Projections of consumption-based emissions for the EU and globally

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In recent years, researchers have used multi-regional input-output (MRIO) analysis to estimate the carbon dioxide emissions linked to a country's consumption, sometimes referred to as the 'carbon footprint'. These consumption-based indicators have complemented the more standard measure of production-based emissions that is reported in national inventories. In this paper we use the same approach to provide projections of consumption-based emissions out to 2050.

To carry out the projections, we use the E3ME macro-econometric model and link it to an MRIO framework that is based on the model's own data. We apply this combined tool to three different scenarios of future climate policy in which first the EU and then the rest of the world implement measures to meet global carbon targets. We estimate emissions in each case on a consumption basis and also on a technology-adjusted consumption basis, drawing on the recent literature.

After assessing historical trends in our modelling framework, we present forward-looking results for the EU and China in terms of absolute levels of emissions and 'net trade' in emissions (i.e. comparing consumption to production-based emissions). Our analysis shows some clear trends that are developing, notably that efforts to decarbonise China's electricity system mean that the country will become a net importer of emissions in the 2020s. By comparing the results from the different scenarios, we show that policy makers in any given country have only limited control over their total net trade in emissions.

Introduction

Introduction to the metrics used in this paper

Emission accounting methods are ways of calculating the amount of greenhouse gases (GHG) emitted by a region in a given time-scale. There are two main ways of measuring emissions:

- production-based (PBA), sometimes referred to as territorial-based; or
- consumption-based (CBA), sometimes referred to as the 'carbon footprint'.

The production-based emissions measure covers emissions that are released in a national territory in a single time period. Consumption-based emissions encompass those emissions from domestic final consumption and those caused by the production of its imports. Under the CBA approach the importing country takes responsibility for the emissions that are related to production of the exports from the country that it trades with (see e.g. Peters and Hertwich, 2008; Davis and Caldeira, 2010).

The technology-adjusted CBA (TCBA) approach is similar to the CBA approach, but it takes into account differences in carbon efficiency between exporting sectors in a specific country and the global average (Kander et al, 2015; Jiborn et al, 2018). The reason for this is to capture the impact of a country's relative efficiency in producing exports compared to the average global efficiency. A highly carbon-efficient country contributes to global decarbonisation through its exports to the extent that its exports substitute for goods that would otherwise be produced at a higher carbon intensity.

Background to the measures

At present, based on IPCC guidelines, a country's energy-related emissions are measured based on its consumption of fuels within the country[1]. The measure includes the sum of emissions from all the oil, coal, and gas consumed in a country by private households, industrial production of goods and services, and electricity production. This is the PBA approach. However, this measure of emission accounting has some drawbacks:

- It excludes emissions for international air and sea transport, as they do not happen on the territory of a specific country.
- It does not account for the potential relocation of energy-intensive industries from countries with strong environmental controls to countries where restrictions are fewer, leading to carbon leakage.

CBA seeks to address the two problems outlined above, by subtracting from countries all emissions that are contained in exported products, including transportation emissions, and including the emissions embodied in imports. What this means, particularly in the case of the second bullet point above, is that low emitters under PBA might look less 'clean' in the consumption-based framework if they import carbon-intensive goods. High emission countries might in reality produce goods for the living standard of low emission countries. Thus, the emission accounting method used changes the responsibility for emission reduction at global level; there are many recent studies that argue that a

[1] Similarly, emissions from industrial processes, agriculture and land use change, etc, are counted if they take place within the territorial borders. The analysis in this paper with the E3ME model covers energy and process CO_2 emissions.

large share of global emissions is accounted for by advanced countries' consumption patterns (e.g. Andrew and Forgie, 2008; Serrano & Dietzenbacher, 2008; 2010).

However, the CBA approach also has its drawbacks. The approach is not able to account for differences in the production technology among trade partners when assessing the emission trade balance and the occurrence of emission displacement (carbon leakage). As such, this accounting measure can mistake differences in technology for specialisations in more or less emission-intensive exports compared to the imports' carbon-intensity, resulting in biased emission estimates. In other words, a country with a more carbon efficient production technology compared with their trading partners will be penalised for engaging in trade, in the sense that it will be allocated higher national emissions under CBA accounting, even if the overall result is a reduction of global emissions (because it is more carbon efficient in producing its exports).

The TCBA approach seeks to address this issue, by adjusting emissions to consider the difference in carbon efficiency in export sectors of different countries. The TCBA approach is similar to the CBA approach, but it adjusts for differences in carbon efficiency in the export sectors of different countries. Standard CBA is calculated by adding embodied emissions in imports to production emissions and subtracting embodied emissions in exports, using the average emissions intensity of the relevant production sector in the country producing the goods (as illustrated above). TCBA applies a similar formula, but with the adjustment that export-related emissions are subtracted based on the average carbon intensity for the relevant sector on the world market, rather than the domestic average. In this way, the gap between average global carbon intensity and the domestic equivalent becomes a proxy measure of the different technology levels in countries.

In this paper, the CBA and TCBA methodologies outlined above have been combined with the E3ME macroeconomic model (Cambridge Econometrics, 2014; Mercure et al, 2018a) to produce a set of emission results for the baseline and policy scenarios.

As a macroeconomic model, E3ME combines an MRIO framework with a set of behavioural equations. It is therefore possible to convert E3ME emission results from a PBA approach to a CBA approach, as they contain all the necessary data (input-output tables and bilateral trade flows). The conversion from production to average consumption-based emissions in E3ME has been applied post-solution to the model results, using the input-output and trade data from the model. This exercise essentially builds a separate, off-model MRIO tool based on the input-output and bilateral trade results that come out of the model. This can be done for any year for which the model produces results, either over history (for ex post analysis) or as part of the model's projections. It is therefore possible to obtain projections of emissions on a consumption basis for any country that is defined in the model structure.

The E3ME database covers the period from 1970-2016, with annual projections to 2050. Input-output tables are stored for a base year and projected forwards and backwards using logistic trends that are designed to account for changes in technologies and production patterns. The model database is complete for the period 1995-2016 but it does not cover all countries prior to 1995 due to data availability.

Historical comparison

Table 1 and Figure 1 summarise the historical emission results by region and emissions accounting method: production-based accounting (PBA) and consumption-based accounting (CBA). EU28 data show a substantial decrease in emissions over 1996-2016, irrespective of the accounting measure used. Under PBA, CO_2 emissions decreased by 20.3% over the period, while the consumption-based estimate suggests a reduction of 19.5%.

In terms of levels, the CBA estimate has been higher than the PBA estimate since 2005, suggesting that the EU is now consistently a net importer of emissions. However, the gap between PBA and CBA has remained relatively constant over time, and the emissions reductions since the 1990s are valid regardless of accounting measure. In 2016, the gap between CBA and PBA emissions was equivalent to about 4% of PBA emissions, a slight decrease from 2005, where the gap accounted for about 4.5% of PBA emissions.

Table 1: Changes in historical emissions balances

	1996	2005	2010	2016	1996-2016 % change
			EU28		
PBA	4471.6	4433.1	3868.5	3562.6	-20.3
CBA	4600.6	4634.1	4113.3	3701.3	-19.5
TCBA	4472.2	4414.9	3807.8	3442.2	-23.5
			China		
PBA	3444.5	5338.0	7545.1	9965.0	189.3
CBA	2810.5	4743.1	7076.7	9801.0	248.7
TCBA	3436.3	5293.5	7461.7	9858.0	186.9.

In contrast, China's PBA emissions have exceeded its CBA emissions, although the gap has noticeably narrowed in recent years. Both measures of emissions have seen large increases.

Figure 1 also shows the position of the US for comparison. In 2016, the gap between CBA and PBA emissions in the US accounted for about 10% of total PBA emissions.

Figure 1: CBA emissions by country, m TCO2, absolute difference from PBA

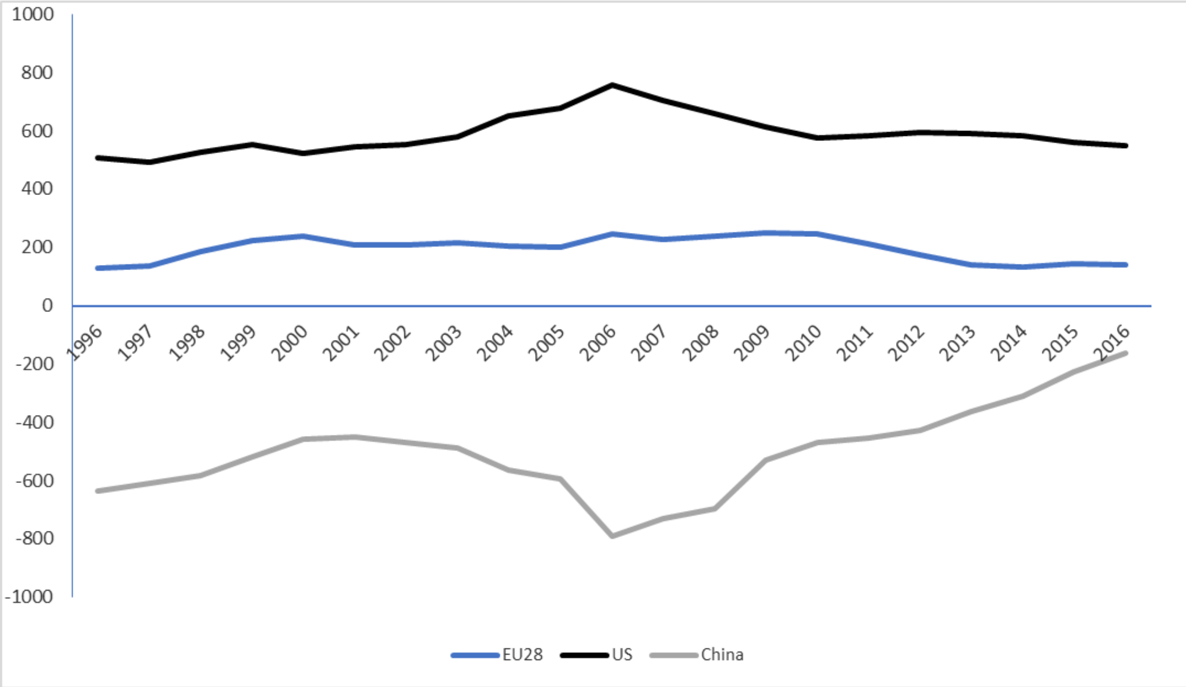


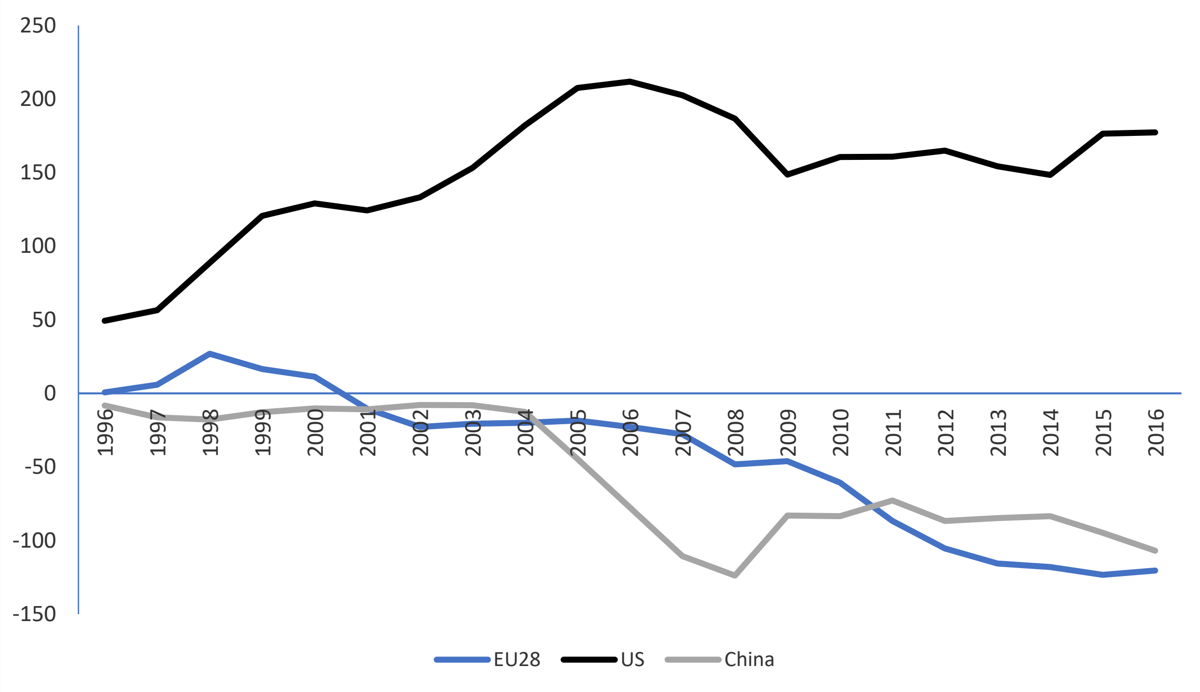
Figure 2 summarises the technology-adjusted (TCBA) CO_2 emissions results over the historical period. The first point to note is that in the EU TCBA emissions are lower in absolute terms than PBA emissions. This finding reflects the relatively less carbon-intensive production processes used within the EU, which in turn reflects both the result of previous EU policy in recent decades and the composition of production within carbon-intensive sectors. By exporting goods in these sectors, the EU has contributed to decarbonisation beyond its own borders.

Turning to growth rates, there is a clear trend that TCBA emissions in the EU decreased by more than PBA emissions over the historical period. TCBA emissions also decrease by more than CBA emissions (see previous section).

For China, the TCBA emission results are similar to the CBA results, indicating that, at least on average, China's export sectors are broadly as carbon efficient as the world average. Given China's large weighting in the estimates of the global average intensities for many of the key traded products, this is perhaps not surprising.

Again, the US is provided for comparison. Here, the TCBA results provide a slightly different picture. Although TCBA emissions in the US are higher than the PBA values, the difference is not as large as for CBA; indicating that at least some exporting sectors in the US are more carbon efficient than the global average. However, the balance is still positive, meaning that even on this basis the US is importing emissions from other countries. This compares to the case of the EU, where the absolute difference between TCBA and PBA emissions is negative, indicating that the EU is progressing in reducing its overall consumption footprint.

Figure 2: TCBA emissions by country, m TCO2, absolute difference from PBA

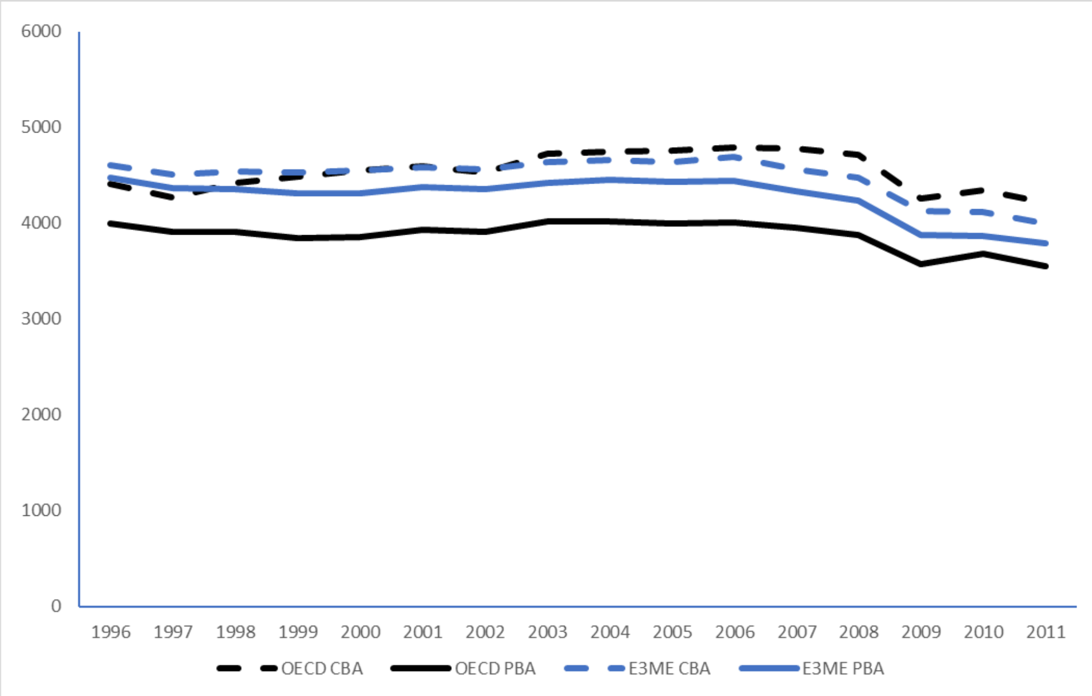


Generally, the consumption-based emission results are consistent with previous work carried out by Kander et al (2015) and data from the OECD (OECD.Stat, 2019).

Trends in the EU28 between PBA, CBA and TCBA align with results from Kander et al (2015), with the pattern resulting from the analysis TCBA<PBA<CBA, in line with the results of their paper. For China the TCBA-CBA estimates from our analysis show more efficient export sectors than the results from Kander (2015) imply.

Figure 3 compares EU28 emissions results for PBA and CBA with results from the OECD analysis quoted above. While the pattern in emissions over time is similar, the figure highlights a difference in PBA levels between our estimates and the ones from the OECD, which is due to the OECD accounts excluding process emissions. CBA estimates from the two analyses appear to be more aligned, meaning that the gap between CBA and PBA is smaller in the E3ME estimates.

Figure 3: EU28 CO_2 emissions



Future projections

Introduction

In addition to a baseline set of projections, there are two policy scenarios. In both the policy scenarios, the EU reduces greenhouse gas emissions to 80% below 1990 levels by 2050. The scenarios vary because other countries take different levels of action:

- In the first scenario, non-EU countries implement their NDCs but do not enact any further policy.
- The second scenario is a 2°C scenario, in which the EU still reduces emissions by 80% but other countries take a similar level of action.

Under the 2°C scenario the types of policies implemented are similar across all countries, but the level of effort varies across countries. The policies include, but are not limited to, carbon pricing. They also cover energy efficiency mandates, specific measures in the power sector, road transport and household heating sectors (e.g. subsidies for clean technologies) and phase-outs of high-polluting fuels. The scenario used is the same as in Mercure et al (2018b).

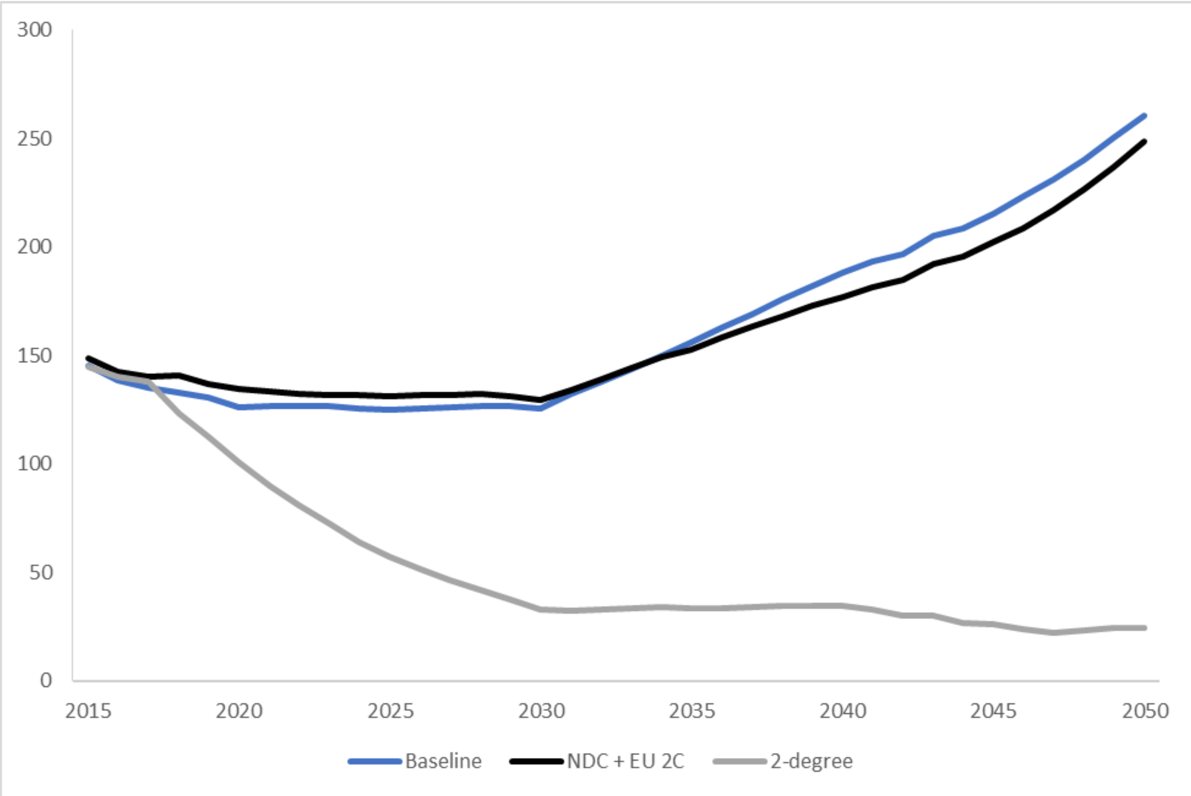
Projections for the EU

In the EU, CBA emission estimates are expected to remain above PBA estimates over the entire projection period (see Figure 4). This means that under all scenarios the EU is expected to remain a net importer of emissions, although this gap closes towards zero by 2050 in the 2°C scenario case.

The important point to note here is that the clustering of the lines is not consistent with the EU's level of action. The two lines that overlap include the baseline case where the EU has a low level of ambition and the NDC scenario where the EU reduces emissions by 80%. The important determinant of the EU's net trading position on carbon is therefore not EU climate policy but what happens in the rest of the world.

This finding makes intuitive sense. Apart from fossil fuels, the EU's trading patterns do not change substantially in the scenarios, and so the only way to reduce the level of imported emissions is for other countries to decarbonise their production methods.

Figure 4: EU28 CBA emissions, mtCO_2, absolute difference from PBA



Turning to the TCBA projections, in the EU the gap between TCBA and PBA is largest in the baseline. As the EU has already undertaken measures to reduce carbon intensity, and more are predicted in the baseline, it is perhaps not surprising that the largest deviation from the rest of the world is in the baseline case. Even when the EU moves to an 80% emissions reduction by 2050, the implementation of the NDCs in the rest of the world is sufficient to close the gap. The gap between TCBA and PBA narrows substantially in the 2°C scenario, from 140 mtCO2 to 40 mtCO2 as carbon intensity falls in other countries (see Figure 5).

Figure 5: EU28 TCBA emissions, $mtCO_2$, absolute difference from PBA

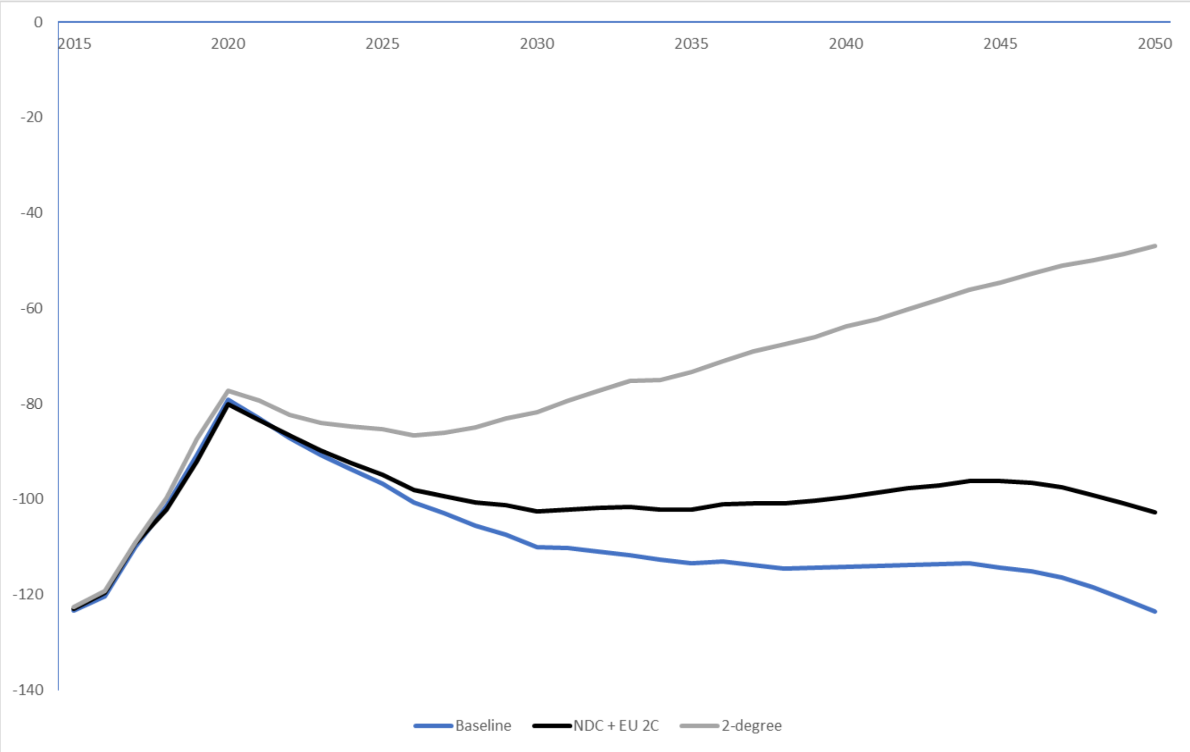


Table 2 summarises the EU overall projections in emissions in the scenarios, using the three different measures. The table shows that the EU continues to make substantial emission reductions in the baseline under all three measures, even in the baseline. The reductions increase (roughly doubling in percentage terms) when moving to a 2°C scenario.

The reductions in PBA and TCBA emissions are broadly consistent in all three scenarios. CBA emissions fall by slightly less in the baseline and NDC+EU2C scenarios because the EU continues to import goods but cannot force other countries to reduce carbon intensity. However, when other countries show a similar level of ambition to the EU (in the 2°C scenario), the gap between the different measures closes.

Table 2: % change in EU emissions between 2015 and 2050

	PBA	CBA	TCBA
Baseline	-30.5	-26.2	-31.6
NDC+EU2C	-65.9	-60.5	-67.7
2°C	-68.6	-69.2	-68.9

Projections for China

In China an interesting story unfolds (see Figure 6). By the early 2020s, China moves from a net exporter of emissions to a net importer in all three scenarios, reflecting its underlying economic trade position. In the baseline, CBA emissions are expected to be 6.7% higher than PBA estimates by 2050. A similar trend is observed in the NDC+EU2C scenario, albeit with a smaller gap between CBA and PBA emissions. The difference between the two emissions estimates is of around 3.6% of total PBA emissions in 2050. This finding results from a continuation of historical trends that were presented previously. Even in the baseline case, China continues to reduce its dependence on coal (in relative terms at least), meaning that the goods it exports become less carbon intensive. At the same time, China imports increasingly large volumes of consumer products, pushing up its levels of imported emissions. In both the baseline and NDC+EU2C scenario, CBA emissions increase at a faster pace over the 2015-2050 period than PBA emission estimates. However, the gap between the two growth rates is smaller in the NDC+EU2C scenario.

Figure 6: China CBA emissions, mtCO2, absolute difference from PBA

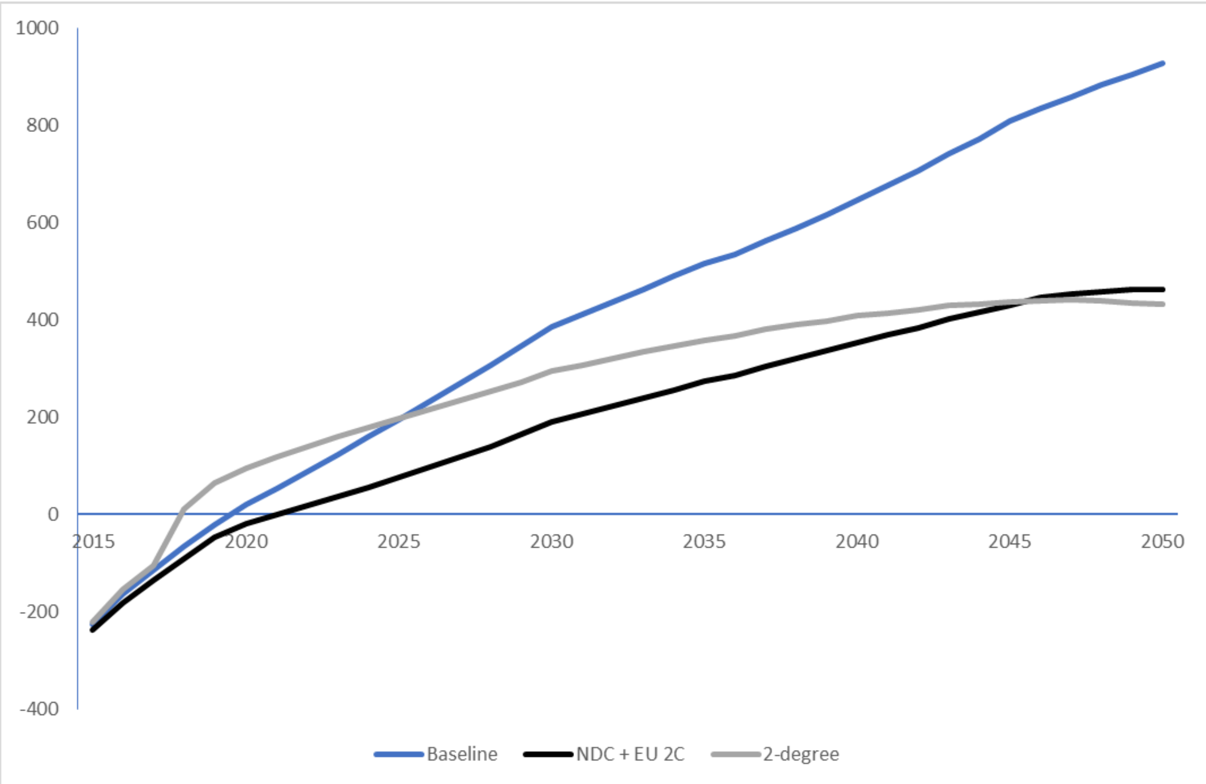
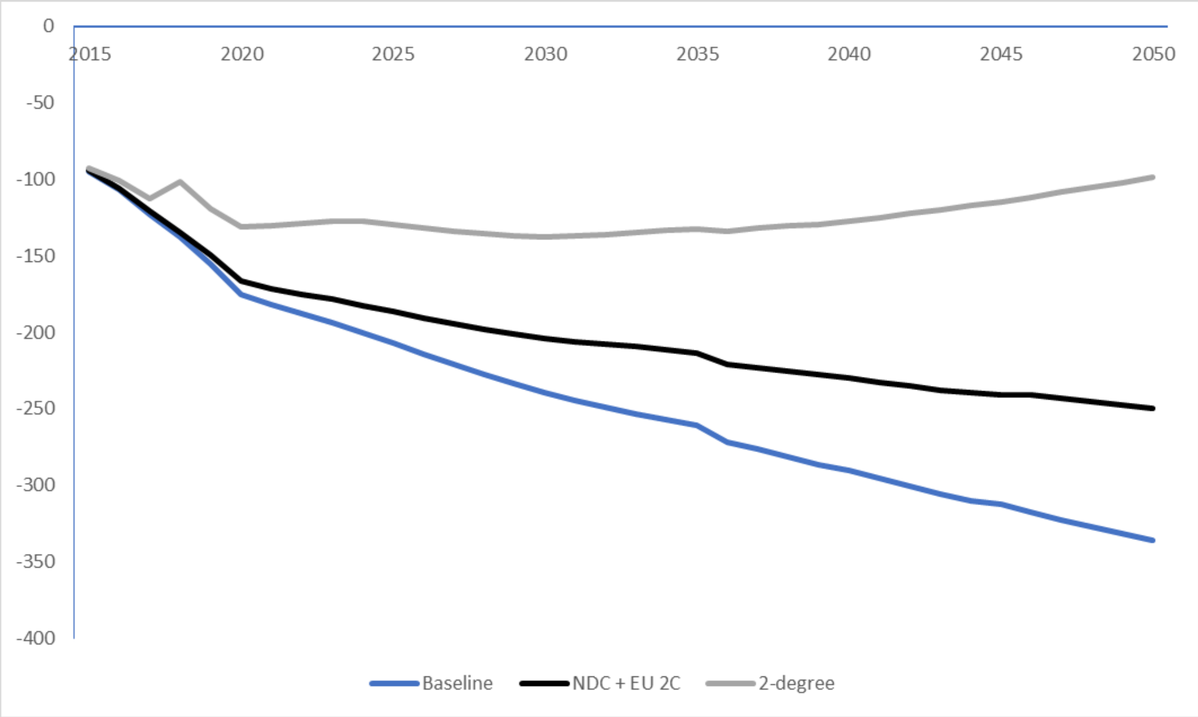


Figure 7 illustrates the gap between TCBA and PBA emissions in China in the baseline and policy scenarios. As noted above, based on TCBA estimates, China remains net exporter of emissions in the baseline and this is also the case in the two scenarios. However, as is the case for the EU, the gap narrows for China in the 2°C scenario, and this is illustrated by the similar emission reduction. The change is only in line with the more general emission reduction, however, i.e. there is no particular impact on traded emissions.

Figure 7: China TCBA emissions, mtCO2, absolute difference from PBA



Discussion

Measuring emissions on a consumption basis is now a well established technique that uses a combination of input-output and bilateral trade data. A technology-adjusted version has in recent years been developed to account for differences in production methods between countries (i.e. trying to account for factors that are outside the importing country's control).

These techniques have been applied many times to historical time periods but have rarely been applied to future projections. The forward-looking aspect is the most novel contribution of this paper. We have assessed three cases: a baseline projection, a case where the EU decarbonises but the rest of the world does not, and a case where all countries aim for a 2C climate target.

There are two main findings from the research:

- First, the results demonstrate the limited control that a region like the EU has over the non-domestic part of its consumption-based emissions. Our model results show that the emissions trade balance between the EU and the rest of the world is mostly independent of the EU's domestic climate policy. In fact, ambitious domestic policy could make the emissions trade balance worse, because exports become less carbon-intensive, while there is no change in the carbon intensity of imports.
- Second, it is likely that there will be a major shift in the balance of emissions in China in the near future, as the country moves from being a net-exporter to a net-importer of emissions. This finding reflects a combination of continued reductions in carbon intensity in China (especially a move away from coal) that reduces the carbon content of exports, and an increase in the imports of final products for consumption.

At present, implemented policy in the EU leads to lower consumption-based emissions for countries that import goods from the EU. In future, if other countries take domestic action to reduce emissions, then we will see a similar pattern in that country's trade partners reducing their footprints. In the modelling results in this paper, we can see that the EU and every country outside China is currently lowering its carbon footprint because of action taken in China to reduce carbon intensity. While the EU could claim some credit for these developments in China (e.g. through encouraging reductions in solar costs), we also show the limitations of consumption-based accounting as a policy indicator.

The technology-adjusted variant of consumption-based emissions therefore becomes more relevant in such circumstances. Our model results show that domestic policy in large world regions can reduce imports of emissions on this basis, because it also reduces the global average intensity of production that is used as a benchmark in this measure. However, the measure is still not perfect from a policy perspective as it shows roughly equal benefits to the EU and China from changes in the EU's policy.

The conclusion is therefore that a range of metrics is needed for a full assessment; using only one indicator could result in misleading conclusions. Of the three measures discussed in this paper, each has its benefits and disadvantages and must be interpreted in its own specific context. But each has its own role to play too.

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