Economic impacts of a carbon tax

Special

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Summary

- It has become increasingly important for financial institutions, policy makers and companies to understand the economic impact of carbon prices.
- RaboResearch investigated the impact of a CO2 tax on combustion on the macro and sector level against a baseline based on the 2030 emission projections of the "current policies" scenario of the UNEP Emission Gap report 2019.
- Three scenarios with different regional scopes were investigated: (1) the tax is only imposed on the Netherlands, (2) the tax is imposed simultaneously on the EU, UK and EFTA (referred to as EU+) and (3) the tax is additionally imposed on major economies beyond Europe (i.e. USA, China, Canada, Australia, New Zealand and Japan).
- Whether the tax is introduced in all EU+ regions or only introduced in the Netherlands, the impact on Dutch GDP would be almost the same. This is because the Netherlands could suffer from lower demand for Dutch exports if EU+ regions also implement the tax.
- In this case, all EU+ regions realize lower GDP, with Greece impacted by far the most.
- Most EU+ countries, including the Netherlands, reach a higher GDP if the tax is also implemented in the major economies beyond Europe.
- Sector impacts vary strongly between sectors, countries and scenarios with different regional scopes.

This research was published as a chapter in a report on The Impact of Carbon Pricing. The report is a reflection of the deliberations of the Working Group on Carbon Pricing set up under the auspices of the Sustainable Finance Platform. The full report can be found at dnb.nl.

Introduction

The COP26 president concluded the negotiations with the statement:

"We can now say with credibility that we have kept 1.5 degrees alive. But, its pulse is weak and it will only survive if we keep our promises and translate commitments into rapid action." Rapid action to mitigate GHGs can come in the form of different policies. A prominent policy tool to mitigate GHG emissions is a carbon price. An instrument, whose "potential [...] is still largely untapped" (World Bank, 2021 p.8). With mitigation action becoming more urgent, it is also becoming increasingly important for policy makers, companies and financial institutions to understand the economic impacts of such policy actions.

One way of putting a price on emissions is to tax the amount of emissions that are released. To provide insights for policy makers, companies and financial institutions on the possible economic effects of a carbon tax, this research looks at introducing a carbon dioxide (CO_2) tax (of USD 100 and 150) with different regional coverage. The effect on macroeconomic variables such as GDP and trade, both at sector and country level, are analysed. We particularly highlight the economic effects of a carbon tax in the Netherlands, but also look at the impacts on other EU countries and beyond.

Model set up and scenario definition

Methodology

The economic effects of a carbon tax are quantitatively assessed using the computable general equilibrium (CGE) model GTAP-E. CGE models allow us to analyse the economy-wide and sector-specific effects of external shocks and policy changes. The interaction between product, factor and international markets is modelled using neoclassical economic optimization theory. A policy change leads to a re-matching of supply and demand by adjusting prices until a new equilibrium is reached. An equilibrium is reached at the price where supply equals demand. This has to be the case simultaneously in each market of the economy.

The GTAP database distinguishes several regions and sectors (65 sectors and 121 regions). In this analysis we used a somewhat higher aggregation of sectors and regions which is described in Appendix II. GTAP-E is an adjusted version of the standard GTAP CGE model: it also allows for energy substitution which is a vital feature for this study. For a more detailed explanation of the GTAP-E CGE model see Appendix I.

As the model is only directly linked to fossil fuel combustion-related CO_2 emissions (see Main limitations of the model), we only apply a carbon tax to CO_2 from the combustion of fossil fuels. Hence, the scenario outcomes reflect the impact caused by a carbon tax to drive the energy transition, while leaving out other processes and other greenhouse gases (GHGs). This means that CO_2 from industrial processes and other GHGs are excluded from the simulations. Therefore the quantitative analysis will not capture the complete impact, especially in sectors where other emissions play a significant role: for example in the agriculture sectors. To address this constraint for the agricultural sector, Chapter 2 of Part I takes a fact-based qualitative approach to assess the impact on the agricultural sector where GHG emissions are driven by non-CO_2 gases.

Defining the model baseline

Like most modelling work, the GTAP CGE model needs a baseline or reference scenario against which the effects of a carbon tax are assessed. The choice of the baseline is crucial for the policy assessment and the question is which assumptions should be made about how the world will develop. The future is generally characterised by uncertainty so the baseline should be seen in that light; and the current global pandemic increases the level of uncertainty of any predictions.

The model is not suitable to provide forecasts of growth rates or levels. Instead, it provides insights into possible impacts resulting from exogenous policy shocks relative to a baseline. Baseline scenarios are not intended to predict the future, but they are counterfactual constructions that can serve to highlight the effects of a shock or a policy change. In this report, we stick to the convention of modelling baseline scenarios on the assumption that no mitigation policies or measures will be implemented beyond those that are already in force (i.e., a Business-as-Usual scenario).

The base year of the GTAP-E database is 2014. To construct the baseline, we use data projections for GDP, labour population and emissions changes from OECD, World Bank and UNEP Emission Gap report 2019 (for details and data sources see Appendix III: Data and main assumptions).

Regarding the emission levels in the baseline, we use the "current policies" projections provided by the UNEP's Emissions Gap Report 2019, as these were the most recent 2030 projections at the level of individual countries when we ran the simulations (in 2021). At that time those baselines were on the low end of the Intergovernmental Panel on Climate Change (IPCC) no-policy scenarios. The UNEP current-policies estimates projected total GHG emissions to reach 60 $GtCO_2e$ in 2030, which corresponded to a world on its way to warming up by way more than 3 degrees Celsius. In fact, even the full implementation of the unconditional Nationally Determined Contributions (NDCs) was expected to steer the world towards global warming of 3.2 degrees Celsius by the end of the century with a probability of 66%. The 2030 emissions associated with this scenario was expected to be about 56 $GtCO_2e$ in 2030 (UNEP 2019). It should be noted that the current-policies projections of the UNEP Emissions Gap Report 2021 give emission estimates for 2030 of about 55 $GtCO_2e$. The difference is partly justified by emission reductions realised on the back of the Covid-19 pandemic and partly by policies implemented and accounted for by studies in the meantime.

It is an important caveat that we do not include measures that have been approved since the end of 2019 (e.g. the Dutch national CO_2 industry tax implemented in 2021, though the impact is likely modest given the increase in EU ETS prices in the past year). The limitation here is the fact that the UNEP Emissions Gap Report 2019 was the most recent source (at the time) that translated current policy to 2030 emission levels at the country level for a large group of countries (the G20). Additional estimates of new policy impacts were beyond the scope of this study.

We also note that, in line with our current policies scenarios, additional pledges are not included in the baseline. This includes the plethora of net-zero country targets announced in recent years as most of these targets have not been translated to measures that are enshrined in law. This of course includes the revisions of adopted targets (including the revised NDCs) such as the EU's 55% 2030 emissions-reduction target.

Finally, in the stylized economic model we model a carbon tax which then also incorporates the EU Emissions Trading System (EU ETS) price. In theory one can regard the carbon tax as a carbon price – both should work the same way, despite the fact that the ETS price is volatile and the carbon tax is fixed. Scientific literature uses carbon pricing as a term encompassing both a price resulting from an ETS and a carbon tax (World Bank; IPCC, 2014). In practice, the EU ETS 2018 revision is included in the 2030 projection by the UN which was used for the 2030 baseline of this modelling exercises. While the exact development in recent years (i.e. the recent rise in EU ETS prices) might not have been anticipated, in principle, average expected long-term price increases must be contained in these projections. We therefore assume that the carbon tax applied in this study accounts for emission reductions that are not induced by the EU ETS (i.e. emission reductions additional to the reductions already accounted for in the emission projections of the baseline).

Describing the model scenarios

Introducing a carbon tax

We discern two ways in which emissions can be priced: through a CO_2 tax or by setting up a cap-and-trade system (an emissions trading system). With a CO_2 tax, the price of emissions is set and the market will then determine the amount of GHG that will be emitted. In an emissions trading system, it is the amount of emissions that is fixed and the market determines the price. In an economically perfect world, the outcome of both systems would be the same: the same emission with the same CO_2 price. In reality, there is uncertainty within both systems: in the case of a carbon tax, it is not easy to predict in advance the exact emission reductions that the tax will trigger; in the case of a carbon trading system, it is difficult to estimate at which CO_2 price the market will clear.

Hence, in both cases it is difficult to estimate the level of policy that will have the desired outcome, namely: how high the carbon tax should be or how many emission permits should be issued, respectively. The economic and climate models designed to estimate these levels are characterized by many uncertainties, among which climate-related estimates perhaps exhibit the highest level of uncertainty. The range of estimates for the prescribed level of CO_2 prices is very wide: 95% of the CO_2 price estimates from the most recent studies are between EUR 10 and around EUR 200 per ton of CO_2. But according to the High-Level Commission on Carbon Prices, a CO_2 price of USD 40-80 per ton was needed by 2020 to meet the Paris targets.

Determining the maximum supply of emission allowances for a specific country or region is even more complicated. The uncertainties make both instruments susceptible to policy errors. We know from empirical data that, in practice, a CO_2 tax is often set too low and the supply of emission permits is often set too generously, resulting in less emission reductions than required. Both systems are also sensitive to lobbying and the influence of vested interests. However, a carbon tax has several advantages over a trading system. A CO_2 tax is more predictable and gives companies and consumers certainty about their costs, which is more conducive for investment and purchase decisions (Kettner, 2011). As mentioned earlier, it is easier to set a tax rate than an emission quantity. Moreover, a CO_2 tax has fewer undesirable interactions with other climate policies (Goulder & Schein, 2013).

Given these advantages, we chose to model the CO_2 price as a carbon tax in this analysis. To stay within the range suggested by the High-Level Commission on Carbon Prices we chose to apply a carbon tax of USD 100 per ton of CO_2. This is also in line with DNB's policy shock scenario in their energy transition risk stress test (DNB, Web-appendix: modelling the energy transition risk stress test). For sensitivity analysis purposes we also apply a tax of USD 150 /tCO_2. This was in line with preliminary NGFS (Central Banks and Supervisors Network for Greening the Financial System) analysis (Berdeen S., Climate change – Plotting our course to Net Zero). though the second set of NGFS climate scenarios places the carbon prices close to USD 200 per ton in a net-zero world.

The geographical areas

In addition to the two different tax rates that we work with, we also introduce three geographical scenarios:

- Scenario 1: The tax rates apply only to the Netherlands;
- Scenario 2: The tax rates apply to the EU, the EFTA countries and the UK;
- Scenario 3: The tax rates apply to all countries in scenario 2 and to other important countries, namely the USA, China, Canada, Japan, Australia and Rest of Oceania (i.e. New Zealand);

We chose to include the EFTA countries (Iceland, Lichtenstein, Norway and Switzerland) in the carbon tax jurisdiction in the second scenario because the EFTA states participate in the EU ETS. We also include the UK because the country was anticipated to stay closely linked to the EU and continue to implement ambitious climate policies. In fact, the UK has decided to roughly replicate the EU ETS system post-Brexit and prices broke through the EU ETS levels at launch in May 2021.

The countries to implement a carbon tax in the third scenario were chosen because they have ambitious climate policies such as a carbon tax or an ETS in place (World Bank, 2020) and are therefore more likely to potentially implement ambitious climate policies in the future.

- Australia: Australia already has an ETS in place.
- Rest of Oceania: New Zealand has a net-zero emissions target in its legislation. Moreover, it has an ETS in place.
- China and Hong Kong: China has the goal to become net-zero in 2060. It launched a national ETS in 2021.
- Japan: Japan has a carbon tax in place.
- Korea: Korea has an ETS in place.

- Canada: Several regions in Canada have ETS in place. There is a national law requiring the regions to implement ETS, otherwise a national carbon tax needs to hold.
- USA: Several U.S. States have an ETS in place. Moreover, the U.S. returned to the Paris Climate Agreement, President Biden announced an emission reduction target for 2030 by around 50% (relative to 2005 emissions) and several pledges were made by the U.S. at the COP26. Also, the USA is of interest to many of the Working Group on Carbon Pricing members, so it is included in the third scenario.

Main limitations of the model

CGE models are complex models, based on neoclassical economic theory. They can be useful for simulations to assess the impact of certain external shocks, such as the introduction of a carbon tax. However, like any model, CGE models abstract from many things which are important in economies in the real world, as the reality is more complex and difficult to reproduce. Some limitations are specific to our study, some driven by characteristics of the GTAP-E model, while others are driven by data constraints.

GTAP-E characteristics

The GTAP-E model can only assess structural long-term changes. The model looks at the economy in a general equilibrium and, after adding a shock, e.g. a policy or a tax, to the original general equilibrium, the model solves to another general equilibrium. Hence, the model captures structural economic changes resulting from an external shock but is not useful for either modelling short-term effects or modelling transition periods (such as a gradual implementation of a carbon tax). The model does not give insight in the path the economy takes to go from one general equilibrium to another. Similarly, the standard GTAP model does not model short-term (year-to-year) fluctuations or business cycles – it is governed by fixed aggregate demand at base-year levels and future trend estimates. Short-term effects may sometimes temporarily be larger than the calculated structural outcomes, for instance due to confidence effects, price stickiness and adjustment costs.

CGE models such as GTAP typically rely on fixed econometrically estimated elasticities as inputs for important model parameters. Model responses to shocks are governed by these elasticities and parameters. These elasticities can vary strongly and there is no consensus on which elasticities to use. CGE models are sometimes criticized for using these off-the-shelf elasticities. However, these uncertainties are to some extent inherent in economic models. Here, we use the elasticities as provided by the GTAP database. To assess the sensitivity of the results to these elasticities, a sensitivity analysis should be undertaken in future research – a sensitivity analysis for the energy-specific elasticities would be most relevant to this study.

There is no explicit modelling of financial markets, but the existence of a financial market is implicit in capital mobility within and across regions. The model reflects the real economy and works with real values. But there are no nominal prices: only relative prices matter. All values in the GTAP database are in USD but real exchange rates are implicitly accounted for by the relative price changes between countries. Other dynamics, such as learning-by-doing, technological and know-how spill-overs and endogenous technological change are not modelled explicitly.

Moreover, since we are not explicitly modelling electricity generation by different power sources, the share of renewable energy is fixed to the base-year values, and these shares cannot be increased. This leads to an overestimation of the impacts, (especially in the electricity sector in regions with high fossil-fuel generation in the base year) as there are no possibilities to substitute away from fossil fuel technologies. This caveat must therefore be kept in mind when interpreting the magnitude of the impacts.

Finally, GTAP-E does not allow to actively steer the recycling of carbon tax revenues. This means that we cannot determine what the tax revenues are used for in the model. Nevertheless, CGE models have a comprehensive accounting of all value flows in the economy and therefore the tax revenue will always be accounted for. In GTAP, the tax revenues in the model are automatically allocated to a representative agent that combines the consumption behaviour of the government and households. Hence, tax revenues are used for consumption by households and the government but it is not possible to steer the consumption to specific sectors.

Data constraints

There is no database of GHG emissions available that is up-to-date, peer-reviewed, fully vetted, published and documented. This is because national and international statistics come out with a lag and the GTAP database is not regularly updated. The newest GTAP-E database depicts the base year 2014 and was released in spring 2020. So researchers have to start with 'out of date' data which they then need to update themselves. Using the data from 2014, we built the baseline based on GDP, population and emissions projections. The 2014 structure of the economy is generally preserved in the projection. Hence, structural changes in the composition of trade and production of the different economic activities in the model after 2014 are not explicitly accounted for in these baseline projections. Important structural changes which are not represented explicitly in the baseline projections include change in natural gas trade. A particular example here is the Netherlands: the changes in the composition of the Dutch economy and trade flows as a consequence of lower domestic natural gas exploration is unlikely to be captured – (the Netherlands shifted from a net exporter of natural gas in 2014 to a net importer in 2018).

Moreover, the model is only directly linked to CO_2 emissions from burning fossil fuels. Linking the GTAP-E to the non-CO_2 database to account for other emissions (e.g. methane or nitrous oxide) is a complex exercise and, due to time constraints, is beyond the scope of this report. Therefore, agricultural emissions remain largely unaccounted for in the quantitative analysis. The same applies for CO_2 emissions which stem from industrial processes.

Some constraints are related to the data we use to build our baseline. The emission reductions projected by the UN are based on all GHG emissions. By using the same change rates for CO_2 fuel combustion emissions we assume that the relative emission reductions in CO_2 from combustion of fossil fuels must be same as the relative reduction of all GHG emissions projected by the 2019 UNEP Emission Gap Report.

Due to the simplifications and constraints described above, the outcome of our simulations should be interpreted carefully. Moreover, the focus of the outcomes is not on forecasting but on the relative changes compared to the Business-as-Usual 2030 baseline. The model should not be used to forecast level or growth rates of the main macroeconomic variables.

Model outcome and interpretation

In this section we report on the results of the GTAP model calculations. We apply two different carbon tax shocks, namely USD 100 and USD 150, to three regions: (1) the Netherlands, (2) the EU, EFTA and the UK (which we will call EU+) and (3) the EU, EFTA, UK as well as the USA, China, Canada, Japan, Australia and Rest of Oceania (which we will call ALL-). This results in 6 scenarios that we run: CT100NL, CT100EU+, CT100ALL-, CT150NL, CT150EU+ and CT150ALL-. To assess the economic impact of the carbon tax we look at the impact on country real GDP, on output in specific sectors, and on exports.

Different taxes, similar relative impacts. We note that across the board the impact of a 50% higher carbon tax (USD 150 compared to USD 100) leads to roughly 50% larger economic impacts. This is the case for most countries when the tax is introduced only in NL or in the EU+ region. When the higher tax is also imposed outside EU+ we see many outliers: among them Denmark, Greece and

New Zealand (Rest of Oceania) see disproportionally stronger impacts in the CT150ALL- scenario compared to the CT100ALL- scenario. In contrast, for Poland the impact decreases in the switch between the two scenarios. The relative impact – which countries or sectors are affected most – remains unchanged.

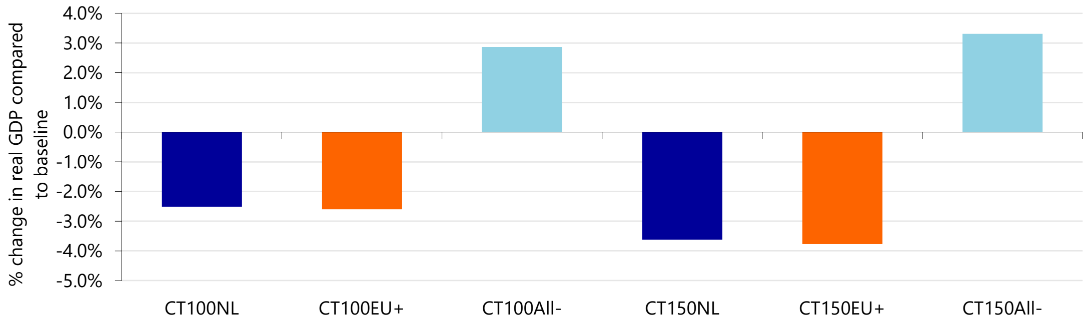
Impact on the Netherlands, a detailed analysis

Macroeconomic effects of different carbon tax scenarios

A CO_2 tax implemented in the Netherlands alone decreases real GDP compared to the baseline. The focus of this study is the Netherlands, so we start with the outcome of the CT100NL and CT150NL scenarios, in which the carbon tax is only introduced by the Netherlands. The model simulations show that under a carbon tax of USD 100, real GDP would be 2.5% lower than in a 2030 baseline without a carbon tax (Figure 1; Figure 2). If the tax was USD 150, real GDP would be 3.6% lower than in the 2030 baseline. While the comparison to the historic impacts in terms of year-on-year changes is not the same as a difference to a baseline (affecting potential GDP, not just the economic growth in one year), it is interesting to see that the impact on the Netherlands even in the more stringent USD 150 tax scenario is not more than the initial impact of Covid-19 on GDP, which was a 3.7% fall in GDP in 2020 (OECD 2021).

If the carbon tax is introduced in the EU+ region, the Dutch economy suffers roughly as much as when only the Netherlands introduces a carbon tax. The outcomes in terms of aggregate macroeconomic impacts for the Netherlands are not significantly different whether the tax is imposed only on the Netherlands or on the whole of the European Union (EU+), as illustrated in Figure 1. The real GDP decrease (compared to the baseline) for the Netherlands in the CT100NL scenario is about 2.5%, and only slightly higher (2.6%) when the carbon tax is imposed on the whole of the EU+ (CT100EU).

Figure 1: Impact of a carbon tax on Dutch real GDP in % changes compared to the 2030 baseline

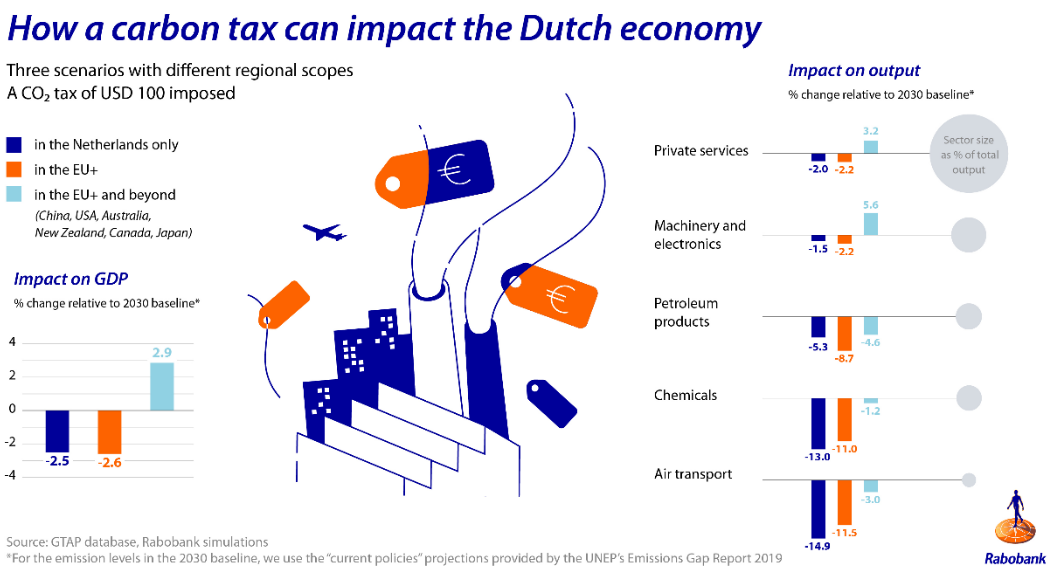


Source: GTAP database, Rabobank simulations

Changes in Dutch exports indicate that general equilibrium effects lead to similar outcomes for the Netherlands if it is taxed alone or as part of the whole EU+ region. If a carbon tax is implemented only on the Dutch national level, one would expect the Netherlands to suffer more due to its loss in competitiveness compared to other EU+ countries. In other words, one might expect a more favourable outcome for the Netherlands in a scenario when the tax is imposed at EU+ level (see e.g. Hebbink et al. 2018). Yet, the outcomes of our analysis suggest that this effect is outweighed by second round (general equilibrium) effects. In fact, total exports from the Netherlands decline by more compared to the baseline, if the tax is also imposed on the whole of the EU+ compared to only taxing CO_2 in the Netherlands (see Table 1 below). This is a result of lower demand for Dutch exports from other EU+ regions: since the introduction of a carbon tax leads to lower GDP compared to the baseline in all these regions, their demand for Dutch exports also decreases. Thus, while the Netherlands might indeed regain some of its competitive advantage with respect to exports to non-EU countries (indicated by a slight increase in Dutch exports to non-EU+ countries when going from the CT100NL to CT100EU+ scenario), the Netherlands would presumably suffer from lower demand for exports from EU+ countries. In other words, the competitive advantage gained outside the EU+ is offset by the decrease in demand for Dutch exports from EU+ regions. Moreover, the introduction of a carbon tax in the EU+ might put additional pressure on the Netherlands through increased input prices for imports from EU+ partners.

The Netherlands gains from a carbon tax introduced beyond the borders of the European Union. When the carbon tax is introduced in the major economies beyond Europe, real GDP in the Netherlands increases by 2.9% under the USD 100 carbon tax and by 3.3% under the USD 150 tax compared to the 2030 baseline. In this scenario exports from the Netherlands increase by 1% above the baseline level (Table 1). This is likely because the tax would increase the competitiveness of the Netherlands compared to the taxed non-EU+ regions (i.e. the additional regions taxed in the CT100All-/CT150All- compared to the EU+ scenarios). In fact, the regions outside of EU+ which are taxed in this scenario are more carbon intensive in the 2030 baseline than the Netherlands.

Figure 2a: Impact of a carbon tax on the Netherlands



Note: This illustration shows the impact on real GDP and on the output of selected sectors in the Netherlands relative to the 2030 baseline. Disaggregation of the sectors illustrates the variation of the impacts per sector, both in strength and direction, which cannot be seen on the aggregate macro level.
Source: GTAP database, Rabobank simulations

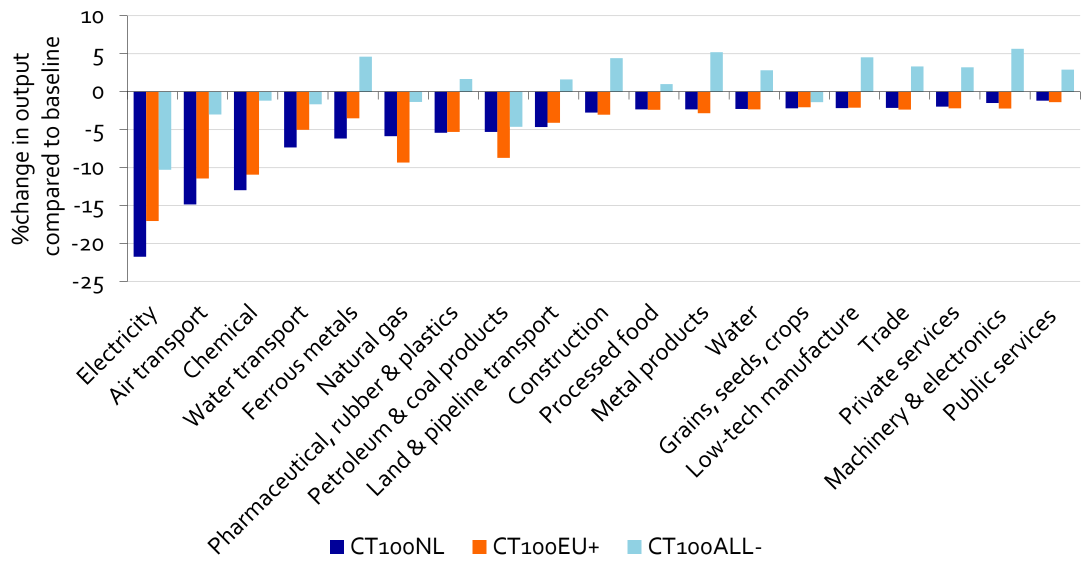
Winners and losers in the Netherlands - A sectoral dimension of the Dutch impact

The most impacted sectors are either CO_2 intensive themselves or use a large share of carbon-intensive intermediate inputs. We observe the strongest impacts in the electricity sector (Figure 2b). As the energy mix in the model is relatively fixed (i.e. the technology mix represented in the 2014 data cannot significantly change endogenously as substitution to renewables is not possible in the model), this outcome should be interpreted carefully; in reality the negative impact on the electricity sector would be softened somewhat by a switch to renewable power. The Dutch air transport sector experiences a strong decline in output compared to the baseline in all scenarios due to its high carbon intensity (here also a switch to less carbon-intensive fuels will be much more difficult in reality as the aviation sector is among the most challenging sectors to reduce emissions (IEA, 2020)). While the chemical sector has comparatively high direct CO_2 emissions, this alone cannot explain the strong impact of the tax in all scenarios. In fact, a further reason for the strong impacts on the chemical sector is the high portion of CO_2 intensive intermediate inputs - among them high inputs from the petroleum products sector, natural gas sector and power production.

The impact on some of the largest sectors is comparatively small and becomes more pronounced when the tax is also imposed on the other EU+ regions. The service sector (private and public services), which is one of the largest sectors in the Netherlands, experiences only a modest fall in output compared to the baseline when the tax is introduced in the Netherlands. In this scenario we find a decline in output of around 2-3% compared to the 2030 baseline (Figure 2a; Figure 2b). Moreover, it is interesting to observe that some of the largest sectors (service sectors, construction, trade, processed food, and machinery and electronics) experience stronger negative impacts on output when the tax is also imposed on the EU+ neighbours than when the Netherlands acts alone. In other words, these sectors lose more in output compared to the baseline when the tax is also imposed on the EU+ neighbours. Together with a stronger decline in exports relative to the baseline in these sectors in the CT100EU+ scenario, this reflects the offsetting negative effects due to lower demand for Dutch exports from EU+ countries that is observed on the macro-level as well.

Extending the carbon price to the whole of the EU+ region can be alleviating for some sectors but not for all. For the top 3 impacted sectors (i.e. electricity, air transport, chemicals) the output decline compared to the baseline when the carbon tax is imposed on all EU+ regions is significantly less severe than when the tax is imposed in the Netherlands alone. However, as discussed in the previous paragraph, some sectors are also hit more strongly in this scenario (Figure 2a; Figure 2b). Nevertheless, this shows that on the sectoral level, it *does* make a difference for some sectors whether the tax is introduced in the Netherlands only or beyond.

Figure 2b: Impacts on Dutch sectors by a CO2 tax of USD 100 /tCO2 (only sectors with share in output ≥ 0.5% are shown)



Source: GTAP database, Rabobank simulations

A carbon tax on all major economies comes with benefits for some Dutch sectors. While the chemicals, electricity (with the caveat of no renewable-substitution options) and air transport sectors experience a decrease in their output compared to the baseline under all tax regimes (Figure 2a; Figure 2b), the negative impact on their output is alleviated further if the tax is further extended beyond the borders of the EU+ in the CT100All-/CT150All- scenarios. Other sectors that see lower output under a Dutch or EU+-wide carbon tax, may experience an increase in output compared to the baseline when the carbon tax is extended to major economies outside EU+. Interestingly, we see output increases in some of the largest sectors (service sectors, construction, trade, and machinery and electronics) of around 3% to almost 6% compared to the 2030 baseline.

These sectors also export more compared to baseline, reflecting the situation found on the macro-level for this scenario.

Impact on European countries

The macroeconomic picture

EU+ economies stand to lose if they remain the only region to introduce a carbon tax. All countries in the EU+ region see their economies shrink compared to the baseline in a scenario where the tax is only introduced there. Greece, Central Eastern European countries and the Netherlands are most impacted in such a scenario (Table 2). The GDP decline (compared to the baseline) for the top 3 most impacted countries (Greece, Poland and the Czech Republic) is much stronger than in most other countries. This is not surprising as these three countries are also the most emission-intense economies in the EU+. The group of least impacted regions is Sweden, France and EFTA. These regions are also characterized by low emission intensity in the baseline.

Trade is also negatively affected across the board among the EU+ countries when the carbon tax is applied only there. Table 1 shows the impacts on aggregate exports for all scenarios. The 3 countries where exports decline most compared to the baseline are Greece (-20%), Portugal (-4.6%) and the Czech Republic (-4.6%). However, the differences between the latter two and the rest of the countries in the EU+ is fairly small, as most countries see exports contracting by 3 to 5% compared to the baseline.

Table 1: % changes in aggregate exports per region compared to baseline 2030

	CT100NL	CT100EU+	CT100ALL-	CT150NL	CT150EU+	CT150ALL-
Greece	0.11	-19.99	-14.81	0.16	-26.34	-20.19
Portugal	-0.02	-4.58	-0.54	-0.03	-6.45	-1.26
CzechRep	-0.04	-4.58	1.51	-0.06	-6.40	1.46
Poland	-0.04	-4.55	0.28	-0.05	-6.44	-0.25
Finland	-0.03	-4.46	-1.92	-0.05	-6.28	-3.03
Netherlands	-3.73	-4.32	0.87	-5.28	-6.16	0.53
RestEU	-0.03	-4.18	0.94	-0.04	-5.96	0.61
Italy	-0.01	-4.14	-0.38	-0.01	-5.86	-1.02
Spain	-0.01	-4.01	-1.96	-0.01	-5.63	-3.01
Hungary	-0.02	-3.81	1.06	-0.03	-5.45	0.87
Belgium	-0.25	-3.79	0.63	-0.34	-5.41	0.27
Romania	-0.02	-3.69	2.88	-0.03	-5.29	3.24
Germany	-0.05	-3.32	-0.84	-0.07	-4.66	-1.47
France	-0.02	-3.24	-1.37	-0.03	-4.57	-2.16
Austria	0.00	-3.20	0.36	0.00	-4.54	0.05
Denmark	0.00	-2.64	-0.80	0.00	-3.75	-1.39
UK	-0.05	-2.57	-0.04	-0.08	-3.64	-0.39
Sweden	-0.01	-1.95	0.35	-0.01	-2.80	0.19
Ireland	0.02	-1.59	2.92	0.03	-2.28	3.57
EFTA	0.01	-1.04	1.19	0.01	-1.48	1.45
Russia	-0.05	-0.57	0.96	-0.07	-0.78	1.17
SaudiArabia	-0.01	-0.15	1.14	-0.02	-0.21	1.51
Turkey	-0.03	-0.10	6.17	-0.04	-0.14	8.14
CHG	-0.01	-0.07	-3.47	-0.01	-0.10	-5.32
Iran	-0.02	-0.07	1.99	-0.02	-0.09	2.46
USA	-0.01	-0.06	1.17	-0.02	-0.08	0.40
Brazil	-0.01	-0.04	0.43	-0.01	-0.06	0.53
Australia	0.00	-0.03	-0.29	0.00	-0.03	-0.98
SouthAfrica	-0.03	-0.03	3.71	-0.04	-0.03	4.88
ROW	-0.02	0.03	3.01	-0.02	0.04	4.00
Indonesia	-0.01	0.05	1.16	-0.01	0.06	1.39
India	0.01	0.06	0.80	0.01	0.09	1.07
Japan	-0.01	0.11	-4.02	-0.01	0.15	-5.91
Canada	0.00	0.13	2.00	0.00	0.18	1.09
RestAM	-0.01	0.15	2.00	-0.01	0.23	2.63
RestOceania	0.00	0.18	-3.74	0.00	0.26	-5.16
Mexico	-0.01	0.21	4.48	-0.02	0.29	5.79
RestEurope	0.03	0.21	3.42	0.04	0.32	4.61
RestAsia	-0.01	0.23	3.43	-0.02	0.32	4.53
Korea	0.00	0.25	-4.99	-0.01	0.36	-7.12

Note: Numbers highlighted orange indicate lower exports compared to the baseline, numbers highlighted blue indicate higher exports compared to the baseline. The shading of both colours indicates the strength of the deviation to the baseline.
Source: GTAP database, Rabobank simulations

Table 2: Real GDP impacts % changes compared to baseline 2030

	CT100NL	CT100EU+	CT100ALL-	CT150NL	CT150EU+	CT150ALL-
Greece	0.01	-6.39	-1.39	0.01	-9.14	-2.77
Poland	-0.02	-4.21	1.01	-0.04	-5.90	0.83
CzechRep	-0.04	-4.08	2.53	-0.06	-5.70	2.86
Romania	-0.03	-2.64	4.04	-0.05	-3.86	4.89
Netherlands	-2.51	-2.60	2.86	-3.62	-3.77	3.31
Hungary	-0.02	-2.59	1.85	-0.03	-3.78	1.99
RestEU	-0.03	-2.54	2.36	-0.05	-3.71	2.63
Italy	-0.02	-2.49	2.13	-0.02	-3.61	2.40
Portugal	-0.02	-2.21	2.01	-0.03	-3.24	2.27
Finland	-0.01	-2.18	0.27	-0.02	-3.17	0.00
Germany	-0.01	-2.06	0.37	-0.02	-2.96	0.19
Belgium	-0.14	-1.84	2.53	-0.20	-2.73	2.93
Austria	-0.01	-1.67	1.65	-0.02	-2.43	1.87
Denmark	-0.01	-1.46	-0.05	-0.02	-2.09	-0.28
UK	-0.01	-1.41	1.10	-0.02	-2.08	1.18
Spain	-0.01	-1.34	1.70	-0.01	-1.98	1.99
Ireland	0.01	-1.26	2.55	0.01	-1.87	3.08
EFTA	-0.03	-1.26	0.90	-0.05	-1.81	0.99
France	0.00	-1.03	1.07	-0.01	-1.53	1.21
Sweden	-0.01	-0.72	1.46	-0.01	-1.07	1.78
Russia	-0.05	-0.47	1.83	-0.07	-0.65	2.33
ROW	-0.02	-0.13	2.50	-0.03	-0.17	3.24
SaudiArabia	-0.02	-0.10	2.09	-0.02	-0.14	2.74
Iran	-0.03	-0.07	3.59	-0.04	-0.11	4.63
Canada	-0.01	-0.01	-1.82	-0.01	-0.01	-2.85
RestAM	-0.02	0.01	2.61	-0.03	0.02	3.43
Indonesia	-0.02	0.02	3.28	-0.02	0.03	3.97
Australia	-0.01	0.02	-1.01	-0.01	0.03	-1.69
USA	0.00	0.03	-1.28	0.00	0.04	-1.85
Mexico	-0.02	0.07	3.80	-0.03	0.10	4.85
Brazil	-0.01	0.08	2.33	-0.01	0.11	3.06
SouthAfrica	-0.02	0.08	3.44	-0.03	0.12	4.53
RestOceania	-0.01	0.10	-0.49	-0.01	0.14	-1.11
CHG	-0.01	0.11	-5.52	-0.01	0.16	-7.65
RestAsia	-0.01	0.13	3.26	-0.02	0.17	4.28
RestEurope	0.00	0.15	2.74	0.00	0.21	3.64
India	0.00	0.16	2.26	0.00	0.23	3.01
Korea	-0.01	0.19	-1.24	-0.01	0.26	-2.17
Japan	0.00	0.23	0.38	-0.01	0.31	0.04
Turkey	-0.02	0.23	6.92	-0.03	0.32	9.19

Note: Numbers highlighted orange indicate lower real GDP compared to the baseline, numbers highlighted blue indicate higher real GDP compared to the baseline. The shading of both colours indicates the strength of the deviation to the baseline.
Source: GTAP database, Rabobank simulations

Winners and losers

In the EU+ scenario Greece suffers by far the biggest economic impact from a carbon tax out of all EU+ regions. The GDP of the Greek economy is estimated to be more than 6% lower compared to the baseline if the EU+ implements a carbon tax of USD 100 (Table 2). Exports are estimated to be

20% lower compared to the baseline. Again, this is not entirely surprising given the fact that Greece has the most emission-intense economy in the EU+ in the 2030 baseline (though Greece does score 'average' on the share of renewables in energy consumption).

While in Poland and the Czech Republic only 2-3 small sectors see a double-digit reduction in output compared to the baseline, in Greece the number of sectors is 10 and some are bigger in size compared to the total economy, namely water transportation (3% of total output in size; output reduces by 39% compared to the baseline) and petroleum & coal products (4% of total output; output declines by 20% compared to the baseline - probably linked to Greek refineries). On top of that, the coal extraction and other metals sectors, though small in size, see output fall compared to the baseline by a staggering 58% and 50%, respectively. Finally, a couple of large sectors also register a decline in output relative to the baseline, though less than for the sectors mentioned above: trade accounts for 7% of output and its output is 6% lower compared to the baseline in 2030, while private services (includes tourism) accounts for 21% of the economy and its output declines by 5% compared to the baseline. Against this background perhaps it was only logical that Greece proposed a carbon-price funded hedging mechanism to limit the impact of soaring fossil fuel prices on consumers and companies (see Bloomberg 2021) in September 2021.

Most EU countries are expected to gain from a broader carbon tax. Most EU+ countries see an increase in real GDP compared to the baseline in a scenario where the carbon tax is implemented outside the EU+ borders. The only exceptions are Denmark and Greece. In this scenario, not only would Greece's economy still be negatively impacted, it would also still be the third most heavily impacted economy in the world. Nevertheless, the impact on Greece is much less pronounced than under a tax regime that applies only to EU+ regions.

The sectoral perspective

From a sectoral perspective we see the usual suspects lining up for the highest impact, namely coal and natural gas extraction, electricity, air transportation, petroleum and coal products, chemicals, and water transportation. Often, these sectors see a double-digit decline of output (compared to the baseline) in the scenario where the tax is imposed on the EU+ region but not beyond. While for some sectors this double-digit decline of output is visible in most regions across the board in the EU+, for others the size of the impact is country-specific. While generally the coal sector is shrinking in size compared to the baseline, it is still a sector of relevance to the economies of Germany, Greece, Poland, Romania and the Czech Republic, (though the size is lower than 1% of output in all countries). Again, the natural gas sector sees substantial losses relative to the baseline, but is nonetheless relevant in Denmark, EFTA, and the UK. (For Hungary, the Netherlands and Romania, natural gas also plays a considerable role and the decline in output is just below 10% compared to the baseline). Big double-digit declines in output compared to the baseline are found in the chemicals sector in Greece, the Netherlands and Romania when a carbon tax is imposed on the EU+ region, while for EFTA, Sweden and Denmark the impact remains at less than 1% below the baseline. The decrease in output compared to the baseline of electricity and oil/petroleum products is particularly big in Greece. Water transportation impact is sizeable in Greece and Denmark. An outlier in the negative double-digit impact row is the other animal food sector in the Netherlands, which includes pork and poultry.

Some sectors in the EU will benefit, but these gains are small. The largest output increases are seen in electricity in Sweden (2% compared to the 2030 baseline in a USD 100 carbon tax scenario) and in EFTA (5% compared to the 2030 baseline in a USD 100 carbon tax scenario). This is likely a result of a combination of modelling dynamics and constraints: as mentioned before, the energy mix for electricity production in the model is relatively fixed to the structure of the base year (2014) as there is no explicit differentiation of electricity production based on renewables and fossil fuels. Substitution between technologies within the power sector is therefore strongly restricted. As a consequence, the power sector in countries which have a high share of fossil fuels in the base year suffer comparatively strong output reductions compared to the baseline, while the power sectors of countries with a high share of renewable technologies may even gain due to higher demand from other regions for electricity. In fact, in the simulation exports of the electricity sector increase by more than 20% (relative to the 2030 baseline) for these regions.

Impact at the global level

The macroeconomic perspective

Most economies outside of the EU+ region see lower GDP compared to the baseline upon the implementation of a carbon tax (Table 2). The only exception is Japan, which registers a slightly higher real GDP relative to the 2030 baseline in this scenario. China, and Canada are the countries that experience the largest impact on GDP from a carbon tax implemented in these major global economies in scenario 3. The impact on the Chinese economy stands out as it is much larger than on the other countries where a tax was imposed in scenario 3. The Chinese economy is expected to decline by 5.5% compared to the baseline. From a policy perspective this means that China's incentives to implement a carbon price of this magnitude will have to be driven by domestic reasons. For instance, the fact that the economic costs of no climate mitigation measures could be larger. The second vintage of NGFS scenarios indicates that this is the case at the global level (see Presentation on NGFS scenarios dated June 2021, p 37). The only graph revealing the impact on the Chinese economy concerns unemployment and it indicates that China is indeed worst off in a current policies scenario (no further mitigation).

Sensitivity analysis

Impact on the Chinese economy similar even if India also applies a carbon tax. We note that our major economies scenario does not include the third largest emitter in the world, India, which accounts for roughly 11% of global CO_2 fossil fuel combustion emissions. We excluded India because the country does not have a track record of ambitious climate change policy, though it did announce a net-zero target for 2070 at COP26. To see whether the impact on China would change if India joined the carbon taxation club, we did a sensitivity analysis by running an additional major economies scenario that also includes India. We see that in this scenario India becomes the economy that shrinks most (7% lower real GDP compared to the baseline), but we also see that the Chinese real GDP is still lower by almost 5% compared to the baseline in 2030 and that there is no significant change in the impact on other countries outside of the EU+ group. Hence, we note that from a real GDP-impact perspective India's participation does not affect the outcome of other countries, so they could decide to implement a carbon tax irrespective of India's participation.

Sensitivity analysis on the past impact of the EU ETS: We note that the relative economic impact could be influenced if the EU ETS pricing is also included in the simulations. To get an idea of how much the results could change we carried out a sensitivity analysis by applying a USD 150 carbon tax to the EU+ countries (who currently participate in the EU ETS, or, in the case of the UK, have an equivalent ETS) and a USD 100 carbon tax to the other major economies; the difference is roughly the average EU ETS prices over the year 2021. The results show that higher carbon taxation in the EU+ does not alter the results dramatically: the Chinese economy still sees lower GDP, roughly 5% compared to the baseline; the top 5 of countries suffering most economic damage remains the same; non-EU+ countries implementing a carbon tax witness an economic loss compared to the baseline; most EU+ countries benefit, though this time Poland, Germany and Finland experience a slight GDP decline compared to the baseline (<1%). The actual impact will be somewhere in between the scenario with a uniform carbon tax and the one with a higher tax for the EU+ countries since various sectors in the EU ETS system currently get the lion share of their allowances for free, so not all emissions are currently priced in. Moreover, the baseline projections rely on numbers that include the impact of the EU ETS as it was anticipated in 2019.

The sectoral dimension

Higher sectoral impacts are concentrated in a few energy-intense sectors. Double-digit declines in output compared to the baseline are concentrated in the coal, natural gas, electricity and transportation sectors. Output in other metals is also lower compared to the baseline with the biggest difference in Greece and Ireland, while chemicals sees the biggest negative difference compared to the baseline in China and rest of Oceania (New Zealand). Most sectors falling in this high-impact category are small in size compared to the country output, which is why the impact at the macro level is contained.

No sector is seeing a negative impact on output across the board. Most sectors see lower output relative to the baseline in some parts of the world and higher output in others. Even sectors with negative impacts on output in a higher number of countries, such as natural gas, show an output increase compared to the baseline in some countries such as Russia and Saudi Arabia (Note, however, that no carbon price is imposed on Russia and Saudi Arabia).

Winners

A more broadly applied carbon tax also benefits some economies. At the country level Turkey, Romania and Mexico are estimated to benefit most if a carbon tax is introduced beyond EU+ regions (i.e. EU+ and USA, China, Canada, Japan, Australia and Rest of Oceania). At the sectoral level it is energy-intense sectors that benefit – chemicals, other metals, ferrous metals, electricity - in countries that do not implement a carbon tax, such as Saudi Arabia. Interestingly, Romania and the EFTA see a double-digit increase compared to the baseline in the output of other metals and of electricity, respectively, even though they implement a carbon tax. The latter can be attributed to the fact that the energy mix in power generation of the EFTA regions is low in carbon intensity (i.e. high shares of renewables and nuclear).

The bigger picture

Although global economic pains are modest, that masks large impacts on some countries and even more so on particular sectors. World GDP is fairly unaffected by a CO_2 tax in all scenarios. However, there are countries that do register a sizeable negative impact on their economies compared to the baseline, especially when considering that the impact is structural in nature (affecting potential GDP, not just the economic growth in one year). The difference to the baseline in GDP of the Dutch economy in a Dutch and EU+ scenario is comparable in size to the contraction in GDP seen under the Great Financial Crisis (GFC) of 2007/8 (Erken et al, 2020). For the U.S. the impact (compared to the baseline) is smaller than during the GFC, but similar to the energy crisis (1974-1975) or the 80's recession. For most countries the impact is smaller than the one seen during the economic turbulence triggered by the Covid-19 pandemic. China is one of the exceptions though. The country has weathered both the GFC (Erken, 2016) and the Covid-19 pandemic (Erken et al, 2020) without an economic contraction. A USD 100 CO_2 tax would however shave around 5% off its economy compared to the baseline and would do so structurally.

On top of aggregate country impacts, sectoral impacts are in some cases even more pronounced. As expected, country impacts do not capture the full impact of a carbon tax, which has both winners and losers at the sector level. As highlighted in the analysis above, there are quite some sectors that register a double-digit reduction of output compared to their output in the 2030 baseline. Outliers are coal in China and Greece which see output fall by 55% in a CT100ALL-scenario, compared to the 2030 baseline. Coal sees a fall in output of 40-50% compared to the 2030 baseline in several countries (Czech Republic, Romania, Poland) in both a CT100EU+ and a CT100ALL- scenario. Natural gas sees similar negative impacts in a few countries, as does other metals in Greece.

Model set up does not capture possible gains. The projected economic impacts are strongly negative as the model does not capture the mechanisms that could lead to economic gains. The simulation is important because, compared to existing studies, it brings a sectoral dimension that considers substitution effects and other trade and economic dynamics. However, there are limitations that bias the results towards capturing the negative effects. First, the model does not distinguish between fossil fuel and renewable production within sectors (in particular in the power sector) and thus cannot simulate substitution towards these technologies induced by the carbon tax. Hence, it does not allow for the economy to rebalance towards a larger renewables sector when renewables become cheaper. Secondly, the tax scenarios do not allow for endogenous technological change and hence do not capture the impact that a carbon tax is expected to have on inducing more innovation in low-carbon technologies. Thirdly, the model does not allow us to actively steer the expenditure of receipts from the carbon tax (see Main limitations of the model). The second vintage of NGFS scenarios (see Presentation on NGFS scenarios dated June 2021, p. 39) indicates that the economic impact of a net-zero scenario is very sensitive to the fiscal options. Choosing to recycle carbon tax receipts into government investment could actually lead to positive economic impacts of roughly 3% in 2030, compared to negative impacts of roughly 2.5% of GDP in the same year if the receipts were used for an employment tax cut or debt pay down. Finally, it should be noted that the most important gains – namely the gain of avoiding severe climate damage that come with no action – are not accounted for in the model simulation.

Comparison to other studies

There is a large, mostly theoretical, body of literature on the economic effects of carbon prices. We focus on publications which relate to the Dutch/EU context. It must be noted that comparability to our study is limited - among other things due to differences in study design, modelling frameworks, economic indicators analysed. Also, sectoral and regional foci or disaggregation levels, the magnitude of the carbon price shocks as well as the coverage of greenhouse gases differ. Nevertheless, since they all look at the impact of carbon taxes within the Netherlands it is interesting to roughly compare similarities and differences in outcomes.

Schotten et al. (2021) use an Input-Output model to analyse the impact of a EUR 50 /t carbon tax on (among others) production costs in the EU. (In comparison to CGE models, Input-Output models assume no price effects, thus substitution between products and production factors is not taken into account). They look at the impact of taxing all sectors and at the impact of taxing extended ETS sectors. In the extended ETS sector scenario, the carbon tax is applied to the manufacturing, energy and transportation sectors. As only the impact of taxing extended ETS sectors are shown in detail, results can be compared to this scenario only. Similar to what is observed in our study, they also find strong variations in impacts between countries and sectors. In the country breakdown of their results, it can be seen that Greece, the Czech Republic, Poland and Romania are also among the countries that experience comparatively strong impacts. Also, central eastern European (CEE) countries are generally hit harder than EU14 countries. However, while the impact on Greece is striking within the group of EU 14 countries in their study too, they find even stronger impacts on CEE countries (in particular, Bulgaria, Czech Republic and Poland).

Bollen et al. (2020) investigate the impact of a CO_2 tax of EUR 100 /tCO_2 and EUR 200 /tCO_2 on top of the EU ETS price using the CGE model WorldScan. They focus on the impacts in the Netherlands for the three most emission-intensive industry sectors (chemicals, oil and basic metal production). Aside from varying carbon tax levels, they also vary the way carbon tax revenues are re-used in the economy by either distributing them to households or passing them back to industry by means of targeted subsidies. Depending on these two scenario settings (carbon tax level and tax-revenue recycling mode), they estimate production losses of around 2-5% for these 3 industry sectors as a whole in 2030. The basic metals sector is hit hardest (up to 12% depending on the scenario settings) in terms of production losses compared to the other two sectors in all scenarios, followed by the chemical sector and oil products sector. In contrast to this, out of the three sectors our study finds the impact of a EUR 100 /tCO_2 carbon tax to be most severe on the chemical sector, followed by the petroleum products and then metal sector.

Hebbink et al. (2018) estimate how a carbon tax of EUR 50 (applying to all GHG emissions) imposed on the Dutch economy and on the whole of the EU, impacts sector-level sales prices. They first use a variable Input-Output model extended by substitution effects between production factors to calculate the price impacts of the tax. Moreover, they enrich the analysis by using elasticities for domestic and export demand to calculate the impact on sales in the Netherlands.

On the sector level, some results turn out similar, while for other sectors we find different results than Hebbink et al. (2018). Although a comparison to our study is hampered due to different aggregation of sectors, a rough comparison shows that they also find relatively strong negative impacts on sales in the chemical sector in the scenario where the carbon tax is introduced in the Netherlands only and in the scenario where the tax is introduced in the whole European Union. Moreover, they also see a somewhat less severe impact in this sector when the tax is imposed on the whole of the EU compared to introducing it in the Netherlands only. However, the impacts also differ compared to our study with respect to the results of other sectors. For example, they find negative impacts on the mining sector in the scenario where the tax is implemented only in the Netherlands, which changes to an increase in sales when the tax is introduced in the whole of the EU.

The impact on the overall Dutch economy is also less pronounced if the tax is introduced in the whole of the EU compared to introducing it only in the Netherlands. This is also different from our findings: the scenario where the tax is only imposed on the Netherlands shows very similar impacts for the Netherlands compared to the scenario where the tax is imposed on the whole of the EU. Among many differences to our study, Hebbink et al. (2018) used a model framework that does not account for second round (general equilibrium) effects. Thus, we expect that this difference to our study is due to using a CGE model which can take into account the decline in demand for Dutch exports from other (EU+) countries when the carbon tax is introduced there as well.

As part of the same study, Hebbink et al. (2018) also use a macroeconomic model to calculate the impact of a carbon tax imposed on the Dutch economy. They find that the impact on GDP is -0.9% - +0.5% depending on how the tax revenues are used in the model. In any of these scenarios this is less pronounced than what we calculated with the GTAP-E model in our study (i.e. -2.5% compared to the 2030 baseline in the scenario where the tax is imposed on the Netherlands only). Multiple differences between the modelling approaches and design of the research can account for this difference. Aside from our study's assumption of a carbon price almost twice as high as Hebbink et al. (2018), the fact that the energy mix in our model is relatively fixed to the 2014 base year (due to the lack of substitution to renewable technologies) can be a source for overestimation of impacts. On the other hand, our study does not cover all GHGs, which skews the impacts downwards compared to the study by Hebbink et al. (2018), which covers all greenhouse gas (GHG) emissions.

Bollen et al. (2019) use the general equilibrium model WorldScan to analyses the impact of different emission policy regimes for the Netherlands that all reach the same emission reduction in 2030 (46% compared to 1990 levels). The impacts of these different policy schemes are compared to a reference scenario which also reaches 46% emission reductions in 2030. They show the impact of each policy scheme on different sectors in the Netherlands as well as at the macroeconomic level. They find that the impact of a uniform CO_2 price leads to the most favourable welfare effects. Moreover, they show that recycling tax revenue via subsidies leads to better GDP results than recycling tax revenues as a lump sum payment to households.

Conclusions and recommendations

In this study we found that the impacts on Dutch real GDP are similar whether the CO_2 tax is introduced in the Netherlands only or in the whole of EU+ region. This is an important addition to the study by Hebbink et al. (2018). Thus, accounting for general equilibrium effects can be crucial to estimate the impacts of different carbon tax scenarios for countries that are highly interlinked by trade relations.

EU+ countries all experience negative impacts if the rest of the world does not follow. All EU+ regions see real GDP decline compared to the 2030 baseline if the tax is only introduced in this region (i.e. EU+ UK+ EFTA). At the top of the most impacted regions is Greece and the country with the least impact in this scenario is Sweden.

The Netherlands and most EU+ regions benefit from the introduction of a carbon tax in major economies beyond the EU+. However, this comes with mostly negative impacts on major economies outside the EU+ region that implement a carbon tax. Overall Dutch real GDP is higher compared to the baseline if a carbon tax is introduced beyond the borders of the EU+ region. In this scenario real GDP in most EU+ countries is actually higher than in the baseline. However, Greece is highly (negatively) impacted in both scenarios. Countries outside the EU+ that adopt a carbon tax stand to lose, with the exception of Japan. The Chinese economy witnesses the largest decline in real GDP compared to the baseline in such a scenario. But no mitigation is likely to have even higher costs and that is likely to be the driver of carbon pricing in China.

On the sector level, we see that impacts vary strongly depending on sector and scenario. Both in the EU+ and the broader carbon tax scenario we notice that emission-intense sectors such as natural gas and electricity are most negatively impacted in countries that adopt a tax, while in countries that do not adopt a tax it is also emission-intense sectors that gain in output compared to the baseline. Nevertheless, a gain is also found for the electricity sector in countries with a high share of renewable power (EFTA and Sweden) if the carbon tax is imposed on EU+ level only. If the carbon tax is introduced beyond the EU+, each EU+ region has some positive impacts in some sectors.

This study showed again that country-level impacts can mask large sectoral impacts and thus that it is important to also analyse these underlying sector-level changes. Overall, we note that the economic impact can be significant for some countries and sectors. However, the macro level does not reflect large impacts at the sector level as there can be offsetting effects on the sector or disaggregated regional level. Hence, it is important for financial institutions and policy makers to carefully consider the variety of impacts on the sector level. For financial institutions this reveals where the biggest risks (and opportunities) may lie. For policy makers this shows where the most vulnerable sectors are for which additional measures might be necessary to mitigate negative economic impacts (for instance, by directing tax revenues to push additional technology developments).

While any modelling exercises on this regional and sectoral scale are surrounded by limitations and uncertainties, they can be useful for the financial sector and policy makers to gain insights into possible impacts of carbon pricing. Nevertheless, it should be kept in mind that some of the limitations listed below may have skewed the outcomes upwards (e.g. no possibility to substitute away to renewable technologies; not steering the recycling of the carbon tax receipts, for example to use as subsidies in industry); other limitations listed may skew the outcomes downwards (e.g. not including all GHGs from all anthropogenic sources). To refine and enhance insights, additional research should be undertaken to addresses some of the limitations of this study, namely:

- Explicitly include current emission trading schemes. The interactions between ETS and carbon taxes are more complex to model, but this is possible and would bring the results closer to reality.
- Include all greenhouse gases. In this analysis we have only looked at the impact of taxing CO_2 from combustion of fossil fuels. The GTAP database does provide databases that include other

GHGs. Taxing other GHGs (and thereby all industrial processes and emissions) would lead to more accurate estimates of the carbon tax impact. This is possible in the GTAP model, but the data and modelling tasks required went beyond the scope of this project.

- Simulate a gradual implementation. Since the GTAP model moves from one equilibrium to the other, it cannot be used to simulate a gradual transition nor does it capture short-term effects. The model can be adjusted to capture economic stickiness and allow for these dimensions to be estimated.
- Include possibility to substitute to renewables and endogenous (or exogenous) technological change. Such a feature would allow for higher carbon prices to push investments towards lower carbon technologies and would stimulate companies to invest in new, more efficient solutions. This could also translate to more economic benefits in some sectors.
- Steer the recycling of the carbon tax receipt. Being able to steer the fiscal receipt from carbon taxation can make a big difference for the economic impact, as also indicated by the second vintage of NGFS scenarios (NGFS scenarios presentation, page 39) and in the research by Bollen et al. (2019). Hence, it is important to include these options in future research.

TECHNICAL ADDENDUM

Appendix I. A brief introduction into the GTAP-E model

The GTAP-E model is a Computable General Equilibrium (CGE) model. CGE models were developed in the 1970s by applied trade economists. From the 1990s onwards, such models have been commonly used by international organisations, such as the World Bank, the UN, the WTO, the European Commission, and by large research institutes, such as the CEPII, to analyse the effects of taxes and tariffs on trade relations and on economic activity. CGE models are widely used to provide advice and assessments of economic policy. In agricultural, climate and energy economics they are a mainstream tool.

A CGE framework has three key features:

- The model describes economic activity and behaviour, i.e. demand, supply, trade, government and balancing identities;
- The underlying (global) database is balanced (clears out) and internally consistent, e.g. using multi-regional input-output tables;
- There is a set of parameters that drive responses of agents to any given perturbation or shock towards the initial equilibrium; these parameters can be trade elasticities, production function parameters or labour supply elasticities.

The standard GTAP model, where GTAP is an abbreviation from 'Global Trade Analysis Project', is such a CGE model. In addition to the economic equations and economic parameters, the centrepiece of GTAP is a worldwide database, so called input-output tables, in which bilateral trade patterns, production, consumption and intermediary demand of products, services and resources are described. The GTAP database differentiates between 65 economic sectors and 121 countries and regions.

Just like other CGEs, the GTAP model can be used to analyse the effects of taxes and tariffs. To that end, one first needs to estimate a baseline, i.e. a scenario of how the economy develops without the policies whose effect one wants to assess. Then one needs to shock the economy, i.e. introduce the policy change of interest. To assess the impact of this policy we look at the model outcome and focus the analysis on the percentage change of variables of interest, such as GDP or welfare, as a result of the policy shock compared to the baseline. The levels (nominal values) of these variables are not relevant for the scope of this analysis and cannot be interpreted as a precise prediction. It is the predicted percentage change in outcome variables which gives a decent indication of the effect of the shock.

In the standard GTAP model, energy substitution is not possible. The GTAP-E model, an alternative version of the standard model, in contrast, accounts for energy substitution. Furthermore, it accounts for CO_2 emissions from the combustion of fossil fuels, which is essential for our analysis. This framework makes it possible for us assess the impact of the energy transition, which is the focus of this study.

Unfortunately, the GTAP-E model also knows some limitations. It does not directly account for non-CO_2 emissions and process related CO_2 emissions. (There are special versions that do include these emissions, but time and resources constraints did not make it possible to include them in this analysis). GTAP-E also does not allow us to model specific ways in which the government could recycle the carbon tax income nor does it allow for modelling a gradual introduction of a carbon tax.

Appendix II: Technical specifications model

Geographical aggregation

The geographical aggregation reflects the regions of interest to the Working Group on Carbon Pricing members. We separated the biggest European countries, North American countries and the biggest emitters. According to the EDGAR - Emissions Database for Global Atmospheric Research, the following countries in Table AII.1 are the biggest CO2 emitters:

Table AII.1: Top 20 most emitting countries according to EDGAR - Emissions Database for Global Atmospheric Research

Rank	***Country***	***CO_2 emissions (total, in $GtCO_2$)***
1	China	11.30
2	USA	5.28
3	India	2.62
4	Russia	1.75
5	Japan	1.20
6	Germany	0.75
7	Iran	0.73
8	Korea	0.70
9	Saudi Arabia	0.63
10	Canada	0.59
11	Indonesia	0.56
12	Brazil	0.50
13	Mexico	0.50
14	South Africa	0.48
15	Turkey	0.42
16	Australia	0.42
17	United Kingdom	0.37
18	Italy	0.34
19	Poland	0.33
20	France	0.32

Source: https://edgar.jrc.ec.europa.eu/

The final country aggregation looks as follows (using GTAP regions and codes):

Number	Code	Aggregation	Description
1	AUS	Australia	Australia
2	NZL XOC	RestOceania	New Zealand Rest of Oceania
3	CHN HKG	CHG	China Hong Kong, Special Administrative Region of China
4	JPN	Japan	Japan
5	KOR	Korea	Korea, Republic of
6	IND	India	India
7	IDN	Indonesia	Indonesia
8	BRN KHM LAO MYS PHL SGP THA VNM XSE MNG TWN XEA BGD NPL PAK LKA XSA KAZ KGZ TJK XSU	RestAsia	Brunei Darussalam Cambodia Lao PDR Malaysia Philippines Singapore Thailand Vietnam Rest of Southeast Asia - Myanmar - Timor-Leste Mongolia Taiwan Rest of East Asia - Korea, Democratic People's Republic of - Macao, Special Administrative Region of China Bangladesh

	ARM AZE GEO		Nepal Pakistan Sri Lanka Rest of South Asia - Afghanistan - Bhutan - Maldives Kazakhstan Kyrgyztan Tajikistan Rest of Former Soviet Union - Turkmenistan - Uzbekistan Armenia Azerbaijan Georgia
9	CAN	Canada	Canada
10	USA	USA	United States of America
11	MEX	Mexico	Mexico
12	BRA	Brazil	Brazil
13	ARG XNA BOL CHL COL ECU PRY PER URY VEN XSM	RestAM	Argentina Rest of North America Bolivia Chile Colombia Ecuador Paraguay Peru Uruguay

	CRI GTM HND NIC PAN SLV XCA DOM JAM PRI TTO XCB		Venezuela (Bolivarian Republic of)
			Rest of South America - Falkland Islands (Malvinas) - French Guiana - Guyana - South Georgia and the South Sandwich Islands - Suriname
			Costa Rica
			Guatemala
			Honduras
			Nicaragua
			Panama
			El Salvador
			Rest of Central America
			Dominican Republic
			Jamaica
			Puerto Rico
			Trinidad and Tobago
			Rest of Caribbean
14	AUT	Austria	Austria
15	BEL	Belgium	Belgium
16	CZE	Czech Republic	Czech Republic
17	DNK	Denmark	Denmark
18	FIN	Finland	Finland
19	FRA	France	France
20	DEU	Germany	Germany
21	GRC	Greece	Greece
22	HUN	Hungary	Hungary

23	IRL	Ireland	Ireland
24	ITA	Italy	Italy
25	NLD	Netherlands	Netherlands
26	POL	Poland	Poland
27	PRT	Portugal	Portugal
28	ROU	Romania	Romania
29	ESP	Spain	Spain
30	SWE	Sweden	Sweden
31	BGR HRV CYP EST LVA LTU LUX MLT SVK SVN	RestEU	Bulgaria Croatia Cyprus Estonia Latvia Lithuania Luxemburg Malta Slovakia Slovenia
32	NOR CHE XEF	EFTA	Norway Switzerland Rest of European Free Trade Association Iceland Liechtenstein
33	GBR	United Kingdom	United Kingdom
34	RUS	Russia	Russian Federation
35	ALB BLR UKR	RestofEurope	Albania (ALB) Belarus (BLR) Ukraine

	XEE XER		Rest of Eastern Europe (XEE) Moldova Rest of Europe (XER) - Andorra - Bosnia and Herzegovina - Faroe Islands - Gibraltar - Guernsey - Holy See (Vatican City State) - Isle of Man - Jersey - Monaco - Montenegro - North Macedonia - San Marino - Serbia
36	IRN	Iran	Islamic Republic of Iran
37	TUR	Turkey	Turkey
38	SAU	Saudi Arabia	Saudi Arabia
39	ZAF	South Africa	South Africa
40	BHR ISR JOR KWT OMN QAT TUR ARE XWS EGY MAR TUN XNF BEN BFA	RoW	Bahrain Israel Jordan Kuwait Oman Qatar United Arab Emirates Rest of Western Asia - Iraq - Lebanon - Palestinian Territory, Occupied - Syrian Arab Republic (Syria) - Yemen

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- Algeria
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- Western Sahara</td></tr>
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<tr><td>Kenya</td></tr>
<tr><td>Madagascar</td></tr>
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<tr><td>Rwanda</td></tr>
<tr><td>Tanzania, United Republic of</td></tr>
<tr><td>Uganda</td></tr>
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			Zambia
			Zimbabwe
			Rest of Eastern Africa - Burundi - Comoros - Djibouti - Eritrea - Mayotte - Seychelles - Somalia - Sudan
			Botswana
			Namibia
			Rest of South African Customs Union - Eswatini - Lesotho
			Rest of the World - Antarctica- Bouvet Island - British Indian Ocean Territory - French Southern Territories

Sectoral aggregation

For the sectoral aggregation we looked to single out the most polluting sectors and the sectors of interest to the working group, similarly to the geographical aggregation.

The top-15 most polluting sectors in GTAP-E are:

Number	**Sector description**	**Sector code**	**Mtons CO_2 in 2014**
1	Electricity	46 ely	12637
2	Transport nec	52 otp	3253
3	Mineral products nec	36 nmm	1346
4	Air transport	54 atp	1271
5	Ferrous metals	37 i_s	1133
6	Petroleum, coal products	32 p_c	863

7	Chemical products	33 chm	854
8	Water transport	53 wtp	565
9	Gas manufacture, distribution	47 gdt	283.7
10	oil	16 oil	282.1
11	gas	17 gas	187.8
12	construction	49 cns	175.7
13	Paper products publishing	31 ppp	174
14	Metals nec	38 nfm	171.2
15	Trade	50 trd	163.3

Source: GTAP-E database, 2014

Agricultural sector aggregation

Based on Part I Chapter 2 we suggest the following aggregation in order to separate the large emitters in Dutch agriculture.

Number	**Code**	**Description**	**Aggregation name**
1	**v_f**	Vegetables, fruit, nuts	VegFruits
2	**pdr**	Paddy rice	OtherPlants / Grains, seeds, crops
	wht	Wheat	
	gro	Cereal grains nec	
	osd	Oil seeds	
	c_b	Sugar cane, sugar beet	
	pfb	Plant-based fibers	
	ocr	Crops nec	
3	**ctl**	Bovine cattle, sheep and goats, horses	Cattle
	rmk	Raw milk	
4	**oap**	Animal products nec	

	wol	Wool, silk-worm cocoons	OtherAnimalF / Other Animal Food
5	**frs**	Forestry	Forestry & fishing

Processed foods

We compile all processed food in one sector.

Number	**Code**	**Description**	**Aggregation**
6	**cmt**	Bovine meat products	ProcessedF / Processed foods
	omt	Meat products nec	
	mil	Dairy products	
	vol	Vegetable oils and fats	
	pcr	Processed rice	
	sgr	Sugar	
	ofd	Food products nec	
	b_t	Beverages and tobacco products	

Energy, fossil fuels and water

The selection made here is made such that the most emitting sectors are separated. The sectors in the top 15 most polluting sectors are highlighted.

Number	**Code**	**Description**	**Aggregation**
7	**oil**	Oil	Oil
8	**coa**	Coal	Coal
9	**gas**	Gas: extraction of natural gas, service activities incidental to oil and gas extraction excluding surveying	Natural Gas
	gdt	Gas manufacture, distribution	
10	**p_c**	Petroleum, coal products	Oil_pcts / Petroleum & coal products

11	**ely**	Electricity	Electricity
12	**wtr**	Water	Water

Low-tech manufacturing

We have aggregated the following subsectors into low-technology manufacturing, similarly to how it is done in WorldScan simulations.

Number	**Code**	**Description**	**Aggregation**
13	**tex**	Textiles	LowTechMan / Low-tech manufacture
	wap	Wearing apparel	
	lea	Leather products	
	lum	Wood products	
	ppp	Paper products, publishing	
	omf	Manufactures nec	

Metals and minerals

We have separated most metals and minerals subsectors due to the fact that they are high-emissions sectors.

Number	**Code**	**Description**	**Aggregation**
14	**nmm**	Mineral products nec manufacture of non-metallic mineral products	MineralProd / Mineral products
15	**i_s**	Ferrous metals: iron and steel: basic production and casting	FerrousMetal / Ferrous metals
16	**nfm**	Metals nec: non-ferrous metals, production and casting of copper, aluminium, zinc, lead, gold and silver	OtherMetals / Other metals
17	**fmp**	Metal products: manufacture of fabricated metal products, except machinery and equipment	MetalProd / Metal products
18	**oxt**	Other Extraction (formerly omn Minerals nec) other mining extraction, mining of metal ores, other mining and quarrying	OtherExtr / Other extraction

Chemical, rubber and plastics

We have separated chemical products due to the fact that it is a high-emissions subsector.

Number	Code	Description	Aggregation
19	**chm**	Chemical products	Chemical
20	**bph**	Basic pharmaceutical products	Pharmaceutical, rubber & plastics
	rpp	Rubber and plastic products	

Machinery, electronic equipment

Number	Code	Description	Aggregation
21	**ome**	Machinery and equipment nec	MachElectron / Machinery & electronics
	mvh	Motor vehicles and parts	
	otn	Transport equipment nec	
	ele	Computer, electronic and optical products	
	eeq	Electrical equipment	

Construction and housing

Number	Code	Description	Aggregation
22	cns	Construction	Construction

Service industry

Number	Code	Description	Aggregation
23	**afs**	Accommodation, Food and service activities	PrivateServ / Private services
	whs	Warehousing and support activities	
	cmn	Communication	
	ofi	Financial services nec	
	ins	Insurance (formerly isr)	
	rsa	Real estate activities	

	obs	Business services nec	
	ros	Recreational and other services	
	dwe	Dwellings	
24	**osg**	Public Administration and defense	PublicServ / Public services
	edu	Education	
	hht	Human health and social work activities	

Transport and trade

Number	**Code**	**Description**	**Aggregation**
25	**trd**	Trade: wholesale and retail trade, repair of motor vehicles and motorcycles	Trade
26	**otp**	Transport nec land transport and transport via pipeline	OtherTransp/ Land and pipeline transport
27	**wtp**	Water transport	WaterTrans/ Water transport
28	**atp**	Air transport	AirTrans / Air transport

Appendix III: Data and main assumptions

Baseline

Table AIII.1: Data sources used for the construction of the baseline

Baseline data	**Data Name**	**Source**
Percentage GDP change 2014-2019	GDP (constant 2010 USD)	World Bank national accounts data, and OECD National Accounts data files.
Percentage labour change 2014-2019	Population ages 15-64, total	World Bank staff estimates using the World Bank's total population and age/sex distributions of the United Nations Population Division's World Population Prospects: 2019 Revision.
Percentage population change 2014-2019	Population total	World Bank – World Development Indicators
Percentage CO_2 emission change 2014-2018	Sum of 'CO_2_excl_short-cycle_org_C' over all economic activities	EDGAR database; The value for 2019 has been obtained by extrapolating the 2018 value using the yearly average growth rate of 2014-2018
Estimated percentage GDP change 2020-2030	Real GDP long-term forecast (2020-2030)	OECD data
Estimated percentage labour change 2020-2030	Population ages 15-64, total (2020 and 2030)	World Bank – Data bank, Population estimates and projections
Estimated percentage population change 2020-2030	Total population (2020 and 2030)	World Bank – Data bank, Population estimates and projections
Estimated percentage CO_2 emission change 2020-2030	Change per capita emissions 2010-2030	UNEP (2019) Gap report 2019, table 2.2, p. 11

For the 2020-2030 estimations of percentage changes for GDP and emissions, some assumptions needed to be made for certain countries and regions due to the fact that the OECD estimates and the UNEP Emission Gap Report 2019 did not provide estimates for all countries and regions.

Table AIII.2: Assumptions per region

Country/world region in GTAP aggregation	GDP 2020-2030	Emissions 2020-2030
RestAsia	Increase in GDP assumed to be the same on yearly basis as in the period 2014-2019	Estimated using this region's estimated share of world emissions in 2030; the share of world emissions in 2030 is estimated using the share of 2018 and assuming that the share will grow with the same average yearly rates as in the period 2010-2018.
RestAM	Increase in GDP assumed to be the same on yearly basis as overall world GDP increase in 2014-2019	Same as above.
Romania	Increase in GDP assumed to be the same on yearly basis as in 2014-2019	The same change of per capita emissions between 2010 and 2030 has been assumed than for the EU.
RestEU	Increase in GDP assumed to be the same on yearly basis as in 2014-2019	Estimated using this region's estimated share of world emissions in 2030; the share of world emissions in 2030 is estimated using the share of 2018 and assuming that the share will grow with the same average yearly rates as in the period 2010-2018.
Iran	Increase in GDP assumed to be the same on yearly basis as in 2014-2019	Same as above.
RestofEurope	Increase in GDP assumed to be the same on yearly basis as in 2014-2019	Same as above.
RoW	Increase in GDP assumed to be equal to estimated world GDP growth for period 2020-2030	Same as above.

With regard to 2030 emissions estimates based on the UNEP Emission Gap Report, several further assumptions needed to be made:

- The changes in per capital emissions between 2010 and 2030 in Table 2.2 of the UNEP Emission Gap Report (2019) were given for all greenhouse gases, i.e. including methane and nitrous oxide. We have assumed that that the percentage changes enlisted in the table would hold for CO2 only. This probably underestimates the possible emissions reductions in CO2 since reducing CO2, especially as a consequence of burning fossil fuels, is seen to be easier than methane or nitrous oxide, which are emissions predominantly related to agriculture and therefore harder to abate.
- The UNEP Emission Gap Report (2019) estimates that the total CO2-equivalent emissions in 2030 will be around 60 GtCO2e, according to the 'current policies' scenario. For computing the 2030 CO2 emissions, we assumed that the current shares of CO2 emissions to other non-CO2 greenhouse gas emissions stays constant. This, however, is a simplifying assumption, as explained above.
- The UNEP Emission Gap Report (2019) reports only one number for E28. Therefore, we assumed that the same percentage emissions reduction applies the EU28 countries we singled out in the model analysis. This is a simplification – while having a common emission reduction goal, the EU allows countries to reduce their emissions in different speeds, depending on their decarbonisation possibilities and economic development.
- The EU's percentage emission reductions are assumed to hold also for the UK and the EFTA countries.

Scenarios

Two tax rates are employed per scenario.

Three scenarios are constructed, each analysing the effects of the tax in different geographical jurisdictions.

Scenario 1 – Carbon tax in the Netherlands only

Scenario 2 – Carbon tax in the EU+ which includes UK and EFTA countries (see detailed list below).

AUT	**Austria**	Austria
BEL	**Belgium**	Belgium
CZE	**Czech Republic**	Czech Republic
DNK	**Denmark**	Denmark
FIN	**Finland**	Finland
FRA	**France**	France
DEU	**Germany**	Germany
GRC	**Greece**	Greece
HUN	**Hungary**	Hungary
IRL	**Ireland**	Ireland

ITA	**Italy**	Italy
NLD	**Netherlands**	Netherlands
POL	**Poland**	Poland
PRT	**Portugal**	Portugal
ROU	**Romania**	Romania
ESP	**Spain**	Spain
SWE	**Sweden**	Sweden
BGR	**RestEU**	Bulgaria
HRV		Croatia
CYP		Cyprus
EST		Estonia
LVA		Latvia
LTU		Lithuania
LUX		Luxemburg
MLT		Malta
SVK		Slovakia
SVN		Slovenia
NOR	**EFTA**	Norway
CHE		Switzerland
XEF		Rest of EFTA (Lichtenstein and Iceland)
GBR	**UK**	United Kingdom

Scenario 3 – Carbon tax in the EU+ (EU, UK and EFTA) and in the following countries:

Number	Code	Aggregation	Description
1	AUS	**Australia**	Australia
2	NZL XOC	**Rest Oceania**	New Zealand Rest of Oceania
3	CHN HKG	**CHG**	China Hong Kong, Special Administrative Region of China
4	JPN	**Japan**	Japan
5	KOR	**Korea**	Korea, Republic of
7	CAN	**Canada**	Canada
8	USA	**USA**	United States of America

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