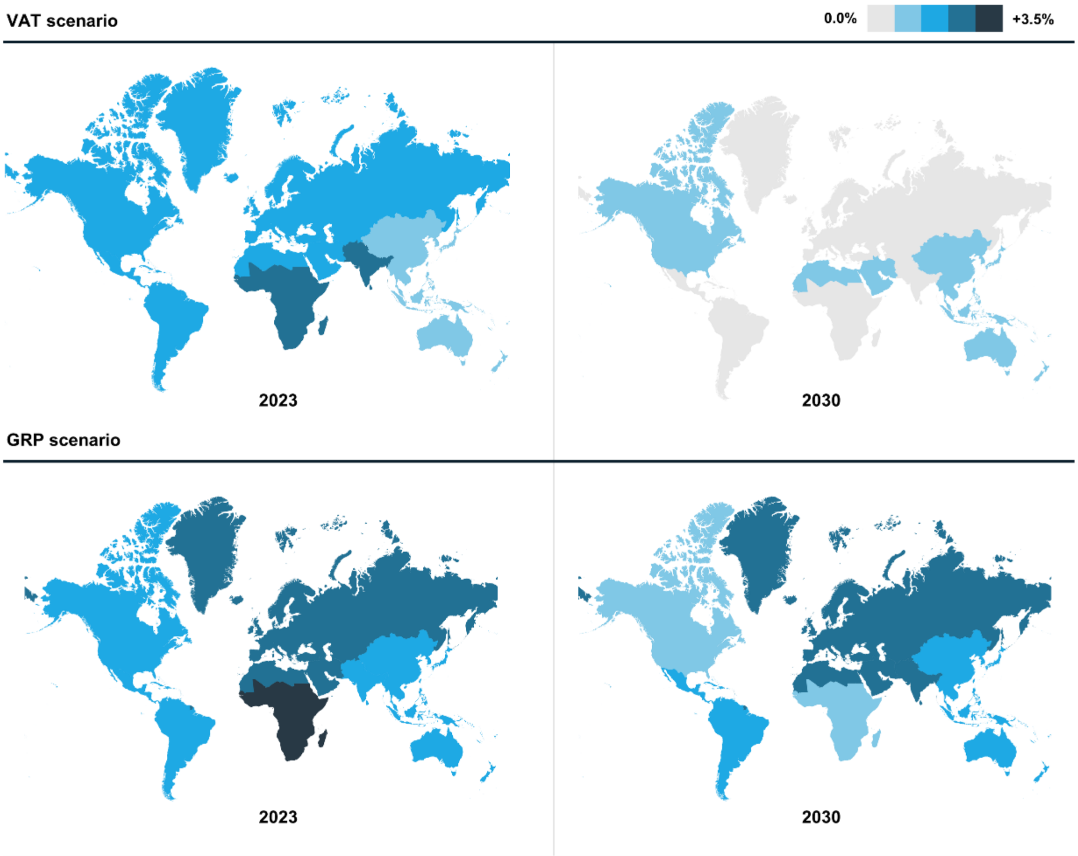
4.3 Results for global macroregions

This section provides a review of how impacts differ across macroregions. We follow the World Bank's classification, distinguishing the seven macroregions shown in Appendix B, way in which E3ME's regions are aggregated to the World Bank macroregions is also shown in Appendix B.

GDP

Figure 4.4 compares GDP results across the seven macroregions in 2023 (left) and in 2030 (right). As noted in the global results, the short-term effects in both scenarios are stronger than the long-term effects, reflecting the temporary nature of the stimulus packages. In the GRP scenario Sub-Saharan Africa gains the most in the short-term, energy-related investments and reforestation efforts provide a large boost both to employment, thus consumption, and to investments.

Figure 4.4: Impacts on GDP by 2023 and 2030 by macroregions, % difference from baseline



Source: E3ME modelling

In the longer term however, the strength of the impacts gradually diminishes. However, as we have discussed, the GRP is able to induce some permanent increases. Gains by 2030 are between 0.6-3.2% compared to the baseline, differing between macroregions.

The long-term effect is the weakest in North America and Sub-Saharan Africa. In both cases gains from temporary boost of the intervention fade by the end of the decade. Sub-Saharan Africa shows an interesting pattern, as short-term effects are also the strongest here. The short-term impact is explained by policies with direct spending: energy efficiency and reforestation. When these direct expenditures are phased out, two effects account for the weaker long-term impact. First, as the scale of electrification is more limited, the continuing increase in power generation renewable energy investments that drive long-term effects in other regions has a smaller impact than elsewhere. This can be also interpreted in a more positive manner: the impact of the recovery program on power generation investments diminish here faster, because power generation investment growth is faster in the region in the baseline. For example, the mean annual growth rate of power generation investments without the incentives discussed here is 0% between 2025-2030 in Europe and Central Asia, while it is 5% in Sub-Saharan Africa. Second, some countries are exporters of fossil fuels and so suffer a larger restructuring impact as global demand for these products is reduced.

Long-term effects stay the strongest in Europe and Central Asia. This is explained by a strong investment response and the induced investment into power generation. Most of the GDP increase in the early years in the region is driven by a boost of investment, triggering long-term employment gains leading in turn to increased consumption in the second part of the analysed period. This kind of short-term to long-term investment in Europe and Central Asia is partially driven by the estimated relationships between output and investment. Estimated coefficients of the E3ME model indicate that in Sub-Saharan Africa output increase leads to roughly half the increase in long-term endogenous investments compared to the global average.

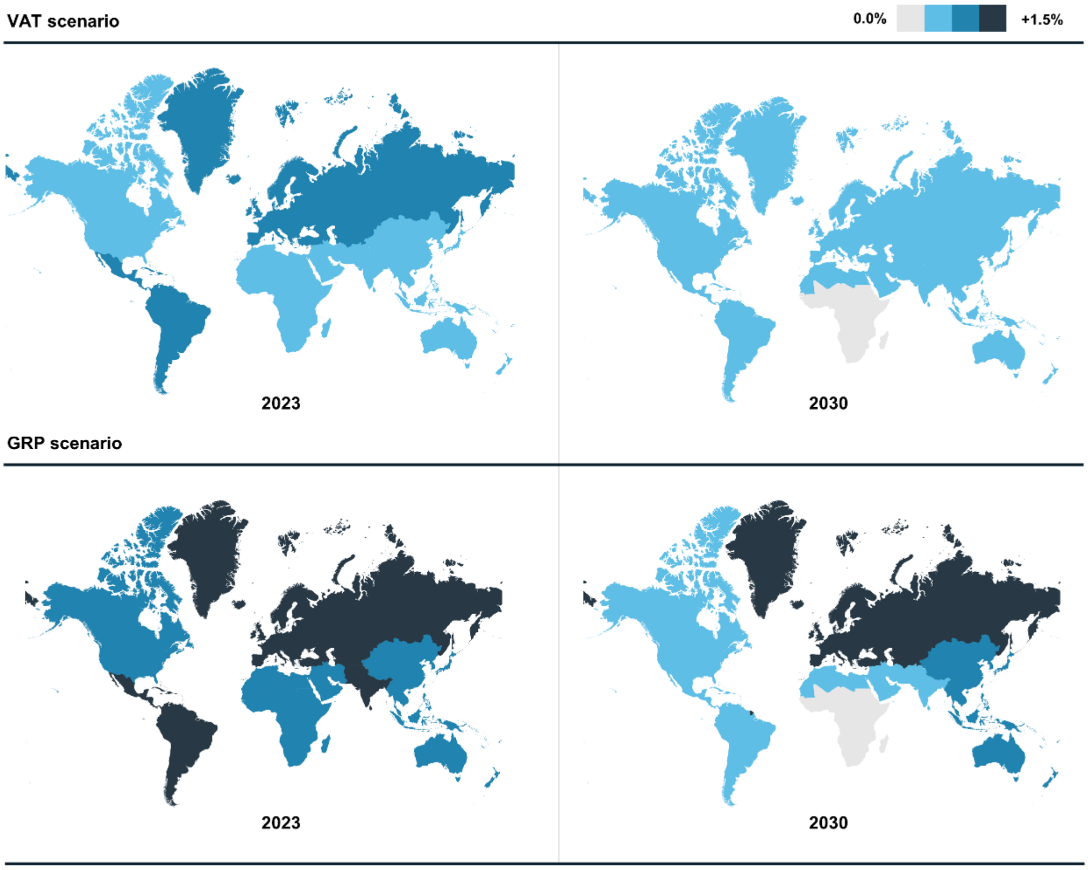
Employment

While employment gains are stronger in the GRP for every region both in the short- and long-term than in the VAT there are substantial differences between the macroregions. Impacts are between 0.5-1.4% in 2023, with long-term effects by 2030 between 0-1.2%.

There are two separate patterns of employment impacts: in the Sub-Saharan Africa, Latin America & Caribbean and South Asia regions a strong short-term employment impact is followed by a fading out of the induced employment additions. Employment gains (compared to the baseline) as much as 1.2% during the policy implementation period largely disappear by 2030. In Sub-Saharan Africa, employment increases due to reforestation are strong, as this is a labour-intensive activity, nevertheless they are ‘project-based’ and thus temporary. While in the South Asia region, despite an initial growth in construction employment as the interventions fade out, employment gains relative to the baseline shrink as well – but average wages grow in the sector.

What needs to be considered is that, in Sub-Saharan Africa and South Asia, employment growth is strong in the baseline, while in Europe for example, impacts are relative to more stagnant employment figures in the baseline.

Figure 4.5: Impacts on employment by 2023 and 2030 by macroregions, % difference from baseline



Source: E3ME modelling

The other pattern is in regions such as North America, Europe & Central Asia and East Asia & Pacific, where after a similar short-term impact a long-term positive impact can also observed. In these cases investments during the policy implementation period trigger long-term investments (e.g. in RES) which keeps employment levels higher than it would be otherwise.

This impact is also driven by the difference in long-term investment response to output growth (see discussion above).

Appendix C shows projected GDP and employment impacts in 2023 and 2030 by macroregions in a tabular format.

4.4 Sectoral results

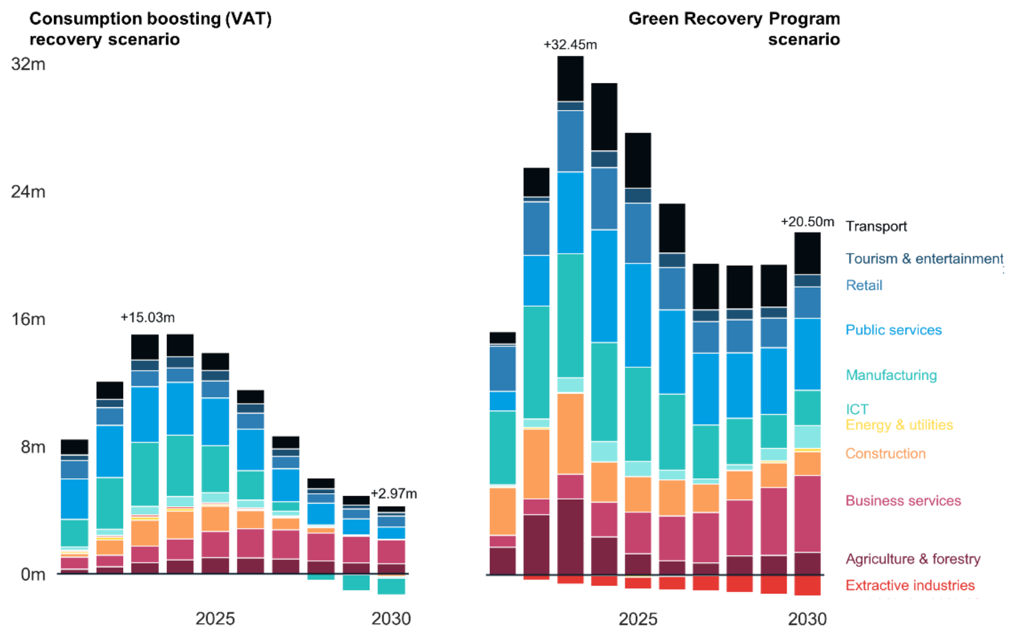
In the sectoral analysis presented here, we aggregate the E3ME industries to 11 broad categories, following the mapping shown in Appendix B. We focus on employment because of its importance for social policy.

Employment

Figure 4.6 presents sectoral employment results (differences from baseline), by year and by broad sectoral aggregates.

Some sectoral effects in both scenarios are due to the general stimulus to the economy, which is the kind of the effect that ’colourless’ policies have. Hence, employment in manufacturing, construction and business services increases in both scenarios. In the VAT scenario, additional employment in construction disappears after the policy implementation period comes to an end, because extra investment spending falls off when the wider economy is no longer receiving the stimulus of lower VAT. The trend of the manufacturing sector also merits discussion here. In the simulation after 2026 the additional impact in manufacturing not only diminishes, but actually turns negative.

Figure 4.6: Impacts on employment by sector globally 2020-2030, employment difference from baseline



Source: E3ME modelling
Note: figures presented at the top of the bars in 2023 and 2030 represent net additional employment (i.e. includes jobs lost). Please note that the figures present employment difference from the baseline in the given year, not employment increase in the given year.

Employment gains in the GRP scenario in agriculture and forestry, manufacturing and construction are a direct consequence of the policy interventions (reforestation, car scrappage, energy efficiency). There are important indirect effects as well: for example, gains in retailing (including car sales) jobs are driven by increasing incomes as well as by policy impacts.

Unsurprisingly, the GRP scenario shows job losses in extractive industries (losses in coal mining and oil and gas extraction offsetting increases in quarrying of building materials). This highlights the importance of Just Transition policies for communities dependent on fossil fuel extraction and processing, to provide reskilling, training and new opportunities in these locations.

Employment targeting

The comparison in Table 4.1 shows that the GRP is expected to raise employment increase in some sectors that have seen major losses, such as transport, manufacturing and construction, and to a lesser extent in agriculture and retailing. However, the package we have modelled is not expected to do much to address job losses in tourism and personal services.

Table 4.1: Labour impacts of the COVID-19 pandemic by economic sector and GRP impacts on sectoral employment

	Employment change (YoY) (%)		GRP impact on global employment (%) from baseline			
Sector (ILO)	*2020 Q2*	*2020 Q3*	Sector (aggregate)	*2021*	*2022*	*2023*
Accommodation and food service activities	-20.3%	-13.6%	Tourism & entertainment	0.1%	0.1%	0.2%
Other services	-13.4%	-6.3%				
Transport, storage	-6.2%	-6.1%	Transport	0.6%	1.4%	2.1%
Agriculture, forestry and fishing	-3.9%	-3.1%	Agriculture & forestry	0.2%	0.4%	0.5%
Wholesale and retail trade; repair of motor vehicles and motorcycles	-7.2%	-2.8%	Retail	0.6%	0.7%	0.8%
Manufacturing	-5.6%	-2.5%	Manufacturing	1.0%	1.4%	1.5%
Construction	-8.4%	-2.2%	Construction	1.2%	1.7%	1.9%
Real estate, business and administrative activities	-2.5%	-2.1%	Business services	0.3%	0.4%	0.6%
Financial and insurance activities	3.4%	3.5%				
Education	-1.4%	0.1%	Public services	0.0%	0.0%	0.1%
Public administration and defence; compulsory social security	-1.2%	1.8%				
Human health and social work activities	-0.8%	0.5%				
Information and communication	5.0%	7.3%	ICT	0.2%	0.8%	1.3%
Utilities	0.1%	1.1%	Energy & utilities	0.4%	0.4%	0.2%
Mining and quarrying	3.6%	2.8%	Extractive industries	-0.2%	-0.8%	-1.5%

Source: ILO 2021 (14) and E3ME modelling

4.5 Financing

We calculate the ex post VAT revenue forgone due to the consumption tax cut as the difference between revenue collected in the baseline and what is collected in the scenarios. The figure therefore includes the consumption tax collected on additional spending stimulated by the tax cut. We estimate that global consumption tax revenue forgone in the VAT scenario is about US$3 trillion (or 3.4-3.6% of estimated global GDP in those years[13]) in each year between 2021-23.

The estimated total ex post fiscal cost of the GRP scenario is between US$2.5-2.8 trillion annually through 2021-2023 (2.9-2.4% of GDP). In this scenario the amount of forgone VAT revenues is smaller because the consumption tax cut is only part of the package: about 50% of the total cost is forgone consumption tax revenues in 2021, falling to less than 20% by 2023 (about 0.4% in GDP terms).

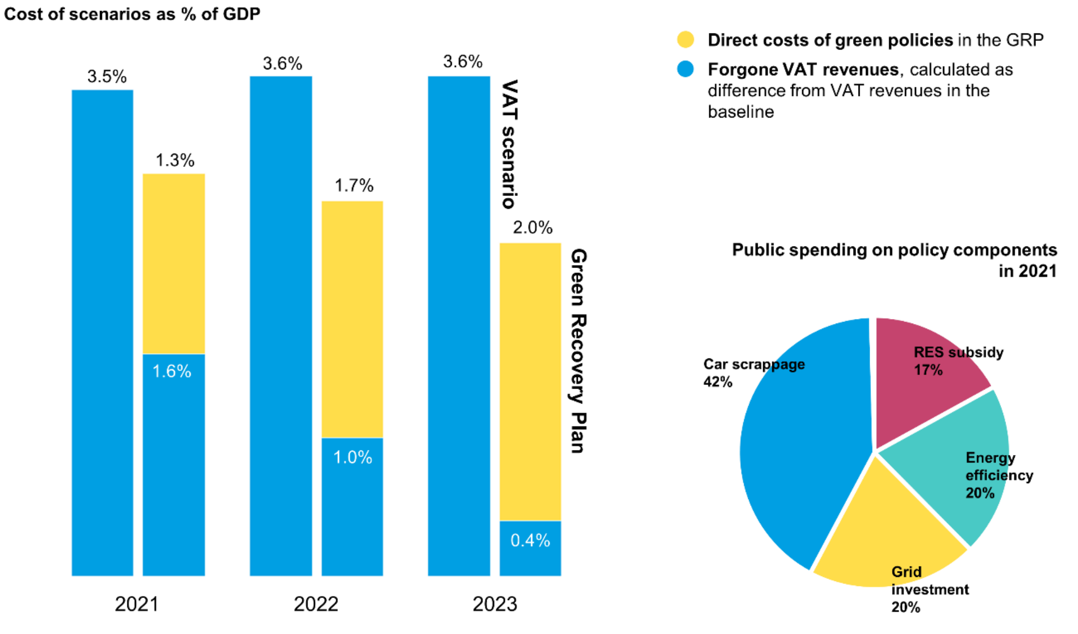
It is important to note that these figures are hardly comparable to the US$15 trillion figure, the total global cost the relief and recovery measures estimated by January 2021 (O'Callaghan et al. 2020). Because as we noted there, the US$15 trillion figure does not have a temporal dimension. Nevertheless, taking

[13] GDP also changes due to the effect of the policies.

the ‘cost’ of the scenarios over 3 years (2021-2023) we can conclude that the overall ‘price’ of the VAT scenario is about US$11 trillion, while it is about US$8 trillion for the GRP scenario.

Most of the direct spending in the GRP scenario is directed towards the car scrappage program (42%), while spending for the RES subsidy, energy efficiency and grid investments are each around 20% (see Figure 4.7). The reforestation measure is relatively inexpensive, accounting for just 0.4% of the overall package.

Figure 4.7: Cost of policy scenarios



Source: E3ME modelling
Note: the costs of reforestation do not appear in the right panel as they are much smaller than spending on other components; spending of reforestation efforts amount to about 0.4% of total GRP spending in 2021.

With gains in employment and incomes the GRP scenario also leads to increased government incomes considering income tax and social security payments. We estimate that, without adjusting tax rates, the GRP increases direct tax revenues by about US$261-306 bn in 2021-23. Due to the long-term effects of the scenario we estimate further additions over US$1 trillion in the subsequent years (total government revenue increase only from income taxes and social security is estimated to be over US$2 trillion).

The scenario also triggers substantial increases in private investments and spending (e.g. RES capital subsidy, car scrappage). In the VAT scenario an initial 1.1-1.3% increase in private investments is likely driven by intertemporal substitution, as investments drop below the baseline by 2030. While in the GRP scenario we see global investment increases between 1.3-3.5% compared to the baseline, even if we subtract direct government spending, with gains are still at 1.9% in 2030. Timing of the investment is notably different: in the policy implementation period the effects are largely driven by public investments and private investments are weaker, but from 2024 private investments effect here are much stronger and the effect is permanent. Additional private investment in 2024 is estimated to be around US$990 bn.

5 Country-level Case Studies of Green Recovery

5.1 Introduction

This chapter summarises the results from two customised applications of the E3ME to model Green Recovery measures at the level of a country or a region. The first application relates to analysis of the South African economy, carried out as part of the present study and the subject of a full, separate report The second application refers to an analysis for Latin America and the Caribbean carried out using E3ME by the UN Economic Commission for Latin America and the Caribbean (UN ECLAC) in 2020.

5.2 South Africa

The first case study was carried out as part of the present PAGE study. It focused on the analysis of potential economic recovery measures in South Africa. Even before the pandemic, South Africa was facing long-standing economic and social challenges. Once the pandemic hit, it prompted the South African government to introduce measures to mitigate the short-term impacts of the pandemic and to announce a long-term recovery plan: the Economic Reconstruction and Recovery Plan (South African Government 2020a; 2020b).

Scenarios

In the case study, we used E3ME to analyse the potential impacts of the announced policies in relation to Green Recovery measures and potential steps towards avoiding environmental harm. We developed three scenarios, representing elements from the published plan (South African Government 2020b), and added one sensitivity case ("Green push") assuming more ambitious decarbonisation targets, notably including moves to phase out coal-based power generation.

Key policies from the Economic Reconstruction and Recovery Plan were grouped into three sets:

- **conventional policies**, including interventions such as infrastructure investment, localisation of production, subsidies for the tourism sector and food vouchers
- **public works**, in the form of public employment programmes in various sectors
- **green policies**, including subsidies for renewables, grid investment, energy efficiency measures and restriction on new investment in coal-fired power stations.

In the analysis these policy sets are accumulated successively: first only the impacts of the 'conventional policies' are modelled; then the effects of the 'public works' package are added; finally, the 'green policies' are added to give the combined effect of all three elements of the Plan.

As the Plan provides only high-level indications for the funding of the measures, the modelling makes certain assumptions about both the extent and the funding of these policies. We follow the assumptions of the Plan regarding the large role attributed to private investment, which the much smaller government spending element is intended to unlock. Unless it is clear that the intention is to repurpose currently planned spending, an increase in government borrowing is assumed to fund the public spending element[14].

Six final scenarios were modelled for the decade to 2030, many of them combining the above-mentioned policy sets:

- No-COVID-19: a projection of what would have happened in the absence of the pandemic
- No-recovery: in the scenario the effects of the pandemic were modelled through demand, supply and investment shocks, with no long-term recovery plan
- A: focusing on ‘conventional policies’: large-scale infrastructure investments, localisation policies, direct sectoral subsidies and food vouchers for vulnerable groups
- A+B: combining scenario ‘A’ with the implementation of a public works program
- A+B+C: combining ‘A+B’ with green policies taking the form of investment subsidies for renewable energy and grid and energy efficiency investments
- ‘Green push’: the scenario builds on ‘A+B+C’, but introduces limits on new coal investments, which leads to a faster transition and more investment in renewables.

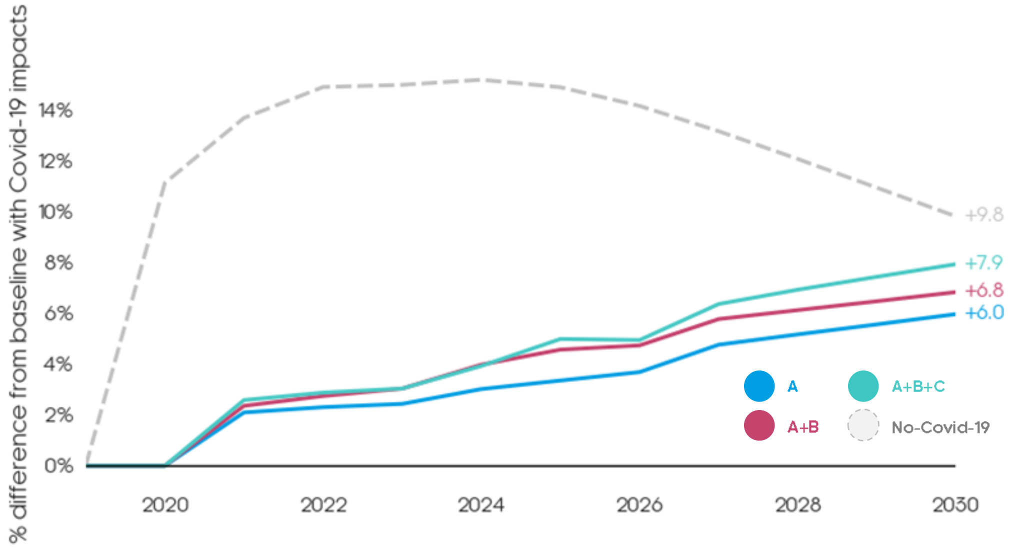
Results

Based on the assumptions made, and notably that the South African government will be successful in attracting substantial private sector investment, the package of measures boosts GDP sufficiently to regain the 2030 level projected before the pandemic. But the respective scenarios vary in their impacts on unemployment and, especially, CO_2 emissions. In the absence of the green policies, the economic recovery results in higher emissions in 2030 than projected in the no-COVID-19 baseline.

Figure 5.1 shows that scenario A, the scenario simulating conventional policies, produces the largest boost to South African GDP: this is the element of the Plan that is projected to incorporate the largest increase in spending. The smaller public works policies (‘A+B’ in Figure 5.1) and green policies (‘A+B+C’ in Figure 5.1) packages boost GDP further when implemented alongside the conventional policies. Because the green policies package focuses on decarbonising power generation, it involves substitution of investment in renewables for investment in coal-fired power stations.

[14] PAGE (2017a) finds that most green economy initiatives in South Africa are publicly funded.

Figure 5.1: Impacts of the scenarios on GDP (difference from COVID-19 baseline or "No recovery")

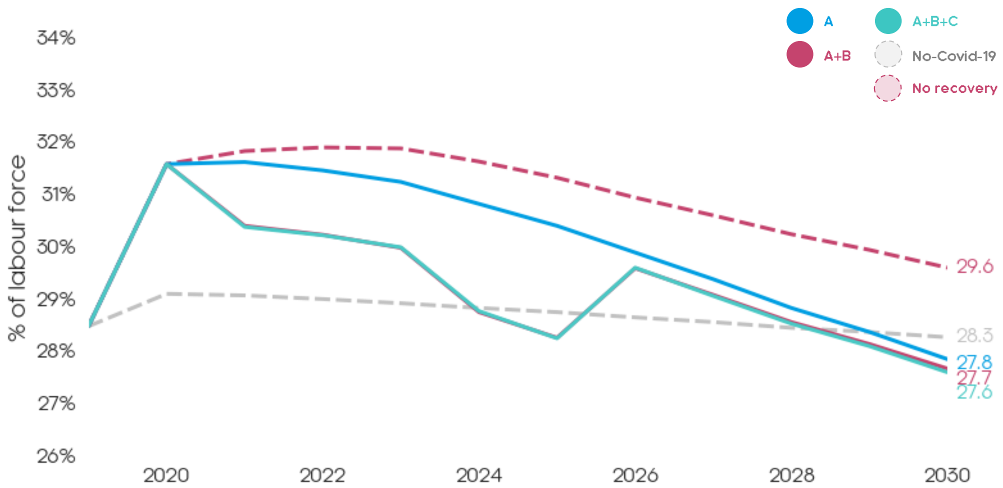


Source: E3ME modelling

Renewables require more up-front investment than coal in return for the elimination of ongoing fossil fuel inputs during operation; hence there is a net increase in investment in the years when the subsidy is in operation.

The stimulus given by the recovery measures creates new jobs and brings unemployment levels below the no-COVID-19 baseline, as shown in Figure 5.2.

Figure 5.2: Unemployment in the scenarios



Note: The chart shows the official rate of unemployment.
Source: E3ME modelling

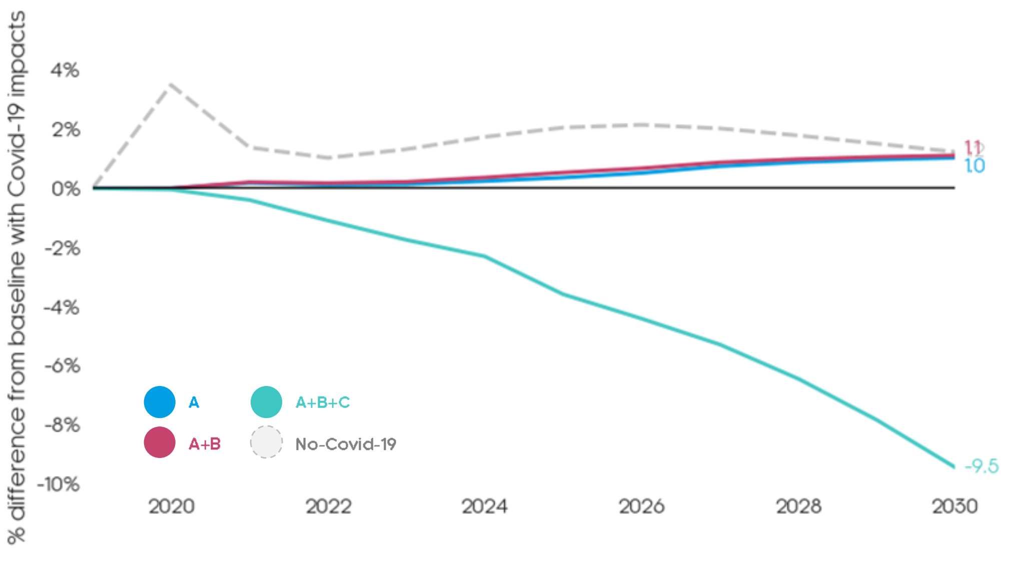
This means that, assuming that the expected private investment is levered in by the policy measures, employment increases can not only offset the losses caused by the pandemic but can contribute towards the goal of addressing the structural issue of unemployment in South Africa. Because scenario A involves the largest level of public and private investment it, has the largest impact on jobs. The public works programme in scenario B drives unemployment down further, but by its nature this impact is temporary and largely disappears when the programme comes to an end. (In Figure 5.2 the 'A+B' result coincides with 'A+B+C' and so is not distinguishable from it).

In scenario C, the focus is on measures to decarbonise the economy, resulting in job losses in coal mining. Nevertheless, these job losses are offset by new jobs created in other areas, notably the renewables supply chain, resulting in a small additional positive impact on economy-wide unemployment ('A+B+C' in Figure 5.2).

Finally, the case study looks at the effects on CO_2 emissions. It notes that despite the country's high reliance on coal, South Africa aims to reach its NDC goals. While the impact of the COVID-19 pandemic on economic activity and travel has reduced CO_2 emissions (Evans 2020; Liu et al. 2020), the challenge is to combine economic recovery with sustained reductions in CO_2 emissions over time.

The CO_2 emission impacts of the modelled scenarios are shown in Figure 5.3. A recovery without strong green policies leads to a quick return to the emissions levels seen before the crisis, in line with others' findings (Evans and Gabbatiss 2020; Peters et al. 2012). The higher economic activity in scenario A and scenario A+B result in an increase in CO_2 emissions, matching the pre-pandemic projection in 2030. Without green policies to foster the transition, the need for expanded and reliable power generation is likely to be met through additional investment in coal-fired power generation, which will not be consistent with meeting targets to reduce carbon emissions.

Figure 5.3: Impact of scenarios on CO_2 emissions (difference from COVID-19 baseline or "No recovery")

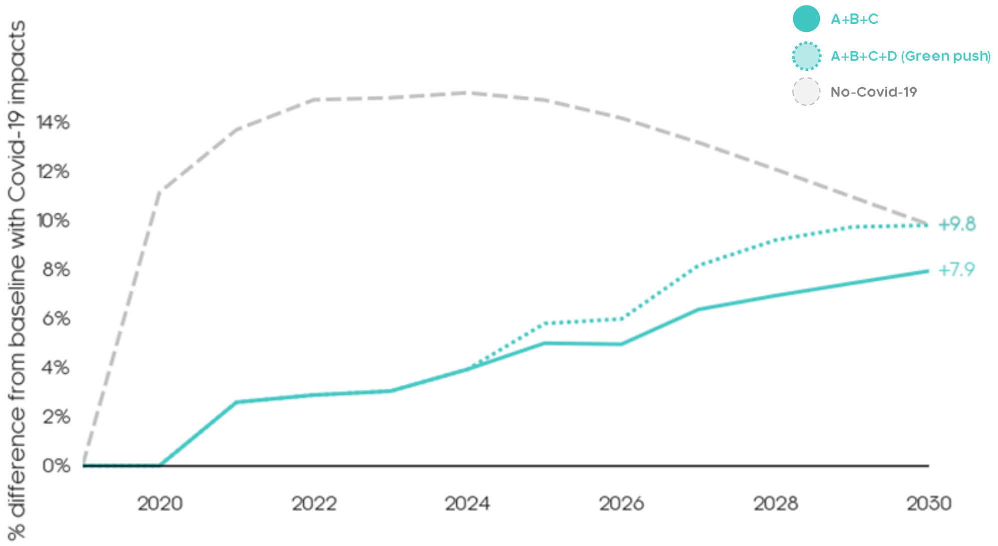


Source: E3ME modelling.

The results for scenario A+B+C indicate that higher economic activity can lead to significant CO_2 emission reductions if policies to green the economy are implemented: a reduction over 9% compared to the baseline is achieved by 2030, equivalent to a reduction of more than 7% from 2010 levels, compared with an increase of 4% from 2010 levels in scenario A+B. Both cases are within South Africa's broad target range for emissions of -26% to +12% of 2010 levels by 2030 (Climate Action Tracker 2020b), but clearly a recovery with green policies secures a much better environmental outcome.

In addition, the case study discusses results from a “Green push” sensitivity. This scenario simulates a future in which South Africa goes beyond its current plans in terms of transitioning to a low-carbon economy[15]. Again, the focus is on the goal of cutting carbon emissions rather than broader green objectives. The scenario assumes the same rate of capital subsidy for renewables that is included in the green policies of scenario A+B+C, but imposes a lower limit for coal-fired generation capacity, resulting in higher investment in renewables.

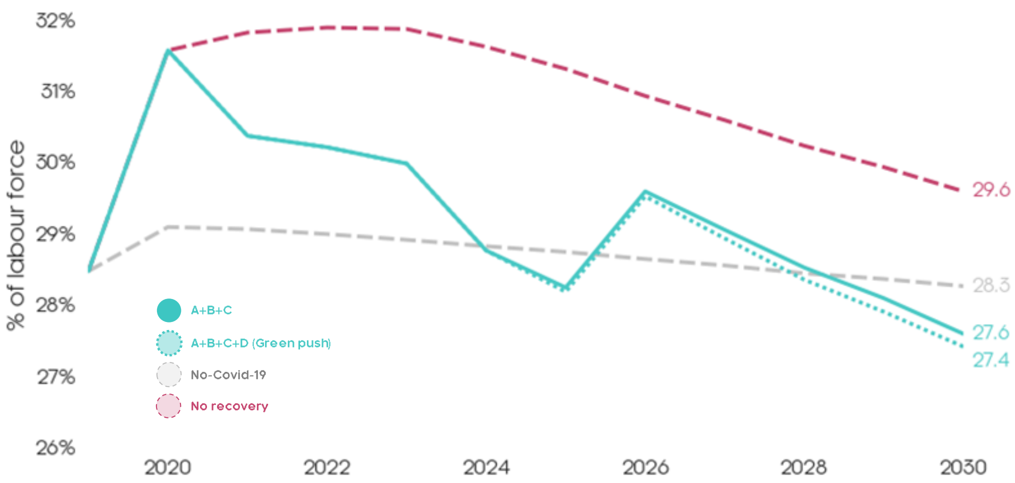
Figure 5.4: Economic activity (GDP), ‘Green push’ results



Source: E3ME modelling.

The greater scale of investment in this scenario gives a substantial further boost to GDP compared with the combined scenario A+B+C, raising GDP gains from 7.9% to 9.8% by 2030 (compared to the COVID-19 baseline).

Figure 5.5: Unemployment, ‘Green push’ results



Source: E3ME modelling.

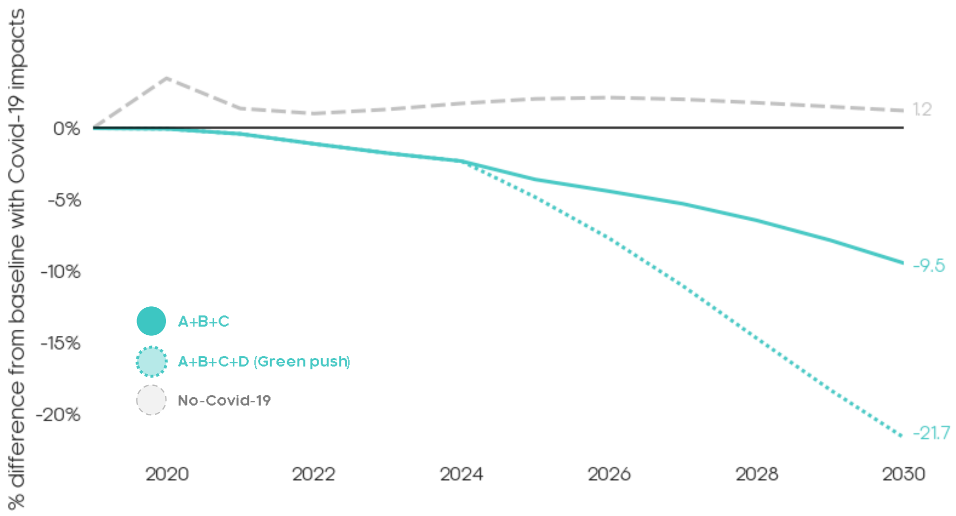
The ‘Green push’ scenario results in job losses in the coal sector but creates new jobs in the renewables sector. The net effect of the ‘Green push’ scenario on employment compared to A+B+C is slightly positive, but the difference

[15] Possibly challenging the limits that the South Africa’s Integrated Resource Plan currently imposes on annual build of renewables (Department of Energy 2020),

between the two scenario outcomes for the rate of unemployment is less than 0.2 percentage points, as shown in Figure 5.5.

Figure 5.6 shows that CO_2 emissions are reduced further, as expected. By 2030, projected CO_2 emissions are 22% lower than in the COVID-19 baseline, or 20% lower than 2010 levels. This puts South Africa much closer to the more ambitious end of the reduction target (a 26% reduction).

Figure 5.6: CO_2 emissions, 'Green push' results



Source: E3ME modelling.

The results suggest that, if the assumed conditions are met, these plans can mitigate the economic effects of the pandemic. While economic activity, even in the combined scenario, stays below the counterfactual no-COVID-19 case, unemployment is lowered. This results from the combination of large-scale investments, localisation policies and a public works program, which provides temporary relief.

Without green elements, the recovery will bring an increase in CO_2 emissions. Policies that achieve cuts in CO_2 emissions will lead to fewer jobs in coal mining, but the net employment effect can be positive, as the growing energy and construction sector provide new opportunities. A more ambitious carbon reduction target than contained in existing plans is projected to boost GDP further while having a net neutral effect on employment[16], while cutting carbon emissions more sharply.

5.3 Latin America and the Caribbean

The second case study was carried out by ECLAC for a report to its member states, *Building a New Future: Transformative Recovery with Equality and Sustainability* (ECLAC 2020b), published in October 2020. ECLAC undertook analysis to support its call for a combination of economic, industrial, social and environmental policies to simulate an economic recovery characterised by equality and environmental sustainability. The summary here draws extensively on that report.

[16] The model does not calculate with skills mismatch and assumes that employees are able to transition across sectors within a year. In reality that transition is likely to require additional reskilling policies and to take longer than allowed for here.

ECLAC's report begins by documenting the three long-term crises facing Latin America and the Caribbean, in common with countries around the world: slow economic growth in the decade since the Great Recession, a widening inequality gap over the past 30 years, and widespread environmental degradation, including global warming, as a result of economic development. The 2020 crisis, precipitated by governments' measures to contain the COVID-19 pandemic, exacerbates acutely the long-term economic and social problems and the pandemic itself is a symptom of the negative impact of economic development on nature (UNEP and ILRI 2020).

These crises are experienced in Latin America and the Caribbean in particular ways. The region's economies are heavily dependent on their role as an exporter of biomass and minerals to the global economy and so are particularly exposed to the problems of intense exploitation of these resources. Deforestation has accelerated. Inequality in the region is high and governments' capacity to address this, and other problems, is constrained by low tax revenue in relation to GDP. Particular groups (women, indigenous people and Afrodescendents) receive lower wages than others with the same level of education.

Interaction among the three crises highlights the nature of the challenge: given pronounced inequality, a high rate of economic growth is needed to raise significantly the living standards of the poor but, under the existing model of economic development. higher economic growth entails more environmental damage which, in time, degrades the ecosystem services on which the economy and society depend. To break this cycle, a different kind of economic development will be required.

ECLAC used the E3ME model to represent its scenarios for alternative paths because it integrates some of the key features of the three crises. It describes the economy in sectoral detail, allowing the sectors most responsible for environment degradation and offering better or worse job opportunities to be distinguished. It has an explicit treatment of the use of fossil fuel and renewable energy sources and the associated CO_2 intensity of energy use. It does not assume that there are strong self-equilibrating processes at work to promote rapid economic recovery from the impact of the pandemic. And it distinguishes four of the region's national economies (Argentina, Brazil, Colombia, and Mexico) together with a fifth region that encompasses the rest of Latin America and the Caribbean.

Scenarios

Four scenarios were modelled for years to 2030:

- Business as Usual: a projection of what would have happened in the absence of the pandemic
- COVID: the impact of the pandemic, constructed by adding shocks to the types of spending and the sectors most exposed to the social distancing restrictions and health impacts of the pandemic
- 'Unconditional Big Push': only the countries of Latin America and the Caribbean introduce a recovery package intended to drive a big push for sustainability
- 'Conditional Big Push': the countries of Latin America and the Caribbean introduce an expanded recovery package intended to drive a big push for

sustainability, while the rest of the world also adopts measures pursuant to a global environmental agreement.

The Business as Usual scenario assumes a continuation with the existing fossil fuel-based path of development, albeit with existing mitigation policies maintained. It follows the Current Policies Scenario of IEA (2018).

The COVID scenario is constructed by adding shocks to consumption and investment spending to the Business as Usual scenario. The size of these shocks is designed to match ECLAC's own estimates of the scale of impact of the pandemic in the region (ECLAC 2020a), together with the scale of impact in countries in the rest of the world estimated by IMF (2020b).

In the study's 'Unconditional Big Push' scenario, the countries of Latin America and the Caribbean introduce a recovery package with policies that target reductions in greenhouse gas emissions in line with their unconditional commitments under their NDCs (implying a 13% cut in emissions relative to the COVID-19 scenario by 2030); only the unconditional targets are met because of the assumption that the rest of the world takes no accompanying action. Specifically, the scenario assumes that governments introduce subsidies to kick-start take-up of non-conventional renewable energy technologies in power generation and extend regulations to promote a higher biofuel blend and adoption of low-emission road transport vehicles. This case study includes non-environmental policies to address social inequality: an increase in public spending on health to support better access to medical care among the poor. Unlike the South Africa case study, budget neutrality is assumed compared with the COVID scenario: financing is provided by the phasing out of fossil fuel subsidies.

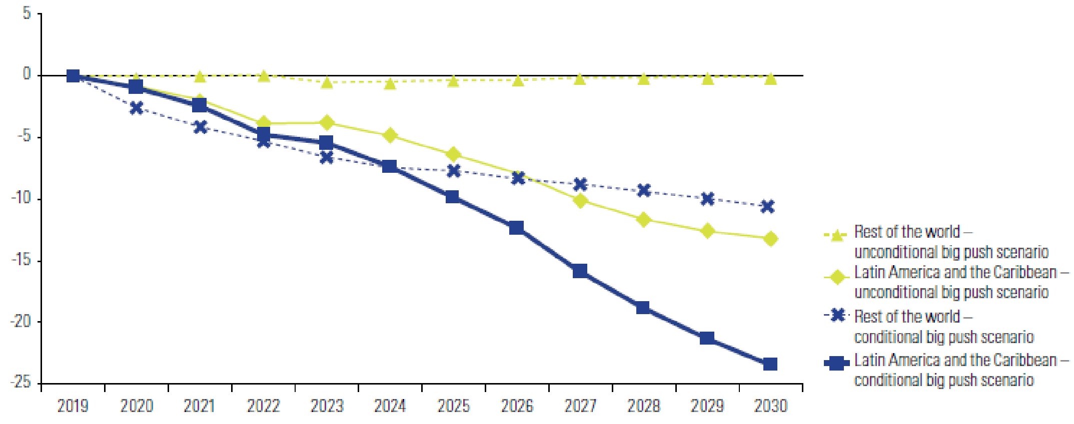
In the 'Conditional Big Push' scenario, the rest of the world introduces green fiscal reforms and provides support to Latin America and the Caribbean to promote reforestation, allowing them to meet the more ambitions targets of their conditional NDCs (a 23% cut relative to the COVID-19 scenario by 2030). The scenario assumes an across-the-board green fiscal reform in the rest of the world, raising a tax of €27 per tonne of CO_2 and using the receipts to lower VAT and payroll taxes, together with support for reforestation programs in Latin America and the Caribbean extending to 3.8m ha over 2020-30 and hence cutting the region's net GHG emissions.

Results

By design, the two scenarios achieve substantial reductions in GHG emissions, as shown in Figure 5.7.

Figure 5.7: Latin America and rest of the world: CO_2 emissions relative to COVID-19 baseline under different big push scenarios, 2019-2030

(Percentages)



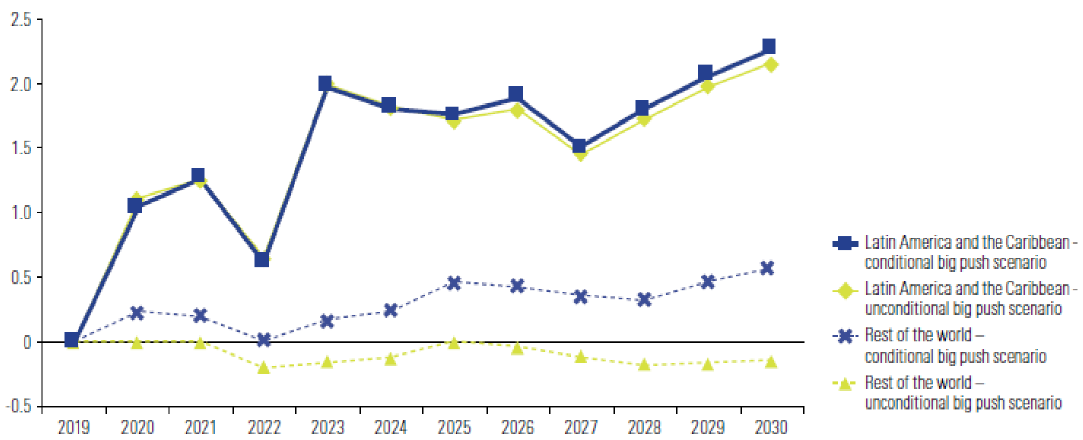
Source: ECLAC (2020b) p 110, based on E3ME simulations.

There are large reductions (over 40%) in CO_2 emissions from land transport as low and zero-carbon vehicles replace those running on petrol and diesel. Increase electrification of final demand (including land transport) increases the use of electricity by about 13% by 2030 compared with the baseline. But the electricity sector's carbon emissions increase by only 6% because of a substantial increase in the capacity of power generation based on non-conventional renewables.

Most of the GDP and employment impacts are brought about by the assumptions in the Unconditional Big Push scenario, notably the additional investment required to substitute capital for fossil fuel energy which is the main feature of decarbonisation. Hence, the economic impacts in the two scenarios are similar: an increase of about 2.3% in GDP by 2030, as shown in Figure 5.8, and an increase in employment of about 0.7% by 2030, as shown in Figure 5.9.

Figure 5.8: Latin America and the rest of the world: GDP impacts relative to COVID-19 baseline under different big push scenarios, 2019-2030.

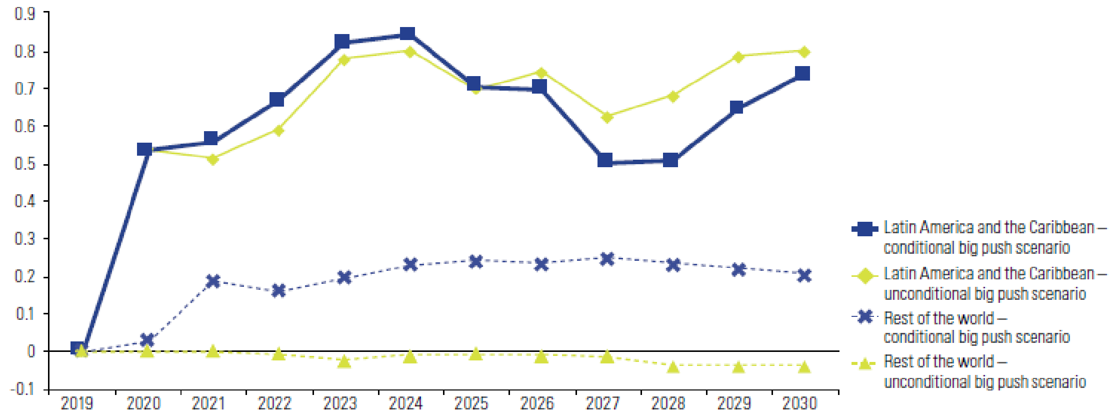
(Percentages)



Source: ECLAC (2020b) p 111, based on E3ME simulations

Figure 5.9: Latin America and the rest of the world: Employment impacts relative to COVID-19 baseline under different big push scenarios, 2019-2030

(Percentages)



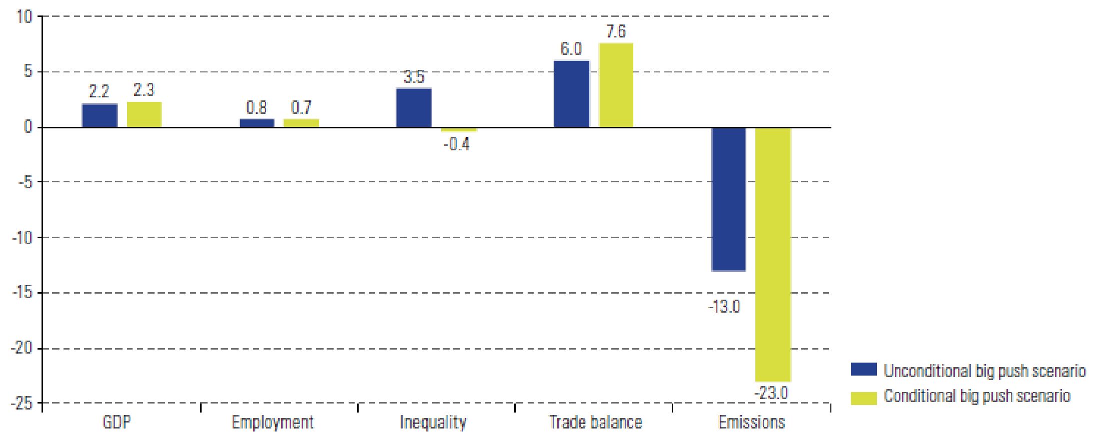
Source: ECLAC (2020b) p 111, based on E3ME simulations.

Figure 5.10 summarises the impacts of the big push scenarios for key indicators for Latin America and the Caribbean. A budget-neutral program promoting mitigation of CO_2 emissions leads to higher levels of GDP and employment by 2030 compared with the scenario of no recovery measures. The trade balance is improved. If agreement can be reached with the rest of the world to pursue the more ambitious, conditional NDC targets for emissions the deterioration in inequality seen in the Unconditional case is reversed.

Figure 5.10 also shows that, without compensating measures, inequality worsens in the Unconditional Big Push scenario because of higher energy prices (which affect poor households more because of the higher share of energy in their consumption spending). But this is reversed in the Conditional Big Push scenario thanks to lower renewable technology costs in a larger global market for those technologies and lower firewood costs due to expanded forests.

Figure 5.10: Latin America and the Caribbean: Impacts of the two big push scenarios on key indicators relative to COVID-19 baseline, 2030

(Percentages)



Source: ECLAC (2020b) p 114, based on E3ME simulations.

6 Environmental Impact

6.1 Introduction

This chapter presents a review by the UNEP World Conservation Monitoring Centre (WCMC) of approaches for understanding wider environmental impacts of economic projections, particularly ecosystem impacts because of the fundamental role that nature plays in underpinning economies and livelihoods (Brondizio et al. 2019). In addition, results of novel analysis carried out by WCMC on the natural capital impacts of economic recovery are presented. WCMC took the detailed sectoral output projections available from E3ME under the various scenarios for the South African economy as inputs to an analysis using the ENCORE model of dependences of environmental change on the economy.

6.2 Linking economics to environmental impact

As early as the 1970s, Meadows et. al. (1972) showed that continuing trends in world population growth, industrialisation, pollution, food production and resources extraction would limit growth and lead a sudden decline in human society within a century.

Subsequent work has developed and employed more sophisticated models of the environmental impacts of future societal development, primarily in the context of a set of plausible future scenarios. At the global scale, environmental scenarios have primarily been developed to understand the impacts of energy and agriculture on climate change or land use configurations (Kok et al. 2017). These scenarios share many assumptions and data, and the projections are typically made using integrated assessment models (Harfoot et al. 2014; van Vuuren et al. 2012).

For example, two recent, important sets of scenarios that are widely used for environmental impact projections derive from the Intergovernmental Panel on Climate Change (IPCC). The first is the Representative Concentration Pathways (RCPs), which were generated using a set of IAMs (van Vuuren et al. 2011). There are four RCP scenarios, which each assume particular greenhouse gas (GHG) concentrations and levels of radiative forcing over time. RCP8.5 has a continual rise in GHG concentration and radiative forcing, and results in a mean projected temperature increase of 3.7°C and an increase in agricultural area. RCP6.0 and RCP4.5 are intermediate scenarios with somewhat lower GHG concentrations, mean temperature increases of 2.2°C and 1.8°C respectively, and reduced overall agricultural areas by 2100. The RCP2.6 scenario has a stabilisation and then a decline in GHG concentration, a 1°C temperature increase, and a large increase in biofuel plantations (and total agricultural area) by 2100.

The second set of scenarios is the Shared Socioeconomic Pathways (SSPs) (O'Neill et al. 2014). The SSPs, rather than focus on specific radiative forcings without necessarily prescribing the pathways that lead to these outcomes, instead describe plausible futures for the society and economy of the world, using a combination of storylines and quantified elements (Riahi et al. 2017). IAMs are used to generate the projections, with resulting outputs of spatially explicit land use, developments in the energy system, and greenhouse gas and air pollution emissions (Bauer et al. 2017; Popp et al. 2017; Riahi et al. 2017; Rao et al. 2017). There are 5 SSPs: SSP1 (‘sustainability’), SSP2 (‘middle of the road’), SSP3 (‘regional rivalry’), SSP4 (‘inequality’), and SSP5 (fossil-fuelled development).

6.3 Linking economics to ecosystem and biodiversity impacts

Until very recently, environmental impacts, and especially any biodiversity outcomes were projected as linear consequences of the economic projections. In other words, biodiversity changes did not feed back to influence the socio-economic projections.

The RCP and SSP scenarios have been used widely to project future biodiversity changes. Primarily, biodiversity impacts have been modelled from the climate or land use outcomes projected for these scenarios. Overwhelmingly these scenarios suggest that biodiversity will continue to decline even under sustainable scenarios such as RCP2.6 and SSP1.

In the oceans, the Fisheries and Marine Ecosystem Model Intercomparison Project (Fish-MIP) ran a multi-model ensemble scenario exercise using climate projections made by Earth system models for the four RCP scenarios. The study found that even in the absence of fishing pressure, by 2100 global marine animal biomass would decline by 5% under RCP2.6 and by 17% under RCP8.5 (Lotze et al. 2019).

On land, many studies have explored the consequences for biodiversity of land use change in the different scenarios. Newbold et al. (2015) project continued declines of species richness under RCP8.5, whilst Jantz et al. (2015) project increased extinctions of plants and vertebrates, as a result of future land use change out to 2100. More recently, in advance of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) Global Assessment, the Expert Group on Scenarios and Models of IPBES carried out an intercomparison of biodiversity and ecosystem services models, using combined SSP-RCP scenarios of land-use and climate change (Kim et al. 2018; Pereira et al. 2020; Brondizio et al. 2019). This showed important regional contrasts of biodiversity change. Under a global sustainability scenario (SSP1), land-use-induced losses by 2050 were moderate and largely restricted to areas in which historical land use has already occurred. While in a fossil fuel driven development scenario (SSP5) over the same period, biodiversity loss was concentrated in Southeast South America, Central Africa, East Africa and South Asia. When climate was considered in addition to land use, losses were further exacerbated, occurring in much of the world, and especially concentrated in the highly biodiverse areas in the Neotropics and Afrotropics (Pereira et al. 2020).

There is a substantial literature reporting on projected ecosystem service outcomes from future socio-economic changes, including evaluation of policies.

A recent analysis of ecosystem services futures showed that consistent with broader biodiversity trends, ecosystem services are also projected to decline in the future, even under sustainable scenarios. Chaplin-Kramer et al. (2019) modelled changes in water quality regulation, coastal risk reduction, and crop pollination as a results of land use and climate change to 2050. They find that under future scenarios up to 5 billion people could face higher water pollution and insufficient pollination for nutritional needs with a particularly focus on Africa and South Asia. Hundreds of millions of people will face heightened coastal risk across Africa, Eurasia and the Americas.

6.4 Linking economics to ecosystem interactively

As the recent UK Government report "The Economics of Biodiversity: The Dasgupta Review" (Dasgupta 2021) states, "Our economies, livelihoods and wellbeing all depend on our most precious asset: Nature." Biodiversity, the diversity of living things, is essential for nature to provide the benefits and services on which humanity depends (Brondizio et al. 2019).

A review carried out by Banerjee et al. (2020) identified no current biodiversity of ecosystem service models that estimate socio-economic outcomes (or macroeconomic impacts) under future scenarios. The principal challenge is to understand and quantify the ways in which economic activity depends on ecosystem services. One solution, proposed by Banerjee et al. (2020), is to link Computable General Equilibrium (CGE) models to biodiversity and ecosystem services models, relying on the parameter values in the CGE to represent the ease with which economic activity can substitute away from inputs whose price rises in response to a degraded environment. If an input is readily substitutable, the economic impact of it becoming more scarcer is small; if it is very costly to reduce the use of the input, the economic cost is high. The difficulty is that, in the absence of time series data to support empirically based estimates of the ease of substitutability, strong assumptions must be made to justify values.

Subsequent work, building on the recommendations of Banerjee et al. (2020) linked the biodiversity and ecosystem service modelling framework InVEST (www.naturalcapitalproject.org) with the Global Trade Analysis Project (GTAP) global CGE model (www.gtap.agecon.purdue.edu) (Roxburgh et al. 2020). This approach used two of the three scenarios used in Pereira et al. (2020) and Chaplin-Kramer et al. (2019), here labelled as "business as usual" and "sustainable pathway". A third scenario "global conservation", included specific grid-cell level conservation actions to prevent habitat conversion in protected areas, wetlands, areas providing high levels of pollination services, areas with high carbon storage and areas with high biodiversity. Roxburgh et al. (2020) also used land use and climate change projections as the primary drivers of ecosystem service change. These projections were run through ecosystem service models for pollination, coastal protection, water yield, forestry production, marine fisheries and carbon storage. The outputs from these models were translated into economic shocks that served as inputs to the GTAP model. The shocks were imposed as changes in endowments and/or changes in sector- and country-specific total factor productivity. The GTAP model was then used to assess resultant impacts on indicators of economic performance such as GDP, prices, trade and production for different economic sectors.

Roxburgh et al. (2020) found that under a business as usual scenario, ecosystem service changes will have significant impacts on the global economy. By 2050, GDP would be 0.67% lower each year in this scenario compared to a business as usual without any ecosystem services feedbacks. Cumulatively from 2011 to 2050, discounted to 2011 terms, the business as usual results in a loss of US$9.87 trillion. The sustainable pathway scenario is projected to result in a smaller cumulative loss of US$2.65 trillion over the same time period, whilst the global conservation scenario could generate a gain of US$0.92 trillion.

6.5 Moving towards linking whole economy changes to ecosystem interactively

The Roxburgh et al. (2020) study represents a valuable first step to understanding the potential feedbacks of ecosystem change on economics. However, the interlinkages between ecosystems and economies incorporated only represent a small subset of the myriad ways in which economic activities depend upon and at the same time impact on ecosystems. A comprehensive quantification of these impacts and dependencies is beyond our knowledge at present. However, there have been recent attempts to capture a much broader, qualitative understanding of the impacts and dependencies of economic activities on ecosystems and the environment more generally.

The ENCORE tool was developed to understand the impacts and dependencies of environmental change on the economy (NCFA and UNEP-WCMC 2018). It describes the sign and relative strength of the impacts different phenomena have on one another, and contains information on:

- economic sectors
- production processes that they drive
- natural resources used as input to - and the non-product outputs from - these processes
- drivers of environmental change resulting from anthropogenic and natural processes
- natural capital assets
- ecosystem services.

and the interlinkages between these nodes. These linkages together represent the causal chain of economic growth in one sector's impacts, and feedbacks, on the environment.

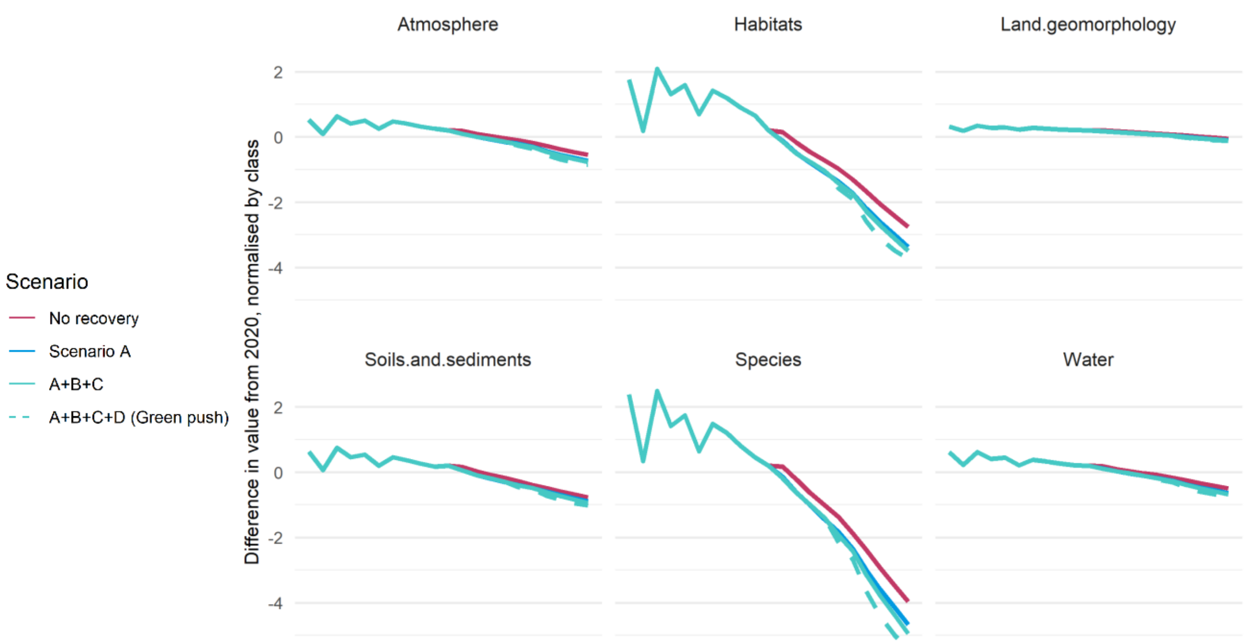
To estimate the broad environmental impacts of a set of post-COVID recovery scenarios for South Africa, we combined data on the growth of economic sectors from the E3ME model, and knowledge about how the economy and environment interact from the ENCORE tool to make fuzzy cognitive maps, which we then perturbed under four economic scenarios.

Cognitive maps are network diagrams which, fundamentally, describe how systems work in a qualitative way (Özesmi and Özesmi 2004). They do this by representing features of a system as nodes, where connections between nodes represent causal relationships.

We mapped E3ME sectors to production processes in the ENCORE tool, guided by a mapping of E3ME sectors to subindustries relevant to each process. We then constructed an interaction matrix using ENCORE's interaction strength. We used the qualitative interaction strength information from ENCORE to guide simulations of fuzzy cognitive maps which fulfilled the criteria set by ENCORE, without explicitly defining any interaction strengths. Finally, we perturbed the model in different ways for each timestep of the scenarios we were interested in projecting the outcomes of, plotting the consequences of each scenario on downstream changes in drivers, natural capital assets, and ecosystem services.

The results of this analysis show that, for South Africa, some natural capital assets, such as water, are already under extreme pressure from production processes in the case study. It also shows that species and habitats will be particularly impacted under future projections (Figure 6.1).

Figure 6.1: Projected changes in natural capital assets for South Africa



Source: ENCORE/E3ME fuzzy cognitive mapping (FCM)

Simulations showed that under all scenarios the largest increases in production processes included: construction materials production, iron extraction, iron metal production and steel production. Importantly, the only difference between the scenarios is the changes in the E3ME sectoral outputs.

The baseline scenario with no COVID recovery led to the lowest impacts on all the natural capital assets, consistent with the ENCORE model property that that generally, as total economic activity increases across the scenarios, so does environmental impact. In the case of the Green push scenario, this arises despite substantial reductions in coal extraction, the benefit of which is offset by growth in demand for construction materials production and metals, which contribute to continued degradation of natural capital. The decline in the state of the natural capital of the Atmosphere is overstated because the ENCORE model only takes account of changes in *sector output*: it does not incorporate the decarbonisation of the power sector or reduced emissions from private car use.

The observation that stimulating growth might continue degradation of at least some aspects of natural capital, even when targeting reductions in greenhouse gases, is likely to be generally valid in the absence of activities to mitigate impacts from the economic sectors undergoing growth. A useful measure may be the economic growth efficiency of the stimulus scenario: the “efficiency” of scenarios in terms of economic return per unit damage to natural capital. Efficiency was calculated by measuring the ratio of overall economic growth across all sectors to the decrease in natural capital asset node values for each scenario and timestep. For each simulation, we noted the scenario which gave the highest efficiency. Nonlinearities in the relationship between economic growth and environmental damage led to scenario A, with low overall extra growth, being selected often. However, the “green push” scenario was selected more often than scenario A+B+C, despite providing greater economic growth.

Another use of the fuzzy cognitive mapping (FCM) simulation models is to identify the most beneficial opportunities for mitigating impacts of recovery. For South Africa, the one driver with a large relative growth is “Disturbance”, which can be interpreted as sensory disturbances to ecosystems; the production process with the largest influence on disturbances is “construction materials production”. We can take the analysis a step further by exploring the economic sectors responsible for the growth in construction materials production, which are basic metals, forestry, metal goods, other mining and wood and paper.

Alternatively, the models can be used to examine sectors at risk under future economic conditions. This can be done by considering the sum of nodes representing ecosystem service deficits feeding back into each production process. In the South African example, it is clear that agricultural processes, and therefore the agriculture sectors, are most at risk under the recovery scenarios assessed.

This South Africa modelling has been valuable in demonstrating the potential to link economic projections to environmental consequences. In particular, it has helped to identify potentially non-intuitive outcomes, such as the fact that there can be “no growth for free”. There are several important next steps that emerge from this work.

First, an important development will be to describe how the growth or decline in ecosystem service deficits influence the performance of economic sectors within the E3ME model. Initially this will involve some assumptions about the functional forms of the dependencies of economic sectors on production processes. With these functional feedbacks in place, running the E3ME and then ENCORE based FCM models iteratively would result in altered economic projections. Such an approach is in line with proposals made by PAGE/UNEP for the integrated green economy modelling (IGEM) framework (PAGE 2017b).

Second, developing the models to work in a spatially explicit manner will enable ecosystem impacts and dependencies to be more realistically represented. This is especially important for impacts to biodiversity because of the spatial distribution of organisms and the typically localised effect of impacts, meaning it matters where impacts occur.

Third, the ENCORE network representation provides an excellent basis on which to build a more quantitative understanding of the impacts and dependencies of economic sectors on natural capital. For countries with detailed information on economic activity and changes in natural capital, it may be possible to use the ENCORE networks to infer quantitatively the strengths of impacts and dependencies.

7 Conclusions

The COVID-19 pandemic has had a huge impact on society and economies. While the rate of economic growth will recover, it will not necessarily mean a recovery to the levels of economic activity that might have been expected without the pandemic, even in the medium to long run.

Governments are considering or introducing recovery packages designed to stimulate long-term growth and employment. But unless these packages incorporate measures to mitigate the environmental impact of recovery, a key opportunity to tackle environmental degradation, including climate change, will be missed. We need to 'build back better'.

The "pause" in human activity has led to an unprecedented drop in carbon emissions as well as to other outcomes benefitting the environment. Nevertheless, an economic recovery without green elements, with continued subsidies for the use of fossil fuels, will result in a strong rebound in carbon emissions.

In this report, we summarised the emerging literature on the estimated effects of Green Recovery. Then, using the E3ME macroeconometric model, we simulated results of a global recovery with and without green elements and have presented results from two regional case studies.

There are consistent findings across the modelling exercises: the Green Recovery scenarios in all cases result in positive GDP outcomes. Furthermore, in our global modelling, the Green Recovery scenario brings a higher and more permanent economic impact than the simulated colourless counterpart. The persistence and the magnitude of these impacts differs across regions. We find that effects can be more durable in markets with high electrification and that net benefits are less in regions with large fossil fuel extraction industries.

The modelling of recovery scenarios for the South African economy suggests that carefully designed policies can promote green growth even in an economy with a large fossil fuel extraction sector. A growing renewable energy sector can provide a substantial number of jobs, including in some sectors where pandemic job losses have been most pronounced. Nevertheless, Just Transition policies will be needed to address workers and communities most affected by the loss of coal mining jobs.

By design, Green Recovery policies lead to significant cuts in CO_2 emissions, consistent with the acceleration in decarbonisation that is required to curb global warming. While the scale of action modelled here is less than is required to put the world on a path towards limiting global warming to 1.5°C or 2°C, earlier analysis with E3ME has shown that more ambitious policies continue to deliver GDP and jobs benefits.

When economic results are linked to environmental impacts other than carbon emissions, the analysis shows that the green policy set needs to be extended to include circular economy measures and nature-based solutions to mitigate the impact of economic growth on the world's natural capital.

Regarding the financing of Green Recovery policies, the results from the global modelling show how the budgetary cost of the package decreases in relation to GDP as the recovery picks up. While most of the modelling considered here assumes a net increase in government borrowing and debt, ECLAC's modelling for Latin America and the Caribbean shows that a budget-neutral package can be designed by removing fossil fuel subsidies.

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Appendix A E3ME

E3ME is a global macroeconometric model of the world's economic, energy systems and the environment, developed and maintained by Cambridge Econometrics. It was originally developed through the European Commission's research framework programmes and is now widely used in Europe and beyond for policy assessment, for forecasting and for research purposes.

E3ME is one of the most advanced models of its type today. Its main strengths are:

- A high level of disaggregation, enabling detailed analysis of sectoral and country-level effects from a wide range of scenarios.
- An econometric specification that addresses concerns about conventional macroeconomic models and provides a strong empirical basis for analysis.
- Integrated treatment of the world's economies, energy systems, emissions and material demand. This enables E3ME to capture two-way linkages and feedbacks between each of these components.
- Economic activity is demand-driven, within supply constraints.

Dimensions and classifications

The current version of the model has the following dimensions:

- 61 regions – all major world economies (i.e. G20), the EU28 Member States and candidate countries plus other countries' economies grouped
- 70 industry sectors (43 for non-EU), based on standard international classifications
- 43 categories (28 for non-EU) of household expenditure
- 22 different users of 12 different fuel types
- 14 different users of seven different raw materials
- 14 types of airborne emissions (where data are available) including the six greenhouse gases monitored under the Kyoto protocol[17]

E3ME's historical database covers the period 1970-2016 and the model projects forward annually to 2050. The main data sources are Eurostat, the OECD (both the National Accounts section and STAN), World Bank, UN, International Monetary Fund (IMF) and International Labour Organization (ILO), supplemented by data from national sources. Energy and emissions data are sourced from the International Energy Agency (IEA) and EDGAR global emissions database. Gaps in the data are estimated using customised software algorithms.

Econometric specification

E3ME's behavioural relationships (i.e. interaction between variables) are validated by historical relationships, expressed by econometrically estimated parameters derived from real-world time series data. In total there are 33 sets of econometrically estimated equations, including the components of GDP

[17] They are: carbon dioxide (CO_2), methane (CH4), nitrous oxide (N2O), hydrofluorocarbons (HFC), perfluorocarbons (PFC), and, sulphur hexafluoride (SF6).

(consumption, investment, international trade), prices, energy demand and materials demand. Each equation set is disaggregated by country and sector. Annual results are generated for the energy, environmental and economic variables using econometric techniques of cointegration and error correction to analyse these variables' short-run fluctuations around their long-run relationship. The system of error correction allows short-term dynamic (or transition) outcomes, moving towards a long-term trend. The dynamic specification is important when considering short and medium-term analysis (e.g. up to 2030) and rebound effects, which are included as standard in the model's results.

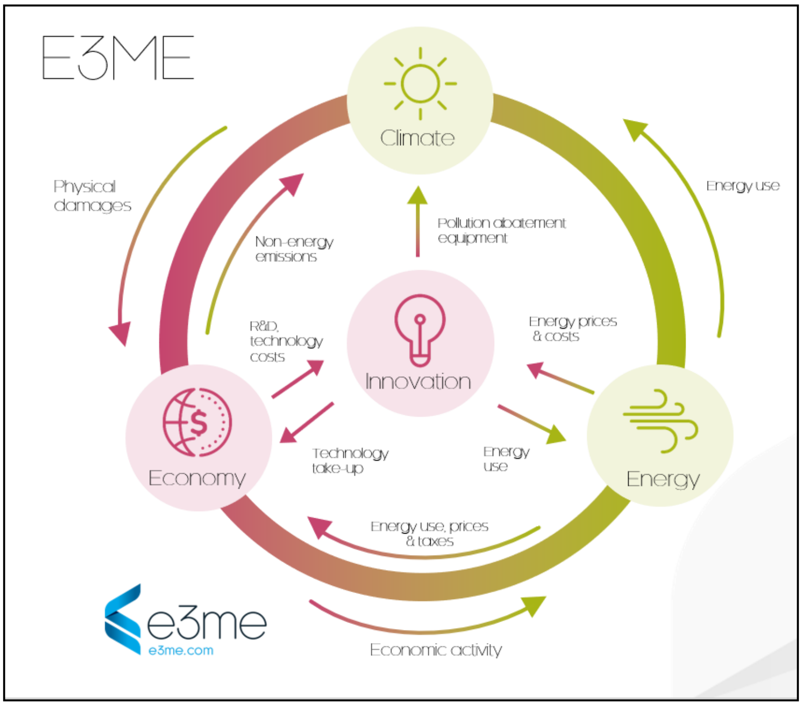
The econometric specification of E3ME gives the model a strong empirical grounding, by simulating responses to policy changes based on historically observed relations between variables, without imposing assumptions about household and firm behaviour (e.g. that agents have perfect knowledge and behave in an optimal manner). Thus, instead of trying to find least-cost pathways, the model simulates the responses to shocks (including changes in drivers such as economic, demographic or technological development, or both regulation and market-based policies).

E3 linkages

E3ME's structure is based on a standard National Accounts framework, with two-way links to energy consumption, emissions and material consumption. Economic activity undertaken by persons, households, firms and other groups in society has effects on other groups spread over time, and the effects persist into future generations, although many of the effects soon become so small as to be negligible. But there are many actors and the effects, both beneficial and damaging, accumulate in economic and physical stocks. The effects are transmitted through the environment (with externalities such as greenhouse gas emissions contributing to global warming), through the economy and the price and money system (via the markets for labour, capital and commodities), and through the global transport and information networks. The markets transmit effects in three main ways: through the level of activity creating demand for inputs of materials, fuels and labour; through wages and prices affecting incomes; and through incomes leading in turn to further demands for goods and services. These interdependencies suggest that a model should be comprehensive and include many linkages between different parts of the economic, environment, and energy systems.

The figure below shows how the three components (modules) of the model - energy, environment (represented as climate in the figure) and economy - fit together. The linkages between the components of the model are shown explicitly by the arrows that indicate which values are transmitted between components. For example, the economy module provides measures of economic activity and general price levels to the energy module and the energy module provides detailed price levels for energy carriers distinguished in the economy module and the overall price of energy as well as energy use in the economy. The E3ME environmental module covers 14 different air pollutants generated from end-use of different fuels and from primary use of fuels in the energy industries. There is also a separate module[18] which calculates physical demand for seven raw materials with feedbacks to the economy module in E3ME.

E3ME linkages



Demand-driven

E3ME is a hybrid model with top-down and bottom-up components in which output is driven by demand but subject to supply constraints. The category of demand-driven macroeconometric models to which E3ME belongs is often compared to the category of Computable General Equilibrium (CGE) models. In many ways, the modelling approaches are similar in scope and application. They are used to answer similar questions and use similar inputs and outputs, and they are based on the same statistical economic framework of the National Accounts. However, there are important differences between the modelling approaches, due to a different theoretical orientation (i.e. views on how the macro-economy works, what the most important mechanisms are at macro level and how they function). In a typical CGE framework, behaviour is determined through an optimising framework on markets, with constraints and often including an expectations formation mechanism (micro-foundations). Because of the assumption that prices clear markets, output is ultimately determined by supply factors (such the amount of labour and capital available) and prices adjust fully so that all the available capacity is used. In E3ME, supply adjusts to demand subject to constraints but not necessarily at maximum capacity. The model does not assume that prices always adjust to market clearing levels nor that all resources are fully utilised. As a result,

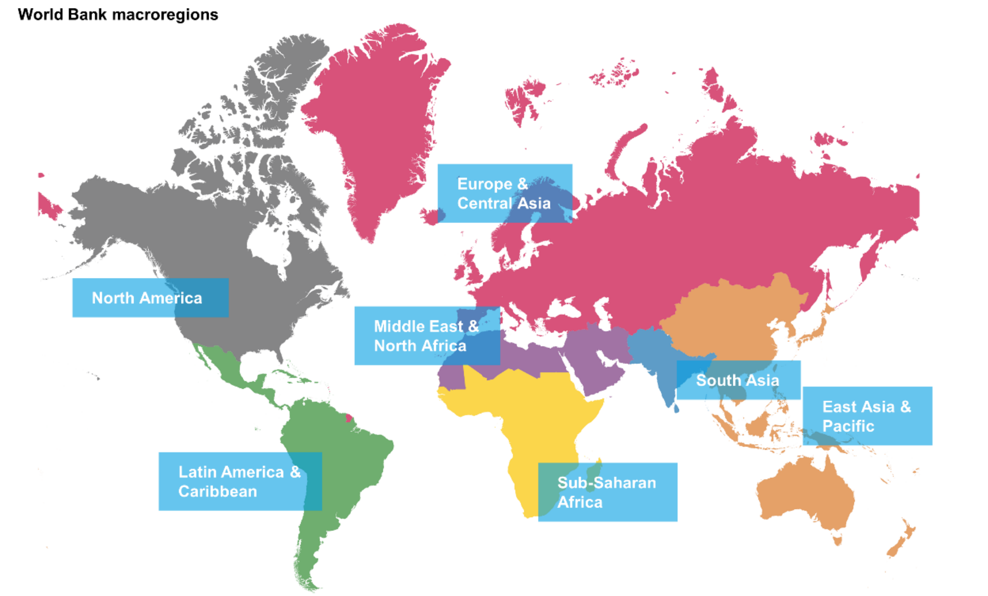
[18] The module distinguishes 15 material user categories. However, not all these categories will use a particular material. The feedback to the economy is through Input-Output relationships of these user categories with the extraction sector: agriculture, forestry and other mining. The following link below provides information on previous applications using material submodule in E3ME: https://ec.europa.eu/environment/enveco/resource_efficiency/pdf/RMC.pdf

regulation and other policy can lead to increases in investment, output and employment if the regulation or policy is able to draw upon spare economic capacity (i.e. unused capital and labour resources).

Appendix B Classifications

World Bank macroregions

Figure 8.1: World Bank macroregions



Source: World Bank

Correspondence between World Bank macroregions and E3ME world regions

World Bank macroregion	E3ME region
East Asia & Pacific	Japan
	Australia
	New Zealand
	China
	Korea, Republic Of
	Taiwan, Province of China
	Indonesia
	Rest of ASEAN
	Malaysia
Europe & Central Asia	All EU regions, excluding Malta
	United Kingdom
	Norway
	Switzerland
	Iceland
	Turkey
	North Macedonia
	Russian Federation
	Belarus
	Ukraine
	Kazakhstan
Latin America & Caribbean	Mexico
	Brazil

	Argentina
	Colombia
	Rest of Latin America
Middle East & North Africa	Malta
	OPEC excluding Venezuela
	Saudi Arabia
	Africa OPEC
North America	United States
	Canada
South Asia	India
Sub-Saharan Africa	Nigeria
	South Africa
	Rest of Africa

For a full description of World Bank macroregions see: https://datahelpdesk.worldbank.org/knowledgebase/articles/906519-world-bank-country-and-lending-groups

Correspondence between E3ME industry sectors and broad sectoral aggregates used in this report

Aggregated sector	E3ME sector
Agriculture & forestry	1 Agriculture etc
	43 Forestry
Extractive industries	2 Coal
	3 Oil & Gas etc
	4 Other Mining
Manufacturing	5 Food, Drink & Tob.
	6 Text., Cloth. & Leath
	7 Wood & Paper
	8 Printing & Publishing
	9 Manuf. Fuels
	10 Pharmaceuticals
	11 Chemicals nes
	12 Rubber & Plastics
	13 Non-Met. Min. Prods.
	14 Basic Metals
	15 Metal Goods
	16 Mech. Engineering
	17 Electronics
	18 Elec. Eng. & Instrum.
	19 Motor Vehicles
	20 Oth. Transp. Equip.
	21 Manuf. nes
Energy & utilities	22 Electricity
	23 Gas Supply
	24 Water Supply
Construction	25 Construction
Retail	26 Distribution
	27 Retailing
Tourism & entertainment	28 Hotels & Catering
	41 Misc. Services
Transport	29 Land Transport etc
	30 Water Transport
	31 Air Transport

ICT	32 Communications
	35 Computing Services
Business services	33 Banking & Finance
	34 Insurance
	36 Prof. Services
	37 Other Bus. Services
Public services	38 Public Admin. & Def.
	39 Education
	40 Health & Social Work

Appendix C Result tables

Global GDP, employment, and CO_2 emission results

Percentage difference from baseline, except third row (employment million jobs)

VAT scenario

Indicator	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
GDP	1.5%	1.7%	1.8%	1.6%	1.5%	1.2%	0.9%	0.6%	0.5%	0.4%
Employment	0.2%	0.3%	0.4%	0.4%	0.4%	0.3%	0.2%	0.2%	0.1%	0.1%
million jobs	*8*	*12*	*15*	*15*	*14*	*12*	*9*	*6*	*4*	*3*
CO_2	0.3%	0.4%	0.5%	0.5%	0.4%	0.4%	0.3%	0.2%	0.1%	0.1%

GRP scenario

Indicator	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
GDP	1.9%	2.1%	2.4%	2.5%	2.4%	2.1%	1.7%	1.6%	1.7%	1.9%
Employment	0.4%	0.7%	0.9%	0.8%	0.7%	0.6%	0.5%	0.5%	0.5%	0.5%
million jobs	*15*	*26*	*32*	*31*	*27*	*23*	*19*	*19*	*19*	*20*
CO_2	-0.6%	-2.1%	-4.2%	-5.5%	-6.4%	-7.4%	-8.6%	-9.8%	-11.0%	-12.3%
CO_2 (w ref.)*	-0.6%	-2.9%	-5.5%	-7.4%	-8.2%	-9.2%	-10.4%	-11.6%	-12.8%	-14.1%

* Including reforestation impacts.

GDP and employment result by macroregions in 2023, 2030

Percentage difference from baseline

VAT scenario

	GDP		Employment	
Macroregion	2023	2030	2023	2030
East Asia & Pacific	1.0%	0.6%	0.3%	0.1%
Europe & Central Asia	2.2%	0.1%	0.9%	0.3%
Latin America & Caribbean	2.5%	0.2%	0.7%	0.1%
Middle East & North Africa	2.1%	0.7%	0.4%	0.2%
North America	1.6%	0.7%	0.4%	0.2%
South Asia	3.3%	-0.1%	0.5%	0.0%
Sub-Saharan Africa	3.2%	0.3%	0.3%	0.0%

GRP scenario

	GDP		Employment	
Macroregion	2023	2030	2023	2030
East Asia & Pacific	2.2%	2.3%	0.9%	0.8%
Europe & Central Asia	3.0%	2.5%	1.2%	1.2%
Latin America & Caribbean	2.4%	1.8%	1.4%	0.2%
Middle East & North Africa	2.8%	2.8%	0.6%	0.4%
North America	1.8%	0.6%	0.8%	0.3%
South Asia	2.2%	3.2%	1.0%	0.2%
Sub-Saharan Africa	3.7%	1.4%	0.5%	0.0%

GDP and employment result by sectors in 2023, 2030

Percentage difference from baseline

VAT scenario

	GDP		Employment	
Macroregion	**2023**	**2030**	**2023**	**2030**
Agriculture & forestry	0.8%	0.3%	0.1%	0.1%
Business services	1.7%	0.5%	0.4%	0.5%
Construction	0.7%	0.1%	0.6%	-0.1%
Energy & utilities	1.9%	-0.1%	0.7%	0.0%
Extractive industries	0.2%	0.0%	0.3%	0.1%
ICT	1.3%	0.3%	0.7%	-0.1%
Manufacturing	1.0%	0.3%	0.8%	-0.2%
Public services	0.6%	0.2%	0.6%	0.1%
Retail	2.2%	0.6%	0.2%	0.1%
Tourism & entertainment	1.8%	0.5%	0.2%	0.1%
Transport	1.3%	0.3%	1.1%	0.3%

GRP scenario

	GDP		Employment	
Macroregion	**2023**	**2030**	**2023**	**2030**
Agriculture & forestry	1.8%	1.4%	0.5%	0.2%
Business services	3.0%	2.6 %	0.6%	1.5%
Construction	3.9%	0.9%	1.9%	0.5%
Energy & utilities	13.8%	14.9%	0.2%	0.7%
Extractive industries	-1.8%	-5.9%	-1.4%	-3.2%
ICT	2.5%	2.1%	1.3%	1.7%
Manufacturing	5.1%	1.0%	1.5%	0.4%
Public services	0.7%	0.9%	1.0%	0.8%
Retail	5.8%	2.0%	0.8%	0.4%
Tourism & entertainment	2.2%	2.6%	0.2%	0.3%
Transport	3.5%	2.0%	2.1%	1.7%

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