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Modelling the sustainability transition in between the EGD and the Next Generation EU

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1 Introduction

The EU Green Deal, a strategy aligned with the United Nation's 2030 Agenda and the sustainable development goals, was designed to benefit all economic actors, via cleaner air, water and soil, healthier food, and better health for current and future generations. This will be achieved through the adoption of reusable or recyclable packaging, reducing waste, reduced used of pesticides and fertilizers, expansion of renewable energy generation and transition to cleaner transport modes, in addition to the renovation of homes, schools and hospitals. The EU Green Deal is designed to be implemented with a Just Transition Mechanism, aligning investors and beneficiaries for achieving considerable societal gains. In practice, it links a low carbon future to sustainable and more equitable development for the EU.

This report presents the results of a hybrid modeling exercise, linking Systems Thinking (ST) with a Computable General Equilibrium (CGE) model to assess the outcomes of the EU Green Deal. ST is used to identify the main indicators of the system analyzed, conceptualize the interconnections existing among these indicators and explore emerging dynamics of change with the use of feedback loops. The improved systemic understanding achieved with ST informs the development of the CGE model, and the formulation of scenarios, in addition to supporting the interpretation of quantitative results.

The approach proposed is aligned with previous work on Green Economy and Green Growth, and builds on previous research done by the EEA. It provides an assessment of the social, economic and environmental outcomes of the implementation of the EU Green Deal, also in the context of the COVID-19 pandemic. As such, it contributes to policymaking by providing indications on synergies and tradeoffs emerging from the implementation of green investments, supporting the creation of a roadmap toward the goal of decarbonization by 2050. The introduction of COVID-19 into the modeling exercise allows considering potential benefits arising from the transition process toward a cleaner energy system in the EU as a way forward to recover from the economic crises.

The study is organized as follows: (a) it first provides an overview of Green Economy assessments, with the renewed interest in global assessments due to policy priorities (e.g. Paris Agreement) and the COVID-19 pandemic; (b) it then proposes a snapshot, with information collected up to February 2021, of the literature on the economic impacts of COVID-19, both based on data and on modeling exercises, and on possible pathways for the post-pandemic; (c) it then presents the modeling approach, linking ST and the CGE model, and the results of various simulations.

2 Modelling exercises in the context of green economy and green growth

The understanding of Green Economy and Green Growth has evolved over time, as so have the tools that have been used over the years to support decision makers.

The Green Economy was defined by UNEP as *"one that results in improved human well-being and social equity, while significantly reducing environmental risks and ecological scarcities. It is low carbon, resource efficient, and socially inclusive"* (UNEP, 2011). The concept was coined earlier by Pierce et al. (1989) but became widely used in 2008 as a strategy to recover from the economic and financial crisis of 2008-2009. Green Growth was instead introduced at the Fifth Ministerial Conference on Environment and Development (MCED) in 2005 in South Korea, where was defined as a strategy to achieve sustainable development and poverty reduction (Cameron & Stuart, 2012). To give a definition, the UNESCAP defined Green Growth *"as a pre-requisite for building a green economy in the context of sustainable development and poverty reduction"* (UNESCAP, n.d.).

Initially Green Economy and Green Growth were very comparable, considered objectives of development planning. On the other hand, over time, Green Economy turned more into an action-oriented approach or method for development planning, resulting in Green Growth and ultimately supporting the achievement of the Sustainable Development Goals (SDGs). Many countries adopted the green economy approach for development planning, including the EU, especially for the use of systems thinking, while linked concepts related to resource efficiency, green jobs, and nature-based solutions (EEA, 2014).

A first strong contribution to making the Green Economy and Green Growth concepts operational was provided by UNEP's Green Economy Report (GER) (UNEP, 2011), which was conceptualized in 2008 and published in 2011. The Green Economy emerged as a concept, and for many as a goal for an economic transition that would support redirecting investments to more sustainable interventions. New, and integrated modeling work was prepared for that study, linking together ten sectors to assess the impacts of conventional and green investments on sectoral and system performance. In other words, it provided an economy-wide Cost Benefit Analysis (CBA) - capturing social, economic and environmental indicators - that could complement project-specific assessments.

Ahead of Rio+20, the attention moved from conceptualization to implementation. Many countries started creating and customizing their own Green Economy Assessments, and growing attention was put on Green Growth (a goal), rather than on Green Economy that, by that time, was considered to be more of a framework for development planning than a goal. Various methods for assessing country performance were developed at this point, going from minor adjustments to existing models, to brand new approaches. These are described in many reports, both comparing approaches (UNEP, 2014; UNEP, 2014b; UNECA, 2016) and practical country applications (UNEP, 2013; UNEP, 2014; GGGI, 2018; UNEP TEEB, 2018).

Implementation at the country level has dominated the field in the past years due to the recognition of global dynamics (e.g. climate change), corresponding local impacts (e.g. floods, droughts, air pollution) and required policy goals (e.g. Kyoto Protocol and the Paris Agreement). On the other hand, recent emerging dynamics, including emerging macrotrends on population ageing, technological change and fiscal sustainability (Bassi, Costantini, & Sforna, 2020) and now the COVID-19 pandemic and the stronger commitment of the European Union with the Green Deal towards climate change mitigation and adaptation, has sparked new interest in global assessments of green economy policy and resulting social, economic and environmental outcomes. In this context, all three dimensions of sustainable development have equal relevance, with COVID-19 being an example: the relationship between humans and nature has given rise to the pandemic, resulting social concerns have led to economic impacts, whose magnitude is also a result of our interconnected economies and lifestyles. These green economy assessments are systemic, in that they aim at the estimation of outcomes across sectors, for several economic actors, for all three dimensions of development, and over time. Practically, the goal is to assess the societal value of policy interventions and investments, clarifying the interconnections existing between “low carbon” and “development” in Low Carbon Development Strategies, like the EU Green Deal.

An example is the work of the European Environment Agency (EEA) on global macrotrends (Bassi, Costantini, & Sforna, 2020), which includes a description of methods and models used for green economy assessments, including (a) economy-wide and sectoral models, (b) thematic or integrated models, (c) coarse or spatially explicit, as well as the underlying methodology used to solve equations (e.g. optimization, econometrics and simulation). This report also provides an integrated modeling framework linking Systems Thinking, providing a systemic view of various development paths, with a global dynamic Computable General Equilibrium model, providing an assessment of the economic outcomes of such scenarios. The modelling work is part of the background work for the EEA report on demographic change, technological change and the sustainability transition (EEA 2019a).

The approach has been improved and extended in this study, with the introduction of policies included in the EU Green Deal and the creation of scenarios that consider various impacts of COVID-19 on the economy. By combining the already existing financial mechanisms envisaged within the EU climate policy, as the Emission Trading Scheme and the Innovation Fund, with new insights from the theoretical debate on carbon tax revenue recycling mechanism and endogenous technical change, this report provides insights on the relevance of system thinking also in the case of a unexpected shock as the COVID-19 pandemic, revealing that the EU Green Deal is not only an environmentally oriented development strategy but also a radical shift toward a more sustainable growth paradigm. Similar outcomes have emerged from other studies, including earlier work done by UNEP at global level (2011) and more recently by the EEA for the EU (Bassi, Costantini, & Sforna, 2020). Such an interpretation allows reducing those concerns on potential economic losses due to competitiveness reduction that many skeptics assigned to the EU climate policy, turning costs to become benefits in the long term.

3 Literature review on the economic impacts of COVID-19

The economic impacts of COVID-19 are many and varied, and are growing and becoming more diversified by the day. At the time of the finalization of this report, February 2021, there is no certainty on the extent to which the economy will be impacted by COVID-19 throughout the lifecycle of the pandemic. Several studies are being published on a regular basis, with new statistics emerging every month. In light of this, the information presented in this section should be interpreted considering the different stages of the pandemic that we have already experienced, and the ones to come. For instance, we have observed a constant worsening of statistics throughout the first wave of COVID-19 in mid-2020. We have then seen a progressive improvement in the second half of 2020, up to the emergence of the second wave. At this moment, the data are still underwhelming, but expectations have been improving due to the rollout of vaccines being closer in time. For this reason, the analysis presented in section is incomplete, and it should be interpreted as such.

Providing more detail and the above, following the COVID-19 outbreak financial conditions have worsened at an unparalleled speed, weakening economies worldwide (IMF, 2020a). Emerging dynamics include the increased risk of defaults of private companies due to weaker demand, higher volatility in the stock market due to future uncertainty on the profitability of businesses and impacts on the solidity of national finances due growing expenses and reduced revenues. These impacts depend on both global and local dynamics, with local consumption as well global trade being impacted by the number of infected countries and the duration and severity of epidemiological shocks (McKibbin & Fernando, 2020). The uncertainty of impacts, effectiveness of policy responses, and duration of current challenges leads to consideration and creation of various scenarios for a possible recovery.

The forecasts created in 2020 expected that the GDP of all major economies would substantially decrease in 2020. The forecasts published by the IMF in January 2021 show a recession in 2020 in the range of 3.4 % (USA), 5.4 % (Germany), 9 % (France) and 11.1 % (Spain). The recovery in 2021 is expected to offset part of these losses with economic growth in the range of 5.1 % (USA), 3.5 % (Germany), 5.5 % (France) and 5.9 % (Spain) (IMF, 2021).

The expected magnitude of the economic downturn has generally declined over time, with projections of the IMF published in the World Economic Outlook showing larger expected declines in June (in relation to the first period of lockdown in most Asian and European countries) than in October. Further reductions in economic impacts were estimated for 2020 also in the January 2021 forecasts when compared to the estimates published in October 2020. The forecasts beyond 2020 show similar patterns, with a stronger recovery reported in the 2021 forecasts, primarily due to the increased certainty of the availability of vaccines (IMF, 2021).

More specifically, larger economic impacts were expected and measured for smaller economies that are less diversifies and more exposed to tourism and trade. For example, China's GDP was forecasted to decline between 2 % are 3 %, relative to baseline expectations (OECD, 2020; Institut Montaigne, 2020). Recessions were expected in various western economies, including the United States (-5.9 %) and the Euro Area (-7.5 %) (IMF, 2020b). Overall, global GDP was expected to decline between 0.3 % and 2.4 % in 2020 (Baldwin & Di Mauro, 2020; OECD, 2020; McKinsey&Company, 2020a) triggering a global -albeit temporary- recession.

When comparing the crisis of 2008-2009 with EUROSTAT and EC European Economic Forecast (European Commission, 2020) expectations for economic contraction in 2020 and rebound in 2021, it emerges that the economic recession of 2020 is steeper than what observed in 2009 for most EU countries. Exceptions include Estonia, Latvia, Lithuania, the countries most exposed to speculation in the construction sector and subprime loans. For the EU-27 the recession in 2009 reached -4.3 %, and the expectation for 2020 is -7.4 %. The rebound is also expected to be stronger in 2021 when compared to 2010. The growth rate of

GDP in 2010 was 2.2 % and for 2021 is expected to reach 6.1 %. Finally, the impacts of the current crisis are of similar magnitude across all EU-27 countries. This is due to the simultaneous impact on both production and consumption, similar duration of the impact on mobility and the degreed of integration of the economy of EU-27 countries.

While all forecasts reviewed expect a rebound in the range of 6 % globally in 2021, it is unclear the extent to which there will be permanent negative impacts on economic performance. This will be determined both by the impact of COVID-19, as well as by the responses implemented to counter the crisis (e.g. investment in technology to reduce vulnerability and modernize value chains, further exploitation of remote services, permanent social distancing). Different scenarios for recovery are possible: global growth could be restored in 2021 if impacts are limited primarily to consumption (S&P Global Ratings, 2020c; McKinsey&Company, 2020b; OECD, 2020), in 2022 if production is also affected extensively (S&P Global Ratings, 2020c; McKinsey&Company, 2020b), or by 2023 if we will face additional waves of the outbreak (McKinsey&Company, 2020b). The most severe economic risk posed by the current pandemic is currently unemployment, which would hinder recovery due to lower consumption, and the erosion of savings. In the Asia-Pacific region alone, unemployment is forecasted to return to 2019 level only in 2023 (S&P Global Ratings, 2020a) indicating the possibility to lose 4 years of job creation potential. Worst-case scenarios are less likely to occur for GDP (McKinsey&Company, 2020c) due to the implementation of several response measures and the adaptive behavior emerged in the past months (e.g. with the increase of online purchases and the provision of remote services). On the other hand, these same interventions may have further negative impacts on employment (e.g. when production and services switch to less labor intensive sectors and activities). Companies are already put at risk by the pandemic, and the severity of the economic consequences of the virus will depend on three factors: impacts on demand, length of the pandemic, and effectiveness of recovery packages.

Overall, our literature review finds that four main impacts have emerged from the COVID-19 outbreak. This highlights difference with previous economic crises, e.g. the 2008-2009 global financial and economic crisis, as in the case of COVID-19 both consumption and production have been impacted, as presented below:

1. Reduction of GDP via the reduction of production (due to demand and limited labour force availability)
2. Reduction of GDP via the reduction of consumption (due to social distancing, avoided travel)
3. Increased cost of doing business and insurance premiums
4. Increase of country risk and public costs (higher country risk leading to higher debt costs, higher public costs related to health and stimulus packages)

This document reviews the current estimates and forecasts for the impact of COVID-19, and assesses the models that have been used to generate such estimates and projections.

3.1. Economic impacts

3.1.1 GDP Impacts: reduction of production

The outbreak of COVID-19 and resulting lockdown is affecting many sectors, but some are more affected than others. Impacts can be assessed by reviewing changes in stock price, capitalization for private companies. Sectors can be analyzed at a higher level of aggregation, based on their business model, reliance on global trade for production, and cost structure. Finally, sectoral performance can be aggregated at national level, to determine the impact that changes in production and production cost can have on national GDP.

According to McKinsey&Company (2020b) the average stock price change of both aviation and holiday service sectors has been severely hit by the pandemic due to protracted bans on international travels (-40 and -36 % respectively, Figure 3-1). In this context, both developed and developing countries that strongly depend on tourism and remittances would be more affected than more diversified economies. For instance, it has been estimated that Egypt's national GDP could decrease by 0.8 % each month due to the expected reduction of revenues from international travel restrictions (IFPRI, 2020), while Namibia's private consumption could be taken to the levels of 4 – 5 years ago (MPRA, 2020). Many European countries are also at risk from the fall of international tourism. Examples include Croatia, with inbound tourism expenditure accounting for about 20 % of GDP (UNCTAD, 2020). Besides, lockdowns are also affecting the average stock prices of the automotive and insurance carries sectors by -21 and -22 % respectively, due to oversupply and the reduction of economic activities, which have led to a reduction of oil & gas stock prices by -34 % (Figure 3-1).

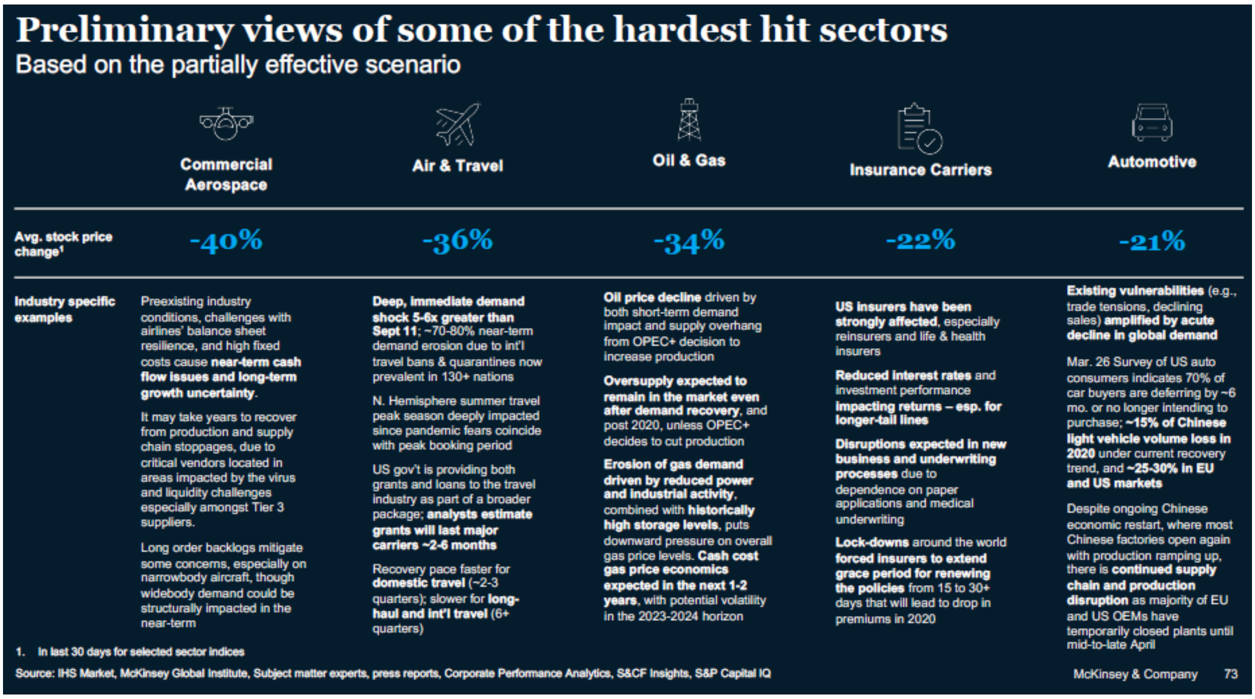


Figure 3-1: Average stock price changes in the hardest-hit sectors (McKinsey&Company, 2020b)

Among the most exposed sectors are also banks, which show the largest absolute reduction in value (Figure 3-2). On the other hand, for other industries, such as pharmaceuticals and healthcare, consumer services, retail, and high-tech, the damage will be less severe (**Error! Reference source not found.**). It is worth noting that there are differences between countries. For example, in France the construction sector is particularly vulnerable compared to other major European economies, such as the UK or Germany, while its banking sector is more resilient. In Italy, high-tech manufacturing is more exposed than other key economies like Spain, France, or Germany, while the wholesale sector is less vulnerable (McKinsey&Company, 2020).

It should be noted that there is a high degree of variability in the COVID-19 impacts also within sectors. Figure 3-3 shows that there are many companies that have seen positive shareholder returns, even if their sector has recorded a negative performance. Examples include pharmaceuticals, retail, customer services, or media. Several companies, with more resilient business models benefit from the pandemic.

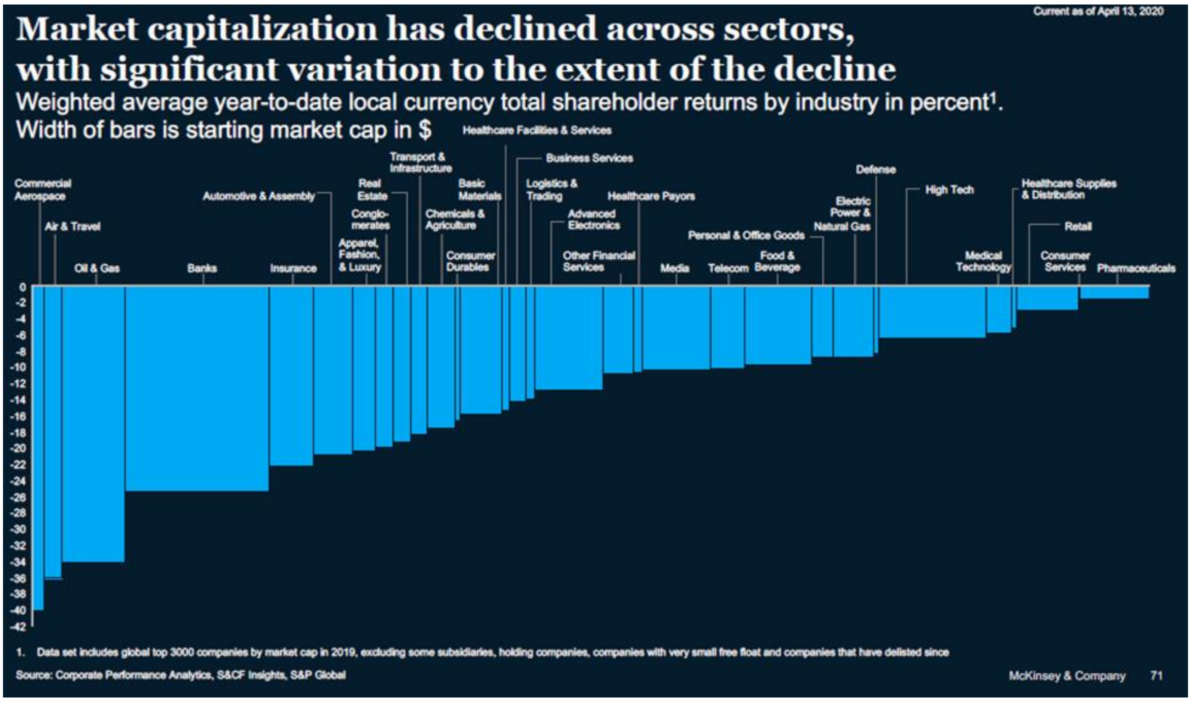


Figure 3-2: the most affected sectors (McKinsey&Company, 2020b).

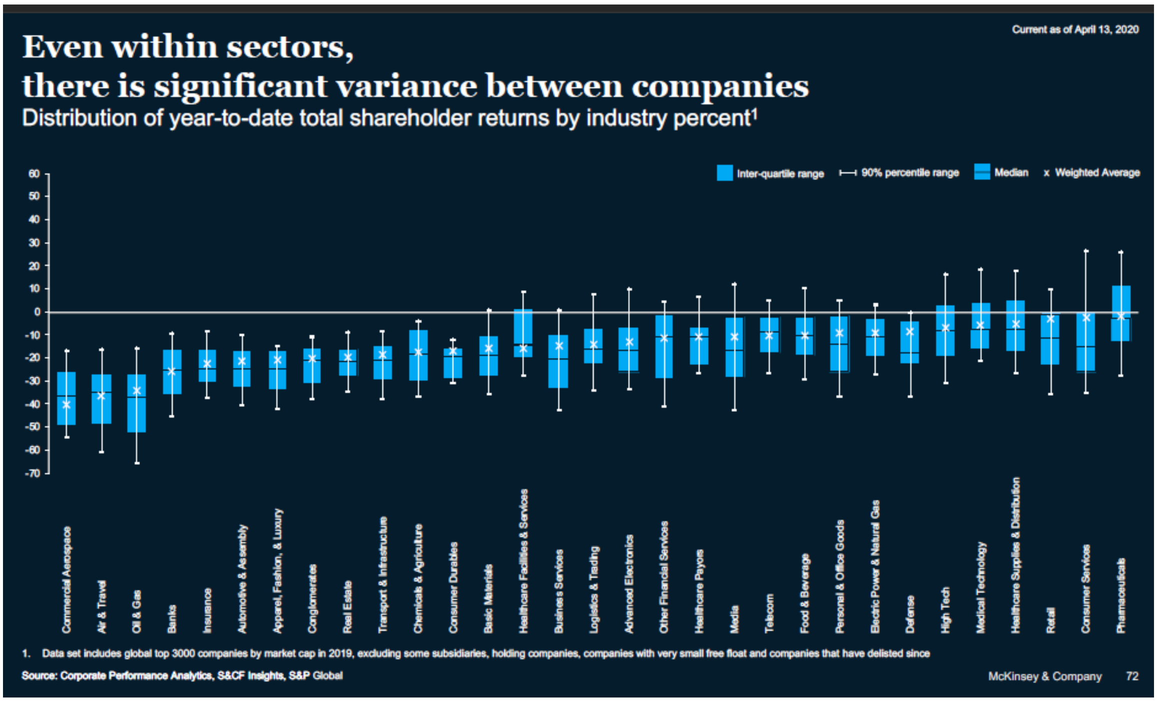


Figure 3-3: potential gains from the pandemic by sector (McKinsey&Company, 2020b).

COVID-19 and related lockdown and value chain disruption are forecasted to lead to an increase in production costs. The shock to production cost, calculated by McKibbin and Fernando (2020) based on the exposure of key economic sectors to sectors exposed to COVID-19 disruptions, could impact countries differently (Table 3-1). For instance, nations with a trade-depended energy industry (both for technology and consumption, as well as delivery), such as Russia or other oil producing countries, could experience large shocks (0.54 and 0.49 respectively). Moreover, industries like non-durable and durable manufacturing would be impacted similarly in most of the countries considered, due to the presence of global value chains for these sectors. Saudi Arabia represents an exception, experiencing the lowest shock to cost of production in all sectors. On the other hand, China and the US could be placed among the most impacted countries in almost all the considered industries due to their strong participation in global trade.

Region	Energy	Mining	Agriculture	Durable Manufacturing	Non-durable Manufacturing	Services
Argentina	0.37	0.24	0.37	0.35	0.40	0.38
Australia	0.43	0.43	0.42	0.39	0.41	0.45
Brazil	0.44	0.46	0.44	0.42	0.45	0.44
Canada	0.44	0.37	0.42	0.40	0.41	0.44
China	0.50	0.50	0.50	0.50	0.50	0.50
France	0.38	0.31	0.36	0.40	0.42	0.46
Germany	0.43	0.37	0.40	0.45	0.45	0.47
India	0.47	0.33	0.47	0.42	0.45	0.43
Indonesia	0.37	0.33	0.31	0.36	0.40	0.38
Italy	0.36	0.33	0.38	0.42	0.44	0.46
Japan	0.45	0.40	0.45	0.47	0.47	0.49
Mexico	0.41	0.38	0.39	0.42	0.42	0.41
Other Asia	0.44	0.39	0.44	0.45	0.45	0.47
Other oil producing countries	0.49	0.41	0.47	0.40	0.43	0.45
Republic of Korea	0.39	0.30	0.37	0.43	0.42	0.43
Rest of Euro Zone	0.42	0.41	0.43	0.43	0.46	0.48
Rest of OECD	0.42	0.38	0.41	0.41	0.43	0.46
Rest of the World	0.52	0.46	0.51	0.45	0.49	0.48
Russia	0.54	0.37	0.43	0.41	0.42	0.45
Saudi Arabia	0.32	0.25	0.29	0.29	0.25	0.35
South Africa	0.40	0.35	0.39	0.41	0.43	0.38
Turkey	0.37	0.36	0.39	0.39	0.42	0.42
United Kingdom	0.39	0.37	0.39	0.39	0.42	0.46
United States of America	0.53	0.40	0.51	0.50	0.51	0.53

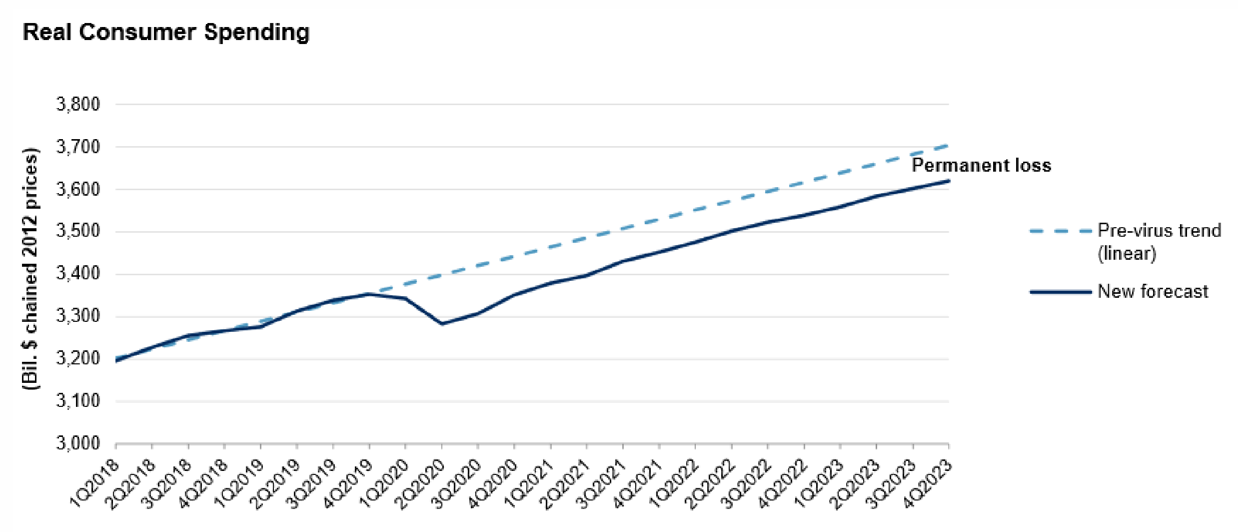
Table 3-1: Shocks to cost of production (McKibbin & Fernando, 2020).

3.1.2 GDP impacts: reduction of consumption

Forecasts show that because of social distancing, 14 % of consumer spending will be put at risk during 2020 in the US (S&P Global Ratings, 2020b). Some services, public transportation, or recreation will be in full or partial lockdown until at least mid-May. Such a standstill would affect the US national GDP by 2.6 % in Q1 and 7.7 % in Q2 (Table 3-2). Services are expected to be most impacted, followed by non-durable and durable goods. Overall, S&P has estimated that by 2023 the amount of loss from consumer spending will amount to $84 billion (S&P Global Ratings, 2020b), a permanent loss.

				--March-only effect on Q1 growth--		--April and May effect on Q2 growth--	
Consumer spending major categories	Share of consumer spending	Share of GDP	Hypothetical potential impact weekly average for six weeks (versus pre-virus actual)	Consumer spending	GDP	Consumer spending	GDP
(In real terms, %)							
Durable goods	14	9.5	(40)	(0.9)	(0.6)	(2.7)	(1.9)
Non-durable goods	23	15.8	(25)	(0.9)	(0.7)	(2.8)	(2.0)
Services: at risk from social distancing	14	9.8	(75)	(1.5)	(1.2)	(4.6)	(3.7)
Services: other (excluding social)	50	35.0	(1)	(0.1)	(0.1)	(0.2)	(0.2)
Total	100.0	70.0		(3.5)	(2.6)	(10.4)	(7.7)

Table 3-2: Impact of social distancing on consumer spending and the US' GDP (S&P Global Ratings, 2020b)



Sources: Bureau of Economic Analysis and S&P Global Economics' forecasts.

Figure 3-4: real consumer spending in the US (S&P Global Ratings, 2020b).

McKibbin and Fernando have generated forecasts for various countries, based on the severity of both epidemiological shocks and the duration of the pandemic, (McKibbin & Fernando, 2020) (Table 3-3). Scenarios 4 to 6 consider that the epidemiological shocks will occur in all countries with different degrees; however, these hypotheses assume that the shocks are temporary. Scenario 7 assumes that the pandemic's impacts are mild, but that these will occur each year for an indefinite time. In other words, if the virus will spread in all countries producing minor consequences, both temporarily or permanently (S04 and S07), the shocks to consumption demand would range between -0.8 % and -1.0 % in all countries. However, if the consequences of the virus will be more severe (S05 and S06), the shocks will span from around -2 %/-2.5 % to -3.5 %/-4.5 %.

Region	S04	S05	S06	S07
Argentina	- 0.83	- 2.09	- 3.76	- 0.83
Australia	- 0.90	- 2.26	- 4.07	- 0.90
Brazil	- 0.92	- 2.31	- 4.16	- 0.92
Canada	- 0.90	- 2.26	- 4.07	- 0.90
China	- 1.00	- 2.50	- 4.50	- 1.00
France	- 0.93	- 2.31	- 4.16	- 0.93
Germany	- 0.95	- 2.36	- 4.25	- 0.95
India	- 0.91	- 2.29	- 4.11	- 0.91
Indonesia	- 0.86	- 2.15	- 3.86	- 0.86
Italy	- 0.93	- 2.32	- 4.18	- 0.93
Japan	- 1.01	- 2.51	- 4.52	- 1.01
Mexico	- 0.89	- 2.22	- 4.00	- 0.89
Other Asia	- 0.95	- 2.38	- 4.28	- 0.95
Other oil producing countries	- 0.92	- 2.31	- 4.16	- 0.92
Republic of Korea	- 0.89	- 2.23	- 4.01	- 0.89
Rest of Euro Zone	- 0.98	- 2.45	- 4.40	- 0.98
Rest of OECD	- 0.92	- 2.31	- 4.16	- 0.92
Rest of the World	- 0.98	- 2.45	- 4.42	- 0.98
Russia	- 0.92	- 2.31	- 4.16	- 0.92
Saudi Arabia	- 0.74	- 1.86	- 3.35	- 0.74
South Africa	- 0.82	- 2.05	- 3.69	- 0.82
Turkey	- 0.88	- 2.19	- 3.95	- 0.88
United Kingdom	- 0.94	- 2.34	- 4.22	- 0.94
United States of America	- 1.06	- 2.66	- 4.78	- 1.06

Table 3-3: shocks to consumption demand depending on different scenarios (McKibbin & Fernando, 2020).

3.1.3 Increased cost of doing business ad premiums

McKibbin and Fernando have analysed the impact of COVID-19 on the equity risk premium, based on country performance related to mortality, governance and financial risk and health policy. Four scenarios were analysed in (McKibbin & Fernando, 2020). Scenarios 4 to 6 consider that the epidemiological shocks will occur in all countries with different degrees; however, these hypotheses assume that the shocks are temporary. Scenario 7 assumes that the pandemic's impacts are mild, but that these will occur each year for an indefinite time. As shown in Table 3-4, scenarios 4 and 7 would produce identical results, as well as the lowest shocks. On the other hand, the risk would increase in both scenarios 5 and 6.

Generally, western countries like Australia, Canada, France, Germany, Italy, the UK, and the US, as well as Japan, Korea and Saudi Arabia, would not reach a shock higher than 2 in all scenarios (this is a score relative to the US, current value). On the other hand, the most vulnerable countries, appear to be located in Asia; for example, India, Indonesia, and China would surpass the value of 2 in almost all scenarios.

Region	S04	S05	S06	S07
Argentina	1.90	2.07	2.30	1.90
Australia	1.23	1.37	1.54	1.23
Brazil	1.59	1.78	2.03	1.59
Canada	1.23	1.36	1.52	1.23
China	1.97	2.27	2.67	1.97
France	1.27	1.40	1.59	1.27
Germany	1.07	1.21	1.41	1.07
India	2.20	2.62	3.18	2.20
Indonesia	2.06	2.43	2.93	2.06
Italy	1.32	1.47	1.66	1.32
Japan	1.18	1.33	1.53	1.18
Mexico	1.76	1.98	2.27	1.76
Republic of Korea	1.25	1.43	1.67	1.25
Russia	1.77	1.96	2.22	1.77
Saudi Arabia	1.38	1.52	1.70	1.38
South Africa	1.85	2.06	2.33	1.85
Turkey	1.98	2.20	2.50	1.98
United Kingdom	1.35	1.50	1.70	1.35
United States of America	1.07	1.18	1.33	1.07
Other Asia	1.51	1.75	2.07	1.51
Other oil-producing countries	2.03	2.25	2.55	2.03
Rest of Euro Zone	1.29	1.42	1.60	1.29
Rest of OECD	1.11	1.22	1.38	1.11
Rest of the World	2.21	2.51	2.91	2.21

Table 3-4: shocks to equity risk premium for different scenarios (McKibbin & Fernando, 2020).

3.1.4 Increased country risk and public costs (for health, debt servicing)

To contain the spread of COVID-19, countries must increase health expenditures (McKibbin & Fernando, 2020). However, shocks to government expenditure are affected by the duration and the severity of the pandemic. As Table 3-5 shows, scenarios 4 and 7 would produce identical results, as well as the lower shocks. On the other hand, the risk would increase in both scenarios 5 and 6.

Generally, western countries like Australia, Canada, France, Germany, Italy, the UK and the US, as well as Japan, Korea and Saudi Arabia, would reach a shock higher than 1 only in the sixth scenario. On the other hand, countries like China, India, Indonesia, Mexico, Russia, South Africa, and Turkey would surpass the shock of 1 from the fifth scenario (S05).

Region	S04	S05	S06	S07
Argentina	0.39	0.98	1.76	0.39
Australia	0.27	0.67	1.21	0.27
Brazil	0.39	0.98	1.76	0.39
Canada	0.26	0.66	1.19	0.26
China	0.50	1.25	2.25	0.50
France	0.30	0.74	1.34	0.30
Germany	0.27	0.68	1.22	0.27
India	0.52	1.30	2.34	0.52
Indonesia	0.47	1.18	2.12	0.47
Italy	0.34	0.84	1.51	0.34
Japan	0.30	0.74	1.33	0.30
Mexico	0.43	1.07	1.93	0.43
Republic of Korea	0.31	0.79	1.41	0.31
Russia	0.49	1.23	2.21	0.49
Saudi Arabia	0.38	0.95	1.71	0.38
South Africa	0.43	1.08	1.94	0.43
Turkey	0.47	1.17	2.11	0.47
United Kingdom	0.27	0.68	1.22	0.27
United States of America	0.22	0.54	0.98	0.22
Other Asia	0.39	0.99	1.77	0.39
Other oil producing countries	0.54	1.35	2.42	0.54
Rest of Euro Zone	0.33	0.81	1.46	0.33
Rest of OECD	0.28	0.70	1.26	0.28
Rest of the World	0.59	1.49	2.67	0.59

Table 3-5: shocks to government expenditures depending on different scenarios (McKibbin & Fernando, 2020)

3.2. Path to recovery: possible trends

The recovery of global and national GDP will depend on the containment of the pandemic within the second half of 2020, which would allow to restore both consumer and investor confidence (IMF, 2020b). In this scenario global economies will see a rebound in growth (well above previous years), due to the normalization of economic activities from the low level reached in 2020 (Figure 3-7, (IMF, 2020c)).

The forecasts available to date point to the following scenarios: global growth could be restored in 2021 if impacts are limited primarily to consumption (S&P Global Ratings, 2020c; McKinsey&Company, 2020b; OECD, 2020), in 2022 if production is also affected extensively (S&P Global Ratings, 2020c; McKinsey&Company, 2020b), or by 2023 if we will face additional waves of the outbreak, e.g. due to the emergence of new variants (McKinsey&Company, 2020b).

The most severe economic risk posed by the current pandemic is currently unemployment, which would hinder recovery due to lower consumption, and the erosion of savings. In the Asia-Pacific region alone, unemployment is forecasted to return to 2019 level only in 2023 (S&P Global Ratings, 2020a) indicating the possibility to lose 4 years of job creation potential. Worst-case scenarios are less likely to occur for GDP (McKinsey&Company, 2020c) due to the implementation of several response measures and the adaptive behavior emerged in the past weeks (e.g. with the increase of online purchases and the provision of remote services). On the other hand, these same interventions may have further negative impacts on employment (e.g. when production and services switch to less labour intensive sectors and activities).

The recovery will depend on the following factors: containment of the virus, policy support, and economic preparedness of countries.

3.2.1 Scenarios

McKinsey and Company provides a framework for identifying possible future scenarios of recovery. Considering three archetypes for describing both *the spread of the virus and health response* and *policy interventions*, six scenarios are possible (Figure 3-5), of which A1, A2, A3, and A4 are the most likely to occur (McKinsey&Company, 2020c). All these four scenarios assume that the virus will be eventually contained, and economic growth will be restored.

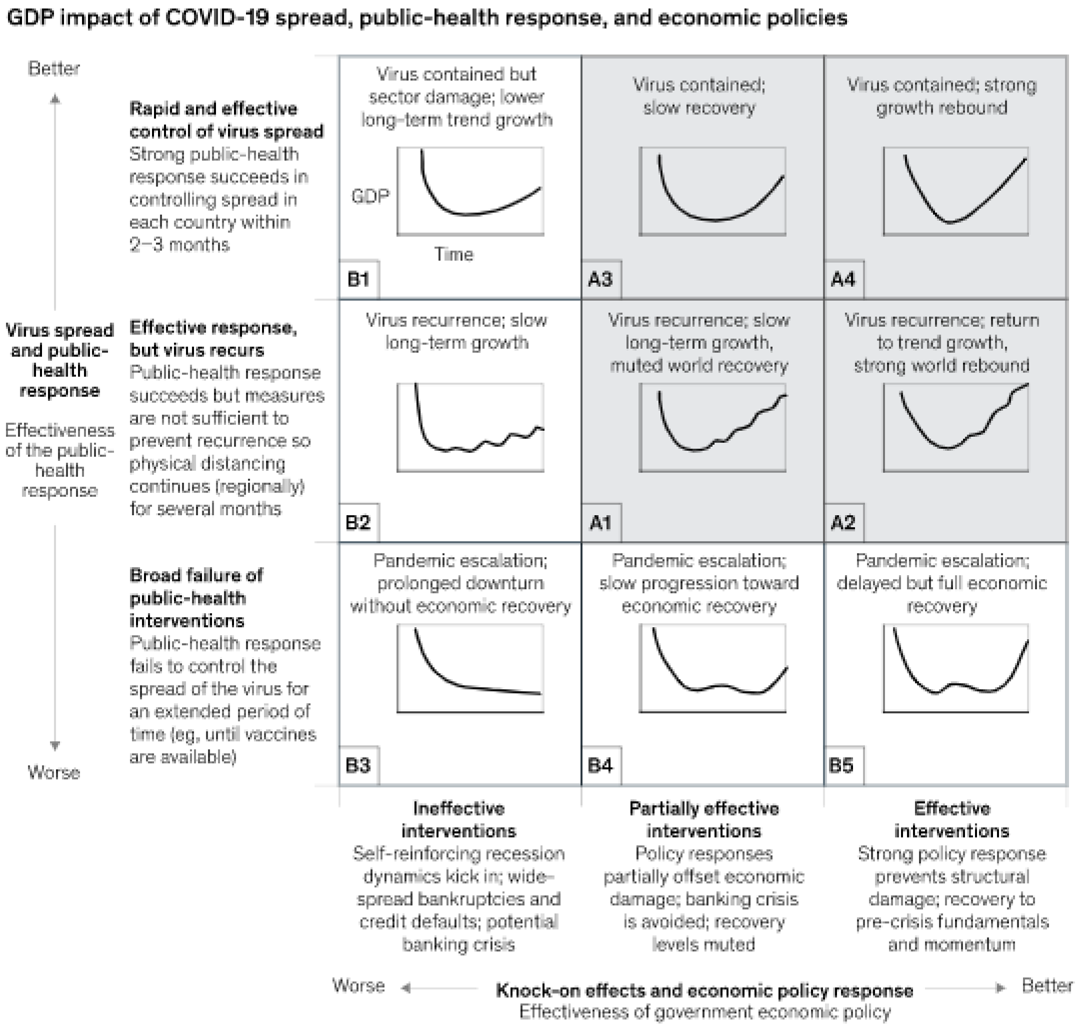


Figure 3-5: possible scenarios describing the economic impacts of COVID-19 *(McKinsey&Company, 2020c)*.

Despite the scenarios that forecast the worst economic outcomes are less likely to occur, business across the world are vulnerable to both the economic and the epidemiological consequences of the pandemic. Figure 3-6 summarizes which indicators could be used to forecast the severity of demand reductions, length of disruption, as well as the shape of future recovery.

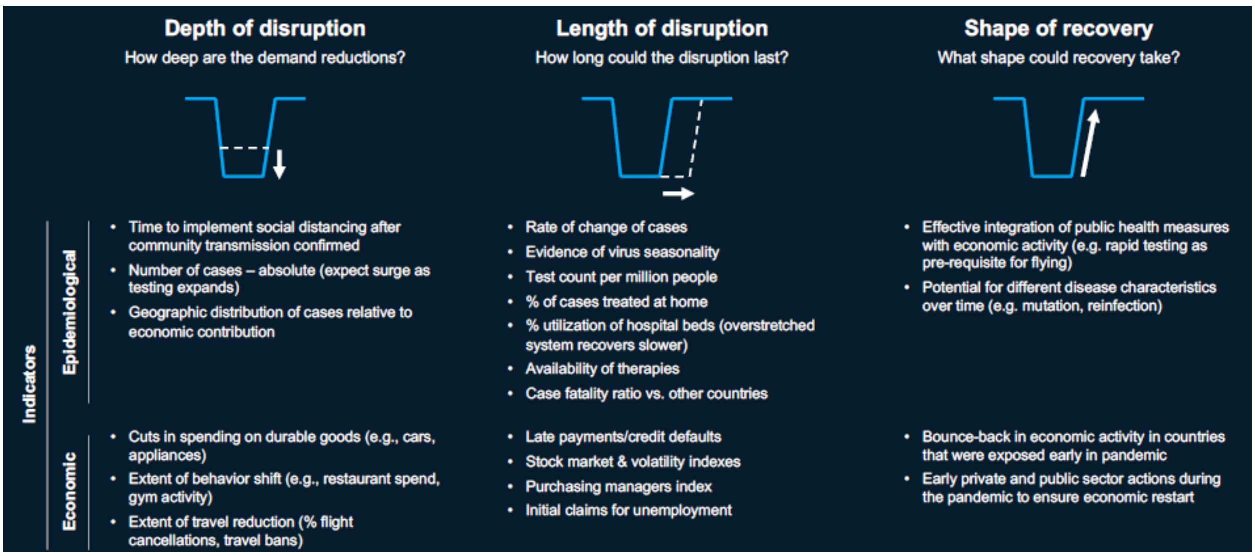


Figure 3-6: Economic and epidemiological indicators for businesses *(McKinsey&Company, 2020b)*.

3.2.2 Forecasts

As indicated above, it is generally forecasted that by the end of 2021 national GDP will remain below pre-virus level for advanced economies (IMF, 2020b) (Figure 3-8). For EU-27 countries only Luxemburg is expected to have the annual growth rate of 2021 (5.7%) being larger than the reduction of 2020 (-5.4 %). Nevertheless, GDP in 2021 will be lower than in 2019 for all EU-27 countries (European Commission, 2020).

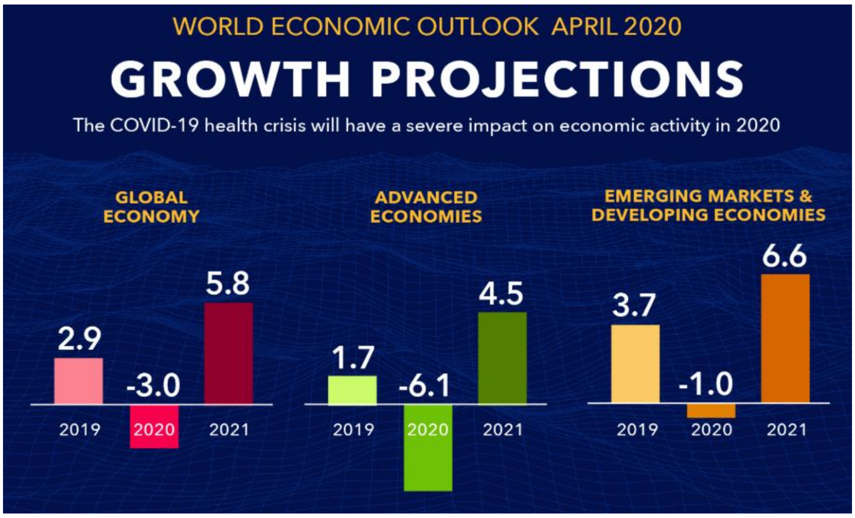


Figure 3-7: Growth projections *(IMF, 2020c)*

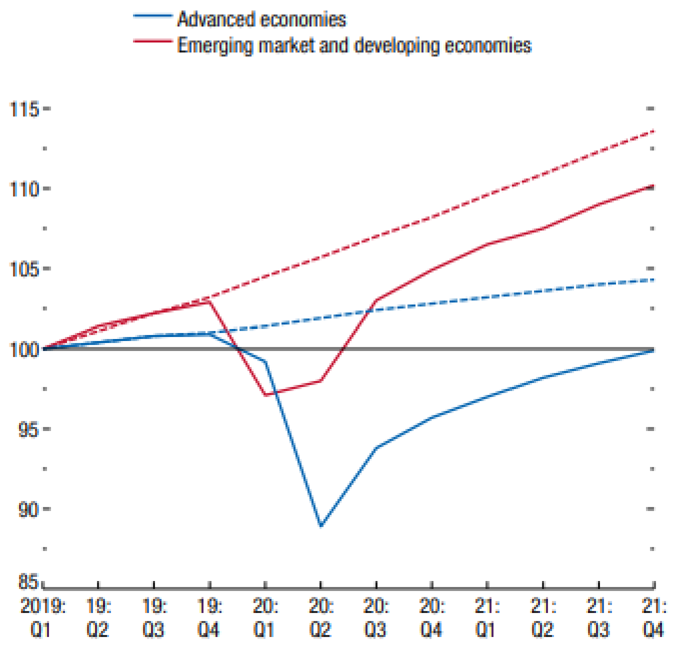
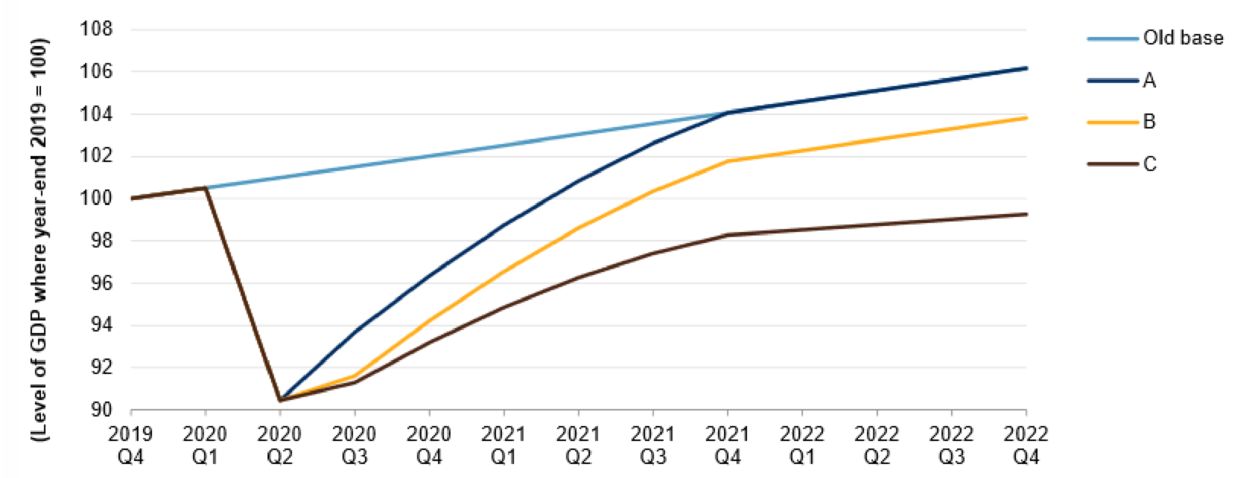


Figure 3-8: Quarterly world GDP projections (dashed lines indicate estimates from January 2020) - (IMF, 2020b).

When creating scenarios of recovery, various assumptions should be considered (S&P Global Ratings, 2020c). Figure 3-9 shows when the GDP recovery will occur and by which extent, when:

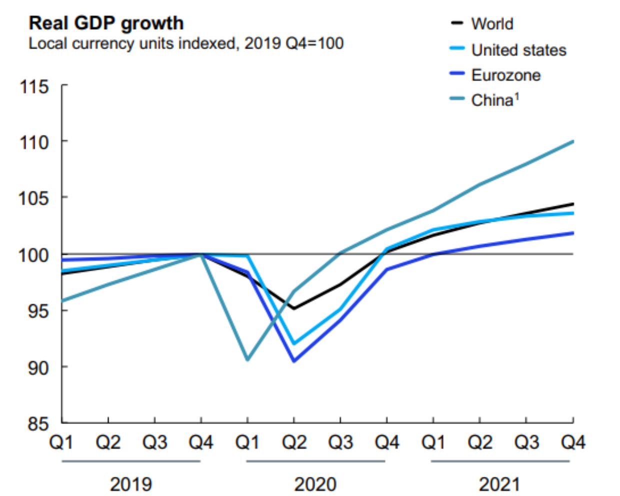
A. Only a demand shock occurs (full recovery).
B. The demand shock includes a loss in the level of output growth (partial recovery – output like the 1990 US recession).
C. The demand shock includes a loss in the level and rate of output growth (no recovery to the year-end 2019 level of GDP by the end of 2022).



Source: S&P Global Economics.

Figure 3-9: GDP recovery scenarios (S&P Global Ratings, 2020c).

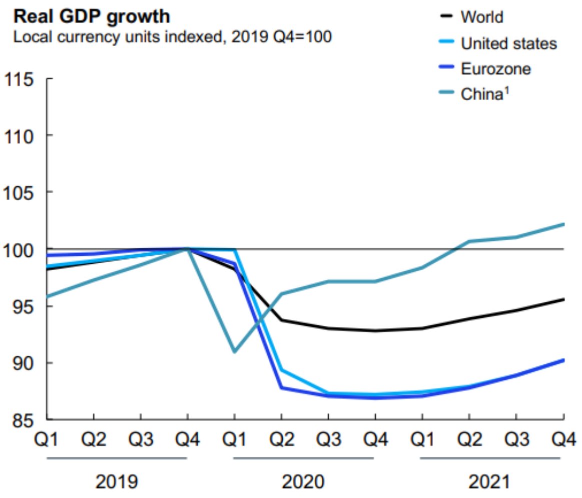
The containment of the pandemic will play a major role in influencing future GDP contractions or recovery: if the virus is seasonal and the public health response is strong, major economies will be able to recover between the end of 2020 and the beginning of 2021 (Figure 3-10).



	Real GDP drop 2019 Q4–2020 Q2 % change	2020 GDP growth % change	Time to return to pre-crisis Quarter
China	-3.3%	-0.4%	2020 Q3
USA	-8.0%	-2.4%	2020 Q4
World	-4.9%	-1.5%	2020 Q4
Eurozone	-9.5%	-4.4%	2021 Q1

Figure 3-10: scenario A – virus contained (McKinsey&Company, 2020b).

However, if the virus is not seasonal, spreading across the world, and if public health facilities will be overwhelmed, China would recover more slowly, while the US and the Eurozone would face a GDP's decline of 35 % and 40 % respectively (Figure 3-11).



	Real GDP drop 2019 Q4–2020 Q2 % change	2020 GDP growth % change	Time to return to pre-crisis Quarter
China	-3.9%	-2.7%	2021 Q2
USA	-10.6%	-8.4%	2023 Q1
World	-6.2%	-4.7%	2022 Q3
Eurozone	-12.2%	-9.7%	2023 Q3

Figure 3-11: scenario b – virus not contained (McKinsey&Company, 2020b).

3.3. Methods and models reviewed

Several methods and models have been used to estimate the economic impact of COVID-19. The two most common methodologies are Computable General Equilibrium (CGE) and macroeconometric models. The table below provides a summary on these studies.

	Source	Method	Link
1	McKibbin and Fernando (2020)	G-Cubed Multi-Country Model: Global hybrid DSGE/CGE general equilibrium model	https://www.brookings.edu/wp-content/uploads/2020/03/20200302_COVID19.pdf
2	Federal Reserve Bank of Minneapolis	SIR model, epidemics	https://www.minneapolisfed.org/article/2020/estimating-economic-impact-of-covid-19
3	IMF Economic Outlook	IMF G-20 model	https://www.imf.org/en/Publications/WEO/Issues/2020/04/14/weo-april-2020
4	IMF Global Financial Stability Report	N/A	https://www.imf.org/en/Publications/GFSR/Issues/2020/04/14/global-financial-stability-report-april-2020
	VOX	Summary of existing knowledge/papers. Two models are mentioned: COMPACT and NiGEM	https://voxeu.org/content/economics-time-covid-19
5		COMPACT: a rational expectations, intertemporal model of the United Kingdom economy (econometric model)	https://ideas.repec.org/a/eee/ecmode/v16y1998i1p1-52.html
6		NIGEM model: macro-econometric set of country models	https://nimodel.niesr.ac.uk/
7	OECD	NiGEM _OECD 2020 model: macro-econometric set of country models	https://www.oecd-ilibrary.org/docserver/7969896b-en.pdf?expires=1587375597&id=id&accname=guest&checksum=CC87F794159E15D9B1B6967CECAF3494
8	London Business School	Now-Casting: Econometric model	https://www.now-casting.com/resources/methodology
9	Darabi and Hosseinichimeh	System Dynamics Modeling in Health and Medicine A Systematic Literature Review	
10	Institut Montiange	No mention of specific method/model	https://www.institutmontaigne.org/en/blog/covid-19-first-estimate-its-economic-impact
11	Namibia Planning Commission, University of Namibia	No mention of specific method/model, only mention of an approach similar to McKibbin and Fernando.	https://mpra.ub.uni-muenchen.de/99641/1/MPRA_paper_99641.pdf
12	UNU-WIDER	G-Cubed Multi-Country Model: Global hybrid DSGE/CGE general equilibrium model	https://www.wider.unu.edu/publication/estimates-impact-covid-19-global-poverty
13	IFPRI	Social Accounting Matrix (SAM), multiplier model for Egypt	ifpri.org/blog/economic-impact-covid-19-tourism-and-remittances-insights-egypt
	EAST ASIA FORUM	The article cites the IMF economic outlook as well as an article that formulates a model similar to the one of McKibbin and Fernando	https://www.eastasiaforum.org/2020/03/27/assessing-the-economic-impacts-of-covid-19-on-asean-countries/
		IDE-GSM, CGE (based on the NEG model)	https://www.ide.go.jp/library/Japanese/Publish/Download/PolicyBrief/IDE/pdf/10_en.pdf
14		NEG model: CGE	
15	The Info Mullet	N/A	http://infomullet.com/2020/03/23/pocketofposies/
16	SP Global	No mention of specific method/model	https://www.spglobal.com/en/research-insights/featured/economic-implications-of-coronavirus
17	McKinsey and Company	No mention of specific method/model	https://www.mckinsey.com/business-functions/risk/our-insights/covid-19-implications-for-business
18	EU DG ECFIN	Structural Macro Model QUEST	https://ec.europa.eu/info/sites/info/files/economy-finance/ip132_en.pdf

Table 3-6. Studies and models reviewed.

4 Identifying and assessing the systemic impacts of low carbon development with Systems Thinking

This section presents a systemic analysis of the outcomes of the EU Green Deal. It supports the creation of a shared understanding of the rationale for -and outcomes of- the EU Green Deal. It provides a simplified system map (or Causal Loop Diagrams, CLD) to understand how they key variables of our socioeconomic and environmental system are interrelated, and how policy intervention can shift the dynamics experienced historically, leading to a more sustainable future.

4.1. Socioeconomic and environmental outcomes of the EU Green Deal

The starting point for the systemic analysis is the review of past drivers of change and the dynamics these have triggered. With an understanding of the known patterns of change that brought us to the need for the introduction of the EU Green deal it will be possible to identify stated entry points for intervention, their direct, indirect and induced outcomes.

Figure 4-1 shows that when GDP increases, a stable trend in the past decades, with only a few exceptions, two main outcomes emerge: (a) consumption increases, leading to higher GDP directly and indirectly via production (reinforcing loop R1) and (b) investment increases, leading to more innovation and cost competitiveness, in turn increasing production and GDP (reinforcing loop R2). These reinforcing Loops (R) that trigger economic growth, also through employment creation and trade.

On the other hand, economic growth has given rise to various balancing factors (or Balancing Loops). One of these is the growing need for mobility, resulting in congestion. Congestion increases time spent in traffic and away from work and families (B1), creating societal costs. It also reduces the potential to grow for productivity, production and value added (B3). It further leads to air pollution (B2) resulting from energy use (both for transport, industries and in buildings), which affects labour productivity via health. Finally, the increase in energy use resulting from higher investment and income has led to higher vulnerability to market dynamics and price volatility and extreme weather events impacting the supply of energy (B4), which has negative impacts on production. Production in turn, leads to the generation of waste, which impacts water pollution and food quality, creating societal costs both in urban and rural areas (B5). These are only a few examples of growing costs to society, those highlighted in the EU Green Deal. In addition, these costs are not emerging in the same measure in all countries and regions. As an example, urban areas are being impacted more strongly by air pollution than rural areas.

When considering historical trends, it emerges that the reinforcing loops R1 and R2 have been dominating the dynamics of the system. This is because GDP, consumption and investment have grown over time, as have congestion and societal costs. In 2009, after the financial crisis of 2008, GDP and investments decreased by 4.3 % and 11.7 % respectively for the EU-28 (Eurostat, 2019a). However, between 2015 and 2018 GDP increased by 2-2.5 % each year, while investments also grew by 2.3-4.9 % during the same period. Moreover, consumption expenditure increased by 9.8 % from 2008 to 2018 (Eurostat, 2019a). On the other hand, thanks to energy efficiency improvements, little change has emerged for energy consumption and emissions, as well as for waste generation, indicating relative decoupling. Gross inland energy consumption was relatively stable between 1990 and 2017, increasing only by 1.6 % (Eurostat, 2019b) while greenhouse gas emissions were around 22 % lower than 1990 levels (EEA, 2019). Waste generation, excluding major mineral waste, slightly increased from 779.5 million tonnes in 2004 to 785.0 million tonnes in 2016 (Eurostats, 2019c). This highlights that the emergence of balancing loops has been countered by energy efficiency, the use of renewable energy, collection, sorting, recycling and reuse of waste. Limiting these balancing factors has allowed GDP to continue growing at 1.5 % to 2.5 % in the last decade, but more should be done both to support the economy via reinforcing loops and reducing constraints to growth via balancing loops.

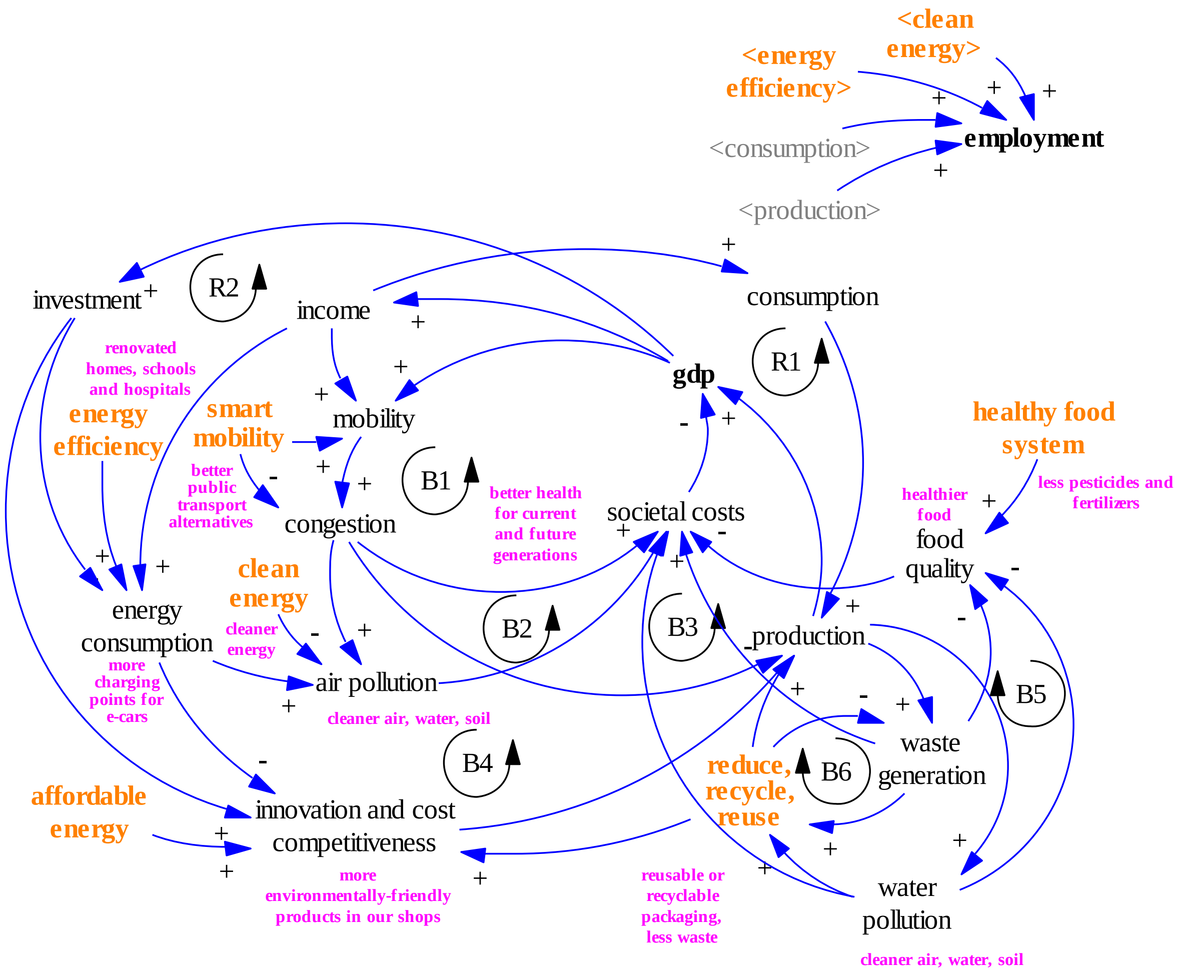


Figure 4-1. A simplified representation of the dynamics influenced and triggered by the EU Green Deal.

Legend:
- All key areas of intervention are covered in the CLD: energy, buildings, industry, mobility (https://ec.europa.eu/commission/presscorner/detail/en/fs_19_6714)
- Pink: EU Green Deal benefits for future generations (https://ec.europa.eu/commission/presscorner/detail/en/fs_19_6717)
- Orange: all key intervention options (areas) (https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:52019DC0640&from=EN)

The EU Green Deal is designed to use various strategies (in yellow in Figure 4-1) to influence energy, buildings, transport and food production. The expected outcomes (in pink) include cleaner air, water and soils (through interventions on energy efficiency, clean energy, waste reduction, improved agriculture practices), also resulting in better human health, better transport alternatives and access to distributed power generation options (and so better access to more modern and resilient services).

Specifically, (a) energy efficiency, (b) clean energy and (c) affordable energy are designed to reduce energy consumption and air pollution, as well as to stimulate innovation and increase competitiveness. As a result, these interventions strengthen reinforcing loops R1 and R2 via GDP, consumption and investment. At the same time, balancing loops B2, B3 and B4 will become weaker, further stimulating economic growth by reducing societal costs and making production more effective. Investments to realize these opportunities include renovated homes, schools and hospitals (energy efficiency), renewable energy use, installation of charging stations for e-vehicles, adoption of environment-friendly technologies (clean and affordable energy).

(d) Smart mobility via better public transport and non-motorized transport will make B1 and B2 weaker, by reducing congestion, energy use and emissions, leading to lower societal costs (e.g. health costs) and more effective production activities. Outcomes include better health for current and future generations, via cleaner air, water, soil (also in conjunction with waste reduction, recycling and reuse).

(e) Waste reduction, recycling and reuse affect primarily B5 and B6, which then indirectly affect R1 and R2. As a result, reducing waste both unlocks opportunities for existing drivers of growth, and stimulates new paths for sustainable growth by stimulating innovation and competitiveness.

(f) Healthy food systems are expected to increase food quality by reducing the use of fertilizers and pesticides. This reduces societal costs (B2, B3), increasing labour productivity, lowering public and private costs, resulting in a stimulus taking place through R1 and R2.

Practically, the EU Green Deal aims at making balancing factors weaker, so that the economy can continue to grow, but in a more sustainable and resilient way. This results in lower costs for society, higher productivity, and improved well-being.

Text box 1: Introduction to Systems Thinking

Systems Thinking (ST) is an approach that allows us to better understand and forecast the outcomes of our decisions, across sectors, economic actors, over time and in space (Probst & Bassi, 2014). It emphasizes the system, being made of several interconnected parts, rather than focusing on its individual parts.

With ST being an approach, there are several methodologies and tools that support its implementation and hence the identification of the underlying functioning mechanisms of a system and their quantification and evolution over time. In general terms, it can be said that the identification of the components of a system and of the relationships existing among these components (e.g. carried out through the use of Causal Loop Diagrams) represents (i) the *soft* side of Systems Theory. Instead, attempts to quantify these linkages and forecast how their strength might change over time (e.g. carried out using System Dynamics models) represent (ii) the *hard* side of the field.

Concerning the former (i), Causal Loop Diagrams (CLD) allow to create a shared understanding of how the system works, and hence identify effective entry points for (human) intervention, such as public policies. When this is done using a participatory approach, it helps to bring people together, creating the required building blocks for the co-creation of a shared and effective theory of change.

On the latter (ii), System Dynamics models allow to quantify policy outcomes across social, economic and environmental indicators (UNEP, 2014) providing insights on the relative strength of various drivers of change (scenario analysis) and supporting the identification and prioritization of policy intervention (policy analysis). These models can be bottom up or top down (Probst & Bassi, 2014; UNEP, 2011).

In the context of this research, the role of ST is to assess the extent to which the main drivers of change considered (i.e. ageing of population, technological change and fiscal sustainability) can shape future trends, affect existing policy effectiveness and require future interventions. This in turn allows to identify a system's safe operating space and limits, anticipating the emergence of side effects, across social, economic and environmental indicators.

Text box 2: Causal Loop Diagrams (CLD)

A causal loop diagram (CLD) is a map of the system analysed, or, better, a way to explore and represent the interconnections between the key indicators in the analysed sector or system (Probst & Bassi, 2014). As indicated by John Sterman, “*A causal diagram consists of variables connected by arrows denoting the causal influences among the variables. The important feedback loops are also identified in the diagram. Variables are related by causal links, shown by arrows. Link polarities describe the structure of the system. They do not describe the behavior of the variables. That is, they describe what would happen if there were a change. They do not describe what actually happens. Rather, it tells you what would happen if the variable were to change.”* (Sterman, 2000)

As indicated by Sterman, CLDs include variables and arrows (called causal links), with the latter linking the variables together with a sign (either + or −) on each link, indicating a positive or negative causal relation (see Table 1). A causal link from variable A to variable B is positive if a change in A produces a change in B in the same direction. A causal link from variable A to variable B is negative if a change in A produces a change in B in the opposite direction. Circular causal relations between variables form causal, or feedback, loops. There are two types of feedback loops: reinforcing and balancing. The former can be found when an intervention in the system triggers other changes that amplify the effect of that intervention, thus reinforcing it (Forrester, 1961). The latter, balancing loops, tend towards a goal or equilibrium, balancing the forces in the system (Forrester, 1961).

By highlighting the drivers and impacts of the issue to be addressed and by mapping the causal relationships between the key indicators, CLDs support the identification of policy outcomes using a systemic approach (Probst & Bassi, 2014). CLDs can be in fact be used to create storylines corresponding to the implementation of policy interventions, by highlighting direct, indirect and induced policy outcomes across social, economic and environmental indicators.

Variable A	Variable B	Sign
↑	↑	+
↓	↓	+
↑	↓	-
↓	↑	-

Table 1: Causal relations and polarity

4.2. COVID-19: threats and opportunities for low carbon development

The inclusion of COVID-19 in the analysis requires the addition of several variables to the CLD, representing (i) impacts of the outbreak (e.g. consumption) and (ii) response measures (e.g. public stimulus). These additions introduce new dynamics and feedback loops (Figure 4-2), namely:

- Reduction of GDP via the reduction of production (due to demand and limited labour force availability);
- Reduction of GDP via the reduction of consumption (due to social distancing, avoided travel);
- Reduced economic performance due to the higher cost of doing business and insurance premiums;
- Reduced country performance due to the increase of country risk and public costs (higher country risk leading to higher debt costs, higher public costs related to health and stimulus packages).

These four dynamics affect two existing reinforcing loops (R1 and R2), having a negative impact on GDP via consumption and production, possibly triggering a vicious cycle and hence a recession. The introduction of public stimulus instead adds reinforcing loops R4 and R5. The former represents the short term solution implemented by governments, to stimulate investments. The latter represents the expectation that, once the economy starts growing again, it will generate additional growth that allows to reduce the debt accumulated in the short term. The dynamics triggered by the increase of debt are represented by the balancing loop B4. Higher debt will reduce the potential for new investments in the future, due to the higher cost of debt servicing and to budget constraints related to financial stability.

It results that COVID-19 has temporarily turned two drivers of growth (R1 and R2) from virtuous to vicious, making them causes of recession rather than growth. This triggers balancing loop B7, which highlights the limited (finite) amount of financial resources available to governments. The expectation is that, if the stimulus is allocated well (R4), after the lockdown ends and the economy recovers, it will kick start production and consumption to levels that will allow to stimulate employment, increase government revenues (R5) and limit the constraints posed by medium and longer term debt (B7).

Concerning environmental performance, the reduction of economic activity reduces energy consumption and air pollution, and hence societal impacts, driven by R2, as well as by B1, B2, B3 and B4. With economic recovery the opposite dynamics return, as described earlier. As a result, little change is expected to these dynamics, unless permanent impacts emerge (e.g. smart working remains common practice).

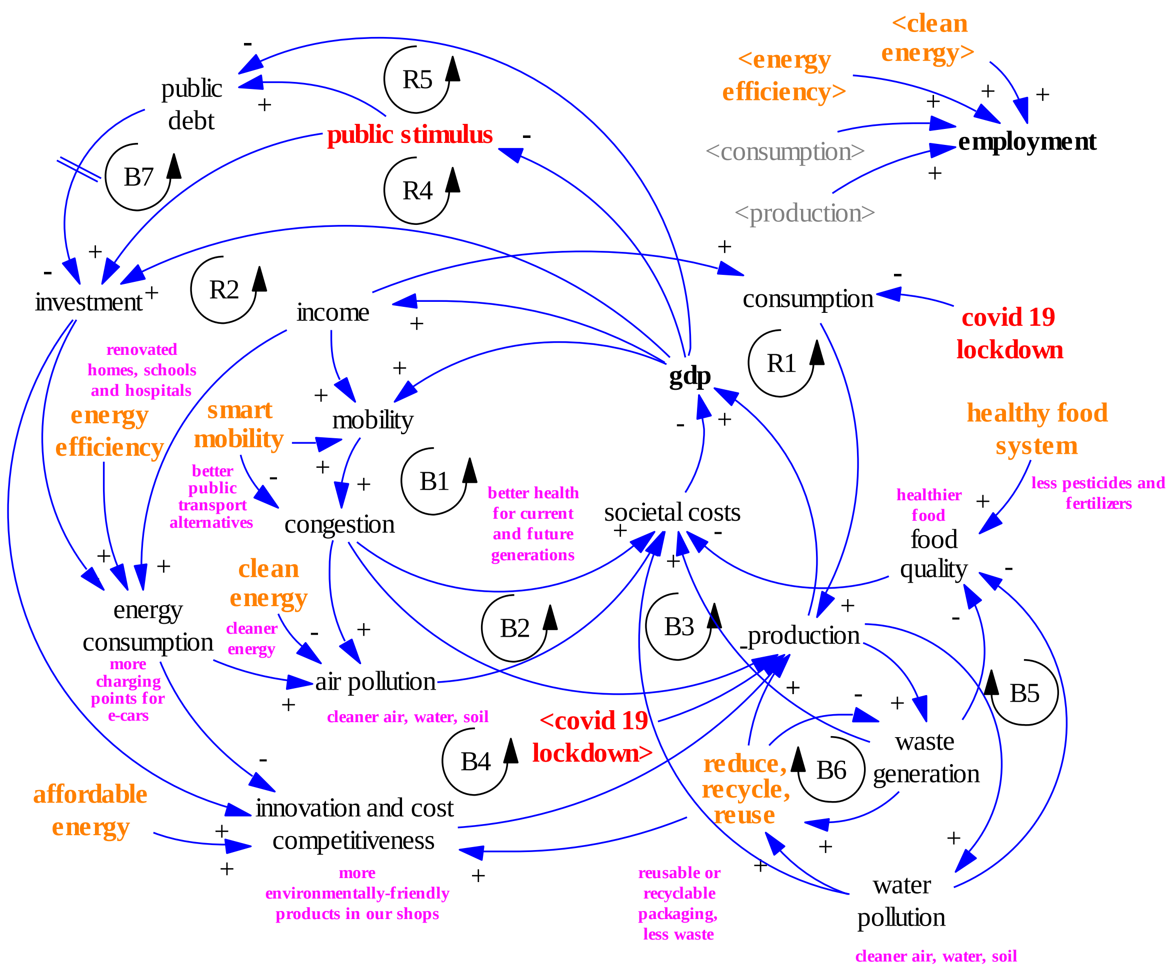


Figure 4-2. A simplified representation of the dynamics influenced and triggered by the EU Green Deal, including COVID-19.

5 Scenario analysis with a dynamic CGE model

This section aims to analyse the mechanisms behind the potential advantages coming from the implementation of the EU Green Deal (EGD) by taking into account a global perspective, where the world economy is also included in the dynamics.

It will provide a broad description of the modelling approach and the assumptions for scenario building exercise, as well as a representation of main findings from a EU perspective on selected aspects of the economic system mainly focusing on impacts on GDP and economic growth rate, competitive advantages, sector specialisation, as well as on aspects related to the energy system.

Scenarios are based on a business as usual reference case (BAU) that is alternatively tested with and without the economic crisis due to COVID-19 pandemic. This would help better investigating the role played by investments in clean energy technologies (CETs) in contributing also to exit from the crisis. By comparing the GDP growth rate with COVID-19 shock with growth patterns associated to a general economic recovery based on GDP levels, it is possible to highlight the magnitude of investments required to escape from the crisis in a short-term perspective. By adding the financial support to CETs associated to the implementation of the EGD targets, we can emphasize the additional impact played by longer term investments.

5.1. The dynamic CGE model: model settings

5.1.1 General settings

The dynamic CGE model is based on RunDynam designed for GTAP-type models. The specific GTAP-type version of the model is called GDyn-EP and all details on the modelling approach are provided in Bassi et al. (2020). With respect to the model version used in Bassi et al. (2020) there are some novelties related to the construction of the base year, the emissions data and the regional aggregation.

- Base year: while the former model was based on the GTAP 9.2 database, the current version has been updated with GTAP 10 database, meaning that the starting point has been shifted from 2011 to 2014, with updated values also for Leontief input-output matrices for the factor costs of sectors included in the database;
- Emissions: while the former model included only combustion-based CO2 emissions, the current version also introduces non-CO2 emissions associated to the use of energy commodities in the production and consumption activities;
- Regional aggregation: while the former model was based on a regional aggregation with the United Kingdom included within the EU28 aggregate, the current version has the EU composed by 27 members excluding the United Kingdom due to the Brexit process.

The dynamic setting is ensured with 8 periods, the first step with one year from the base data in 2014 to 2015, and then 7 steps of 5 years each up to the year 2050.

5.1.2 GTAP Database

A brief description of the new databases used for the construction of the base year related to 2014 is provided.

The GTAP 10 database is a consistent representation of the world economy for a pre-determined reference year. Underlying the data base there are several data sources, including among others: national input-output (I-O) tables, trade, macroeconomic, energy and protection data. The underlying input-output tables are heterogeneous in sources, methodology, base years, and sectoral detail, thus for achieving consistency, substantial efforts are made to make the disparate sources comparable. For these reasons, the objective of the GTAP Data Base is not to provide I-O tables, but to facilitate the operation of economic simulation models ensuring users a consistent set of economic facts. Some users interested in particular Social Accounting Matrices (SAMs) use utilities written by researchers in the network to extract them. A complete description of all features in GTAP10 is provided by Aguiar et al. (2019).

The GTAP-E 10 database provides carbon dioxide (CO2) emissions data distinguished by fuel and by user for each of the 141 countries/regions and the 65 sectors in the GTAP10 Data Base. GTAP-E data is based on: GTAP 10 and extended energy balances compiled by the International Energy Agency (IEA). A complete description of all features in GTAP-E database is provided by McDougall and Golub (2009).

The GTAP-Power 10 database is an electricity-detailed extension of the GTAP 10 database disaggregated into: transmission and distribution, seven base load technologies (nuclear, coal, gas, hydroelectric, oil, wind and other power technologies), and four peak load technologies (gas, oil, hydroelectric, and solar) for 2014. These new sectors are combined with the original GTAP sectors resulting in a data base with 76 sectors and 141 regions. A complete description of all features in GTAP-Power is provided by Peters (2016). Moreover, Chepeliev (2020) provides an updated version of the methodology with changes introduced to the GTAP-Power database construction process consisting in a different way with which output of the electricity and heat generation sector has been split using electricity generation data together with heat generation volumes to provide a more representative sectoral split and better concordance with GTAP sectoral definitions.

The GTAP-NCO2_V10a database compatible with the GTAP10 database version is based on the methodology developed by Irfanoglu and van der Mensbrugghe (2016). The database provides emissions for 24 non-CO_2 emissions categories with 119 unique emissions subcategories for 244 countries. Emissions by region and economic sector, as well as emissions driver, for three major non-CO_2 gases (or groups of gases) are provided, CH_4, N_2O, and the group of fluorinated gases (F-gases), including CF_4, HFCs, and SF_6. Emissions come from three emissions drivers: consumption (by consumers and firms), endowment use (land and capital), and output.

With respect to the emissions associated to consumption by firms and households the original GTAP file has been transformed in order to be compatible with the structure of combustion-based CO_2 emissions used in GTAP-Power with 76 sectors. Accordingly, the new emissions database contains the sum of combustion-based CO_2 emissions and non-CO_2 emissions associated to the use of energy inputs including the chemical sector.

With respect to the time frame, differently from GDyn-EP described in Bassi et al. (2020), we recall that the starting point is 2014, so the first period is 2014-2015, while the following periods are five-year steps up to 2050 with a total of eight periods.

5.2. The dynamic CGE model: scenario building

The source on which scenarios are based are divided between the current period 2014-2020 and projections for the time span 2025-2050. The different variables on which the baseline and the policy scenarios are based are listed.

5.2.1 Model calibration to current baseline - year 2020

For what concerns the calibration for the current period 2014-2020, we provide details on the procedure adopted for each variable.

- Population: for the reference period (2014) data are taken by GTAP10 database while for updates 2015-2020, data come from Eurostat and World Development Indicators (WDI) from the World Bank;

- CO2 emissions: for the reference period on combustion-based CO_2 emissions (2014) data are taken by GTAP-E while for updates 2015-2020, data come from Eurostat, IEA CO_2 emissions highlights and WDI;
- GDP: for the reference period (2014) data are taken by GTAP10 database while for updates 2015-2020, data come from Eurostat and WDI;
- Non-CO_2 emissions: for the reference period (2014) data are based on GTAP-NCO2V10a updated with change in 2015-2020 based on Eurostat and IEA energy balances;
- Labour force: for the reference period (2014) data for skilled and unskilled labour force are calculated as the share of total labour force from CEPII information applied to GTAP population data and for the period 2015-2020 they are also calibrated with ILO information on labour force and CEPII statistics.
- Production of electricity from renewable sources (RSELE) in the electricity sector: for the reference period (2014) data on RSELE are taken from GTAP Power version 10 and for the period 2015-2020 data comes from growth rates computed on Eurostat and IEA energy balances.
- Production of electricity from fossil fuels (FFELE): for the reference period (2014) data on FFELE are taken from GTAP Power version 10 and for the period 2015-2020 data comes from growth rates computed on Eurostat and IEA energy balances.

5.2.2 Model calibration for baseline projection (BAU case) - period 2025-2050

For the projections in the time span 2025-2050, the baseline case (called BAU) is computed on the basis of the combination of data from different sources:

- Data on GDP, population, GHG emissions and production of electricity divided into RSELE and FFELE are based on the reference case used by the JRC model (Keramidas et al., 2020) for all regions in the model setting except with the EU region;
- Data on GDP, population, GHG emissions and production of electricity divided into RSELE and FFELE only for the EU members with country-based information are based on the reference case developed by the European Commission for the PRIMES model (European Commission, 2016);
- Data on labour force divided into skilled and unskilled are based on CEPII projections (Fouré et al., 2013).

The baseline is calibrated with shocks associated to GDP, population, skilled and unskilled labour force and CO2 and non-CO2 emissions that are considered as exogenous and are calibrated with the increase in production and consumption efficiency. This is a requirement for the GTAP modelling exercise because otherwise emissions are not bounded, and they proportionally follow the GDP and population trends without any assumptions on technological improvements that will reduce carbon intensity of economic dynamics.

A further element for building the BAU case is reflected into the energy balances for all regions, and in particular the proportion of renewable and fossil fuel source in the electricity production process. On the basis of the projections available from the JRC model and the EU reference case for PRIMES, the two electricity sub-domains have been treated as exogenous, thus calibrating the BAU case at the end of 2050 with a share of RSELE on total electricity for the EU compatible with the JRC baseline case. The shocks in BAU are based on the evolution over time of the production of electricity by the two sources expressed in GWh, where the starting point is 2014 according to the value of electricity production provided in the GTAP-Power database in GWh. The calibration has been also compared with the composition of the energy mix on the consumption side with respect to the reference case of the EU models, in order to obtain an overall energy consumption at the EU level compatible with expected values simulated with the help of bottom-up technology scenarios.

5.2.3 Model calibration for policy scenarios - period 2025-2050 Paris Agreement

For the projections in the time span 2025-2050 related to the policy case, we consider as a starting point the decarbonization process for the EU27 region according to the implementation of the Paris Agreement with an emissions pattern to 2050 compatible with the EU targets associated to the increase in global temperature by maximum 1.5C° with respect to pre-industrial level. The emissions target designed for the Paris Agreement scenario for the EU is equivalent to the net zero emissions target described in the EU Green Deal with the updated target by 2030 of cutting emissions by -55 % with respect to 1990 levels. Accordingly, there is a common CO2-eq emissions trend in all policy scenarios for the EU.

Given that the GDyn-EP model is an economic-energy model without enough technological details to simulate the role played by LULUCF and CCS activities, the final emissions in 2050 account for gross emission levels without the impacts of carbon sinks. This results in an apparently overestimation of emissions with respect to the EU reference scenario that is fully explained by the absence of sinks. Accordingly, while in the EU reference case emissions in 2050 are around 2 % of the BAU case, in GDyn-EP in 2050 emissions are around 9 % of the BAU case. The remaining 7 % is supposed to be absorbed by carbon sinks to reach the target of net zero emissions by 2050.

In order to obtain the first policy scenario in which the EU will respect the abatement target for the full implementation of the Paris Agreement, resulting into an emission reduction by 2050 of 91 % with respect to the BAU case (called EU-PA), a policy instrument based on a Pigouvian carbon tax is adopted. According to the model version in Bassi et al. (2020), by considering the EU as an aggregated region it is worth mentioning that the cost effectiveness criterion is fully respected, since the value at the margin of the carbon tax is perfectly equivalent to a carbon price level if an emission trading system is applied. The only difference between the EU-ETS and the modelling approach we adopt is that in GDyn-EP all sectors are involved in the carbon policy with the same instrument, without differentiated treatment for energy-intensive and non-energy intensive sectors (Corradini et al., 2018). This assumption allows considering carbon tax and carbon price as fully equivalent market-based environmental policy instruments. Accordingly, in the following sections we will consider carbon tax and carbon price as they are synonymous.

In order to calibrate the model with respect to the emissions trend, we take CO_2 emissions as exogenous only for the EU, with a specific trend that is compatible with the PA target. On the contrary, emissions for the rest of the world are left as endogenous, considering a case in which the other regions are not respecting their NDCs under the PA. This is consistent with a notion of unilateral policy, and in a comparative exercise perspective, it is the only way to compute the economic impacts of a specific policy in an ex-ante evaluation with a counter factual benchmark. If, on the other side, we adopt a multilateral perspective in which all regions implement abatement targets, it is no longer possible to single out the economic impact of the EGD (Antimiani et al., 2016).

Together with the calibration of emissions with exogenous shocks, we also control for the energy mix at the EU level, with particular attention to the electricity production. More specifically, we consider electricity production, both from fossil fuels and for RES as exogenous, following the production trends available in GECO 1.5 C° policy case. This is a requirement because electricity is a carbon free energy source in a sense that consuming electricity is not associated to CO_2 emissions. This brings to an overestimation of electricity consumption in a policy scenario with no control for electricity production. In other words, the model cannot consider for instance technical constraints to substitutability between sources related to competition to inputs (capital and labour mainly), or diffusion obstacles for example associated to the absorptive and distribution capacity of the power grid.

5.2.4 Model calibration for policy scenarios - period 2025-2050 EU Green Deal

In order to make an economic assessment of the impacts associated to the EGD, on top of the first policy scenario (EU-PA), based on a simple carbon tax instrument, we associate a policy mix strategy by developing a revenue recycling mechanism for financing the development and diffusion of CETs. The recycling mechanism is based on the hypothesis that at least part of the carbon tax revenues (CTR) collected by the government can be redirected towards financing CETs. More in detail, given that GDyn-EP is a CGE model with a standard production structure where sectors are classified according to the ISIC codes, this means that it is not possible to disentangle a specific sector producing technology.

The solution is to compute an elasticity factor with which investments in R&D activities for CETs are directly transformed into gains on the consumption and production side.

In the description of model results we test different shares of CTR to be allocated to the CETs innovation fund that can be compared with real figures available in the estimation provided for the ETS innovation fund by the European Commission. It is worth mentioning that in our model, given that a carbon tax (equivalent to an equilibrium carbon price) is paid by all sectors (as if the ETS has been applied to the whole economy without free allowances), from the one side the higher the abatement target the higher the cost, given by the carbon tax, but on the other side an higher carbon tax is associated to a larger CTR and consequently to a higher amount of the innovation fund for CETs.

5.2.5 Model details for R&D investments in CETs according to the EGD

In GDyn-EP it is possible to account for the efforts in development and diffusion of two technology options, energy efficiency, both in the production processes and in the households' consumption patterns, and production of electricity with renewable sources.

In order to quantify how public investments might be translated into CETs at an empirical level, two elasticity parameters are required, whose computation is based on considering data on the last ten years of investments in the EU in the two fields of energy efficiency and renewable in electricity with respect to the starting date of GDyn-EP (2014).

More specifically, for what concerns energy efficiency in order to transform investment efforts (millions of USD) into input-augmenting technical change we use a standard elasticity computation method based on changes over time of total innovation efforts (here represented by R&D stock calculated on IEA R&D statistics, as an average value for industry, residential sector and transport for the EU) and gains in energy efficiency expressed as energy service improvements (Griliches and Lichtenberg, 1984; Hall and Mairesse, 1995). For the sake of simplicity, we assume that energy efficiency uniformly influences productivity across all sectors and that the diffusion of innovation is not influenced by technical barriers.

With respect to financial support to renewable sources in the electricity sector, the elasticity parameter has been computed according to the suggestion provided by Andor and Voss (2016). By promoting renewable energies by capacity investments (rather than by generation subsidies) it is possible to reduce the impact of uncertainty about demand conditions and capacity availability. The elasticity is calibrated considering the public R&D investment in renewable energies given by the IEA R&D database, accounted as R&D stock as for EE, and the corresponding increase in installed capacity in renewable electricity in EU countries during the same period (1994-2014 Eurostat energy balance dataset available online), resulting as an output-augmenting technical change. In this simulation exercise we are not able to define the exact way the policy support is designed in practical terms (e.g., a tax exemption, a fiscal subsidy, etc.). Rather we only consider broad financial support to CETs development, assuming that the elasticity coefficients include all aspects of technology development, deployment, diffusion and adoption.

Summing up, regarding the achievement of energy efficiency targets, the model is programmed in order to use R&D investments to increase input augmenting technical change for the use of energy as an input in the consumption (households) and production (firms) function. Accordingly, for a given amount of the CTR invested in energy efficiency, the effect is measurable into a reduction of the energy intensity with respect to the BAU case, or in other words in a lower cost for saving energy. Technical change is here introduced as the way to make easier the shift from an energy intensive to a non-energy intensive economy.

With respect to RES, the amount of CTR invested for such technologies is directly transformed into an increase installed capacity, or in other words it is modelled as an output technical change. The economic rationale behind this modelling choice is simple: given a certain amount of inputs used for producing RES (mainly capital and labour), the investments in RES allow the system to transform the same amount of inputs into a larger amount of output (electricity in this case).

It is worth mentioning that the investments in RES are combined with the exogeneity of RES production in the EU-PA policy case. This means that the amount of RES produced are exogenously determined but the production cost is endogenously driven by the amount of investments directed to technical change from the CTR. Accordingly, the higher the share of CTR invested into the innovation fund, the higher the output augmenting technical change, the lower the unitary production cost. In order to compare model results with the EU energy strategy pillars, in the case of RES it is possible to compare the amount of energy, and in particular of electricity from RES as a share of total consumption of electricity. Given that the production cost is lower, in the EU-GD scenario it is likely to obtain an increase in the share of electricity from RES consumed than in the EU-PA policy scenario.

The first three scenarios that are available can be synthesized as follows:

- BAU: reference case based on exogenous projections of GDP, population, labour force and CO_2 and non-CO_2 emissions;
- EU-PA: policy scenario with an abatement target implemented at the EU level that is compatible with the Paris Agreement obtained with the imposition of a carbon tax (that is endogenously determined by the target);
- EU-GD: policy scenario that replicates the previous scenario EU-PA with the additional element of the carbon tax revenue recycling mechanism devoted to investments for development, deployment, diffusion and adoption of CETs.

5.2.6 Scenarios accounting for COVID-19 crisis

Together with these three scenarios we introduce the economic impact of the crisis due to COVID-19 pandemic to the BAU case as follows. Starting from the BAU case we implement a policy shock in 2020 with an exogenous reduction of GDP with regard to the BAU case with an impact associated to the main regions according to Table 5-1, according to the distribution of the impact estimated by McKibbin & Fernando (2020) compatible with the IMF and the World Bank estimates at the world level recently provided by the updated report (IMF, 2021). The average reduction at the world level is estimated around -6% in 2020 w.r.t. BAU and around -3% w.r.t. the GDP level in 2019 (see Figure 3-7).

The assumption is that once the shock has been assigned to the 2020 policy scenario then the GDP is left to be determined endogenously by the model. Accordingly, it is possible to obtain changes in GDP from 2025 according to a path dependence approach related to the dynamic recursive nature of the model. It is worth mentioning that in the case of a COVID-19 shock without any recovery measure, the GDP growth pattern can be lower than in the case of a BAU pre-crisis case because the amount of capital stock for the economic system is dependent on savings produced in the previous period in a System of National Account methodology.

The BAU case that accounts for the shock occurred in 2020 assumes that no additional shocks will occur, but the endogenous solution provides GDP values for the period 2025-2050 that incorporate the negative impacts due to capital stock reduction and a demand decrease that persists over time. This BAU case with the COVID-19 shock with no recovery measures is named BAU no-recovery.

A second scenario is built with an exogenous shock that allows GDP in 2025 to turn back to 2025 original BAU values before the COVID-19 hereafter called as BAU full-recovery. This means that the shock is calibrated in order to give impulse to the economic system to completely recover from the negative impacts in the medium term (5 years). In order to make sure that the amount of resources is compatible with policy feasible solutions, we have computed the endogenous increase in capital formation required to recover from the crisis. As a benchmark, we looked at the resources that the EU is allocating in different forms during the 2020 amounting at a recovery package of around €750 billion, that corresponds to around 5 % of the EU GDP in 2020 from GDyn-EP without COVID-19. In 2025, according to the full-recovery scenario, the total resources to be invested along a 5 years period required to go back to a GDP pre-COVID-19 amount around 9.5 % of GDP in 2025. Considering that in the years 2021-2025 additional resources could be invested within the Next Generation EU fund according to the recovery plans presented by member States, together with additional private resources, a total of 9.5 % of GDP in the form of capital investments is reasonable. The same mechanism is applied to all regions belonging to the GDyn-EP, with examples of resources invested in other large economies as a 4 % of GDP in China and an 8 % in the US.

Region	**% change w.r.t. BAU 2020**
Australia	-6.3%
Brazil	-6.5%
Canada	-5.5%
China	-6.3%
EU27	-7.4%
India	-3.2%
Japan	-7.5%
Korea	-4.2%
Russia	-7.4%
United Kingdom	-5.5%
United States	-7.4%
Rest of the World	-3.3%
World	-5.9%

Table 5-1. Reduction in GDP pre-crisis levels in 2020 due to COVID-19 in GTAP (our elaboration of IMF and Table 3 from scenarios (McKibbin & Fernando, 2020).

On the basis of the two additional BAU scenarios that include COVID-19 GDP shock with and without recovery, we are able to compute the new emissions trend for the two BAU cases. Differently from the original BAU where emissions are exogenously projected according to bottom-up energy scenarios, in the two BAU cases with COVID-19 emissions are left free to move endogenously, following the GDP shocks in 2020 and in 2025 (only in the case of full-recovery), and the endogenous GDP patterns from 2025 on. Accordingly, together with the GDP, also CO2-eq emissions will result changed with respect to a BAU pre-crisis, and on this new reference case the two policy options associated to the simple carbon pricing and the additional measures planned within the EGD are implemented and evaluated. As a final calibration check, emissions endogenously determined with the BAU no-recovery and BAU full-recovery GDP shocks have been compared with emissions provided by the bottom-up model by the International Energy Agency available in the World Energy Outlook 2020 (IEA, 2020). In particular, CO2 emissions associated to the BAU no-recovery case are well aligned with the WEO2020 "Delayed Recovery Scenario" that takes a more pessimistic view on the outlook for public health and for the economy, with a prolonged pandemic and longer lasting impacts. CO2 emissions associated to the BAU full-recovery case are also well aligned with the WEO2020 “Stated Policies Scenario” that assumes that significant risks to public health are brought under control over the course of 2021, allowing for a steady recovery in economic activity. Given that in GDyn-EP emissions are related to both combustion-based and non-energy use of fossil fuels, the total emission levels are higher than in the WEO2020. Accordingly, the calibration has been based on percentage change over time for the different recovery cases.

5.3. The dynamic CGE model: main results

The BAU case represents a baseline to be used as a benchmark for policy impact evaluation under different scenarios and assumptions. The introduction of the economic shocks associated to the COVID-19 pandemic is represented for the EU as a region formed by 27 Members excluding the UK (Figure 5-1) and for the rest of the world (Figure 5-2).

The difference highlighted by the two alternative patterns is explained by the introduction of a generally designed recovery package that is supposed to be implemented along 5 years, from 2020 to 2024, in order to obtain a full recovery in 2025. In this case, the only way for endogenously determining the full recovery case is to change the GDP projections from endogenous to exogenous in 2025. This is to say that after 2025 the GDP pattern is endogenous again and the recursive nature of the dynamic CGE here implemented demonstrates that without a long-term perspective in the design of the implementation of investments under the recovery measures, the positive impulse to GDP is large in the short-term but loses weight in the medium to long-term. The reason behind this result is simple: from 2020 to 2025 a huge portion of capital stock has been wasted, and the resources implemented for a short-term recovery are not sufficient for ensuring to go back to the same GDP growth pattern.

Given the difference in the magnitude of the crisis due to COVID-19 for different regions as explained by figures in Table 5-1, the distance between the GDP growth pattern in the BAU case with regard to to the BAU full-recovery is larger for those economies that are experiencing the highest lost. Together with the EU, also Japan and the US present similar trends, while for the rest of the word taken as an aggregate, such distance is lower.

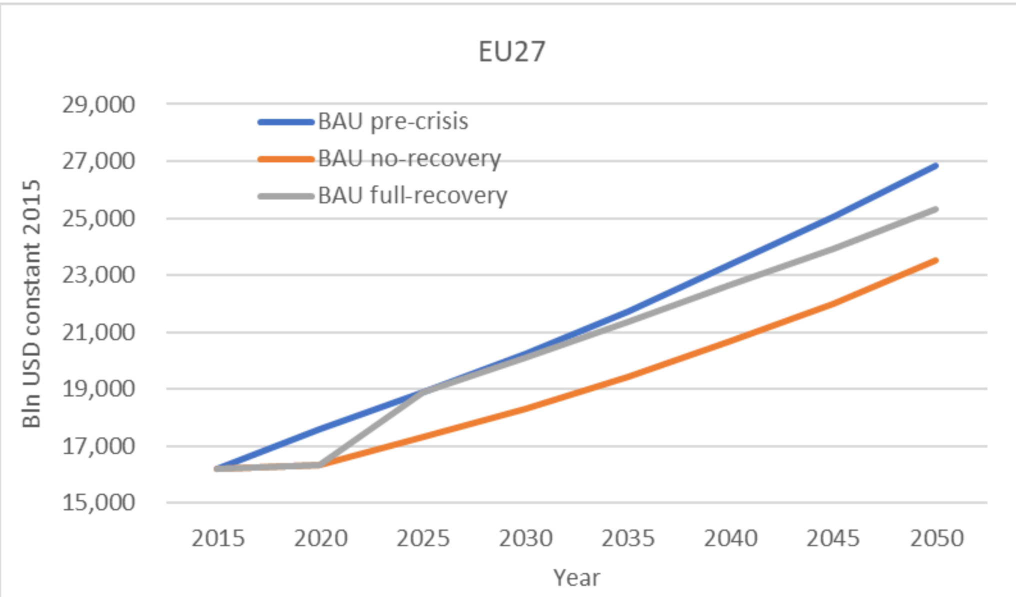


Figure 5-1: GDP patterns in the BAU case under different COVID-19 recovery options for the EU27 – own elaboration on GDyn-EP results.

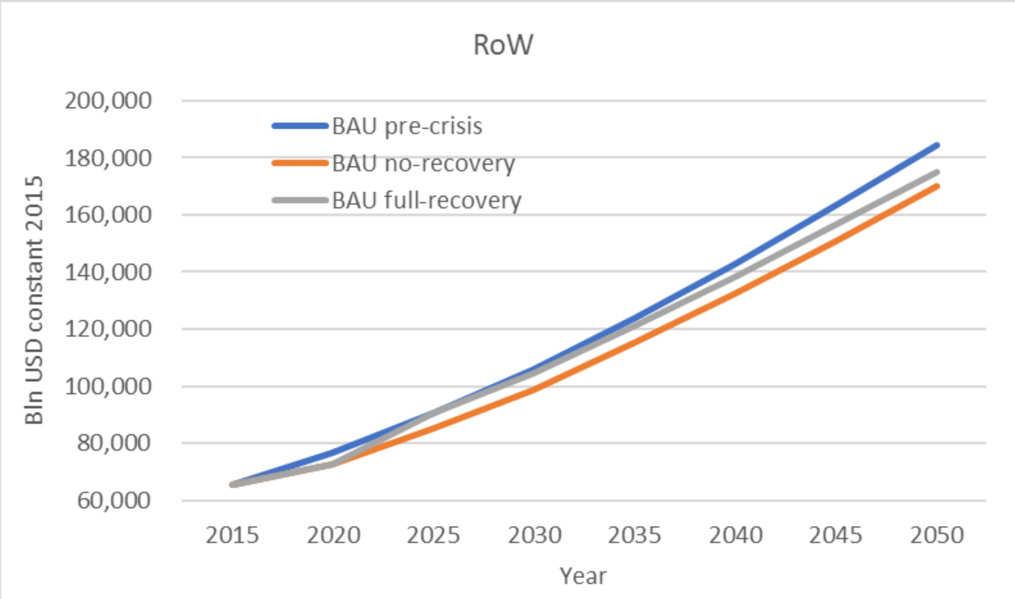


Figure 5-2: GDP patterns in the BAU case under different COVID-19 recovery options for the Rest of the World – own elaboration on GDyn-EP results.

According to the modelling choice described in Section 5.2, together with the GDP pattern that is endogenously modelled from 2025 on, also the CO_2-eq emissions included in GDyn-EP are left free to evolve according to the economic patterns at the regional level. As a result, the reduction in economic activities even in the case of a full recovery in 2025 will bring emissions in the BAU case to decrease, according to the GDP growth gap. This result is valid both for the EU aggregate (Figure 5-3) and for the rest of the world (Figure 5-4).

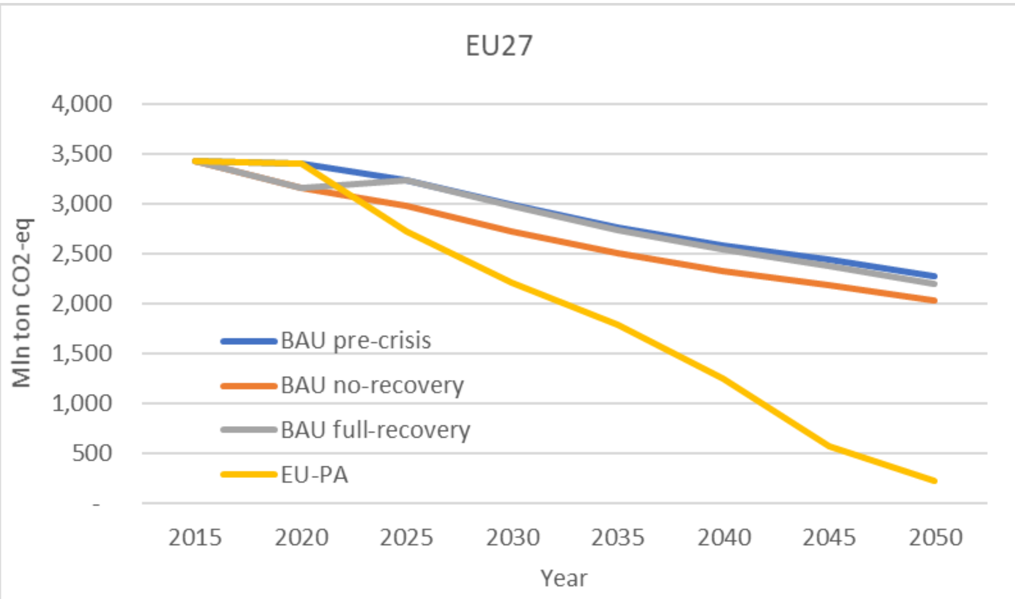


Figure 5-3. CO_2-eq patterns in the BAU case under different COVID-19 recovery options for the EU – own elaboration on GDyn-EP results.

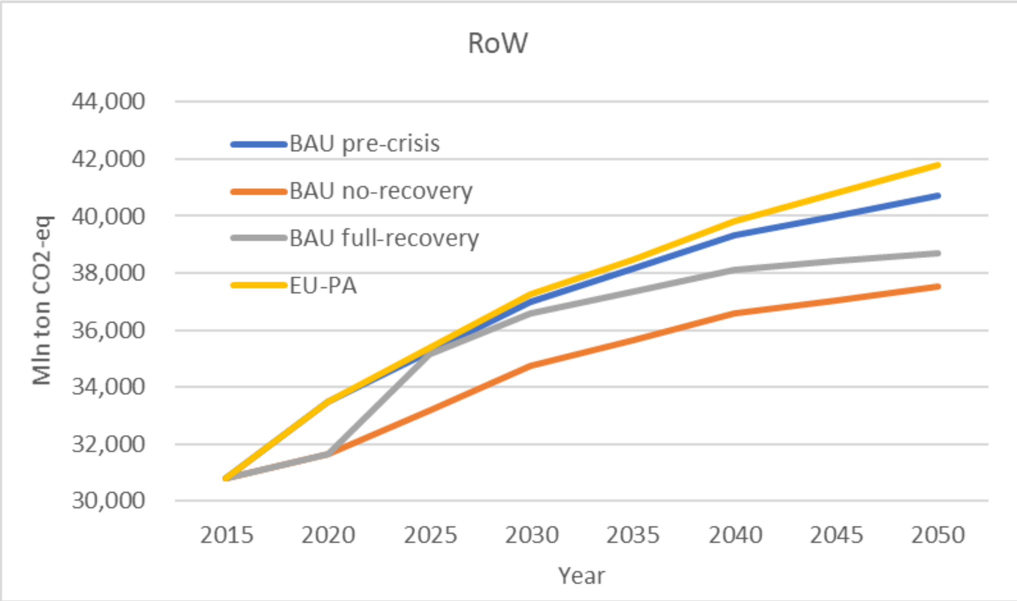


Figure 5-4. CO_2-eq patterns in the BAU case under different COVID-19 recovery options for the Rest of the World – own elaboration on GDyn-EP results.

In Figure 5-3 we compare emission trends for the EU27 in the different BAU cases with the projection of the full decarbonisation strategy included in the EGD. It is worth mentioning that, although in both post-COVID reference scenarios the CO_2 level will drop, the emission gap with the mitigation target is still large. In the case of the emissions trend for the rest of the world, although the COVID-19 crisis will bring to a global reduction by 2050 with regard to the BAU scenario without COVID-19 even in the case of a full recovery, the implementation of a unilateral carbon policy by the EU will bring to a reaction at the global level with an increase in emissions level, as a typical carbon leakage effect (Antimiani et al., 2013). This means that the efforts played by the EU in reducing emission levels that correspond to around 2,000 Mt CO_2-eq abated in 2050 with regard to BAU are partly compensated by the increase in emissions by the rest of the world (estimated around 1,000 Mt CO2-eq), with a carbon leakage rate (computed as the ratio between the change in emissions of the RoW and the absolute value of emission reduction by the EU) by 2050 that is around 51 %. In other words, if the emission reduction by the EU is implemented by adopting a carbon pricing instrument alone, without any additional public support measure for speeding up the technological transition of the energy sector, the reaction of foreign producers will be to increase their demand for fossil fuels to produce goods and services thanks to their increased competitiveness on external markets with respect to the EU companies.

By focusing on the EU region, in Figure 5-5 we represent the GDP pattern associated to the policy scenario where the Paris Agreement emission target is achieved with a Pigouvian carbon tax that at the margin is exactly equal to the carbon price in an ETS scheme with all sectors included and no free allowances.

We compare in this case the impact of the policy under scrutiny with respect to a BAU scenario that alternatively considers or not the COVID-19 crisis. Whatever BAU is considered, the achievement of the emissions level respectful of the Paris Agreement target obtained by a pure carbon price policy without any support to efficiency and innovation has relevant costs for the EU, with a substantial drop in GDP level.

Competitiveness losses are obviously more evident for energy intensive sectors, as those included in the EU ETS. As an example, in Table 5-2 we report for aggregated sectors changes occurring in the revealed comparative advantage (RCA) index calculated for the BAU and the EU-PA cases. The RCA is here computed as the ratio between the export specialization in each sector for the EU and the export specialization of the same sector for the rest of the world. The absolute value of the RCA highlights that if it is higher than 1 the country under scrutiny has a competitiveness gain in exporting that sector on foreign markets with respect to the other exporters.

A negative change in the index comparing the policy scenario with the baseline means that those sectors are particularly harmed on the international market due the implementation of the carbon price mechanism. On the contrary, those sectors with a positive change in RCA are those that are gaining in competitiveness. As an example, pharmaceutics and other manufacturing are two sectors characterized by a relative low energy intensity and a higher value added due to relative technological intensity. The implementation of a carbon price at the EU forces the system to concentrate production inputs into those sectors that are less energy intensive helping them to further gain competitiveness on the international markets thanks to the exploitation of economies of scales.

Sectors	2025	2030	2035	2040	2045	2050
Agriculture	-0.52%	-0.01%	1.08%	1.99%	1.93%	1.18%
Food & Beverage	0.71%	1.32%	1.81%	2.45%	2.86%	1.67%
Paper & Wood	-0.25%	-0.31%	-0.34%	-0.62%	-0.79%	-1.22%
Chemicals	-1.52%	-3.10%	-4.85%	-8.14%	-16.67%	-34.48%
Pharmaceutics	1.46%	2.64%	3.31%	5.07%	9.88%	16.32%
Mineral & Metal	-1.70%	-3.18%	-4.70%	-7.35%	-11.68%	-17.77%
Energy	-5.47%	-11.56%	-17.82%	-29.87%	-53.74%	-76.76%
Other manufacturing	1.31%	2.29%	2.87%	4.40%	9.15%	15.54%
Transport	-9.37%	-17.50%	-25.10%	-39.99%	-69.85%	-89.24%
Services	0.76%	1.60%	2.35%	3.39%	4.96%	6.15%

Table 5-2. Changes in RCA index (revealed comparative advantage) in EU-PA w.r.t. BAU – own elaboration on GDyn-EP results.

Even if such high-value added sectors can gain from the implementation of the carbon policy, nonetheless the overall impact on the economic system is reflected by a reduction in GDP levels and growth rates as in Figure 5-5.

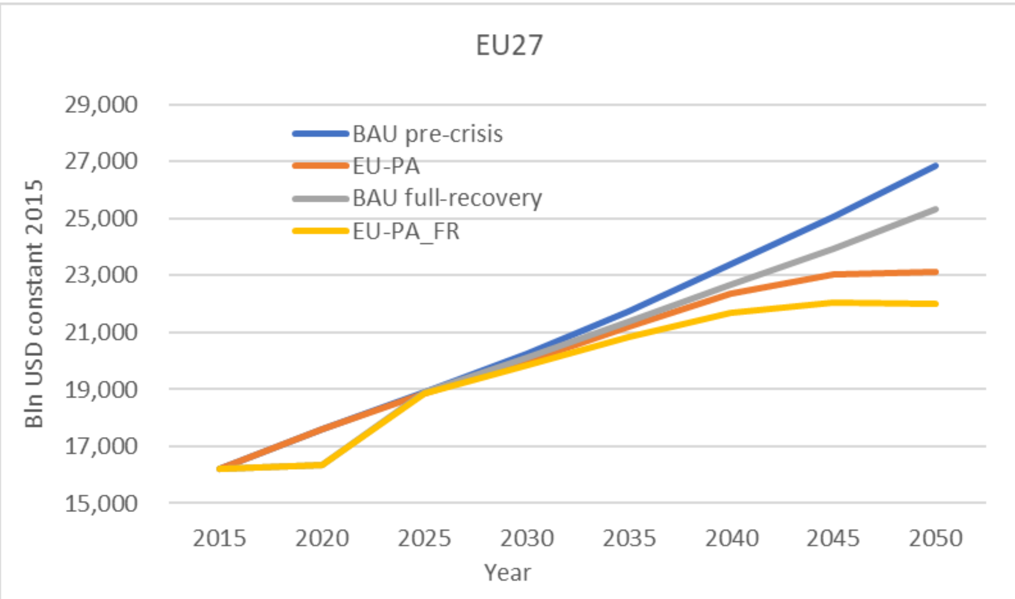


Figure 5-5: GDP patterns in the BAU case under different COVID-19 recovery options for the Rest of the World – own elaboration on GDyn-EP results.

This is not surprising as the final target for the year 2050 is a reduction of 91 % of emissions with regard to 2050 emissions in BAU, corresponding to a net zero emission goal for the EU, with a carbon price that is prohibitive in all scenarios without any financial support to CETs, as in scenario named EU-PA, or even in the case we account for the emission reduction due to COVID-19 as in scenarios EU-PA_NR (with no recovery) and EU-PA_FR (with full recovery), as described in Table 5-3. Although in the case of baselines with COVID-19 the starting emissions are lower, the implementation of the net zero emissions target (consistent with both the fulfilment of the Paris Agreement and the EGD abatement profile) is nevertheless extremely expensive in the long-term. The emissions abatement profile is consistent with the currently debated intermediate targets, as it ensures to cut emissions by -55% in 2030 with regard to 1990 levels. It is worth mentioning that whatever scenario is considered, the last emissions cut to be obtained in the period 2045-2050 is extremely expensive. This is explained by exponential function characterizing the marginal abatement cost curve, which is associated to the increased difficulties in substituting fossil-based energy sources when their marginal productivity is at a maximum level determined by their scarcity (that is represented by the input share in the production and consumption functions).

On the contrary, when adding the public support to CETs deployment and diffusion, the overall cost of achieving the target is considerably lower and the situation changes. We first test the impact of an innovation fund mechanism that is fuelled by 50 % of the pricing mechanisms in the form of carbon tax revenue (CTR) derived from the collection of the Pigouvian tax (remembering that it is equivalent to a carbon price in an ETS covering the whole economy). By looking at the first two rows, the unitary cost of one ton of CO_2-eq by 2050 is more than halved when the half of CTR is recycled for CETs improvement. The same relative impact is associated to the case when the crisis for COVID-19 in 2020 is included in the baseline and in the policy.

In addition, it is worth mentioning that a higher share of CTR devoted to CETs is a key element for cost competitiveness for the EU as the unitary carbon price is inversely correlated with the share of CTR recycled. Given that the amount of resources invested in CETs via the innovation fund in this modelling approach is endogenously determined by the abatement target that in turns influences the carbon tax level, the reduction in carbon price obtained with a higher CTR share also results into a relative reduction in the proportionality of the amount of the innovation fund with respect to the carbon tax level.

As a result, the higher the share of CTR the higher the innovation fund but with a decreasing proportionality, as revealed by results in Table 5-4. The first result is the substantial reduction in the total resources invested especially in the first periods due to the reduction in carbon price associated to lower gap between the BAU emissions with COVID-19 and the target as reported in Table 5-5.

Scenario	2025	2030	2035	2040	2045	2050
EU-PA	64	67	81	237	1,249	5,092
EU-GD_50%	47	48	55	153	704	2,425
EU-GD_100%	37	35	42	116	517	1,699
EU-PA_NR	31	53	68	205	1,086	3,857
EU-GD_NR_50%	24	38	48	140	652	1,958
EU-GD_NR_100%	20	30	38	108	488	1,431
EU-PA_FR	62	66	77	227	1,197	4,611
EU-GD_FR_50%	28	41	68	148	686	2,244
EU-GD_FR_100%	20	35	40	112	504	1,580

Table 5-3. Carbon tax (constant 2015USD per ton of CO2-eq) – own elaboration on GDyn-EP results.

Scenario	2025	2030	2035	2040	2045	2050
EU-GD_50%	63,770	52,838	49,205	95,814	199,500	268,734
EU-GD_100%	101,646	77,193	75,312	145,581	293,041	376,654
EU-GD_NR_50%	32,732	42,240	43,138	87,573	184,866	217,017
EU-GD_NR_100%	53,818	66,379	67,348	135,844	276,726	317,287
EU-GD_FR_50%	40,921	50,499	60,755	92,616	194,414	248,752
EU-GD_FR_100%	54,459	77,149	72,250	140,710	286,001	350,352

Table 5-4. Carbon tax revenue recycled into the Innovation Fund (Mln constant 2015USD) – own elaboration on GDyn-EP results.

Scenario	2025	2030	2035	2040	2045	2050
BAU pre-crisis	3,241	2,992	2,764	2,593	2,440	2,285
EU-PA	2,723	2,213	1,787	1,252	567	222
Reduction w.r.t. BAU	-16%	-26%	-35%	-52%	-77%	-91%
BAU no-recovery	2,987	2,732	2,504	2,334	2,187	2,040
EU-PA_NR	2,723	2,213	1,787	1,252	567	222
Reduction w.r.t. BAU	-9%	-19%	-29%	-46%	-74%	-89%
BAU full-recovery	3,241	2,989	2,744	2,552	2,380	2,205
EU-PA_FR	2,723	2,213	1,787	1,252	567	222
Reduction w.r.t. BAU	-16%	-26%	-35%	-51%	-76%	-90%

Table 5-5. CO2-eq emissions (Mton CO2-eq) and variation w.r.t. the related baseline – own elaboration on GDyn-EP results.

The second result is the increase of the total amount of resources disposable if the share of CTR is increased, that is evident when comparing the three scenarios with and without the COVID-19 impact.

From the one hand, the introduction of public support to CETs deployment and diffusion is expected to help the EU economy to achieve the low carbon targets without being excessively harmed by a reduction in cost competitiveness with respect to the rest of the world. As a result, the green innovation trajectory helps the EU to pay a lower carbon price given the emission target. The overall revenue from carbon pricing is given by the carbon price multiplied by the CO_2-eq emissions. Given than the target is fixed, CTR is dependent only on carbon price (which is endogenously given by the model) and on the share of CTR to be directed to the investment fund (which is exogenously targeted by policy makers). As a result from the complexity approach, the final value of the investment fund is simultaneously affected by a positive impact related to the increase in the share of CTR and by a negative impact associated to the reduction in carbon price. The lower the carbon price the smaller is the revenue collected from carbon taxation, and consequently the amount of resources to be invested in the innovation fund.

From the other hand, given the assumption of decreasing marginal productivity of public support associated to constant returns to scale, the relative contribution of each additional unit of the innovation fund on the carbon price reduction is decreasing. From results in Table 5-3 it is possible to compute the additional contribution of the R&D support to carbon price reduction in the case of alternative shares of the CTR invested into CETs. Starting from the 50 % share, one unit of R&D invested in CETs contribute reducing in 2025 the carbon price by around 38 %. The incremental contribution of the second half (from 50 % to a 100 % share of CTR) is only by 16 % reduction of the carbon price.

This specific pattern of innovation is driven by the conservative assumption used in the model with constant returns to scale in input and output technical change associated to R&D investments in CETs. By adopting increasing returns to scale, the magnitude of the impact can be substantially higher, thanks for example to a learning by doing effect, or even higher if positive knowledge spillovers are also included. Given that no reasonable empirical estimations for such parameters are available for the GTAP structure, the assumption of constant returns to scale is the best way to reproduce the mechanisms behind the policy instruments mix interactions.

When we introduce the recovery action with general forms of capital investments up to 2025, the carbon price is higher (but lower than in the no-COVID-19 case) and the innovation fund is higher than in the COVID-19 no recovery case.

Turning to the key issue of the potential benefits associated to the adoption of a complex climate-energy policy mix, as in the EGD strategy, a first sign of the relevant role played by the deployment and diffusion of CETs financed through public support to R&D activities can be detected by comparing different GDP patterns under different CTR share devoted to CETs.

For the sake of simplicity, we report only data for the year 2050 and we compare the GDP change of alternative policy scenarios with regard to the BAU adopting a baseline that includes the economic impacts due to COVID-19 and the effects from a full recovery up to 2025 policy (Figure 5-6).

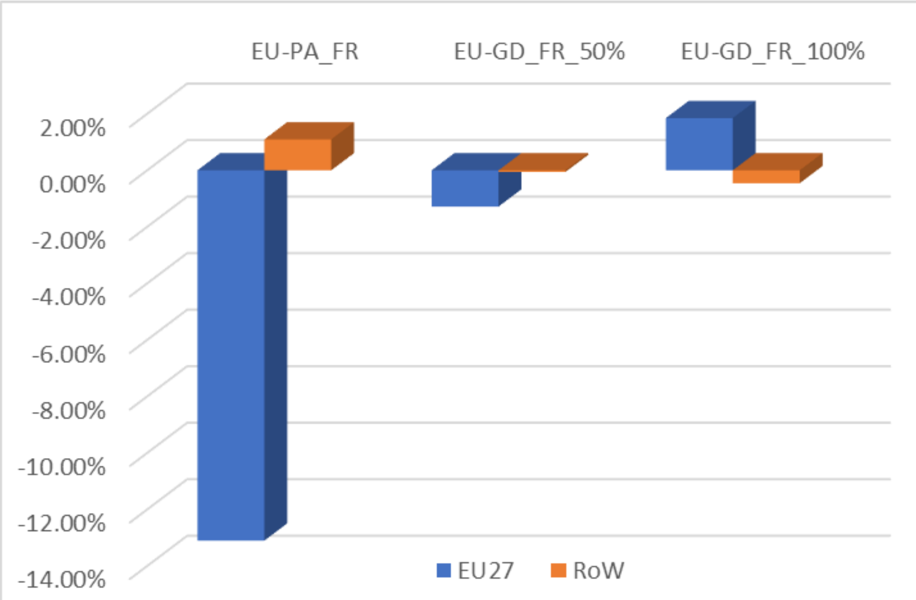


Figure 5-6: GDP change w.r.t. BAU (%) in 2050 – own elaboration on GDyn-EP results.

The implementation of a carbon price policy uniformly paid by all countries belonging to the EU27 aggregate will bring a strong reduction to GDP level, with a decrease by around 13 % in 2050 and slight increase in the GDP of the rest of the world. By introducing the innovation fund financed through a share of the carbon tax revenue collected by government, the negative impact in GDP terms is substantially smoothed. Quite intriguingly, with a CTR share larger than 60 % results are not reported in the graphical representation) the overall impact on the EU economic system is positive.

If the whole CTR is invested into the innovation fund for financing CETs (with a share of 100 % in the modelling design) the EU Green Deal turns to be a long-term strategy that effectively helps the EU to become a more competitive and carbon neutral economy.

A specific result is worth of commenting referring to the GDP trend across different scenarios. In Figure 5-7 we report the GDP for the EU over the time span in which the EU Green Deal is implemented with three alternative shares of CTR.

By comparing the results with the GDP in the BAU case, if the CTR share is equal to 50 %, there is a positive effect along the first periods but, given the assumption of decreasing marginal returns on CETs investments, once the mitigation target becomes more stringent, the positive impact of adopting clean technologies is no longer sufficient to compensate competitiveness losses.

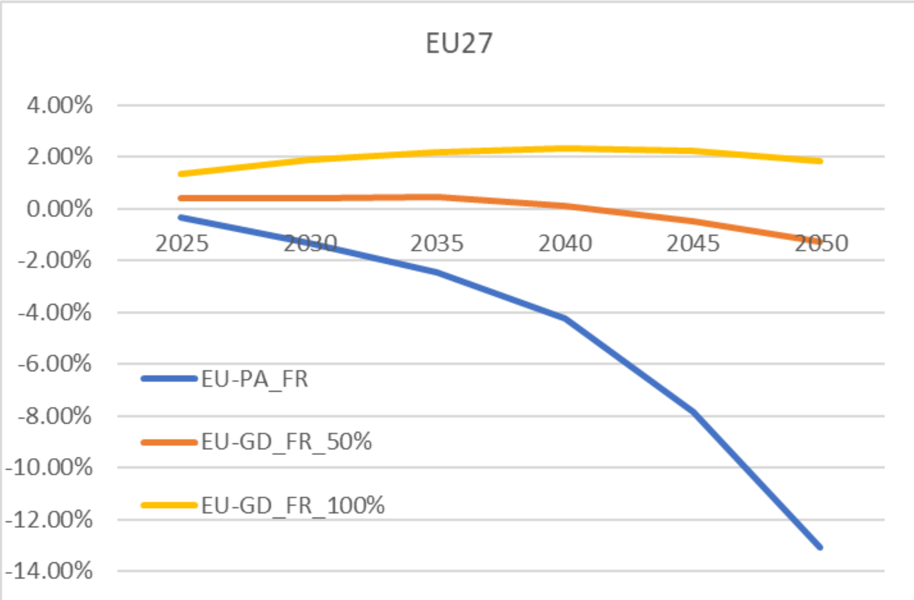


Figure 5-7: GDP change w.r.t. BAU in alternative EU climate policy scenarios – own elaboration on GDyn-EP results.

If the maximum share is tested, we can notice that the increase in GDP assumes a stable (positive) trend from 2035 resulting in a constant increase in GDP with regard to the BAU case. It is worth mentioning that carbon pricing and the related revenue collected by the government for the implementation of the mitigation target are associated to an additional fiscal policy to that measures that are already into force, as for instance the energy taxation that remains collected and used as if the carbon policy has not been implemented. This is to say that no other revenues are directed to sustain the deployment and diffusion of CETs. If such assumption is relaxed, or if we assume for instance increasing returns to scales and the role played by positive externalities as those related to knowledge co-creation in a smart specialization strategy approach, the positive outcomes related to the CTR recycling mechanism could be achieved at a lower cost. At the same time, resources collected by the carbon price policy could be used for other purposes, as for improving income distribution, or reducing the tax burden paid by firms.

By looking at changes in GDP growth rate with regard to the BAU case (Figure 5-8) for the period after the recovery (2030-2050), for the full CTR recycling case (EU-GD_FR_100%) up to 2045 the growth rate is even higher than the BAU case, even if a decreasing rate. From 2045, despite the huge investments in CETs, the burden in terms of marginal abatement costs is so high that the GDP growth rate is slightly lower (-0.04 %) than the BAU case. On the opposite, if carbon pricing is the only instrument adopted for reaching the emissions target, the average GDP growth rate drops with regard to the BAU case from the first period after the full recovery (2030) reaching a reduction by around 6 percentage points by 2050, revealing a green but unsustainable development pattern.

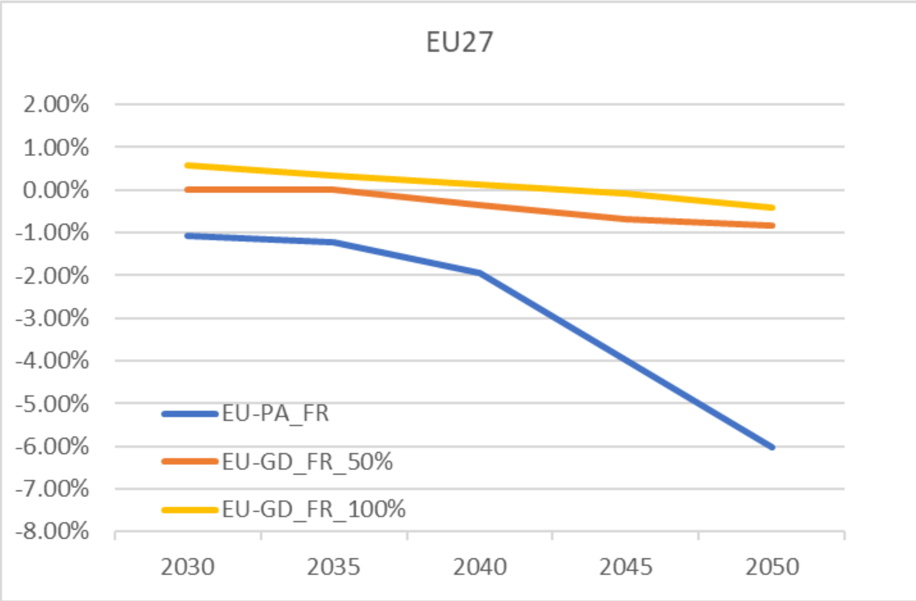


Figure 5-8: GDP growth rate changes w.r.t. BAU in alternative EU climate policy scenarios – own elaboration on GDyn-EP results.

By making a comparison with the current debate on financial efforts to be directed to the IF, we can see that in 2025 the available public resources devoted to foster CETs are around 0.3 % of GDP, while by 2050 they will represent around 1.4 % of GDP, consistently with the expected financial burden. When combining results obtained for the carbon price level (Table 5-3), the amount of CTR recycled within the IF (Table 5-4) and GDP effects we can emphasize that although in absolute terms carbon price will reach by 2050 an apparently unfeasible value, the overall burden in terms of public budget to be collected for reaching the net zero emission target under the EU Green Deal policy strategy is maximum equal to 1.5 % of GDP (fully in line with the EU-GD_FR_100% result) with a corresponding increase in GDP levels compared to the BAU case.

In this modelling exercise we assume that the overall revenue coming from carbon pricing that is recycled according to the share under scrutiny (here 50-100 %) is completely invested for reinforcing the sustainable energy transition. It would be part of the next research agenda to design different mixes of final destination targets for the recycled revenues from carbon tax, as for instance investing part of them into CETs and the remaining for reducing labor cost, or improving social welfare systems.

As a final remark, the mitigation target by 2050 is obtained without the adoption of carbon capture and storage technologies. This means that the only way for reducing the amount of emissions, given that the carbon content of fossil-based energy sources remains unchanged, is to reduce the overall volume of fossil fuels consumed at the regional level. Accordingly, the two pillars of the long-term EU energy strategy associated to the increase in energy efficiency gains and to the larger diffusion of renewable sources in energy production and consumption. In Table 5-6 we report an index of energy intensity measured as the ratio between the overall energy consumed in volume terms and the GDP for each period, while in Table 5-7 we report the share of renewables sources in electricity consumption. The BAU case corresponds to the implementation of the EU2030 energy strategy, with targets settled for the year 2030. As an example, the share of electricity from renewable sources on total electricity consumption in BAU is 46 %, in line with the EU2030 objective of reaching by 2030 a 45% share of RES in electricity consumption.

When introducing the fulfillment of mitigation targets under the Paris Agreement, the model is forced to adapt to the required reduction in energy consumption and it is calibrated for an increase in renewable sources compatible with the energy scenarios of the EU. The key point is here the positive impulse provided by public support to CETs financed through the innovation funds, that helps reducing the cost of reaching a higher energy efficiency and also adds incremental electricity produced by RES.

In economic terms, a way of reflecting the reduced cost of using energy as an input into the production and consumption activities is the computation of the energy bill for the different scenarios under scrutiny. In Table 5-8 we report the relative weight of the energy bill computed as the monetary value of primary energy imported from abroad as a share of the total GDP for each year. The massive investments into CETs from the innovation fund financed by the CTR recycling mechanism allow halving the energy bill with respect to the scenario in which carbon emissions are abated with the carbon price as the only instrument adopted. The gain in energy efficiency for all sectors of the economic system including households' consumption activities will help reducing the burden on the balance of payments related to energy imports. The quantification of the contribution of R&D to efficiency improvement can be represented in a broad sense by the trend of the energy intensity index as reported in Table 5-6, measured by the ratio between the volume of total final energy consumption and the GDP value for each period. By looking at the final period, in 2050 a carbon tax implemented with a mitigation target compatible with the more stringent Paris Agreement goal in the EU will halve the energy intensity. By adding the complementing technology instruments envisaged by the EU Green Deal, the energy intensity of the EU will result even lower, but more importantly the cost of achieving the target will be transformed into a competitiveness gain and into an economic development opportunity.

At the same time the efforts played in improving output technical change in renewable electricity production will help the system to reduce the unitary cost of electricity substitution on the EU power grid, thus resulting into a relative lower cost of domestic electricity with respect to the imported one.

The remaining electricity share produced by fossil fuel sources ranges in 20-24 %. It is worth mentioning that in GDyn-EP electricity production is divided into renewable source from one side and all the other sources (including nuclear power) here referred to as electricity from fossil fuels. Accordingly, the remaining 24 % of electricity not produced by renewables in 2050 under the EU-PA scenario is almost carbon free (with 10 Mt CO_2-eq) thanks to energy efficiency also in electricity production process and to the contribution played by nuclear power.

Scenario	2020	2025	2030	2035	2040	2045	2050
BAU pre-crisis	126	107	89	74	63	55	48
EU-PA	126	97	73	56	40	26	22
EU-GD_50%	126	95	71	54	38	22	17
EU-GD_100%	126	94	70	53	36	21	15
BAU full-recovery	128	107	90	75	65	57	50
EU-PA_FR	128	96	74	57	42	27	22
EU-GD_FR_50%	128	100	77	55	39	24	17
EU-GD_FR_100%	128	94	71	54	38	22	16

Table 5-6. Energy intensity in the EU (toe / Mln 2015USD) – own elaboration on GDyn-EP results.

Scenario	2020	2025	2030	2035	2040	2045	2050
BAU pre-crisis	33.66%	41.40%	46.52%	50.52%	55.01%	60.15%	64.77%
EU-PA	33.66%	43.82%	50.99%	59.70%	67.06%	71.32%	76.00%
EU-GD_50%	33.66%	43.89%	51.14%	60.09%	68.20%	73.71%	80.02%
EU-GD_100%	33.66%	43.92%	51.19%	60.20%	68.45%	73.92%	80.10%
BAU full-recovery	33.66%	41.39%	46.52%	50.50%	54.99%	60.14%	64.77%
EU-PA_FR	33.66%	43.82%	51.00%	59.72%	67.15%	71.52%	76.68%
EU-GD_FR_50%	33.66%	43.87%	51.11%	60.10%	68.22%	73.74%	80.04%
EU-GD_FR_100%	33.66%	43.92%	51.20%	60.21%	68.47%	73.94%	80.08%

Table 5-7. Share of electricity from RES on total electricity consumption– own elaboration on GDyn-EP results.

Scenario	2020	2025	2030	2035	2040	2045	2050
BAU pre-crisis	5.19%	4.28%	3.41%	2.71%	2.20%	1.82%	1.52%
EU-PA	5.19%	3.83%	2.73%	1.92%	1.24%	0.64%	0.44%
EU-GD_50%	5.19%	3.76%	2.64%	1.83%	1.14%	0.50%	0.23%
EU-GD_100%	5.19%	3.71%	2.59%	1.79%	1.09%	0.47%	0.21%
BAU full-recovery	5.27%	4.27%	3.43%	2.74%	2.25%	1.87%	1.56%
EU-PA_FR	5.27%	3.83%	2.75%	1.96%	1.28%	0.67%	0.43%
EU-GD_FR_50%	5.27%	3.97%	2.91%	1.88%	1.18%	0.53%	0.24%
EU-GD_FR_100%	5.27%	3.71%	2.62%	1.83%	1.14%	0.50%	0.22%

Table 5-8. Energy bill (value of energy commodities import) as share of GDP – own elaboration on GDyn-EP results.

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