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Economic Growth and Decarbonisation

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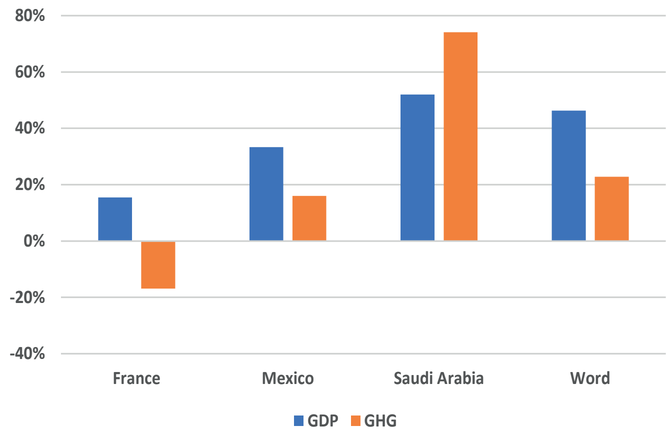
- In all sectors (manufacturing, construction, transportation etc.), economic activity goes hand in hand with greenhouse gas (GHG) emissions. However, the carbon intensity of such activity – the quantity of emissions generated by unit of production – can vary, depending on the technology used for example. While economic activity has decoupled from territorial emissions in some countries in the past few years, achieving climate change mitigation objectives will require a faster and more significant cut in emissions. Therefore, a more extensive decoupling is needed to preserve economic growth (see Chart), and it has to take into account imported GHG emissions too.

- Public policy measures will be needed to drastically reduce GHG emissions. Environmental policies seek to encourage or compel economic agents to change their practices and shift their investments to emission-free or low-emission activities. Various types of instruments can be deployed to this end, including carbon pricing, regulation and public funding.

- From a macroeconomic perspective, the transition to net-zero emissions could primarily have a twofold effect: a rise in the relative price of GHG emissions and a sharp increase in decarbonisation investments. The macroeconomic impact of the transition remains very uncertain, yet it is a subject addressed in a growing body of work. Even though this twofold effect could hamper economic growth and increase inflation during the transition phase in certain scenarios, the cost of the transition would remain well below the cost of inaction.

- In particular, the economic impacts during the transition phase depend on the frictions and the adjustment costs in the economy. Decarbonisation policies could be implemented alongside measures that aim to support the most vulnerable agents to mitigate the transition's negative impacts. In this respect, vocational training policies are key to ensuring job reallocation.

Four examples of changes in territorial GHG emissions and economic activity (2005 to 2018)



Source: The World Bank (GDP in constant dollars – 2015) and CAIT Data: Climate Watch (GHG emissions in tCO_2eq).

Note: GDP refers to gross domestic product, and GHG to territorial greenhouse gas emissions. An "absolute" decoupling was observed in France (rise in GDP and decline in emissions); a relative decoupling in Mexico (increase in emissions smaller than GDP increase); and no decoupling in Saudi Arabia (a greater emissions increase than GDP growth). At global level, a relative decoupling is observed.

1. Relationship between economic growth and GHG emissions

Human economic activity is the source of various forms of environmental degradation not only by producing GHG emissions – the atmospheric concentration of which is continually increasing and responsible for climate change – but also by causing land take, pollution (air, water, noise) and other pressures weighing on biodiversity. Economically speaking, these forms of environmental degradation are considered negative externalities i.e. impacts with a social cost that is not borne by the producer or the consumer. This paper focuses on the climate aspect of the matter, with the European Union (EU) and France having set a target to reach net-zero GHG emissions[1] by 2050,[2] and on the relationship between GHG emissions and economic activity.

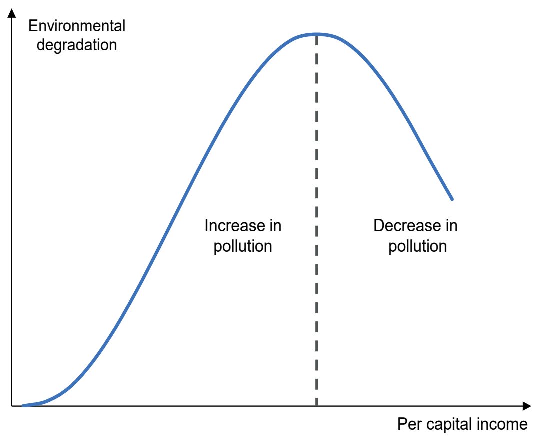
GHG emissions can be broken down into constituent parts by using the identity developed by Yoichi Kaya and Keiichi Yokobori (1997)[3] – the so-called "Kaya Identity" – to identify the major factors at play:

$$GHG = POP \times \frac{GDP}{POP} \times \frac{GHG}{GDP}$$

GHG emissions equal the product of the population (POP), gross domestic product (GDP) per capita (*GDP*/*POP*) and the economy's carbon intensity (*GHG*/*GDP*) The economy's carbon intensity can itself be broken down into the economy's energy intensity and the carbon intensity of the energy used. By reducing the economy's carbon intensity, emissions for a given population and a given economic activity can be cut.

Depending on its level, economic activity can have a varying impact on GHG emissions. Grossman and Krueger (1995)[4] posited a relationship dubbed the Environmental Kuznets Curve,[5] in which environmental degradation increases with economic development to a certain level, at which point it decreases (see Chart 1). According to the two economists, this inverted U-shape relationship can be explained by the fact that societies prioritise support to their fundamental needs and they focus on environmental issues only thereafter. Once this point is reached, the higher a country's development level rises, the more able it is to mitigate the adverse environmental impact of its economic activity. The theory posits that there will then be a decoupling of economic activity from pollution. However, Grossman and Krueger's postulate is the subject of debate in relation to its real-world application and the point at which pollution falls, which could potentially exceed development levels presently recorded.[6]

Chart 1: Environmental Kuznets curve



Source: Grossman and Krueger (1995).

(1) Or "carbon neutrality" or "climate neutrality" depending on the context: residual GHG emissions are equal to GHG removals (natural and technological carbon sinks).

(2) This objective is based on the work of the Intergovernmental Panel on Climate Change (IPCC), which underscores that restricting climate change to an increase of 1.5°C, a goal set as part of the 2015 Paris Agreement, requires (i) global GHG emissions to stop increasing by 2025 – falling 43% by 2030 – and (ii) net-zero CO_2 emissions to be achieved by 2050. IPCC (2022), "Climate Change 2022: Mitigation of Climate Change", Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change.

(3) Y. Kaya and K. Yokobori (1997), *Environment, Energy, and Economy: Strategies for Sustainability*, Tokyo: United Nations University Press.

(4) G. M. Grossman and A. B. Krueger (1995), "Economic Growth and the Environment", *The Quarterly Journal of Economics*, 110(2):353- 377.

(5) The original Kuznets Curve focuses on the positive and then negative correlation between levels of wealth and inequality of a given country.

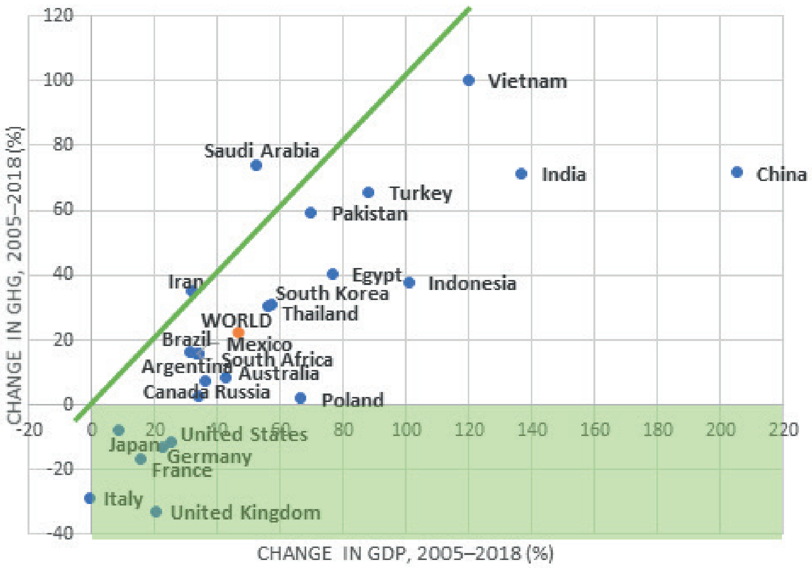
(6) See Purcel's meta-analysis on developing countries. A. A. Purcel (2020), "New Insights into the Environmental Kuznets Curve Hypothesis in Developing and Transition Economies: A Literature Survey", *Environmental Economics and Policy Studies*, 22 (4).

What does this mean in concrete terms on a global scale? GHG emissions continually increased up until 2019, even if the rate of increase fell in the 2010s. Recently, the only times when a decrease in global emissions was observed – the global financial crisis and then lockdowns during the COVID-19 pandemic – a rebound shortly followed.

At national level, the drop in GHG emissions in certain countries might be attributed to shifting these emissions to other countries with less ambitious climate policies that are often dubbed "pollution havens" (in the case of greenhouse gases, the term "carbon leakage" is used instead).[7] The pollution generated is partly converted into "imported" pollution, with no aggregate environmental benefit: the "footprint" approach (i.e. a measure of consumption-related emissions, including imported emissions) could therefore bring nuance to observations of the territorial emissions of a given country.

Changes in footprints (except CO_2 footprints) cannot be established by using international data: France's footprint has shrunk since 2005, but this decrease is smaller and less regular than the decrease in territorial emissions.[8] Building on territorial emissions data, Hubacek et al. (2021)[9] observed that between 2015 and 2018, 32 countries (out of the 116 monitored) managed to achieve an "absolute" decoupling of economic activity from territorial GHG emissions, i.e. an increase in GDP with a decrease in emissions (in footprint terms, however, this figure drops to 23 countries). The main driver behind this decoupling is the reduction in the economy's carbon intensity: the carbon intensity decreases at a faster rate than the other factors in the Kaya identity. Between 2005 and 2018, five of the 25 countries with the largest GHG emissions – of which France is one – achieved an absolute decoupling of their emissions from their GDP[10] (see Chart 2). Hubacek et al. (2021) also define the term "relative decoupling" as an increase in emissions that is smaller than GDP growth.

Chart 2: Change in GHG emissions and economic activity from 2005 to 2018 in the 25 countries producing the most emissions in 2018



Source: World Bank (GDP in constant dollars – 2015) and CAIT Data: Climate Watch (GHG emissions in tCO_2eq).

Note: Between 2005 and 2018, France's GDP rose 15.5% and its GHG emissions fell 16.8%. The countries in the green zone are those that achieved absolute decoupling between 2005 and 2018; those under the green straight line achieved relative decoupling over the same period.

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(7) W. L'Heudé, M. Chailloux and X. Jardi (2021), "A Carbon Border Adjustment Mechanism for the European Union", *Tresor-Economics* No. 280.

(8) L'Heudé et al. (2021), op. cit. High Council on Climate, "Maîtriser l'empreinte carbone de la France", 2020. Data and Statistical Research Department of the Ministry for the Ecological Transition (General Commission for Sustainable Development), "Estimation de l'empreinte carbone de 1995 à 2020", 2021.

(9) K. Hubacek, X. Chen, K. Feng, T. Wiedmann and Y. Shan (2021), "Evidence of Decoupling Consumption-Based CO_2 Emissions From Economic Growth", *Advances in Applied Energy*, 4, 1-10. See also C. Le Quéré, J.I. Korsbakken, C. Wilson, J. Tosun, R. Andrew, R.J. Andres, J.G. Canadell, A. Jordan, G. P. Peters and D.P. van Vuuren (2019), "Drivers of Declining CO_2 Emissions in 18 Developed Economies", *Nature Climate Change* 9, 213-217.

(10) An absolute decoupling is an emissions decrease accompanied by a GDP increase, whereas a relative decoupling is where an emissions increase is outstripped by a GDP increase.

However, climate change mitigation objectives, and in particular the 2050 net-zero goal, need a much faster and significant reduction in emissions at the aggregate level than a mere absolute decoupling. For the EU, whose intermediary goal is a 55% reduction in net emissions by 2030 versus 1990, such objectives involve doubling the annual rate of emissions cuts over the 2020-2030 period versus the 2005-2019 period.[11] Unless a massive drop in activity levels is an acceptable option, these objectives will require a significant increase in the rate at which the carbon intensity of our economies is reduced.

2. Two interpretations of "green growth"

The required decoupling of GHG emissions from economic growth has led several international organizations to promote the concept of "green growth", such as the OECD and the World Bank. The OECD defines it as "economic growth that ensures that natural assets continue to provide the resources and environmental services on which our well-being relies". This differs from the concept of "degrowth", which is based on the idea that the net-zero transition is only possible by reducing production. There are two interpretations of green growth as to the form it may take and its macroeconomic consequences.[12]

The first interpretations argues that the net-zero transition would have positive economic impacts as from the short term: investments to ensure the transition would stimulate demand, and activity and employment along with it.[13] This theory is based on the usual Keynesian arguments, under the additional assumption that a "green" investment will have more economic benefits than a "brown" investment in the short term. A green investment (such as in the energy efficiency renovation of buildings) would be more job-intensive and its economic impact would be more locally concentrated. However, empirical literature on green stimulus measures is limited.[14] This theory also encompasses techno-optimist arguments according to which the transition should be supported by breakthrough carbon-free innovations that could be the source of significant productivity gains. Critics of this theory point to the high degree of uncertainty surrounding the emergence of these technologies and their ability to generate spillover effects on the rest of the economy.[15]

The second interpretation, that is becoming a consensus view, posits that the net-zero transition would result in benefits in the long term – relative to the negative impacts of inaction on climate change – but would be costly in the short term. Thus, according to Pisani-Ferry (2021),[16] fossil fuel phase-out –which is a prerequisite to reduce GHG emissions quickly and significantly – could be akin to a negative supply shock. Moreover, the additional investment needed to achieve the transition would come at the expense of consumption and other short-term investments. In any case, the cumulative costs for economic activity would remain below the costs of inaction on climate change. The cost of inaction could exceed 15% of global GDP by 2050 for a temperature increase of 2 to 3°C.[17]

(11) European Commission (2020), Impact assessment of the communication "Stepping Up Europe's 2030 Climate Ambition – Investing in a Climate-Neutral Future for the Benefit of Our People", SWD/2020/176 final.
(12) M. Jacobs (2013), "Green Growth", in *The Handbook of Global Climate and Environmental Policy*, Oxford: Wiley Blackwell.
(13) A. Bowen, S. Fankhauser, N. Stern and D. Zenghelis (2009), "An Outline of the Case for a 'Green' Stimulus", Grantham Research Institute on Climate Change and the Environment, London School of Economics, Policy Brief.
(14) S. Agrawala, D. Dussaux and N. Monti (2020), "What Policies for Greening the Crisis Response and Economic Recovery? Lessons Learned From Past Green Stimulus Measures and Implications for the COVID-19 Crisis", *OECD Environment Working Paper* no. 164.
(15) M. Jacobs (2013), op. cit.
(16) J. Pisani-Ferry (2021), "Climate Policy is Macroeconomic Policy, and the Implications Will Be Significant", Peterson Institute for International Economics, Policy Brief.
(17) M. Burke, S. Hsiang and E. Miguel (2015), "Global Non-Linear Effect of Temperature on Economic Production", *Nature* 527, 235- 239, N. Lancesseur, M. Labrousse, M. Valdenaire and M. Nakaa (2020), "Impact économique du changement climatique : revue des méthodologies d'estimation, résultats et limites", *Document de travail de la DG Trésor* no. 2020-04, and B. Carantino, N. Lancesseur, M. Nakaa and M. Valdenaire (2021), "The Economic Effects of Climate Change", *Tresor-Economics* No. 262.
IPCC (2022), op. cit., Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change.

3. Public policies to support decarbonisation

Decarbonising economic activity does not happen voluntarily, because behaviour changes often reduce the utility of households and the profits of businesses in the short-run. A wide range of tools can be deployed to make economic agents decarbonise their activities: carbon pricing, eliminating fossil fuel subsidies, regulation (sector-specific or financial), financial support for decarbonisation (in the form of subsidies and public investment) and improved access to information. All these initiatives send a signal to economic agents to shift their private financing and spending from non-environmentally friendly activities to sustainable activities.

Sector-specific regulation ensures that the goods and services delivered meet performance standards and rely on technology compatible with climate change mitigation objectives. Regulation is often tailored to a given sector: examples include mandatory energy efficiency renovation of housing, the introduction of "low-emission zones" in urban areas where only the cleanest vehicles are allowed on the road, and emission standards for vehicles.

Carbon pricing can take the form of a carbon tax or an emissions cap and trading scheme. This is in line with the notion of a Pigouvian tax by internalising the cost of environmental externalities into prices. Assuming that it is reasonably ambitious and foreseeable, a carbon pricing scheme can send a price-signal to encourage economic agents to cut their emissions and invest in decarbonisation (e.g. green technology development and rollout). The revenue generated from carbon pricing can be used to finance public decarbonisation policies and provide support to the households and businesses most exposed to transition costs. Although adopting pricing schemes is becoming more widespread, only 23% of global emissions are subject to carbon pricing currently, and less than 4% are priced at more than \$40/tCO_2eq.[18]

Acemoglu et al. (2012, 2016)[19] stress that, without government intervention, companies keep producing without considering their environmental impact, resulting in pollution exceeding critical thresholds and thereby triggering environmental disasters. Government intervention can therefore shift business' decisions towards green technologies rather than "brown" ones. This intervention can be temporary, provided that research and development (R&D) eventually makes green technologies relatively more cost-effective than brown ones. Once this milestone is achieved, investments will align with green technology on their own. The quicker and stronger the government intervention, the greater the reduction in the transition's economic cost.

Major public and private investments in decarbonisation will be vital across all sectors of the economy, whether it is a matter of decarbonising energy generation and industrial processes, building transportation infrastructure, replacing vehicles, carrying out energy renovation works on buildings, or developing new low-carbon technologies. In view of the capital stock to be renewed, the European Commission estimates that the additional (public and private) investment needed over the 2021-2030 period compared to the previous decade to achieve the EU's new climate objectives by 2030[20] – in the energy generation, industry, transportation and construction sectors – would be equivalent to about 2 to 3 percentage points of GDP per year at EU level (i.e. an increase of over 55% from 2011-2020 levels). These investment needs for the climate transition mostly relate to "gross" amounts to be committed for emissions reductions. They do not relate to the net additional investment that may be observed at a macroeconomic level (some financing can be shifted from "brown" investments to "green" investments), nor to the final cost for economic agents who, for example, may recoup all or part of these investments through energy savings thanks to the energy efficiency renovation of buildings.

(18) World Bank (2022), "State and Trends of Carbon Pricing 2022".
(19) D. Acemoglu, P. Aghion, L. Bursztyn and D. Hemous (2012), "The Environment and Directed Technical Change", *American Economic Review*, vol. 102 (1) pp. 131-166 and D. Acemoglu, U. Akcigit, D. Hanley and W. Kerr (2016), "Transition to Clean Technology", *Journal of Political Economy*, vol. 124 (1), pp. 52-104.
(20) European Commission (2021), "Impact Assessment Accompanying the Proposal for a Directive of the European Parliament and of the Council: On Energy Efficiency" (Fit for 55 package), SWD/2021/623 final.

4. The macroeconomic impacts of decarbonisation

In this section, a qualitative description of the direct and indirect macroeconomic impacts of climate policies with respect to the current situation is given in order to provide an easily understandable point of comparison. In fact, the impacts of climate policies on a given country will vary depending on the degree to which climate change's effects materialize. Moreover, these impacts should be compared with the cost of inaction. Although the degree of uncertainty surrounding the net-zero transition's economic impacts is very high (see below), recent studies share the conclusion that the transition's costs would remain much lower than the cost of inaction on climate change.

From a macroeconomic perspective, the transition to net-zero emissions could have a twofold effect: a rise in the relative price of carbon emissions and a sharp increase in decarbonisation investments.

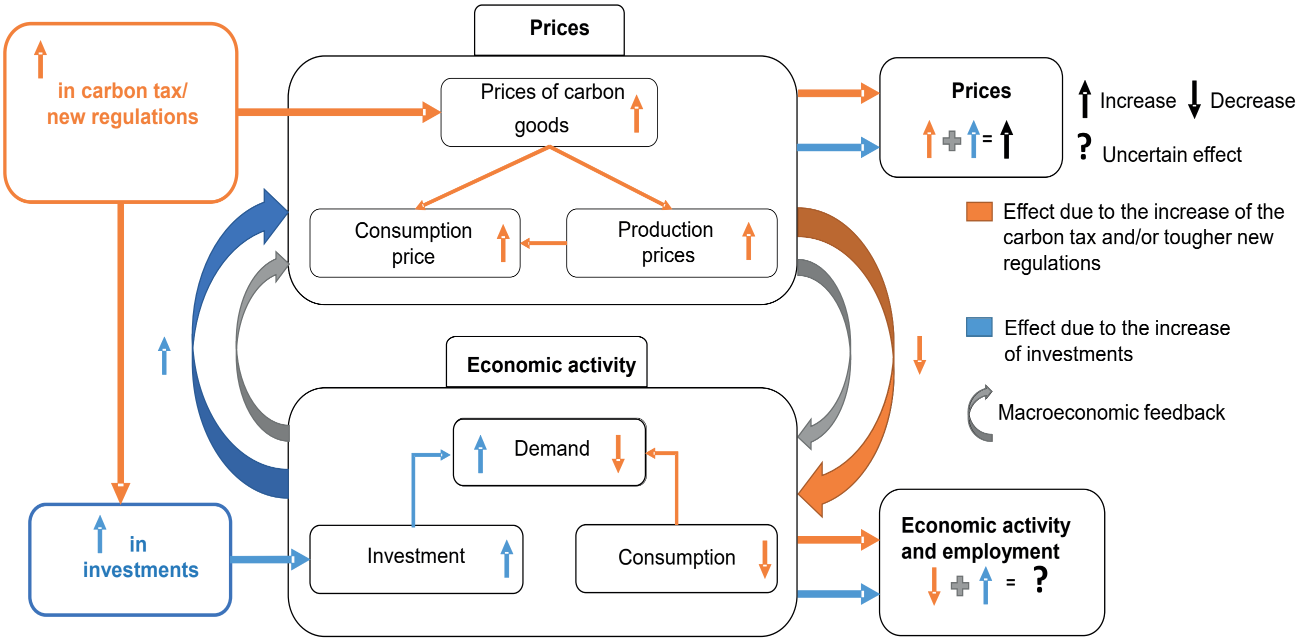
Increasing the costs of carbon emissions through carbon pricing and new regulations is akin to a negative supply shock. It will raise the prices of goods and services in the sectors affected and therefore producer and consumer prices through the interconnections between firms (see Chart 3). Although regulation is not an explicit carbon price, it does make it more difficult to implement a high-emission production process. It also involves a cost due to the substitution with low-carbon or decarbonized alternatives. A rise in production costs would have a direct negative impact on activity, as well as an indirect impact resulting from price hikes that would hamper consumption. Although empirical studies have stressed that a carbon tax increase would have a moderate or even non-significant macroeconomic impact, these studies were conducted when carbon prices were low (up until the end of the 2010s).[21]

Additional investments are akin to a positive demand shock. This shock stimulates economic activity in the short term by generating a demand surplus for firms and thus increasing employment. However, this increase in demand drives prices up temporarily as long as supply cannot immediately meet all of the demand surplus (see Chart 3). Financing requirements for these investments may also drive interest rates upwards which may cause a crowding-out effect (see below).

While the cumulative macroeconomic impact of these two shocks is rather inflationary, the impact on other macroeconomic variables of interest, such as household purchasing power, is uncertain. On the one hand, rising production costs should hamper activity and income growths. On the other hand, additional investments to decarbonize the economy would stimulate activity and household income through both lower unemployment and increased wages that the rise in prices might cause. Other mechanisms must also be taken into consideration to measure the total macroeconomic impact. In this case, a drop in the energy consumption of households caused by investments and improved energy efficiency could support other consumption purposes thanks to income and substitution effects. In addition, a portion of the wages and social security benefits indexed to inflation would be automatically adjusted in line with the price hike.

(21) G. Metcalf, J. Stock (2020), "The Macroeconomic Impact of Europe's Carbon Taxes", NBER Working Papers for Europe. M. Konradt and B. W. di Mauro (2021), "Carbon Taxation and Greenflation: Evidence from Europe and Canada", IHEID Working Papers for Europe and Canada.

Chart 3: Transmission channels of (i) a rise in carbon tax and new regulations, and (ii) an increase in investments in the net-zero transition, excluding the impact of climate change



Source: DG Trésor.

Note: The diagram shows shocks on the left and impacts on prices, activity and jobs on the right. The upper section covers price mechanisms, while the lower section shows real mechanisms. The arrows between these two sections indicate macroeconomic feedback. For example, if prices rise, demand falls and if demand increases/falls, prices rise/fall.

The net-zero transition's macroeconomic impacts, as well as their magnitude, will depend on other mechanisms, the emergence and magnitude of which are uncertain:

- The crowding-out effects of decarbonisation investments on other investments, public investment on private investment (unless savings rates are high) and aggregate investment on consumption. The magnitude of these crowding-out effects will ultimately depend on changes in savings rates at national and global levels
- Friction and adjustment costs in the production process, particularly in relation to job and capital reallocations (e.g. the rigidity of employment, the cost of skill acquisition, premature write-down of assets in carbon-intensive sectors – referred to as "stranded assets"[22]), and to bottlenecks for critical raw materials

(22) B. Caldecott, J. McDaniels (2014), "Stranded Generation Assets", Working Paper, Smith School of Enterprise and the Environment, University of Oxford.

Moreover, these mechanisms do not take into account the global dimension of the net-zero transition, whereas its impact will depend on the level of cooperation between countries. If a coordinated net-zero transition were carried out, inflation should increase in similar proportions across all countries depending on their productive structure, as a result of the mechanisms described above. Coordination would limit the losses of both competitiveness and market shares for the companies facing ambitious climate policies, and thus the deterioration in the balance of trade. The global dimension also includes the risks of supply bottlenecks for critical raw materials for green technologies and the rollout of renewables.

The time frame of decarbonisation efforts is also a factor to consider. Two opposing scenarios are generally taken into account when assessing the net-zero transition's macroeconomic impact. It depends on whether the transition is orderly and begins right away or is delayed for several years before being rushed, therefore increasing its costs. This is for example the approach that the Network of Central Banks and Supervisors for Greening the Financial System (NGFS) uses to assess the impact of climate and transition risks on the economy and the financial system.[23]

Finally, other factors will have an important role to play in the trajectory of the decarbonisation of the economy and thus in the resulting macroeconomic impacts. The emergence of new carbon-free technologies (which depend on R&D investments), their diffusion in production and their macroeconomic impact remain largely uncertain (see Box 1). The method of financing mitigation measures is another aspect to consider. The carbon tax revenue generated could be recycled into various economic support measures, while public decarbonisation subsidies will have to be financed, with a possible recessionary effect of tax increases or cuts in related public spending. In addition to the economic impacts of mitigation policies, there will also be the impacts of climate change and the adaptation policies induced, the cost of which remains uncertain.

Looking beyond economic mechanisms, uncertainty is also apparent in the very modelling exercise of the net-zero transition's impact on economic aggregates. Although several models perform such exercise, none have yet been able to transpose the frictions described in order to quantify their impact.[24]

These uncertainties are reflected in the estimates of the net-zero transition's macroeconomic impact. For example, notwithstanding significant disparities in the estimates across economies, the IPCC estimates that the impact on activity would range between -4.2% and -1.3%[25] at the global level by 2050, depending on whether the transition policies aim to limit climate change to an increase of 2°C or 1.5°C. Moreover, the NGFS has published estimates ranging between -8% and 0%, depending on whether the transition is "delayed" or "orderly".[26] These estimates are calculated in comparison to a theoretical scenario in which neither climate change nor decarbonisation policies are accounted for. Thus, damages from climate change in scenarios where mitigation policies would be insufficient to limit it would lead to an even more negative impact on economic activity (see Section 2).

(23) Network for Greening the Financial System (2022), "NGFS Scenarios for Central Banks and Supervisors".
(24) T. Gantois, P. L. Girard and C. Le Gall (2022), "Évaluation de l'impact macroéconomique de la transition Écologique : Revue des modèles macro-environnementaux, usages et limites", *Document de travail de la DG Trésor* no. 2022/2.
(25) IPCC (2022), op. cit.
(26) NGFS (2022), op. cit.

Box 1: Impacts of environmental policies on productivity

Questions can be raised about the impact of environmental policies not only on growth, but also on productivity.[a] Do more stringent regulations adverse have an impact on productivity, or do they stimulate it by boosting innovation as theorised by Porter?[b] The weak version of the Porter's Hypothesis suggests that environmental policy leads to more innovation; the strong version argues that the positive impacts of environmental policy on productivity through innovation outweigh the negative impacts (therefore leading to higher overall productivity).

While the majority of studies mention a possible short-term cost of these policies on competitiveness and productivity resulting from the restriction of inputs in production processes,[c] very few studies back the strong version of Porter's Hypothesis. These outcomes depend on the scope of analysis (firm-, industry- or economy-wide level), the characteristics of a given company (size, financing constraint) and the type of pollution covered by the policy.[d] According to Albrizio et al. (2017),[e] a positive short-term impact of increased productivity is noted for companies that are already among the most productive, but this effect diminishes to nothing with respect to the distance to the technological frontier. Therefore, the net impact is neutral at the economy-wide level. A study conducted by *DG Trésor* also suggests that the EU Emissions Trading System (EU ETS) has not adversely affected the productivity of companies on the whole. The EU ETS also improves the productivity of large and more efficient companies, and those with less limiting financial constraints.[f] The outcomes can also be affected by the design of the environmental policies: explicit carbon price increases have a more positive impact on productivity growth than other tools (standards and regulations).

The weak version of Porter's Hypothesis is generally accepted in the literature. Calel and Dechezleprêtre (2016)[g] for example highlight that companies regulated under the EU ETS have filed more patents, particularly in the field of decarbonisation. Galeotti et al. (2015) provided evidence, examining 17 EU countries from 1997 to 2009, that a stringent environmental policy bolsters patent filing, but did not observe a net positive impact on productivity.[h]

a. See C. Franco and G. Marin (2017), "The Effect of Within-Sector, Upstream and Downstream Environmental Taxes on Innovation and Productivity", *Environmental & Resource Economics*, 66, 261-291 and S. Albrizio, T. Kozluk and V. Zipperer (2017), "Environmental Policies and Productivity Growth: Evidence Across Industries and Firms", *Journal of Environmental Economics and Management,* 81(C), 209-226.
b. A. Jaffe, K. Palmer (1997), "Environmental Regulation and Innovation: A Panel Data Study", *The Review of Economics and Statistics*, 79:610-619.
c. S. Ambec, M. Cohen, S. Elgie and P. Lanoie (2011), "The Porter Hypothesis at 20: Can Environmental Policy Enhance Innovation and Competitiveness?", RF Discussion Paper 11-01, Washington DC: Resources for the Future.
A. Dechezleprêtre and M. Sato (2017), "The Impacts of Environmental Policies on Competitiveness", *Review of Environmental Economics and Policy,* 11(2):83-206.
d. T. Kozluk and V. Zipperer (2014), "Environmental Policies and Productivity Growth: A Critical Review of Empirical Findings", *OECD Journal: Economic Studies*, 2014/1.
e. S. Albrizio, T. Kozluk and V. Zipperer (2017), op. cit.
f. A. Alla (2022), "European Union's Emissions Trading System and Productivity: Firm-Level Evidence for France, Italy and Spain", *Document de travail de la DG Trésor* no. 2022/3.
g. R. Calel and A. Dechezleprêtre (2016), "Environmental Policy and Direct Technological Change: Evidence from the European Carbon Market", *Review of Economics and Statistics*, 98(1).
h. M. Galeotti, Y. Rubashkina and E. Verdolini (2015). "Environmental Regulation and Competitiveness: Empirical Evidence on the Porter Hypothesis From European Manufacturing Sectors", *Energy Policy*, 83:288-300.

In addition to the long-term impact, the magnitude of the macroeconomic impacts during the net-zero transition will depend on the pace of implementing mitigation policies, economic agents' anticipation and other factors such as international coordination. A fast implementation of the investments needed to decarbonise the economy would support economic activity in the short term. It would also allow for energy efficiency improvements to be more quickly leveraged in the medium term, supporting household income for example.

5. Implementing transition support policies

The macroeconomic impact of the net-zero transition will depend on the combination of public climate policies adopted and how this combination is implemented, and particularly on the degree of predictability of these policies for economic agents (so that they can effectively anticipate measures and accordingly adapt their practices). In this respect, the French Energy and Climate Strategy, which will include an energy and climate planning law (by mid-2023) and a national low-carbon strategy (by mid-2024), must set out the emissions reduction objectives at national level and within each major sector for the next few years and provide a roadmap for France to achieve net-zero emissions by 2050.

In addition to decarbonisation-specific policies, the transition to net-zero is intertwined with policies supporting the actors most exposed to the costs of the transition. These costs vary greatly from one economic agent to another, and are related to various factors (type of equipment used, location, etc.). Assessments of the Fit for 55 package proposed by the European Commission show that the transition could proportionally hit low-income households and companies in the most emission-intensive sectors harder.[27] A range of measures could be introduced to mitigate this impact, including income support for low-income households, particularly in periods when energy prices quickly rise, and enhanced financial support to help them make the investments required for the transition. Depending on their design, their macroeconomic and climate impacts could vary widely. Lump-sum transfers targeted on the most vulnerable households would avoid an incentivisation of burning fossil fuels and support the consumption of the economic agents most affected by restrictions, all while limiting the long-term pressure on public finances.

Lastly, structural reforms would smooth the reallocation of production factors and limit the adjustment costs triggered by the green transition. To give an example, this would mean facilitating the acquisition of the skills required for the transition, such as in the field of the energy renovation of buildings. Decarbonising the economy will be carried out through job reallocations across and within sectors. Jobs in emission-intensive sectors will be cut or converted, while a recruitment drive will occur for strategic job positions for the green transition, provided that workers with the requisite skills – or with the capacity to quickly acquire them – can be identified.[28] Training policies will also have a vital role to play in facilitating career transitions.[29]

(27) Macroeconomic assessment of the European Commission's Fit for 55 package (2020), "Stepping Up Europe's 2030 Climate Ambition, Investing in a Climate-Neutral Future for the Benefit of Our People – Impact Assessment".
(28) The OECD and the European Centre for the Development of Vocational Training (Cedefop) define green skills as skills required to adapt the goods, services and production processes to climate change and environmental needs. OECD/Cedefop (2014), "Greener Skills and Jobs", *OECD Green Growth Studies*.
(29) M. Patnam (2022), "An Anatomy of Occupational Pathways for the Climate Transition in France", International Monetary Fund, "France: Selected Issues", 22–19 and International Monetary Fund (2022), "Chapter 3: A Greener Labor Market: Employment, Policies, and Economic Transformation", *World Economic Outlook*, April 2022.

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