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# ABSTRACT

## THE CARBON FOOTPRINT OF GLOBAL TRADE IMBALANCES*

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International trade is highly imbalanced both in terms of values and in terms of embodied carbon emissions. We show that the persistent current value trade imbalance patterns contribute to a higher level of global emissions compared to a world of balanced international trade. Specifically, we build a Ricardian quantitative trade model including sectoral input-output linkages, trade imbalances, fossil fuel extraction, and carbon emissions from fossil fuel combustion and use this framework to simulate counterfactual changes to countries' trade balances. For individual countries, the emission effects of removing their trade imbalances depend on the carbon intensities of their production and consumption patterns, as well as on their fossil resource abundance. Eliminating the Russian trade surplus and the US trade deficit would lead to the largest environmental benefits in terms of lower global emissions. Globally, the simultaneous removal of all trade imbalances would lower world carbon emissions by 0.9 percent or 295 million tons of carbon dioxide.

Keywords: Carbon emissions; international trade; gravity

JEL classification: F14, F18, Q56

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# 1 Introduction

A quarter to a third of global CO2 emissions is embodied in goods that are traded internationally. In 2017, the two countries with the largest trade deficits in the world (the United States and the United Kingdom) were at the same time the countries with the two largest net imports of carbon emissions. China, on the other hand, had the largest trade surplus and also by far the largest amount of net exports of carbon emissions. The third largest net carbon exporter (South Korea) also had a very large trade surplus (3rd largest in the world). Contrary examples (such as Germany, which had the second largest trade surplus but was a net carbon importer) notwithstanding, the question arises whether global trade imbalances allow specialization and consumption patterns that magnify the global carbon footprint.

The question is not straightforward to answer. First of all, maybe the United States and China are net importer and net exporter of carbon *only because* they are net importer and exporter overall, respectively. The data can give an answer to this if we consider the embodied emissions per dollar of exports and per dollar of imports, i.e. the ex- and import carbon intensities. Focusing on the two most prominent examples for now, it turns out that Chinese exports are about twice as carbon-intensive as its imports, while US exports are only about half as carbon-intensive as its imports. This pattern magnifies these countries' imbalances in embodied emissions in comparison to their trade value imbalances. It further suggests that there may be scope for lower overall emissions if a trade re-balancing limited the United States' possibility to buy more of its “dirty” imports than it sells comparably “clean” exports (decoupling its *consumption footprint* of emissions associated with products ending up in the US from its *production footprint* of emissions being emitted by US producers) and put a constraint on China to act as the world's supplier of carbon-intensive products (with a corresponding over-proportional production footprint). However, eliminating trade imbalances would reshuffle trade and production all around the world and we cannot rule out a-priori that some of China's “dirty” production will end up in countries that produce the same products with an even larger use of fossil fuels and hence higher emissions. Therefore, if we want to know the “carbon footprint of global trade imbalances”, we need to simulate the balancing of all current accounts in a quantitative model.

Beyond the differences in production vs. consumption carbon intensity, another group of countries with large trade surpluses, including, e.g., Russia, Saudi Arabia, or Australia, points to an additional important dimension: the role of trade in fossil fuels. A considerable share of these countries' exports is the sale of fossil fuels. The fact that the production of fossil fuels is itself carbon intensive shows up in their carbon trade balance, the fact that the burning of these fossil fuels in their destination countries will cause additional emissions does not. This implies that the fossil fuel exporters' *extraction footprint* can exceed the emissions associated with their production or consumption. The possibility of running a trade surplus enables fossil fuel exporters to focus their production on fossil fuel extraction to a larger extent than they could if they had to align their production more strongly with their own consumption patterns. Therefore, global trade imbalances can have important implications for fossil fuel supply, which also have to be taken into account when quantifying the carbon footprint of imbalances.

For our quantitative analysis, we develop a Ricardian trade model along the lines of Eaton and Kortum (2002). To capture the full integration of countries into global value chains, we include a sectoral input-output structure as in Caliendo and Parro (2015). Additionally, we incorporate carbon emissions from fossil fuel combustion with varying carbon intensities for different types of fossil fuels. Together with the input-output structure, this allows a fine-grained consideration of embodied carbon flows and a clean distinction of countries' production, consumption, and extraction footprints. As an environmentally extended version of Caliendo and Parro (2015), the model is closely related to the contributions by Shapiro (2021), Caron and Fally (2022), and Klotz and Sharma (2023), which in turn are the latest additions to a young, but growing literature incorporating emissions into structural gravity models (Egger and Nigai, 2015; Shapiro, 2016; Larch and Wanner, 2017, 2019; Shapiro and Walker, 2018).[1]

We use the quantitative framework for two types of counterfactual analyses. First, we eliminate individual countries' trade imbalances, altering the rest of the world's surpluses and deficits only to the extent necessary to ensure that global supply equals global

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[1] Shapiro (2021) is observationally equivalent to the original Caliendo and Parro (2015) framework, but additionally captures global emissions and its welfare implications; Caron and Fally (2022) include a more detailed modeling of fossil fuel production and trade and incorporate non-homothetic preferences; Klotz and Sharma (2023) incorporate fossil fuel use and emissions in transportation.

demand. We calculate how the country's different emission footprints react to the elimination of the trade imbalance and how global emissions are affected. We use these country-level re-balancing exercises to identify patterns in countries' consumption habits and production specialization, as well as resource abundance, that determine which imbalances are particularly problematic in terms of their effect on global emissions. Second, we simulate a global re-balancing in which all countries' surpluses and deficits are jointly erased. This allows us to assess whether the current pattern of trade imbalances around the world is in fact partly responsible for the high level of global carbon emissions. In addition to insights on the level of global emissions, this counterfactual is also informative concerning the distribution of carbon emissions across the globe and how this is shaped by trade imbalances.

We find that a global re-balancing of international trade would lower global emissions by 0.9 percent. While this is not a huge number on first sight, it is considerable given that (i) the scenario does not explicitly implement any environmental policy and (ii) prior literature finds that a move to total autarky for all countries would lower emissions by a rather mild (considering the extreme scenario) 5 percent (Shapiro, 2016). In terms of individual countries' imbalances, the US deficit indeed fosters emissions by sustaining the carbon-intensive US consumption. Most of the individual countries' imbalances that are particularly environmentally detrimental, however, are found to be the surpluses of major fossil fuel exporters with their disproportionately large extraction footprints.

Our exercises come with one important disclaimer. Unlike a growing literature on the *sources* of trade imbalances (cf. e.g. Reyes-Heroles, 2016; Felbermayr and Yotov, 2021; Cuñat and Zymek, 2023), our paper purely examines the *consequences* of their removal, standing in the tradition of Dekle, Eaton, and Kortum (2007, 2008). To this respect, we do not point towards a policy that would eliminate the imbalance, but we calculate the magnitudes of the adjustments that such a balancing would entail in terms of carbon emissions.

Until now, the role of trade imbalance in shaping global emission patterns has received little attention. In their recent handbook chapter, Copeland, Shapiro, and Taylor (2022) briefly refer to imbalances as one factor that could contribute to emissions outsourcing. Li, Chen, Li, Li, and Chen (2020) consider embodied energy in the US-Chinese bilateral trade imbalance, showing that the United States implicitly net imports large amounts of energy from China.

The remainder of this paper is structured as follows. Section 2 presents a collection of stylized facts about global trade imbalances in terms of both values and embodied emissions, their interrelation with one another and with the countries' resource abundance. Section 3 lays out the quantitative model and Section 4 introduces the data used for the quantification. In Section 5, we present the results of the counterfactual exercises. Section 6 concludes.

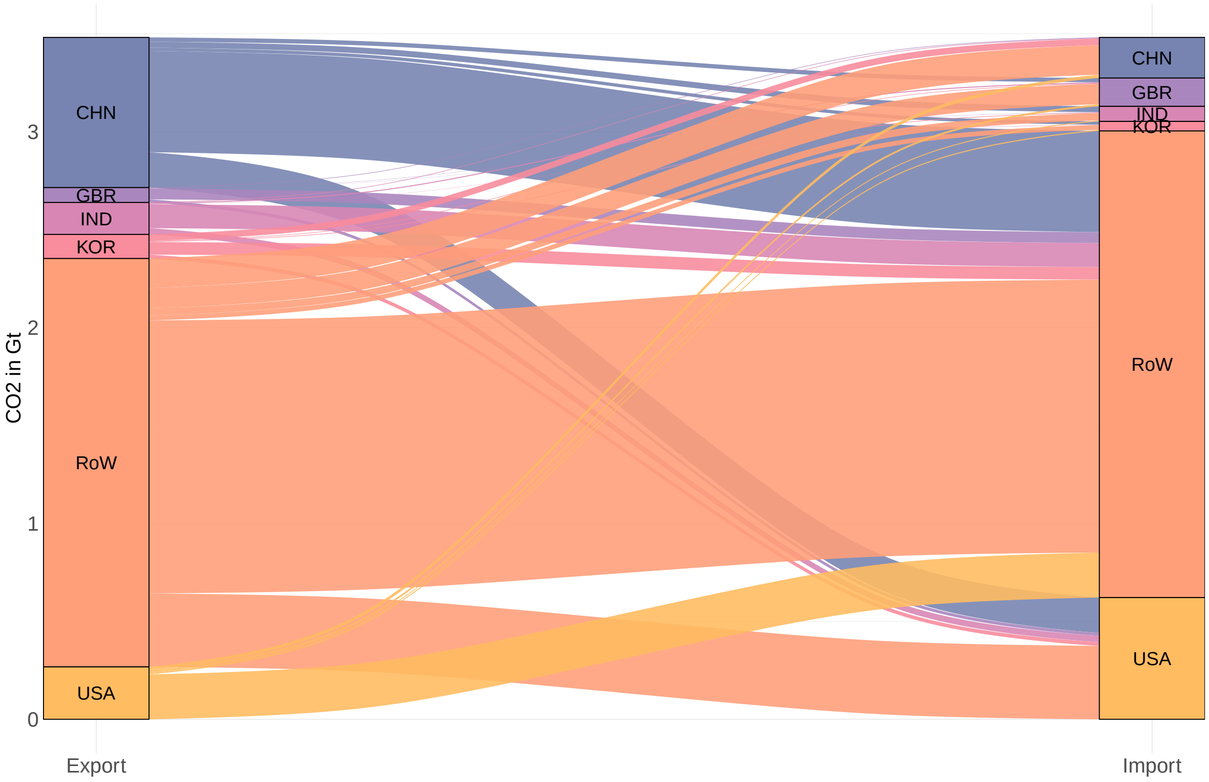
## 2 Trade Imbalances and Embodied Emissions: A Look at the Data

In this section, we take a look at the data and establish four stylized facts about value and embodied emission trade imbalances across countries and time. While not novel individually and in part very straightforward, the aim of this *collection* of stylized facts is to motivate that trade imbalances have the potential to play an important role in shaping the level and distribution of global carbon emissions. In this section, in line with the calibration of our quantitative model later on, we use data from the Global Trade Analysis Project 11 database (GTAP, see Aguiar, Chepeliev, Corong, and van der Mensbrugghe, 2022), which captures the period from 2004 to 2017.

**Stylized Fact 1.** *Embodied emissions in international trade are highly and persistently asymmetric.*

Bilateral flows of embodied CO2 emissions for the five countries with the largest absolute imbalance of embodied carbon emissions in trade, plus an aggregated "Rest of the World", are depicted in Figure 1. The height of a country's box on the vertical axis relates to the corresponding total embodied emissions in their exports (left) and imports (right) in 2017. China, Great Britain, India, South Korea and the USA account together for 40.1 percent of total embodied carbon emissions in exports and for 31.6 percent of total embodied carbon emissions in imports. For individual countries, the contrast can be very stark: while China exports 766 Mt, it only imports 207 Mt of embodied CO2. For the

Figure 1: Bilateral Flows of Embodied CO2 Emissions in International Trade, 2017



US, the pattern is similarly extreme, but in the opposite direction. Their exports embody 268 Mt, while the embodied emissions in their imports amount to 622 Mt of CO2. As the US, Great Britain is also a net importer of embodied CO2, while India and South Korea are net exporters. China is also the country with the largest share of net exports to total exports in embodied emissions, which amount to 73 percent, followed by South Korea with 60 percent. Figure 1 implies large gaps between production and consumption footprints. Importantly, these imbalance patterns have been very persistent.[2] All individual countries keep their role as a net ex- or importer of embodied emissions throughout the period. This persistence magnifies the importance of understanding the role that the trade imbalances play in shaping global emissions. If trade imbalances contribute to a production and consumption pattern around the world that goes in hand with higher carbon emissions and this pattern persists over time, the resulting additional emissions will add up over time.

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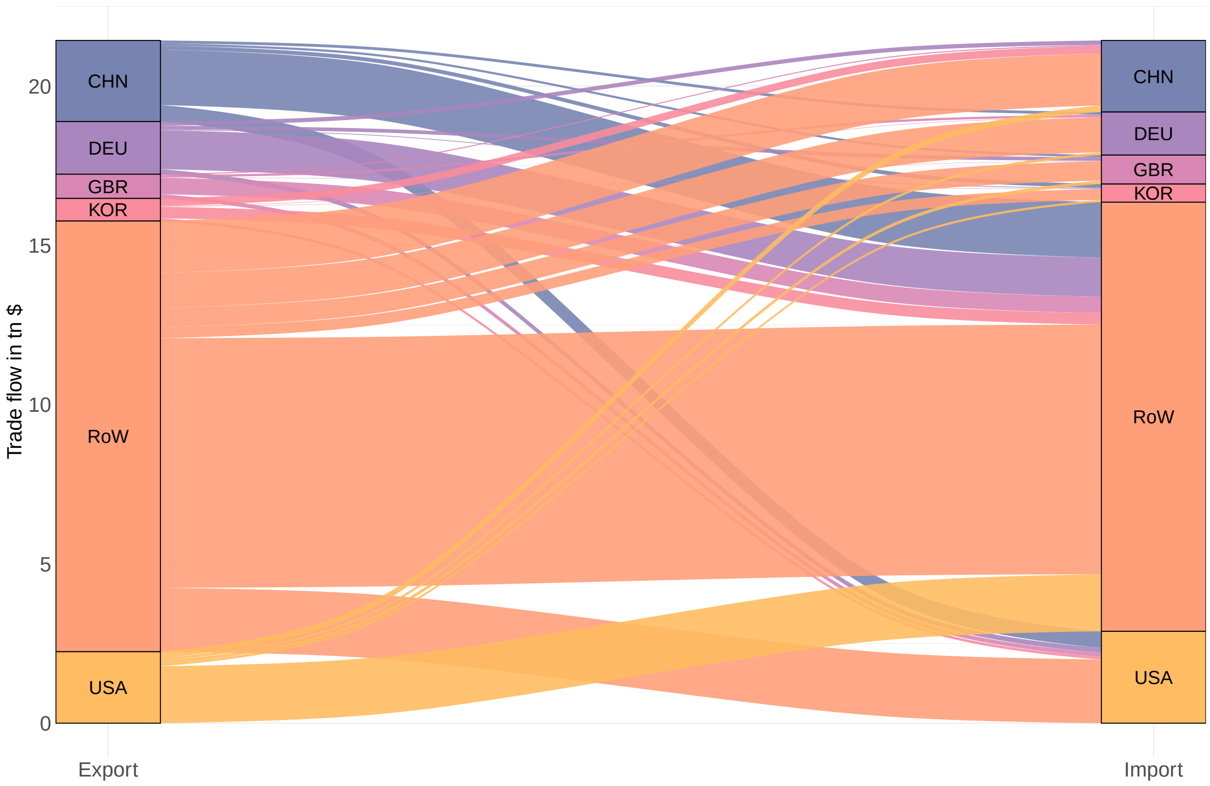
[2] See Figure A1 in the appendix for a representation of the pattern in Figure 1 since 2004 (the first base year of the GTAP 11 data base).

Figure 2: Bilateral Trade Flows, 2017



**Stylized Fact 2.** *Trade is highly and persistently asymmetric in value terms, too.*

Figure 2 shows bilateral trade flows of goods and services of the five countries with the world's largest absolute trade imbalances. The height of a country's box on the vertical axis relates to their total exports (left) and imports (right) in trillions of USD in 2017. It hence reproduces Figure 1, substituting embodied emissions for values. Even though the asymmetry in value trade is not as drastic as in embodied emissions trade, the value imbalances are substantial, too. China, Germany, Great Britain, South Korea, and the USA account together for 37 percent of total exports and of total imports. China has a trade surplus of 303 bn USD, followed by Germany (299 bn), and South Korea (137 bn). The USA have the largest trade deficit with 638 bn USD, followed by Great Britain (150 bn USD). Even though this stylized fact is well-established, we restate it here because it takes center-stage in our analysis which asks whether these well-known imbalances have an additional, so far overlooked environmental implication to them. Similarly to the embodied emissions imbalances over time shown, this pattern is highly persistent.[3] If trade

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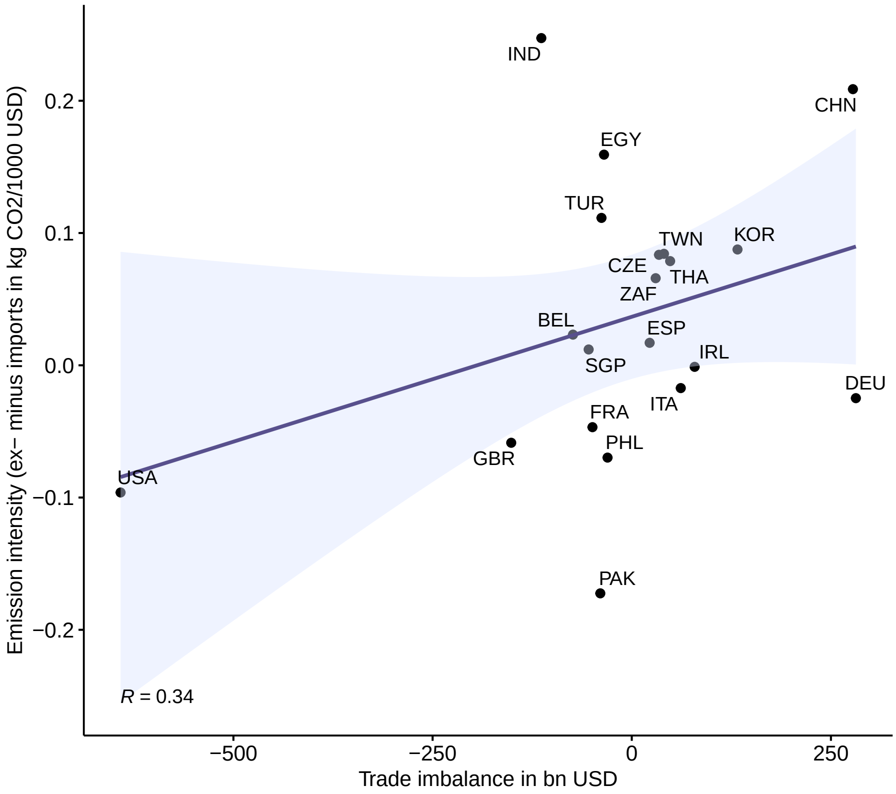
[3] See Figure A2 in the appendix for a graphical representation.

Figure 3: Correlation of Trade Imbalances and Carbon Intensities of Exports vs. Imports, 2017



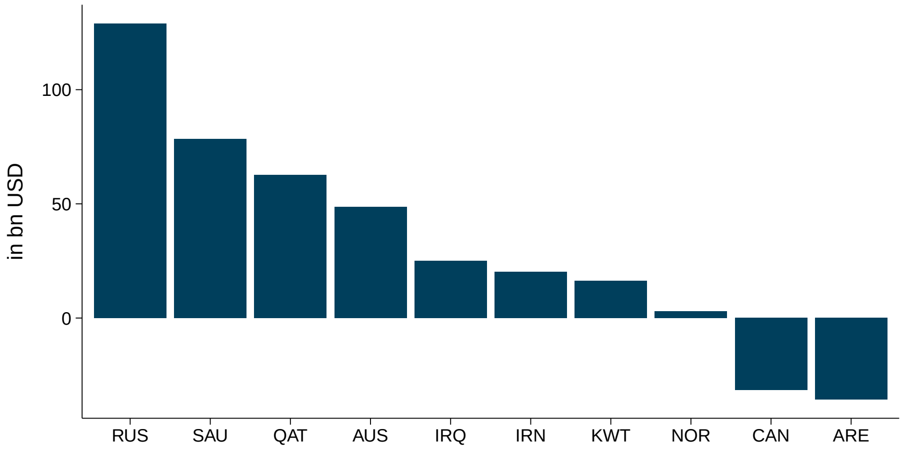
*Note:* Figure displays the 20 fossil fuel net-importers with the largest trade imbalances (Source: GTAP 11).

imbalances were a short-lived phenomenon, potential emission implications would be of little concern. This year's surpluses would turn into next year's deficits and a specialization pattern made possible in one year that leads to particularly high carbon emissions would be followed by a different pattern that would imply comparably low emissions. The persistence implies, however, that a high-emission global imbalance distribution could be a sustained phenomenon.

**Stylized Fact 3.** *Countries with large value deficits [surpluses] tend to import more [less] emission-intensive products than they export.*

In order to assess whether global trade imbalances are likely to drive world emissions up or down, we need to know which type of countries is running the major deficits and which type of countries is running the major surpluses. If countries that sell less carbon-intensive products internationally than they buy were the surplus countries, imbalances

Figure 4: Trade Imbalance of the 10 Largest Fossil Net-Exporters, 2017



might actually be environmentally beneficial. As Figure 3 makes clear, however, the opposite tends to be true: the imbalances are positively correlated with the relative carbon-intensity of exports.[4,5] Countries supplying "dirty" goods to the rest of world, while importing comparably clean products, tend to run surpluses. On the other hand, the countries exporting relatively "cleanly" tend to run deficits. Most clearly and most importantly, this pattern is evident for the United States and China, as we already briefly discussed in the introduction. The (far from perfect) separation into clean deficit and dirty surplus countries suggests that today's global trade imbalances may contribute to upholding a trade pattern that implies higher carbon emissions than would prevail in a world of balanced trade.

**Stylized Fact 4.** *Many large fossil fuel exporters are consistently running strong trade surpluses.*

The relative carbon intensity of a country's production vs. consumption is not the only dimension that determines how the country's trade surplus or deficit impacts carbon emissions. Importantly, international trade is not only about products of varying carbon intensities, but it's also about the products, the use of which *causes* carbon emissions,

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[4] The relative carbon-intensity of exports is calculated by subtracting the country's carbon intensity per imported USD from its carbon intensity per exported USD.

[5] Note that Figure 3 only shows countries that are net fossil fuel importers. As discussed in the introduction, fossil fuel exporters' imbalances likely play a special role and they are therefore considered in a separate stylized fact below. Considering the 20 countries with the largest imbalance (including net fuel exporters) lowers the correlation from 0.34 to 0.25.

namely fossil fuels. If countries that are rich in fossil resources (and hence have large extraction footprints) run trade surpluses, this has the potential to drive up the global supply of fossil fuels and in turn the global level of emissions. As Figure 4 shows, this is exactly the case for many of the world's largest fossil fuel net-exporters.[6] Out of the top ten, eight countries have a trade surplus in 2017, which are partly huge in relation to these countries' overall GDPs.[7] It seems, therefore, that current global trade imbalances may contribute to high carbon emissions in a second way, namely by fostering the global supply of fossil fuels.

To sum up, we have shown that international trade is highly unbalanced both in value and in embodied emissions terms. While this need not be bad news for global emission levels, the fact that there are positive associations between running a trade surplus and both exporting fossil-fuel intensive products and exporting fossil fuels, there is strong reason to suspect that today's global imbalances are indeed driving up global carbon emissions and — given the persistence of the observed imbalances — will continue to do so. To quantitatively assess *the carbon footprint of global trade imbalances*, however, we need to take into account the equilibrium adjustments that would result from a global re-balancing. In the following section, we present a model that will allow us to simulate such a re-balancing.

# 3 Model

We build a Ricardian quantitative trade model a la Eaton and Kortum (2002, henceforth EK), which incorporates a sectoral structure with input-output linkages, trade imbalances, and carbon emissions from fossil fuel combustion. It closely follows the sectoral extension of EK by Caliendo and Parro (2015, henceforth CP), but additionally includes fossil fuel extraction and carbon emissions from fossil fuel combustion in the production of other goods or for final consumption. As an environmental extension of the framework by CP, the model is also closely related to Shapiro (2021), Caron and Fally (2022), and Klotz and Sharma (2023).

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[6] Based on GTAP 11. Fossil exports are calculating by summing up the export values of the *coal, oil, natural gas* and *petroleum* sectors.

[7] Qatar's trade surplus is as high as 38 percent of their GDP, followed by Kuwait (13 percent), Saudi Arabia (11 percent) and Russia (8 percent).

As our focus is on the effect of changes in trade imbalances (as in Dekle, Eaton, and Kortum, 2007, 2008), we will keep the expressions as simple as possible by not considering tariffs as in CP or other policy variables that would allow explicit climate policies (such as a carbon tax).

## 3.1 Preferences

There is a set of countries $\mathcal{N}$, denoted by $i$ and $n$, and a set of sectors $\mathcal{J}$, indexed by $j$ and $k$. Both primary and secondary fossil fuel sectors are part of $\mathcal{J}$ and the distinction between the different types of sectors will be discussed further below. In each sector, there is a continuum of goods $\omega^j \in [0,1]$. Households in $n$ obtain utility from consumption $C$ according to a two-tier Cobb-Douglas utility function:

$$u_n = \prod_{j \in \mathcal{J}} \left( \exp \int_0^1 \ln C_n(\omega^j) d\omega^j \right)^{\alpha_n^j}$$

where $\alpha$ is the constant sectoral expenditure share, $\sum_{j \in \mathcal{J}} \alpha_n^j = 1$. Note that the choice of a lower-tier Cobb-Douglas instead of a more general CES utility function does not affect any results and is solely motivated by the attempt to keep parameters to the necessary minimum (see Eaton and Kortum, 2012, for the corresponding comparison in the one-sector EK framework). While the aggregation of utility from different varieties *within* one sector is the same for all countries, expenditures shares *across* sectors vary between countries, allowing for differently emission-intensive consumption patterns. This flexibility is crucial as the trade deficit or surplus of a country that consumes a lot of fossil fuels or products that require high fuel input in production will have different emission implications than the deficit or surplus of a country with a high share of e.g. clean services expenditure.

## 3.2 Production

There are three types of sectors that are all part of the overall set $\mathcal{J}$: primary fossil fuels ($p \in \mathcal{P}$), secondary fossil fuels ($s \in \mathcal{S}$), and ordinary sectors ($o \in \mathcal{O} = \mathcal{J} \setminus \{\mathcal{P}, \mathcal{S}\}$). Primary fossil fuels are the fuels extracted from the earth, secondary fossil fuels are the ones burnt in production or consumption. The two may but do not have to coincide and the sets $\mathcal{P}$ and $\mathcal{S}$ therefore overlap, but are not identical. E.g. in the case of coal, what is extracted and what is used at later points is the same, while for oil, we distinguish the primary sector raw oil and the secondary sector petroleum.

All goods are produced using labor $l$ and composite intermediate input bundles $m$ from the own and other sectors. In all sectors, countries differ in their productivity for different goods from the continua, inversely captured by the input requirement $a$, and in the input cost shares $\gamma$. Primary fossil fuel sectors additionally use a sector-specific natural resource input $r^p$, which we think of as the different types of fossil fuel reserves. Secondary fossil fuel sectors that are not also primary sectors are linked to one specific primary fossil fuel sector (which we will index by $p^s$) in requiring a fixed quantity input from it, with the relative physical inputs shares for the primary fuel and other inputs determined by two additional technology parameters $\nu^{p^s}$ and $\nu^s$. Intuitively, e.g. one liter of petroleum cannot be produced without a fixed quantity of raw oil. Other than the latter Leontief component, the production technologies are Cobb-Douglas and hence given by:

$$
\begin{aligned}
q_n(\omega^o) &= [a_n(\omega^o)]^{-1} \left[l_n(\omega^o)\right]^{\gamma_n^{l,o}} \prod_{j\in\mathcal{J}} \left[m_n^j(\omega^o)\right]^{\gamma_n^{j,o}} \quad \forall o \in \mathcal{O}, \\
q_n(\omega^p) &= [a_n(\omega^p)]^{-1} \left[r_n^p(\omega^p)\right]^{\gamma_n^{r,p}} \left[l_n(\omega^p)\right]^{\gamma_n^{l,p}} \prod_{j\in\mathcal{J}} \left[m_n^j(\omega^p)\right]^{\gamma_n^{j,p}} \quad \forall p \in \mathcal{P}, \\
q_n^s(\omega^s) &= [a_n(\omega^s)]^{-1} \times \min\left\{ \nu_n^{p^s} m_n^{p^s}, \nu_n^s \left[l_n(\omega^s)\right]^{\tilde{\gamma}_n^{l,s}} \prod_{j\in\mathcal{J}\setminus\{p^s\}} \left[m_n^j(\omega^s)\right]^{\tilde{\gamma}_n^{j,s}} \right\} \quad \forall s \in \mathcal{S}\setminus\mathcal{P},
\end{aligned}
$$

with $\gamma_n^{l,o}+\sum_{j\in\mathcal{J}}\gamma_n^{j,o}=1$, $\gamma_n^{r,p}+\gamma_n^{l,p}+\sum_{j\in\mathcal{J}}\gamma_n^{j,p}=1$, and $\tilde{\gamma}_n^{l,s}+\sum_{j\in\mathcal{J}\setminus\{p^s\}}\tilde{\gamma}_n^{j,s}=1$. Note that we distinguish $\tilde{\gamma}$ to indicate that these are not the overall cost shares in the exclusively secondary fossil fuel sectors. We still refer to the actual cost shares in this sector by $\gamma$, too, but note that they are endogenous in these sectors and will react to changes in the relative price of the primary fossil input compared to the remaining inputs. The intermediate input bundles are themselves Cobb-Douglas composites[8]:

$$m_n^j = \exp \int_0^1 \ln d_n(\omega^j) d\omega^j,$$

where $d_n(\omega^j)$ are the demands for the specific varieties $\omega^j$ as intermediate inputs. Unit costs (which equal the price due to perfect competition and constant returns to scale) in the ordinary, primary fossil fuel and secondary fossil fuel sectors are given by $c_n^o a_n(\omega^j)$, $c_n^p a_n(\omega^p)$, and $c_n^s a_n(\omega^s) \forall s \notin \mathcal{P}$, where the cost of the input bundles are given by

$$c_n^o = \Upsilon_n^o \left[w_n\right]^{\gamma_n^{l,o}} \prod_{j \in \mathcal{J}} \left[P_n^j\right]^{\gamma_n^{j,o}} \quad \forall o \in \mathcal{O}, \tag{1}$$

$$c_n^p = \Upsilon_n^p \left[p_n^{r^p}\right]^{\gamma_n^{r,p}} \left[w_n\right]^{\gamma_n^{l,p}} \prod_{j \in \mathcal{J}} \left[P_n^j\right]^{\gamma_n^{j,p}} \quad \forall p \in \mathcal{P}, \tag{2}$$

$$c_n^s = \frac{P^{p^s}}{\nu_n^{p^s}} + (\nu_n^s)^{-1} \Upsilon_n^s \left[w_n\right]^{\tilde{\gamma}_n^{l,s}} \prod_{j \in \mathcal{J} \setminus \{p^s\}} \left[P_n^j\right]^{\tilde{\gamma}_n^{j,s}} \quad \forall s \in \mathcal{S} \setminus \mathcal{P}, \tag{3}$$

where $\Upsilon_n^o = (\gamma_n^{l,o})^{-\gamma_n^{l,o}} \prod_{j \in \mathcal{J}} (\gamma_n^{j,o})^{-\gamma_n^{j,o}}$, $\Upsilon_n^p = (\gamma_n^{r,p})^{-\gamma_n^{r,p}} (\gamma_n^{l,p})^{-\gamma_n^{l,p}} \prod_{j \in \mathcal{J}} (\gamma_n^{j,p})^{-\gamma_n^{j,p}}$, $\Upsilon_n^s = (\tilde{\gamma}_n^{l,s})^{-\tilde{\gamma}_n^{l,s}} \prod_{j \in \mathcal{J} \setminus \{p^s\}} (\tilde{\gamma}_n^{j,s})^{-\tilde{\gamma}_n^{s,o}}$, $w$ denotes the wage, $P$ the price of a composite intermediate bundle, and $p^{r^p}$ is the price of a specific fossil resource factor. Input requirement coefficients in all sectors are assumed to be drawn from type-III extreme value (Weibull) distributions, i.e. $Pr[a_n(\omega^j) \leq a] = 1 - \exp(-(A_n^j a)^{\theta^j})$, where $A$ is a location parameter capturing a country's overall technology level in a sector capturing (the productivity component of) comparative advantage across sectors and $\theta$ is a dispersion parameter (inversely) capturing the extent of comparative advantage differences within sectors.[9]

Importantly, the production structure implies that countries not only differ in their productivities, but also in the extent to which they rely on fossil fuel inputs in producing different goods. Just as the differences in the "greenness" of consumption, this can have important implications for how a country's trade surplus/deficit affects global emissions: it can enable "dirty" (i.e. fossil fuel intensive) producers to serve a larger share of global

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[8] Note that just as in the utility function, this could be generalized to a CES composite without changing any of the final results.

[9] Note that both EK and CP equivalently have countries draw productivities from a type-II extreme value (Frechet) distribution instead. We follow Eaton and Kortum (2012) here and use the original Ricardian technology measure of input requirements.

demand or it can help them cover more of their own demand with cleaner products from abroad. Note also the two-layer structure of comparative advantage: the probabilistic EK notion of comparative advantage determines which countries produce which products *within* sectors and additionally, comparative advantage *across* sectors as determined by sectoral productivities and input costs determines which countries specialize into production in which sectors. Crucially, in the primary fossil fuel sector, factor endowment differences enter as another source of comparative advantage, complementing the otherwise Ricardian trade structure in the model with a Heckscher-Ohlin component.

How can international trade allow emission-relevant specialization patterns in our model then? In one important dimension, countries can specialize in producing fossil fuel intensive goods vs. products that rely on less fossil fuel inputs — with different implications for the consequences of the countries' trade imbalances on emissions. In a second dimension, countries can specialize in ordinary goods or in the *production* of fossil fuels. If countries of this latter (fossil resource abundant) type run a trade surplus, this increases global fossil fuel supply and hence drives up global emissions, pointing to a potentially problematic role of imbalances of fossil fuel exporters.

## 3.3 International Trade

### 3.3.1 Gravity

Both consumers and producers source the goods they buy from the lowest-cost supplier. International trade faces iceberg trade costs $t^j_{ni}$, i.e. $t$ units have to be shipped to deliver one unit from $i$ to $n$. The cost distribution for country $i$ delivering goods to country $n$ depend on $i$'s productivity and input costs, as well as on bilateral frictions between $i$ and $n$ and is given by

$$Pr[c_{ni}(\omega^j) \leq c] = 1 - e^{-(A^j_{ni}c)^{\theta^j}},$$

with $A^j_{ni} = A^j_i/(t^j_{ni}c^j_i)$. Country $i$ is hence likelier to be able to provide goods at a low price to $n$ if (i) its overall productivity in the respective sector is high (large $A$), (ii) its input costs are low (small $c$), and/or (iii) its trade costs with $n$ are low (small $t$).

Under perfect competition, producers price at their costs. The price at which consumers and producers in country $n$ end up buying a good $\omega$ is the minimum price across the bilateral cost distributions just shown. The resulting price distribution inherits the Weibull form from the technology and cost distributions and is given by:

$$F^j_n(p) = 1 - e^{-(\bar{A}^j_n p)^{\theta^j}}, \quad \text{with} \quad \bar{A}^j_n = \left[\sum_{i\in\mathcal{N}} (A^j_{ni})^{\theta^j}\right]^{1/\theta^j}.$$

$\bar{A}$ summarizes how the three price influences (technology, input costs, and geography as captured by the trade costs) *all around the world* shape the price level in a country. Specifically, we can obtain sectoral price indices by integrating over the price distributions:

$$P^j_n = \exp\left(\int_0^\infty \ln(p) dF^j_n(p)\right) = \frac{\exp(-\varepsilon/\theta^j)}{\bar{A}^j_n}, \tag{4}$$

where $\varepsilon = 0.5772\ldots$ is Euler's constant. Note that the possibility of non-tradable sectors is implicitly also captured. In these non-tradable sectors, trade costs are prohibitively high ($t^j_{ni} = \infty$) and the price hence simplifies to $P^j_n = \exp(-\varepsilon/\theta^j)/A^j_{nn}$.

Country $n$'s total spending on goods from sector $j$ is $X^j_n$. The share of this expenditures that is spent on goods from country $i$ equals the share in which $i$ is the lowest cost supplier and is given by a sectoral version of the EK gravity expression[10]:

$$\pi^j_{ni} = \frac{X^j_{ni}}{X^j_n} = \left(\frac{A^j_{ni}}{\bar{A}^j_n}\right)^{\theta^j}. \tag{5}$$

International trade links carbon emissions across countries in a direct and an indirect way. Directly, countries with a comparative advantage in fossil fuel intensive goods will specialize in the production of these goods, emit more $CO_2$, and tend to implicitly export more emissions to other countries than importing from them. Indirectly, emissions in different countries are additionally linked because the fossil fuels causing them are themselves traded. Lower (higher) demand for fossil fuels in one country will drive down (up) the price for fossil fuels and hence on the one hand incentivize other countries to produce more (less) fossil fuel intensively, but on the other hand incentivize fossil resource-abundant countries

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[10] As described in EK, this share can be calculated as the probability that $i$ has the lowest costs of delivering a good $\omega$ to $n$: $Pr[c_{ni}(\omega^j) \leq \min\{c_{ns}(\omega^j); s \neq i\}] = \int_0^\infty \prod_{s\neq i}[\exp(-(A^j_{ns}c)^{\theta^j})]d(\exp(-(A^j_{ni}c)^{\theta^j}))$. To move to EK's explicit gravity equation for trade *flows*, multiply the trade shares with the destination country's total sectoral expenditure, solve the market clearing condition for $(A^j_i/c^j_i)^\theta$, substitute the expression into (5) and simplify using (4).

to extract less (more) fossil fuels from the ground.

### 3.3.2 Trade balance

Total expenditures for sector $j$ combines expenditure on intermediate bundles and for final consumption:

$$X_n^j = \sum_{k \in \mathcal{J}} \gamma_n^{j,k} \sum_{i \in \mathcal{N}} X_i^k \pi_{in}^k + \alpha_n^j I_n, \tag{6}$$

where the final absorption $I_n$ consists of labour income (given by the total labour endowment $L_n$ times the wage), resource income from the different types of fossil resources (given by the respective endowments $R_n^p$ times the resource prices) and the trade deficit ($D_n$):

$$I_n = w_n L_n + \sum_{p \in \mathcal{P}} p_n^{rp} R_n^p + D_n. \tag{7}$$

Trade is multilaterally balanced up to the exogenously given trade deficit:

$$\sum_{i \in \mathcal{N}} \sum_{j \in \mathcal{J}} \left( X_n^j \pi_{ni}^j \right) - D_n = \sum_{i \in \mathcal{N}} \sum_{j \in \mathcal{J}} \left( X_i^j \pi_{in}^j \right). \tag{8}$$

International trade allows countries to decouple their production and consumption patterns. They can specialize in producing certain varieties and they can focus their production on the sectors in which they have a comparative advantage. At the same time, they are free to still consume a product basket that is determined by their preferences rather than their comparative advantage. Just because a country extracts a lot of fossil fuels, it does not have to spend a large share of its income on these fuels. Trade balance puts a limit to the decoupling: the overall value of produced goods has to equal the overall value of the purchased ones. If a country wants to export another dollar worth of its products, it has to also import an additional dollar worth from elsewhere. With trade imbalances, the limit is softened. Up to the level of the deficit or surplus, they decouple not only *what* a country produces and buys, but also *how much*. The equilibrium effects of this further decoupling on carbon emissions are ambiguous. One country's surplus necessarily is another country's deficit. A deficit [surplus] will increase [lower] the respective country's consumption footprint. Globally, deficits in countries with "green" preferences, relatively "brown" production technologies, and large levels of production of fossil fuels will tend to lower emissions, while deficits in countries demanding fossil-intensive products that produce with small fossil input shares will tend to increase them.

## 3.4 Equilibrium

The definition of an equilibrium closely mimics the expression by CP, somewhat expanded by the presence of the fossil fuel sector and the non-constant input cost shares in a subset of these sectors.

**Definition 1.** *For given labor endowments $L_n$, resource endowments $R_n^p$, technology parameters $A_n^j$, $\theta^j$ $\gamma_n^{l,o}$, $\gamma_n^{j,o}$, $\gamma_n^{r,p}$, $\gamma_n^{l,p}$, $\gamma_n^{j,p}$, $\tilde{\gamma}_n^{l,s}$, $\tilde{\gamma}_n^{j,s}$, $\nu_n^{p^s}$ and $\nu_n^s$, trade costs $t_{ni}^j$, and trade imbalances $D_n$, an equilibrium is a set of wages $w_n$, fossil resource prices $p_n^{r^p}$, composite intermediate goods prices $P_n^j$, and input cost shares in secondary fossil fuel production $\gamma_n^{l,s}$ and $\gamma_n^{j,s}$ that satisfy conditions* (1)–(8).

### 3.4.1 Equilibrium in relative changes

Just as in CP, the determination of an equilibrium for a given policy change simplifies if, following Dekle, Eaton, and Kortum (2007, 2008), equilibrium conditions are re-expressed in terms of relative changes where possible. Denote values of any variable or parameter in the baseline equilibrium by $x$, under the counterfactual scenario by $x^{'}$, and its relative change by $\hat{x} = x^{'}/x$. Then, the equilibrium can be defined in relative changes as follows:

**Definition 2.** *Let $\{w_n, p_n^{r^p}, P_n^j, \gamma_n^{l,s}, \gamma_n^{j,s}\}$ be a baseline equilibrium for global trade imbalances $D_n$ and $\{w_n^{'}, p_n^{r^p\prime}, P_n^{j\prime}, \gamma_n^{l,s\prime}, \gamma_n^{j,s\prime}\}$ be a counterfactual equilibrium for global trade imbalances $D_n^{'}$. Then, $\{\hat{w}_n, \hat{p}_n^{r^p}, \hat{P}_n^j, \hat{\gamma}_n^{l,s}, \hat{\gamma}_n^{j,s}\}$ satisfy the following equilibrium conditions* (9a)–(15b)*:*

*Cost changes of the input bundles:*

$$\hat{c}^o_n = [\hat{w}_n]^{\gamma_n^{l,o}} \prod_{j\in\mathcal{J}} \left[\hat{P}^j_n\right]^{\gamma_n^{j,o}} \quad \forall o \tag{9a}$$

$$\hat{c}^p_n = \left[\hat{p}^{r^p}_n\right]^{\gamma_n^{r,p}} [\hat{w}_n]^{\gamma_n^{f}} \prod_{j\in\mathcal{J}} \left[\hat{P}^j_n\right]^{\gamma_n^{j,p}} \quad \forall p \tag{9b}$$

$$\hat{c}^s_n = \gamma_n^{p^s,s}\hat{P}^{p^s}_n + (1-\gamma_n^{p^s,s})\,[\hat{w}_n]^{\tilde{\gamma}_n^{l,s}} \prod_{j\in\mathcal{J}\setminus\{p^s\}} \left[\hat{P}^j_n\right]^{\tilde{\gamma}_n^{j,s}} \ \forall s \notin \mathcal{P} \tag{9c}$$

*Input cost share changes:*

$$\hat{\gamma}_n^{p^s,s} = \frac{\hat{P}^{p^s}_n}{\hat{c}^s_n} \quad \forall s \notin \mathcal{P} \tag{10a}$$

$$\hat{\gamma}_n^{l,s} = \hat{\gamma}_n^{j,s} = (\hat{c}^s_n)^{-1}\,[\hat{w}_n]^{\tilde{\gamma}_n^{l,s}} \prod_{j\in\mathcal{J}\setminus\{p^s\}} \left[\hat{P}^j_n\right]^{\tilde{\gamma}_n^{j,s}} \quad \forall s \notin \mathcal{P} \wedge j \neq p^s \tag{10b}$$

*Price index change:*

$$\hat{P}^j_n = \left[\sum_{i\in\mathcal{N}} \pi^j_{ni}\left(\hat{c}^j_i\right)^{-\theta^j}\right]^{\frac{-1}{\theta^j}} \tag{11}$$

*Bilateral trade share change:*

$$\hat{\pi}^j_{ni} = \left[\frac{\hat{c}^j_i}{\hat{P}^j_n}\right]^{-\theta^j} \tag{12}$$

*Counterfactual total expenditure by country and sector:*

$$X_n^{j'} = \sum_{k\in\mathcal{J}\setminus\{\mathcal{S}\setminus\mathcal{P}\}} \left(\gamma_n^{j,k}\sum_{i\in\mathcal{N}}\hat{\pi}^k_{in}\pi^k_{in}X_i^{k'}\right) + \sum_{s\in\mathcal{S}\setminus\mathcal{P}}\left(\hat{\gamma}_n^{j,s}\gamma_n^{j,s}\sum_{i\in\mathcal{N}}\hat{\pi}^s_{in}\pi^s_{in}X_i^{s'}\right) + \alpha^j_n I_n^{'} \tag{13}$$

*Counterfactual final absorption:*

$$I_n^{'} = \hat{w}_n w_n L_n + \sum_{p\in\mathcal{P}} \hat{p}^{r^p}_n p^{r^p}_n R^p_n + D_n^{'} \tag{14}$$

*Factor price changes:*

$$\hat{p}^{r^p}_n = \frac{\gamma_n^{r,p}\sum_{i\in\mathcal{N}}\hat{\pi}^p_{in}\pi^p_{in}X_i^{p'}}{p^{r^p}_n R^p_n} \tag{15a}$$

$$\hat{w}_n = \frac{1}{w_n L_n}\left(\sum_{j\in\mathcal{J}\setminus\{\mathcal{S}\setminus\mathcal{P}\}}\left(\gamma_n^{l,j}\sum_{i\in\mathcal{N}}X_i^{k'}\hat{\pi}^k_{in}\pi^k_{in}\right) + \sum_{s\in\mathcal{S}\setminus\mathcal{P}}\left(\hat{\gamma}_n^{l,s}\gamma_n^{l,s}\sum_{i\in\mathcal{N}}X_i^{s'}\hat{\pi}^s_{in}\pi^s_{in}\right)\right) \tag{15b}$$

Note that this second equilibrium definition has the advantage that there is no need to identify the level of the technology parameters $A$ and $\nu$ and of the bilateral trade frictions $t$ anymore. Also, for the primary production factors $L$ and $R^p$, information on the baseline income earned from them is sufficient rather than separate information on their quantities and prices. Further note that rather than simply restating the counterfactual counterpart of (8) in our depiction of the equilibrium in changes, we directly translate trade balancing into the implied changes of the factor prices in order to have the equations exactly coincide with the ones used in our solution algorithm, which simply iterates over equations (9a)–(15a), with a dampening factor included in the factor price updates.[11] Finally note that in order to keep the expressions as simple as possible, we only consider exogenous changes in trade balances. Naturally, e.g. counterfactual trade cost changes could readily be incorporated.

## 3.5 Carbon Emissions

### 3.5.1 Territorial emissions / Production footprints

Carbon emissions stem from fossil fuel combustion and are therefore modeled to be proportional to the usage of the secondary fossil fuel composite, either as an intermediate in production or in final consumption, weighted by the varying carbon intensities $\iota^s$ of the different fossil fuel types. Classic national emissions (i.e. production footprints) are hence given by

$$E_n = \sum_{s \in \mathcal{S} \setminus \mathcal{P}} \frac{\iota^s X_n^s}{P_n^s} + \sum_{p \in \mathcal{P} \cap \mathcal{S}} \frac{\iota^p (X_n^p - \gamma_n^{p,s^p} Y_n^{s^p})}{P_n^p}, \tag{16}$$

where $s^p$ is defined analogous to $p^s$ above as the secondary fossil fuel factor $s$ that uses primary fossil fuel $p$ as its necessary input and $Y_n^{s^p} \equiv \sum_i \pi_{in} X_i^{s^p}$ is $n$'s total production in this secondary fossil fuel sector. The second part of (16) accounts for the fact that gas inputs into the "gas distribution" sector are not actually burnt and cause emissions at this stage, but only turns into $CO_2$ once the output from the "gas distribution" sector is consumed or used as an input in a different sector. Subtracting this part of the demand for the respective primary fossil fuel sector hence avoids a double-counting of emissions.

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[11] As the equilibrium is only defined up to a a normalization, we adjust factor prices in each iteration in such a way as to keep global nominal factor income constant.

Note that the territorial emissions that we denote as production footprints as part of our footprint trinity in fact also contain a consumption component which stems from the combustion of fossil fuels in final consumption (think of car fuel, for example).

### 3.5.2 Consumption footprints

With international trade, territorial emissions (i.e. production footprints) generally don't coincide with the amount of emissions embodied in the products *consumed* in a country. Our model including input-output linkages across sectors and countries allows us to track emissions along the whole global value chain and contrast territorial emissions to a country's consumption footprint, which is given by:

$$CF_n = \sum_{s\in\mathcal{S}} \underbrace{\iota^s[\check{\boldsymbol{\gamma}}^{s,\cdot} \oslash \mathbf{P}^s]'}_{\text{emission intensity}} \underbrace{[\mathbf{I}-\mathbf{A}]^{-1}}_{\text{Leontief Inverse}} \underbrace{[\boldsymbol{\pi}_n \odot \boldsymbol{\alpha}_n I_n]}_{\text{final demand}} + \underbrace{\frac{\iota^s \alpha_n^s I_n}{P_n^s}}_{\text{consumption emissions}}, \qquad (17)$$

where $\check{\boldsymbol{\gamma}}^{s,\cdot} = [\gamma_1^{s,1}, \ldots, \gamma_1^{s,J}, \gamma_2^{s,1}, \ldots, \gamma_N^{s,J}]'$ collects secondary fuel input shares in all sectors and countries (while avoiding double accounting of emissions by putting the respective share to zero if the secondary fossil fuel is processed further and re-sold, rather than burnt[12]), $\mathbf{P}^s = [P_1^s, \ldots, P_N^s]' \otimes \mathbf{i}_J'$ collects secondary fossil fuel prices of all countries, $\otimes$ denotes the Kronecker product, $\mathbf{i}_J$ is a unit vector of length $J$, $\mathbf{A} = \begin{pmatrix} \mathbf{A}_{11} & \ldots & \mathbf{A}_{N1} \\ \cdot & \cdot & \cdot \\ \mathbf{A}_{1N} & \ldots & \mathbf{A}_{NN} \end{pmatrix}$ is the global input coefficient matrix, $\mathbf{A}_{in} = \begin{pmatrix} \gamma_i^{1,1}\pi_{in}^1 & \ldots & \gamma_i^{1,J}\pi_{in}^1 \\ \cdot & \cdot & \cdot \\ \gamma_i^{J,1}\pi_{in}^J & \ldots & \gamma_i^{J,J}\pi_{in}^J \end{pmatrix}$ is a bilateral input coefficient matrix, $\boldsymbol{\pi}_n = [\pi_{n1}^1, \ldots, \pi_{n1}^J, \pi_{n2}^1, \ldots, \pi_{nN}^J]'$ collects country $n$'s trade shares with all partners and in all sectors, $\boldsymbol{\alpha}_n = [\alpha_n^1, \ldots, \alpha_n^J]' \otimes \mathbf{i}_N'$ collects country $n$'s consumption shares across sectors, and $\oslash$ and $\odot$ denote element-wise division and multiplication, respectively. If a country e.g. uses a lot of steel, but does not produce it itself, this will drive up the consumption footprint, but not the production footprint. The calculation of the consumption footprint will also take into account whether this steal is sourced from countries with a dirty, e.g. coal-intensive, or a cleaner energy mix.

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[12] Recall the discussion of gas inputs into the "gas distribution" sector above.

### 3.5.3 Extraction footprints

Territorial emissions and consumption footprints are the two common ways of carbon accounting. In line with Kortum and Weisbach (2021), we also consider a third dimension. Specifically, besides where the fossil fuels are burnt and where the products end up being consumed, we consider where the fossil fuels themselves originate from. We refer to this third way of carbon accounting as extraction footprints and they are given by:

$$EF_n = \sum_{p \in \mathcal{P} \cap \mathcal{S}} \iota^p \sum_{i \in \mathcal{N}} \frac{\pi_{in}^p (X_i^p - \gamma_i^{p,s^p} Y_i^{s^p})}{P_i^p} + \sum_{s \in \mathcal{S} \setminus \mathcal{P}} \sum_{i \in \mathcal{N}} \pi_{in}^{p^s} \iota^s \sum_{m \in \mathcal{N}} \frac{\pi_{mi}^s X_m^s}{P_m^s}. \tag{18}$$

The first part corresponds to the primary fossil fuels that are at the same time secondary fossil fuels, i.e. that are directly burnt as part of the production process of other goods. Here, we simply need to know which quantity of the fuel a country sells overall and how carbon-intensive the fuel is (and to account for the fact that part of the input use is not actually burnt in the process, but is used as an input in the "complimentary" secondary fuel sector). The second summand corresponds to the primary fossil fuels that are used as an input for a different, secondary fossil fuel which then goes on in a further step to be burnt and actually cause the carbon emissions. We don't attribute these secondary fossil fuels' emissions to the secondary producer (i.e. for example to the country where the oil refinery is located), but trace them back to where the primary fuel originated from (i.e. where for example the raw oil was extracted). For this second part, we obtain in the last sum (over $m$) the total sales of the solely secondary fossil fuels of country $i$. We can translate them into emissions using the emission intensity $\iota$ and they are connected to the corresponding primary fuel in a fixed way due to the Leontief component of the production structure. Knowing which share of the primary fuel was sourced from country $n$ is therefore equivalent to knowing which part of the emissions from $i$'s secondary fuels $s$ can be traced back to the extraction of country $n$.

## 3.6 Counterfactual Scenarios

The primary counterfactual analysis will consider the complete elimination of trade imbalances, i.e. a scenario in which $D_n^{'} = 0 \ \forall \ n$. Additionally, we will also consider what happens if only a specific individual country $n$ eliminates its deficit or surplus. In this case, we need to make sure that world trade remains balanced. Specifically, if $n$ was a surplus country initially, we calculate its share in the surpluses over all surplus countries. In the counterfactual scenario, we put its surplus to zero and lower all deficit countries' deficit by $n$'s baseline share of the global surpluses. If $n$ was a deficit country, we obtain its deficit share out of all trade deficits and proceed accordingly.

# 4 Data

To simulate the effects of a (simultaneous) removal of trade imbalances in general equilibrium, we need to identify the model parameters. Consumption shares and input coefficients ($\alpha$, $\beta$, and $\gamma$), as well as bilateral trade shares ($\pi$), labor income ($wL$), fossil resource income ($p^{r^p} R^p$), and initial trade imbalances ($D$) are obtained from input-output tables. Sectoral dispersion parameters ($\theta$) are taken from the online database of Fontagné, Martin, and Orefice (2018).[13] For the service sectors we rely on estimates of Egger, Larch, and Staub (2012).

**Data Source**

The main input for our simulation comes from the GTAP 11 database (Aguiar, Chepeliev, Corong, and van der Mensbrugghe, 2022). The data supplies the model with all information that is needed from input-output tables ($\alpha$, $\beta$, $\gamma$, $\pi$, $wL$, $p^{r^p} R^p$, $D$) for the year 2017.[14] We also calculate carbon intensities of different fossil fuel types ($\iota$) from the database. We choose GTAP because of its rich geographical (141 countries and 19 aggregated regions) and sectoral (65 sectors) coverage. It includes 5 fossil sectors (coal, oil, gas, petroleum and coal products, gas manufacture and distribution). For a full list of all countries see Appendix A.

# 5 Results

Quantitative trade models à la Eaton and Kortum (2002) allow the investigation of counterfactual scenarios, taking into account full general equilibrium effects. We use the model

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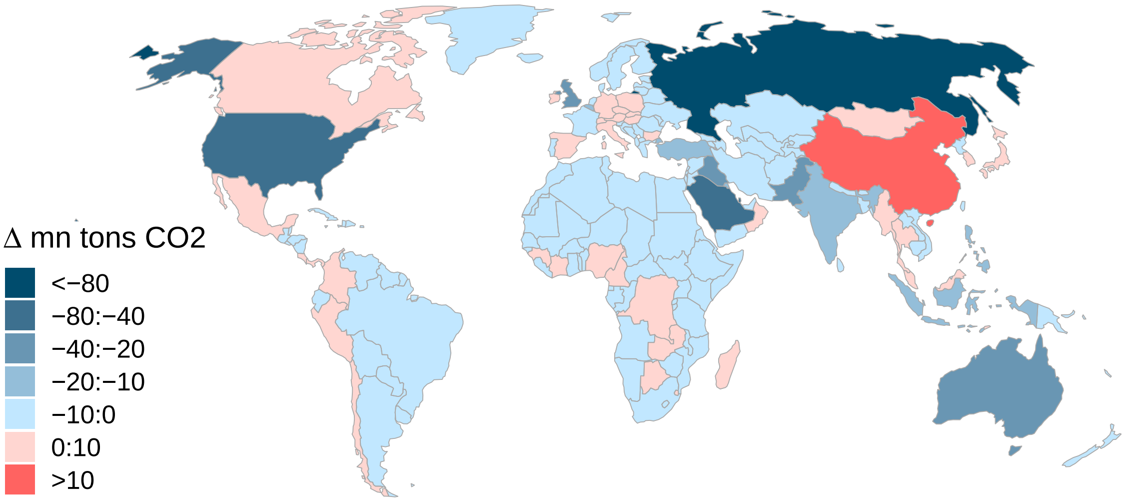
[13] Their GTAP 10 estimates are from October 2020 and can be found on their website.

[14] This is the most recent year for which input-output data for 160 countries/regions is available. We do not predict baseline values for some future year since this would introduce additional margins of error.

Figure 5: Change in Global Carbon Emissions from the Removal of the Corresponding Country's Trade Imbalance, Each Country Balanced Separately



presented in Section 3 to conduct scenarios in which we — partly or fully — re-balance global trade. We first simulate the elimination of an individual country's imbalance for each country separately in turn. Afterwards, we analyze the case of globally balanced trade, i.e. of a simultaneous elimination of all trade imbalances.[15]

## 5.1 Balancing Individual Country's Trade Separately

In this section, we conduct a set of counterfactual experiments, in which we always set one country's trade imbalance to zero. For the removed trade imbalance of a single country the value of their imbalance is subtracted from the imbalances of the remaining 159 countries to ensure that world supply still equals world demand. If the single country has a trade surplus the imbalances of trade deficit countries are reduced proportionally,[16] leaving the values of the other trade surplus countries unchanged. This is done vice versa if the single country has a trade deficit. As each country's individual trade re-balancing is separately considered here, this leads to 160 different counterfactuals.

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[15] Please note that the presented results are still preliminary and based on a simplified version of the model presented in Section 3, featuring the full input-output structure, but a single factor and Cobb-Douglas production functions in all sectors.

[16] If the trade surplus of a single country accounts for 2 percent of all trade deficits, the trade imbalance of each deficit country is reduced by 2 percent.

Figure 5 shows the change of global carbon emissions for all 160 counterfactuals. The value of each country represents the change in global carbon emission in the scenario where the respective country's imbalance is removed.[17] Generally and in line with our expectations based on the stylized facts established in Section 2, we find that eliminating country-level trade imbalances is environmentally beneficial in most cases. For 77.5 percent of countries, trade re-balancing leads to lower global emissions. For those countries, where re-balancing leads to an increase of global emissions, this increase is far smaller than the strongest decrease we see for countries like Russia or the US.

The large effect on global emissions resulting from an elimination of the huge US trade deficit fits the intuition described in the stylized facts and in the model section. The US not only import more than they export, but they also import clearly more carbon-intensive products. Taking away the United States' possibility to sustain parts of their immense consumption footprint by consistently running a deficit indeed leads to a lower-emission new global production and consumption pattern. Specifically, global CO2 emissions would go down by 78 Mt or 0.24 percent.[18] This is roughly equivalent to Bangladesh's total annual emissions. Note that the global emission reduction in response to a US re-balancing does not mostly stem from lower US territorial emissions. The US in fact decreases its production footprint by 27 Mt, while its consumption footprint falls much more drastically by 324 Mt percent and a larger share of the global reduction hence comes from countries that previously served the US market with carbon-intensive products to larger extents or from countries that are indirectly affected from the global reshuffling of the international trade network resulting from the elimination of the world's largest trade deficit.[19]

The largest drop in global emissions results from the elimination of the Russian trade surplus. Bringing down Russia's 118 billion US-Dollar surplus to zero would lower global emissions by 113 Mt or 0.35 percent. This is roughly equivalent to Venezuela's total annual emissions. The Russian example is linked to our final stylized fact on fossil fuel exporters running surpluses and the corresponding concern that this type of imbalance fosters global fossil fuel supply and therefore global emissions. Taking away the Russian

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[17] For the exact values of the change in global carbon emissions see the second column of Table B1 in the Appendix.

[18] All emission quantities refer to CO2 emissions only and to the model base year 2017.

[19] For a graphical representation of all countries' production, consumption, and extraction footprint changes in reponse to a US re-balancing, see Figure B2 in the Appendix.

surplus reduces Russia's possibility to maintain its very large extraction footprint. Indeed, the Russian extraction footprint drops strongly by 249 Mt when Russian trade is re-balanced. The reduction in Russian production emissions is much less pronounced (33 Mt) and the Russian consumption footprint actually increases strongly (by 105 Mt). The global reduction hence results mostly from other countries burning less Russian fossil fuels and consuming goods that have less Russian fossil fuels embodied in them.[20]

Taking a further look at which countries' trade re-balancing lowers global emissions, the role of fossil fuel exports becomes even more evident: out of the top six countries, only the US has an initial deficit, while in all other cases the emission reductions result from bringing down surpluses of high-extraction footprint fossil fuel exporters, namely Russia, Qatar (53 Mt world emission reduction), Saudi-Arabia (46 Mt), Iraq (31 Mt) and Australia (26 Mt).

In many cases, in which re-balancing a country's trade leads to higher global emissions, this is also perfectly in line with our expectations. Take for example Canada: it is the world's eight largest fossil fuel exporter and it has a trade deficit. If Canada needs to earn every dollar it wants to spend on imports by selling exports, it does so by extracting and selling more fossil fuels. Or take Germany: German imports are more carbon-intensive than its exports, but it doesn't import as much as it could actually afford. Closing the German spending gap considerably drives up the German consumption footprint.

One case that is not straightforwardly in line with the expectations is the Chinese re-balancing. Just as Germany, China has a strong trade surplus, but different from Germany, Chinese exports are more emission-intensive than its imports. Intuitively, limiting China's role as a pollution haven for other countries' emission-intensive consumption by erasing its surplus should reduce global emissions. Two factors appear to counteract the expected effect. First, Chinese consumption is very emission-intensive in absolute terms. Specifically, it is 72 percent more emission-intensive than the global average. Even though its exports are even dirtier, it is globally emission-increasing if China increases its consumption. In line with this effect, the Chinese consumption footprint increases dramatically by 263 Mt. Second, we need to keep in mind general equilibrium adjustments of the global trade system. As Chinese demand increases, Chinese producers will focus to

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[20] For a graphical representation of all countries' production, consumption, and extraction footprint changes in reponse to a Russian re-balancing, see Figure B3 in the Appendix.

a larger extent on serving the domestic market. Countries that previously sourced large amounts from China will have to consider alternative suppliers. While Chinese production is relatively emission-intensive, alternative sources may be even dirtier, implying that the shift leads to higher overall emissions.

The patterns in Figure 5 are of course driven to a considerable amount by the sheer size of national trade imbalances. To make effects more comparable across countries, we calculate the change in global emissions per million dollar trade imbalance.[21] This metric indicates e.g. that while the US trade deficit has a huge carbon footprint in absolute terms, it is not particularly dirty in relative terms — the large effect is primarily driven by the magnitude of the deficit.

We can use this standardized measure of the countries' imbalances' carbon footprints to evaluate more systematically how a country's emission and trade patterns determine whether its trade re-balancing increases or lowers global emissions. Specifically, we separately run the following regression for surplus and deficit countries:

$$\frac{\sum_n E_n^{'} - E_n}{D_i} = \beta_0 + \beta_1 \frac{CF_i}{E_i} + \beta_2 \frac{EF_i}{E_i} + \varepsilon_i, \tag{19}$$

where $E_n^{'}$ refers to the counterfactual emissions in case country $i$'s trade is re-balanced (i.e. $D_i^{'} = 0$). We hence investigate whether the relative carbon footprint of a country's imbalance is determined by it consuming more embodied emissions than it emits and/or by it extracting more fossil fuels than it burns domestically.

Column (1) of Table 1 displays the results for surplus countries. Eliminating a trade surplus is less environmentally beneficial, if the country consumes more embodied carbon relative to how much it emits and more beneficial if the country extracts more fossil fuels relative to how much it burns. Think of the German example as an illustration of the former and the Russian example as an illustration of the latter effect. The regression makes clear that these cases are part of a systematic pattern.

The opposite pattern emerges for deficit countries, as shown in column (2). Eliminating a trade deficit is more environmentally beneficial if the country consumes more embodied carbon relative to how much it emits and more beneficial if the country extracts more

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[21] See Figure B1 in the Appendix for a graphical representation.

Table 1: Change in global emissions per rebalanced trade balance

| | (1) | (2) |
|---|---|---|
| $CF/E$ | 162.879** | −77.194* |
| | (59.147) | (32.100) |
| $EF/E$ | −57.660*** | 96.363*** |
| | (8.377) | (13.678) |
| Obs. | 59 | 101 |
| $R^2$ | 0.506 | 0.374 |

+ $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

*Note:* Dependent variable: Change in global emissions in ton CO2 per re-balanced absolute trade balance in mn USD. $CF$: Consumption footprint. $EF$: Extraction footprint. $E$: Production footprint. Column (1): Subset of countries with a trade surplus. Column (2): Subset of countries with a trade deficit.

fossil fuels relative to how much it burns. The US and the Canadian deficits illustrate these systematic patterns.

Hence, in line with the mechanisms described in the model section, from an environmental point of view, trade surpluses of countries with a relatively high consumption footprint and trade deficits of countries with a relatively high extraction footprint are desirable, while deficits of countries with a relatively high consumption footprint and surpluses of countries with a relatively high extraction footprint are undesirable. We have seen that the majority of actual trade imbalances fall into an undesirable category and their individual removal would therefore lower global emissions.

## 5.2 Balancing all Countries' Trade Simultaneously

In our next counterfactual scenario, we set the trade imbalances of all 160 countries and regions simultaneously to zero. Given the trade imbalance patterns established in Section 2, as well as the insights from the re-balancing of individual countries' international trade, we clearly expect that a global re-balancing will lower world emissions. However, it is clear that the exact implications of this large shock on the world trade network cannot be inferred from aggregating the 160 separate, smaller shocks considered in the previous subsection, but a distinct quantitative analysis is required that takes into account that effects will partly offset one another and that adjustment mechanisms will differ, when many countries simultaneously massively alter their import demand and export supply.

Overall, we find that the simultaneous removal of all trade imbalances reduces global carbon emission by 0.9 percent or 295 Mt of CO2 per year. Is this a large effect? It is approximately equivalent to the total annual emissions of Spain — the number 21 emitter of CO2 in the world. One has to keep in mind that re-balancing global trade is not primarily an environmentally motivated scenario. Compare the effect for example to the simultaneous introduction of carbon tariffs for all country pairs at a level that equalizes bilateral carbon price differentials studied by Larch and Wanner (2017): they find a much smaller global emission reduction of 0.5 percent for this explicit climate policy measure. Or to the total contribution of international trade to global carbon emissions studied by Shapiro (2016): he finds that international trade in total increases emissions by 5 percent compared to a situation of total autarky. Comparing this to our effect of a global re-balancing suggests that 18 percent of international trade's total contribution to global emissions are due to the imbalances currently characterizing world trade.

Figure 6 breaks down the global emission reduction into changes in national carbon footprints, differentiating the production, consumption, and extraction footprints.[22] Note the difference in how to read these maps in comparison to Figure 5: there, each country's colouring reported the change in *global* emissions in response to a country-level re-balancing, while now, each country's coloring reports the *national* emission change in response to a global re-balancing.

Figure 6 shows several very interesting features of the global re-balancing exercise. First, while global emissions decrease, emissions do not go down in all individual countries, and national effects are very heterogeneous. This is true regardless of which of the three accounting types we consider.

Second, the three footprints don't necessarily move in the same direction for the same country. The United States for example dramatically reduces its consumption footprint and also reduces, though much less strongly, its production footprint. However, it reacts to not being able to source as much fossil fuels from abroad anymore by extracting more fuels domestically, i.e. it increases its extraction footprint considerably. Russia, on the other hand, spends much more and hence considerably increases its consumption footprint.

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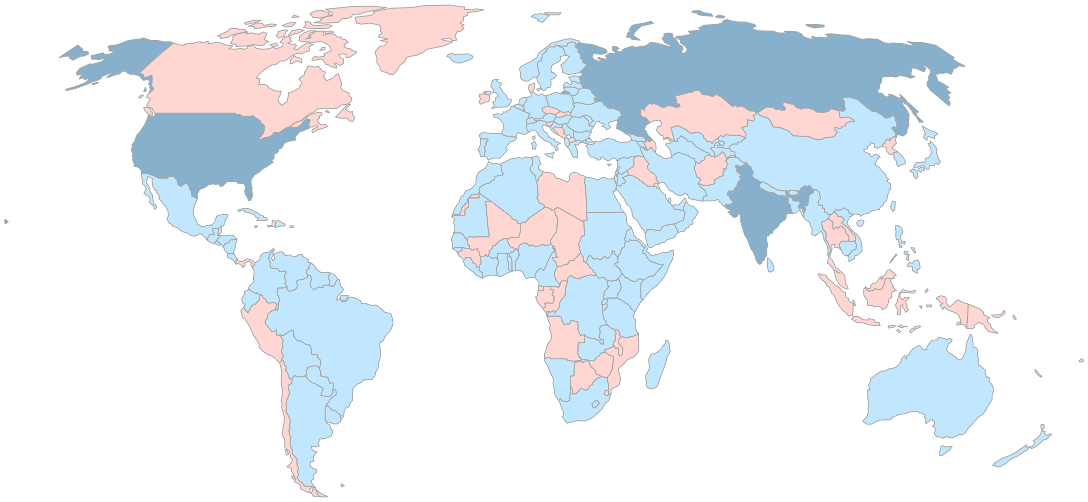
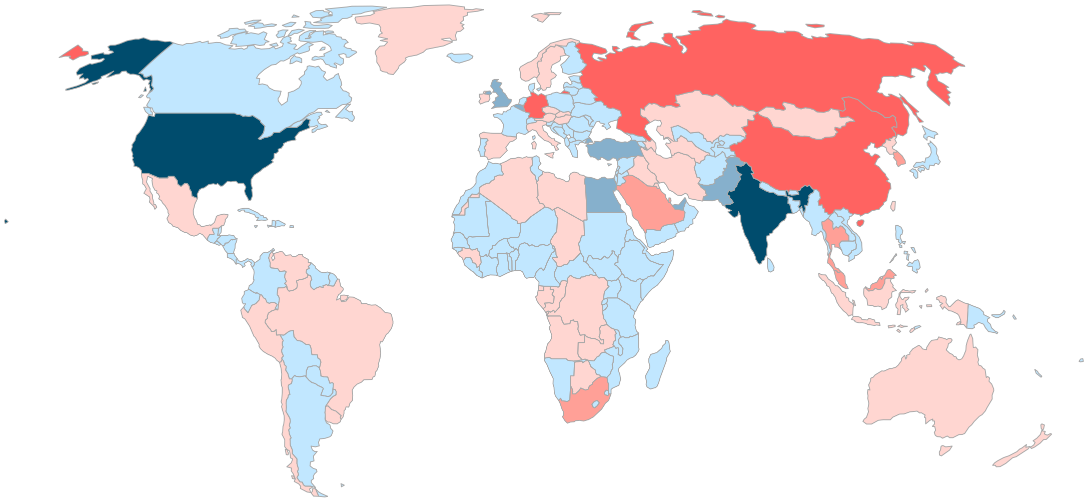
[22] For the exact values of change in carbon emissions and welfare see Table B2 in the appendix.

Figure 6: Percentage Changes in Carbon Emissions, All Countries Balanced Simultaneously

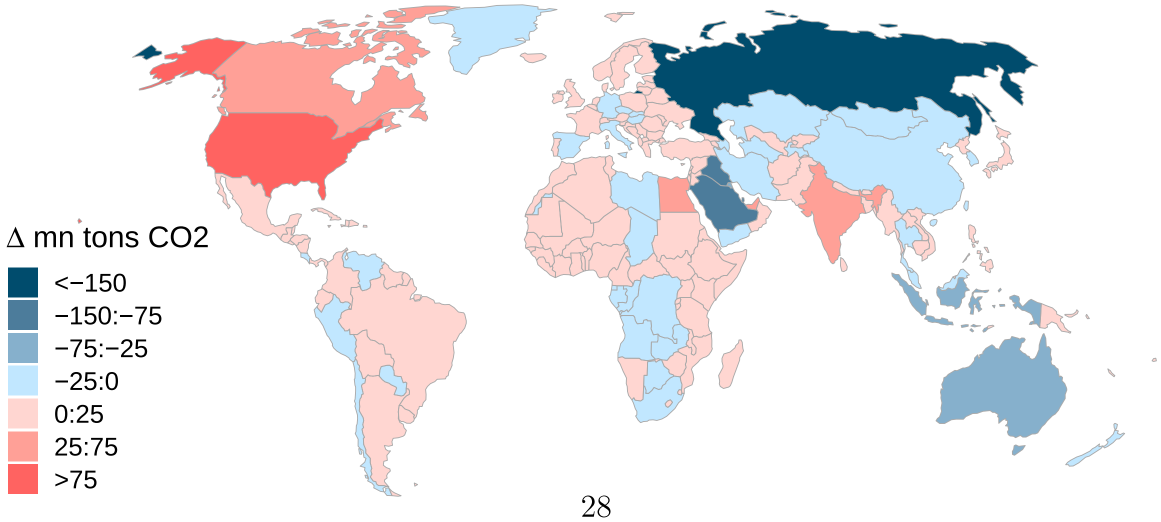
**Production footprint**



**Consumption footprint**



**Extraction footprint**



However, its production footprint falls and the slashing of its trade surplus goes in hand with a drastic reduction in Russian fossil fuel extraction.

Third, the distribution of production footprint changes is most homogeneous and least extreme. In 75 percent of countries, the production footprint decreases in response to the global re-balancing. The effects range from a 8.96 Mt increase in Iraq to 39.42 Mt decrease in the United States. Other key contributors to lower global emissions from a production point of view are India (-31.32 Mt) and Russia (-37.58 Mt).

Fourth, changes in consumption footprints are much more heterogeneous and extreme. Emission reductions from a consumption point of view are much more concentrated. The United States and India lead the field here, with enormous drops in their consumption footprints by 343 and 154 Mt, respectively. Different than in the production-based accounting, there are some countries with very considerable emission increases in this case, too. For Example, the consumption footprints of the large initial trade surplus countries China, Germany, and Russia increase by 199, 93, and 102 Mt, respectively.

Fifth, changes in extraction footprints are also very strong and heterogeneous but additionally are in particularly strong contrast to some of the movements of production and consumption footprints. The effects range from 221 Mt decrease in Russia to a 156 Mt increase in the United States. These countries' footprints were among the most affected in the consumption-based accounting, too, but with opposite signs. Generally, the fossil supply view shows that if we follow the global emission reduction back to where the fuels originate, it is mainly driven by Russia, Arabic countries, and Australia extracting less fossil fuels when they eliminate their initial trade surpluses.

# 6 Conclusions

International trade allows countries to decouple the amount of carbon emissions associated with their production from the emissions embodied in their consumption and in their supply of fossil fuels. Trade balance puts a bound to the decoupling: while a country does not have to export one ton of carbon for every ton imported, under trade balance, it has to export one dollar worth of products for every dollar imported. Trade imbalances soften this restriction. The implications of this softening depend on which types of countries end up consuming more than producing or vice versa. We show that the current pattern of global trade imbalances raises environmental concerns, because countries with a particularly carbon-intensive import mix tend to run a deficit (i.e. import more than they could afford under trade balance), fostering the global production of emission intensive goods, and fossil fuel exporters tend to run a surplus, increasing the globally available supply of these fuels.

We develop a multi-sector Ricardian quantitative trade model with carbon emissions from fossil fuel combustion to simulate the re-balancing of individual countries' current accounts and of global trade. In terms of individual countries' imbalances, world emissions could be brought down most by eliminating the US trade deficit or the trade surplus of major fossil fuel exporters, such as Russia, Qatar, Saudi-Arabia, or Australia. The overall global imbalances are found to contribute considerably to global carbon emissions: re-balancing global trade entirely would bring down global emissions by 0.9 percent, reducing the overall carbon footprint of international trade by 18 percent.

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# APPENDIX

## A Data

| GTAP code | Country | Trade imbalance in mn USD | Value added |
|---|---|---:|---:|
| AFG | Afghanistan | -10962.01 | 17534.50 |
| ALB | Albania | -2084.21 | 11624.34 |
| ARE | United Arab Emirates | -45213.71 | 380190.19 |
| ARG | Argentina | -16467.65 | 614827.57 |
| ARM | Armenia | -2504.12 | 10680.23 |
| AUS | Australia | 44716.61 | 1276879.82 |
| AUT | Austria | 11352.65 | 373994.76 |
| AZE | Azerbaijan | 5830.05 | 39803.11 |
| BEL | Belgium | -77291.52 | 434968.51 |
| BEN | Benin | -6352.55 | 10655.25 |
| BFA | Burkina Faso | -945.36 | 12771.27 |
| BGD | Bangladesh | -23678.83 | 289266.25 |
| BGR | Bulgaria | -461.37 | 53554.38 |
| BHR | Bahrain | -889.43 | 35709.76 |
| BLR | Belarus | -4782.38 | 48861.35 |
| BOL | Bolivia | -3421.33 | 34853.30 |
| BRA | Brazil | 20756.47 | 1899122.24 |
| BRN | Brunei | 280.87 | 12191.09 |
| BWA | Botswana | 653.22 | 15641.08 |
| CAF | Central African Republic | -224.17 | 1991.14 |
| CAN | Canada | -35213.06 | 1555823.75 |
| CHE | Switzerland | 290.61 | 678568.63 |
| CHL | Chile | 11268.76 | 273848.55 |
| CHN | China | 169462.16 | 11604584.72 |
| CIV | Cote d'Ivoire | 65.11 | 48344.80 |
| CMR | Cameroon | -3325.64 | 34297.76 |
| COD | Congo - Kinshasa | 2235.81 | 36566.63 |
| COG | Congo - Brazzaville | 2953.58 | 10316.62 |
| COL | Colombia | -10532.70 | 296636.04 |
| COM | Comoros | -350.67 | 960.17 |
| CRI | Costa Rica | 243.64 | 57987.47 |
| CYP | Cyprus | -1361.80 | 18784.73 |
| CZE | Czechia | 33764.33 | 201846.49 |
| DEU | Germany | 274099.24 | 3368948.40 |
| DNK | Denmark | -12819.62 | 263413.85 |
| DOM | Dominican Republic | -1896.96 | 75781.84 |
| DZA | Algeria | -18.88 | 161263.67 |
| ECU | Ecuador | -571.04 | 101034.63 |
| EGY | Egypt | -39506.28 | 237762.88 |
| ESP | Spain | 19449.08 | 1229429.22 |
| EST | Estonia | -2263.66 | 23607.38 |
| ETH | Ethiopia | -19787.73 | 74451.15 |
| FIN | Finland | -1280.01 | 230256.52 |
| FRA | France | -52728.59 | 2424048.54 |

Continued on next page

| GTAP code | Country | Trade imbalance in mn USD | Value added |
|---|---|---|---|
| GAB | Gabon | 1746.44 | 14765.89 |
| GBR | United Kingdom | -158873.81 | 2513779.14 |
| GEO | Georgia | -4762.61 | 15189.47 |
| GHA | Ghana | -5033.30 | 55668.03 |
| GIN | Guinea | 1306.41 | 9370.98 |
| GNQ | Equatorial Guinea | 3416.36 | 12161.01 |
| GRC | Greece | -15642.04 | 170621.56 |
| GTM | Guatemala | -3502.57 | 70221.50 |
| HKG | Hong Kong SAR China | -6400.83 | 330476.10 |
| HND | Honduras | -2228.27 | 22600.02 |
| HRV | Croatia | -2400.38 | 49892.40 |
| HTI | Haiti | -222.59 | 488.97 |
| HUN | Hungary | 13297.51 | 128689.27 |
| IDN | Indonesia | 27412.07 | 1004428.04 |
| IND | India | -153446.90 | 2557019.65 |
| IRL | Ireland | 78522.20 | 315075.54 |
| IRN | Iran | 19750.17 | 507665.12 |
| IRQ | Iraq | 27813.47 | 195671.75 |
| ISR | Israel | -12401.69 | 314326.08 |
| ITA | Italy | 58076.44 | 1824860.15 |
| JAM | Jamaica | -5072.57 | 12620.69 |
| JOR | Jordan | -14046.57 | 39101.77 |
| JPN | Japan | -16560.47 | 4845079.50 |
| KAZ | Kazakhstan | 6064.39 | 156855.99 |
| KEN | Kenya | -13198.26 | 78993.63 |
| KGZ | Kyrgyzstan | -8570.46 | 6626.25 |
| KHM | Cambodia | -1432.88 | 21567.78 |
| KOR | South Korea | 121166.80 | 1521324.37 |
| KWT | Kuwait | 14973.24 | 121700.99 |
| LAO | Laos | -523.18 | 17241.27 |
| LBN | Lebanon | -16820.45 | 50127.60 |
| LKA | Sri Lanka | -7996.45 | 80303.86 |
| LTU | Lithuania | -4588.10 | 41138.62 |
| LUX | Luxembourg | -4961.38 | 56938.91 |
| LVA | Latvia | -4587.40 | 25358.64 |
| MAR | Morocco | -11949.43 | 107715.16 |
| MDG | Madagascar | -5.44 | 12875.94 |
| MEX | Mexico | 20313.53 | 1112055.76 |
| MLI | Mali | -2055.71 | 14363.57 |
| MLT | Malta | -4584.88 | 11913.43 |
| MNG | Mongolia | 3266.21 | 11112.12 |
| MOZ | Mozambique | -3792.03 | 12184.89 |
| MUS | Mauritius | -2717.46 | 12292.48 |
| MWI | Malawi | -2240.94 | 8604.44 |
| MYS | Malaysia | 49154.61 | 314167.80 |
| NAM | Namibia | -1444.49 | 12407.94 |
| NER | Niger | -536.59 | 10836.20 |
| NGA | Nigeria | -5987.55 | 371978.92 |
| NIC | Nicaragua | -765.97 | 13087.63 |
| NLD | Netherlands | -19662.40 | 735370.41 |
| NOR | Norway | 1593.87 | 356961.67 |

Continued on next page

| GTAP code | Country | Trade imbalance | Value added |
|---|---|---|---|
| | | in mn USD | |
| NPL | Nepal | -9769.62 | 26237.56 |
| NZL | New Zealand | 6337.09 | 195992.05 |
| OMN | Oman | -4524.81 | 81328.24 |
| PAK | Pakistan | -46274.90 | 331450.34 |
| PAN | Panama | -7308.85 | 59047.92 |
| PER | Peru | 12197.26 | 213160.79 |
| PHL | Philippines | -32366.15 | 332338.11 |
| POL | Poland | -1364.46 | 467511.27 |
| PRI | Puerto Rico | -5464.08 | 102332.93 |
| PRT | Portugal | -4591.61 | 199166.84 |
| PRY | Paraguay | -3807.03 | 37558.38 |
| PSE | Palestinian Territories | -2921.53 | 14982.85 |
| QAT | Qatar | 61635.19 | 166365.10 |
| ROU | Romania | -9396.41 | 196511.51 |
| RUS | Russia | 117792.74 | 1558243.56 |
| RWA | Rwanda | -1034.68 | 8708.94 |
| SAU | Saudi Arabia | 72364.16 | 699253.17 |
| SDN | Sudan | -5348.82 | 126007.19 |
| SEN | Senegal | -6114.24 | 18905.88 |
| SGP | Singapore | -50121.32 | 298543.27 |
| SLV | El Salvador | -2859.15 | 24200.11 |
| SRB | Serbia | -2770.33 | 40849.83 |
| SVK | Slovakia | 12750.34 | 88612.48 |
| SVN | Slovenia | -3259.74 | 42458.45 |
| SWE | Sweden | 8965.28 | 489046.11 |
| SWZ | Eswatini | 1.82 | 4468.83 |
| SYR | Syria | -8673.42 | 14254.95 |
| TCD | Chad | 1588.71 | 9829.16 |
| TGO | Togo | -3787.83 | 5021.02 |
| THA | Thailand | 34377.77 | 428723.51 |
| TJK | Tajikistan | -2838.82 | 7101.17 |
| TTO | Trinidad & Tobago | 2144.04 | 22847.23 |
| TUN | Tunisia | -4393.39 | 38060.62 |
| TUR | Turkey | -47818.06 | 797091.82 |
| TWN | Taiwan | 33999.93 | 587944.27 |
| TZA | Tanzania | -6187.20 | 47841.16 |
| UGA | Uganda | -4427.63 | 29712.91 |
| UKR | Ukraine | -4477.49 | 100601.88 |
| URY | Uruguay | -690.31 | 59700.06 |
| USA | United States | -715675.77 | 19122440.09 |
| UZB | Uzbekistan | -3516.47 | 60860.11 |
| VEN | Venezuela | 7623.93 | 241153.28 |
| VNM | Vietnam | -13373.02 | 213178.23 |
| XAC | XAC | 10140.37 | 68598.85 |
| XCA | XCA | -1197.30 | 1422.08 |
| XCB | XCB | -19863.45 | 142383.60 |
| XEA | XEA | 1523.27 | 66711.45 |
| XEC | XEC | -8444.85 | 18323.36 |
| XEE | XEE | -2639.72 | 7973.61 |
| XEF | XEF | -572.81 | 28797.50 |
| XER | XER | -9180.85 | 68013.25 |

Continued on next page

| GTAP code | Country | Trade imbalance<br>in mn USD | Value added |
|---|---|---|---|
| XNA | XNA | 31077.54 | 39272.78 |
| XNF | XNF | 7277.34 | 65982.31 |
| XOC | XOC | -14452.18 | 51387.64 |
| XSA | XSA | -93.24 | 6731.35 |
| XSC | XSC | -590.75 | 2311.48 |
| XSE | XSE | -5421.19 | 62743.72 |
| XSM | XSM | -223.12 | 12708.54 |
| XSU | XSU | 3548.67 | 38080.99 |
| XTW | XTW | -26.81 | 94.25 |
| XWF | XWF | -7987.35 | 14963.57 |
| XWS | XWS | -7035.12 | 19454.74 |
| ZAF | South Africa | 25448.79 | 364549.77 |
| ZMB | Zambia | 1620.75 | 25126.16 |
| ZWE | Zimbabwe | -2424.02 | 16935.33 |

Table A1: GTAP 11 data overview, year 2017

Table A2: GTAP 11 data overview, year 2017

| GTAP code | Emission footprint<br>in mn tons CO2 | | |
|---|---|---|---|
| | Production | Extraction | Consumption |
| AFG | 6.61 | 6.58 | 19.63 |
| ALB | 5.93 | 3.31 | 8.20 |
| ARE | 190.79 | 632.55 | 241.96 |
| ARG | 178.94 | 121.41 | 192.99 |
| ARM | 5.77 | 0.01 | 7.98 |
| AUS | 401.61 | 1710.57 | 404.76 |
| AUT | 68.12 | 4.33 | 90.85 |
| AZE | 32.80 | 155.12 | 33.73 |
| BEL | 105.97 | 0.58 | 145.10 |
| BEN | 6.78 | 0.04 | 12.93 |
| BFA | 5.22 | 0.03 | 6.36 |
| BGD | 80.26 | 55.01 | 132.31 |
| BGR | 46.62 | 22.06 | 38.23 |
| BHR | 31.91 | 44.32 | 24.20 |
| BLR | 56.70 | 6.07 | 52.21 |
| BOL | 20.38 | 63.69 | 24.75 |
| BRA | 451.39 | 538.78 | 496.28 |
| BRN | 7.54 | 44.51 | 7.68 |
| BWA | 7.56 | 5.01 | 12.37 |
| CAF | 0.27 | 0.01 | 0.37 |
| CAN | 585.53 | 1323.78 | 515.19 |
| CHE | 51.85 | 0.60 | 117.28 |
| CHL | 95.37 | 6.62 | 94.12 |
| CHN | 9358.72 | 6021.62 | 8397.05 |
| CIV | 11.17 | 10.61 | 15.79 |
| CMR | 6.53 | 13.61 | 10.44 |
| COD | 2.25 | 5.03 | 7.63 |
| COG | 5.40 | 66.87 | 4.70 |

Continued on next page

Table A2: GTAP 11 data overview, year 2017

| GTAP code | Emission footprint in mn tons CO2 | | |
|---|---|---|---|
| | Production | Extraction | Consumption |
| COL | 74.68 | 338.10 | 95.17 |
| COM | 0.43 | 0.01 | 0.83 |
| CRI | 9.95 | 0.08 | 16.47 |
| CYP | 6.67 | 0.06 | 11.44 |
| CZE | 102.89 | 42.52 | 78.07 |
| DEU | 763.53 | 152.90 | 821.39 |
| DNK | 40.10 | 31.23 | 62.59 |
| DOM | 24.20 | 0.07 | 31.22 |
| DZA | 138.28 | 463.74 | 150.19 |
| ECU | 34.04 | 97.34 | 42.59 |
| EGY | 217.49 | 171.96 | 225.50 |
| ESP | 283.78 | 5.58 | 294.90 |
| EST | 8.42 | 2.84 | 10.60 |
| ETH | 14.88 | 0.16 | 33.22 |
| FIN | 49.13 | 4.29 | 53.62 |
| FRA | 341.11 | 3.20 | 476.56 |
| GAB | 2.71 | 43.01 | 4.03 |
| GBR | 429.57 | 194.04 | 617.45 |
| GEO | 10.01 | 0.62 | 14.48 |
| GHA | 13.17 | 37.05 | 25.64 |
| GIN | 3.64 | 0.03 | 4.86 |
| GNQ | 4.99 | 42.03 | 4.33 |
| GRC | 71.28 | 19.23 | 86.04 |
| GTM | 16.20 | 1.81 | 24.19 |
| HKG | 104.14 | 1.03 | 164.12 |
| HND | 9.40 | 0.07 | 13.10 |
| HRV | 18.48 | 3.29 | 23.66 |
| HTI | 0.11 | 0.01 | 0.23 |
| HUN | 51.19 | 5.85 | 46.26 |
| IDN | 497.35 | 1180.44 | 525.04 |
| IND | 2230.23 | 1000.13 | 2033.70 |
| IRL | 56.82 | 8.15 | 61.15 |
| IRN | 534.17 | 996.91 | 490.91 |
| IRQ | 96.28 | 801.14 | 132.55 |
| ISR | 67.84 | 10.94 | 88.60 |
| ITA | 347.65 | 13.78 | 421.53 |
| JAM | 8.98 | 0.04 | 11.12 |
| JOR | 24.58 | 0.16 | 34.70 |
| JPN | 1140.99 | 4.25 | 1232.25 |
| KAZ | 210.14 | 524.78 | 170.96 |
| KEN | 20.39 | 0.58 | 35.07 |
| KGZ | 9.13 | 2.73 | 17.16 |
| KHM | 11.25 | 0.13 | 16.76 |
| KOR | 607.11 | 3.31 | 488.01 |
| KWT | 80.84 | 488.89 | 73.44 |
| LAO | 17.69 | 14.61 | 10.48 |
| LBN | 28.49 | 0.10 | 42.35 |
| LKA | 24.40 | 0.10 | 42.41 |

Continued on next page

Table A2: GTAP 11 data overview, year 2017

| GTAP code | Emission footprint in mn tons CO2 | | |
|---|---|---|---|
| | Production | Extraction | Consumption |
| LTU | 13.18 | 0.22 | 18.02 |
| LUX | 11.49 | 0.08 | 16.32 |
| LVA | 9.87 | 0.12 | 14.12 |
| MAR | 60.63 | 0.20 | 74.50 |
| MDG | 5.43 | 0.05 | 7.01 |
| MEX | 442.75 | 372.66 | 486.19 |
| MLI | 3.28 | 0.03 | 5.22 |
| MLT | 8.62 | 0.03 | 9.00 |
| MNG | 19.37 | 118.88 | 15.87 |
| MOZ | 7.13 | 36.50 | 11.93 |
| MUS | 4.92 | 0.07 | 7.32 |
| MWI | 1.10 | 0.18 | 3.66 |
| MYS | 230.97 | 192.34 | 194.14 |
| NAM | 4.18 | 0.05 | 9.67 |
| NER | 2.09 | 2.48 | 3.39 |
| NGA | 89.98 | 391.70 | 131.37 |
| NIC | 5.36 | 0.02 | 7.85 |
| NLD | 193.93 | 60.64 | 177.08 |
| NOR | 54.55 | 525.77 | 60.76 |
| NPL | 15.48 | 0.12 | 32.01 |
| NZL | 37.74 | 18.81 | 46.91 |
| OMN | 64.57 | 262.00 | 65.36 |
| PAK | 190.55 | 16.71 | 240.42 |
| PAN | 42.63 | 0.23 | 24.51 |
| PER | 53.02 | 37.20 | 64.60 |
| PHL | 132.70 | 29.79 | 185.14 |
| POL | 308.61 | 165.73 | 279.79 |
| PRI | 11.44 | 0.04 | 21.09 |
| PRT | 60.84 | 0.27 | 63.07 |
| PRY | 7.77 | 0.11 | 14.40 |
| PSE | 3.34 | 0.02 | 8.01 |
| QAT | 87.45 | 707.22 | 44.60 |
| ROU | 74.67 | 42.68 | 85.76 |
| RUS | 1570.73 | 3581.05 | 1179.06 |
| RWA | 1.01 | 0.04 | 2.17 |
| SAU | 452.90 | 1924.04 | 389.41 |
| SDN | 16.08 | 11.75 | 24.25 |
| SEN | 8.65 | 0.10 | 14.41 |
| SGP | 92.94 | 0.57 | 116.22 |
| SLV | 7.31 | 0.03 | 11.37 |
| SRB | 47.88 | 32.50 | 40.17 |
| SVK | 33.05 | 0.44 | 30.45 |
| SVN | 16.06 | 3.78 | 18.49 |
| SWE | 40.63 | 0.36 | 73.73 |
| SWZ | 0.67 | 0.46 | 3.03 |
| SYR | 28.07 | 8.68 | 33.10 |
| TCD | 1.06 | 20.75 | 1.34 |
| TGO | 2.21 | 0.02 | 5.45 |

Continued on next page

Table A2: GTAP 11 data overview, year 2017

| GTAP code | Emission footprint in mn tons CO2 | | |
|---|---|---|---|
| | Production | Extraction | Consumption |
| THA | 258.24 | 52.62 | 225.92 |
| TJK | 7.19 | 4.05 | 9.86 |
| TTO | 19.89 | 60.23 | 9.63 |
| TUN | 28.40 | 7.50 | 28.57 |
| TUR | 411.69 | 51.22 | 454.72 |
| TWN | 274.79 | 0.65 | 203.00 |
| TZA | 10.82 | 3.00 | 19.28 |
| UGA | 4.26 | 0.04 | 9.67 |
| UKR | 188.43 | 75.42 | 130.78 |
| URY | 8.24 | 0.02 | 12.59 |
| USA | 4932.65 | 4202.15 | 5542.54 |
| UZB | 106.39 | 136.32 | 100.99 |
| VEN | 120.47 | 296.47 | 109.84 |
| VNM | 194.56 | 143.61 | 206.70 |
| XAC | 20.18 | 358.65 | 26.75 |
| XCA | 0.48 | 0.11 | 1.10 |
| XCB | 39.26 | 6.21 | 53.86 |
| XEA | 24.51 | 34.41 | 33.37 |
| XEC | 8.37 | 30.70 | 15.32 |
| XEE | 8.25 | 0.12 | 10.10 |
| XEF | 4.46 | 0.05 | 6.21 |
| XER | 49.16 | 21.30 | 50.14 |
| XNA | 6.70 | 0.04 | 2.40 |
| XNF | 43.13 | 173.72 | 47.97 |
| XOC | 23.38 | 11.06 | 30.23 |
| XSA | 3.69 | 0.52 | 4.55 |
| XSC | 3.55 | 0.07 | 5.13 |
| XSE | 31.52 | 128.94 | 43.18 |
| XSM | 5.05 | 2.71 | 5.16 |
| XSU | 68.31 | 203.29 | 56.38 |
| XTW | 0.01 | 0.00 | 0.03 |
| XWF | 32.26 | 0.40 | 19.63 |
| XWS | 8.33 | 4.06 | 14.48 |
| ZAF | 436.15 | 502.87 | 304.39 |
| ZMB | 6.05 | 1.89 | 9.21 |
| ZWE | 9.83 | 6.34 | 12.79 |

Figure A1: Embodied CO2 Emissions Imbalance in International Trade, by Year

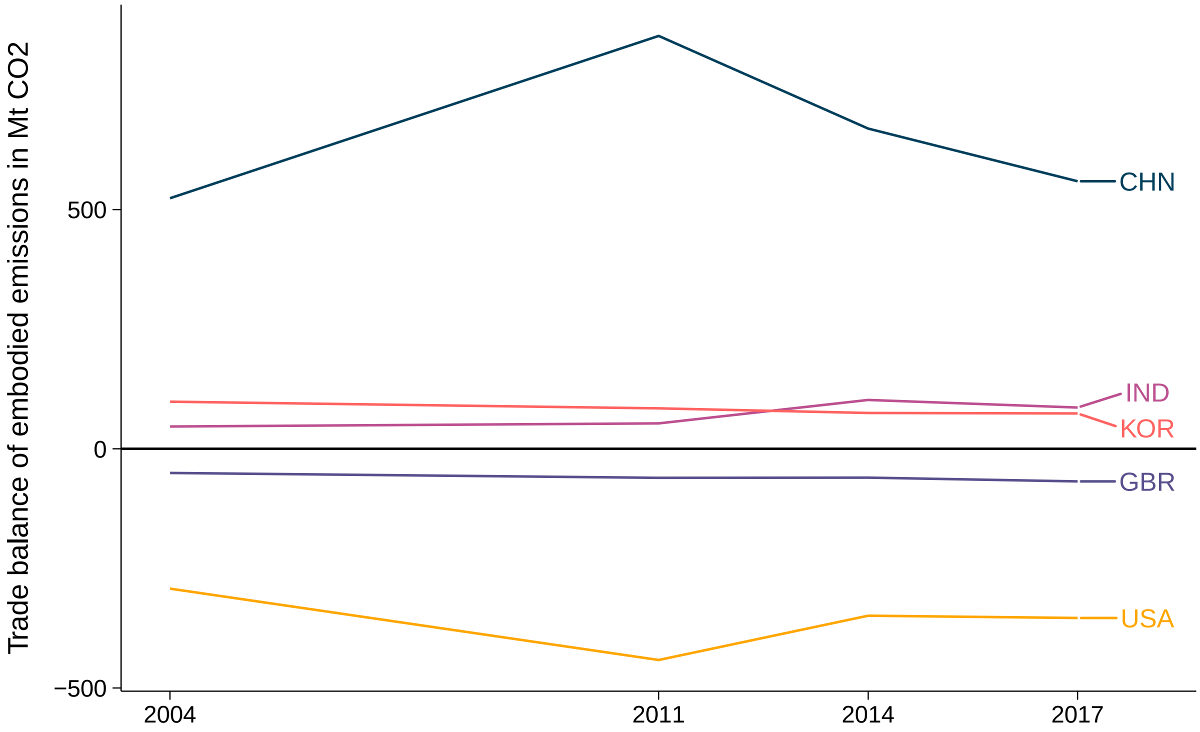
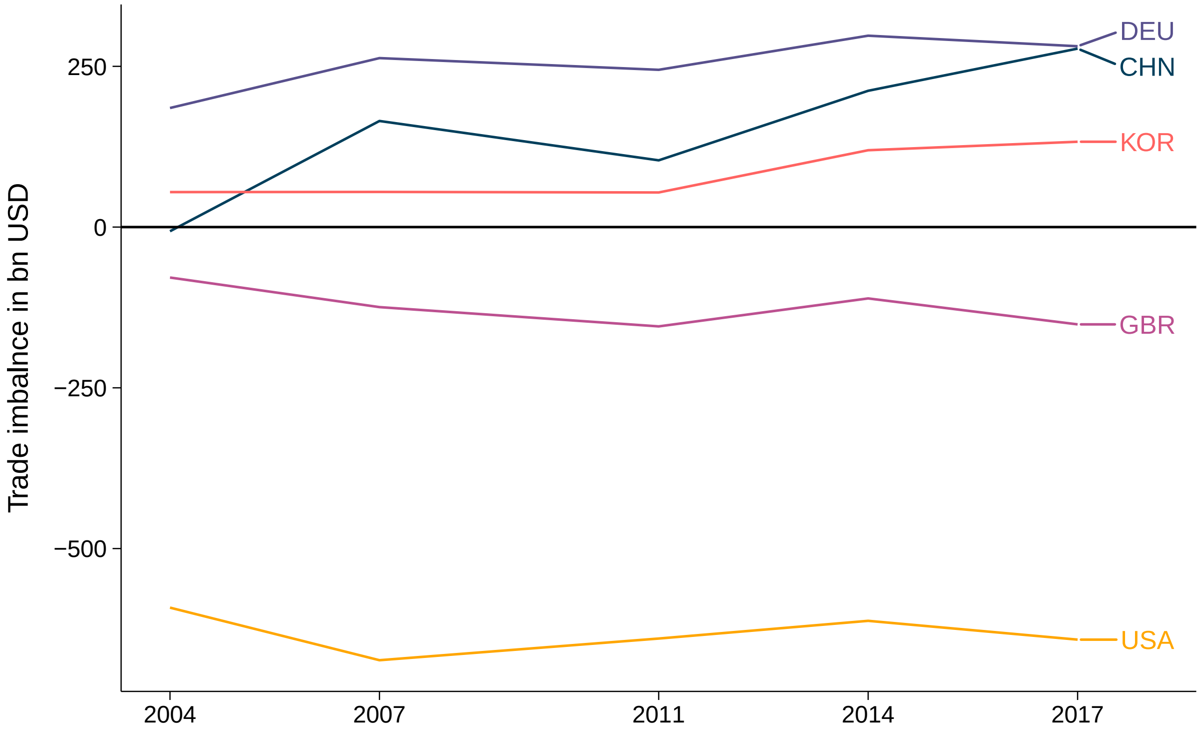


Figure A2: Trade Imbalance, by Year



# B Detailed Results

## B.1 Figures

Figure B1: Change in Global Carbon Emissions per Absolute Value of Removing Trade Imbalance per Country, Each Country Balanced Separately

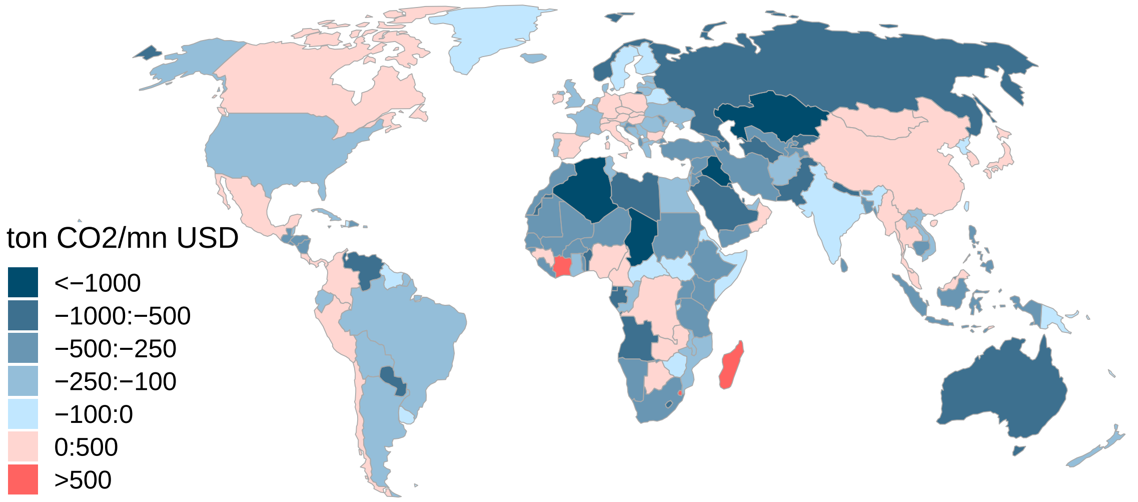


Figure B2: Percentage Changes in Carbon Emissions, USA Balanced

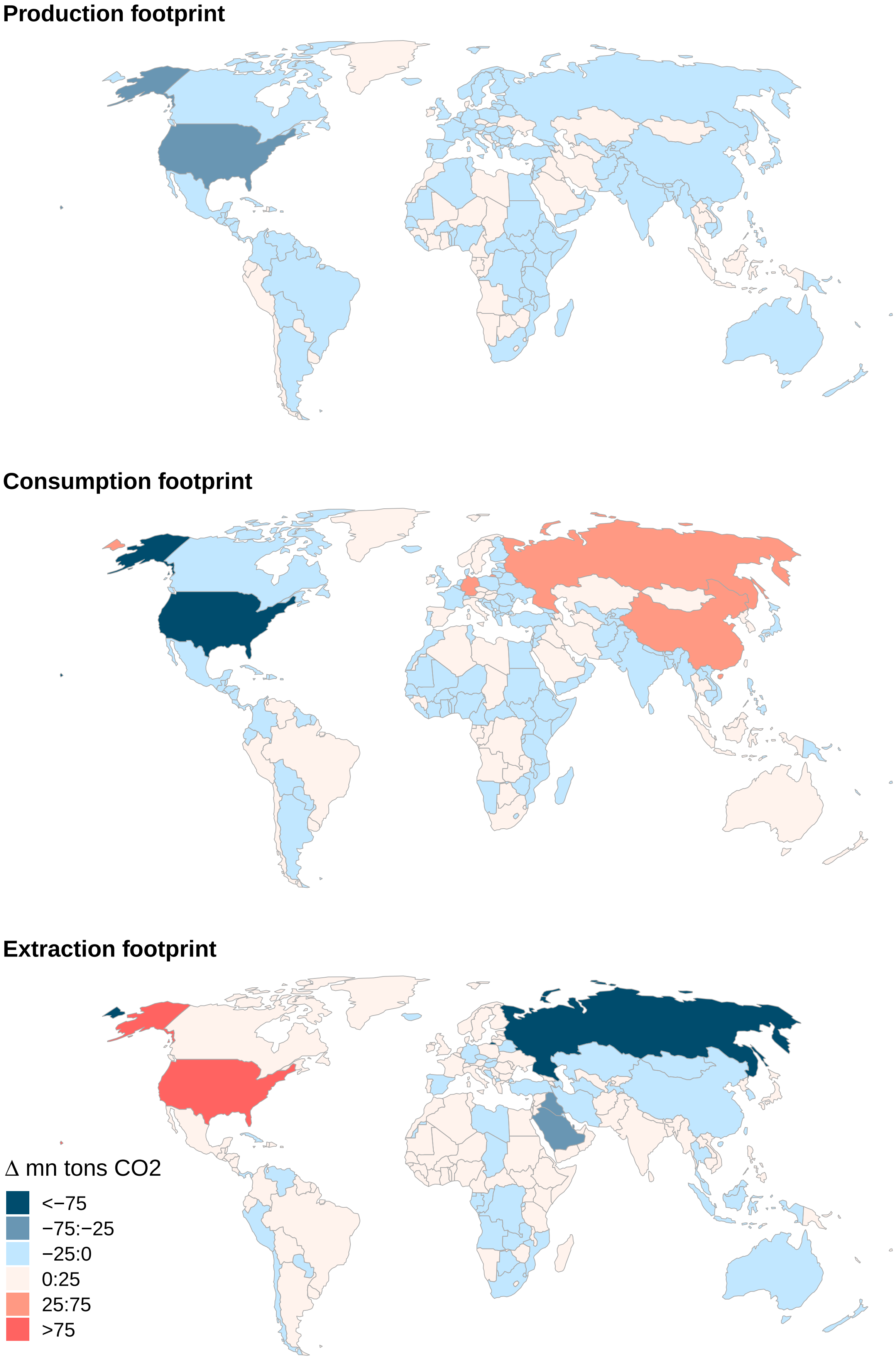
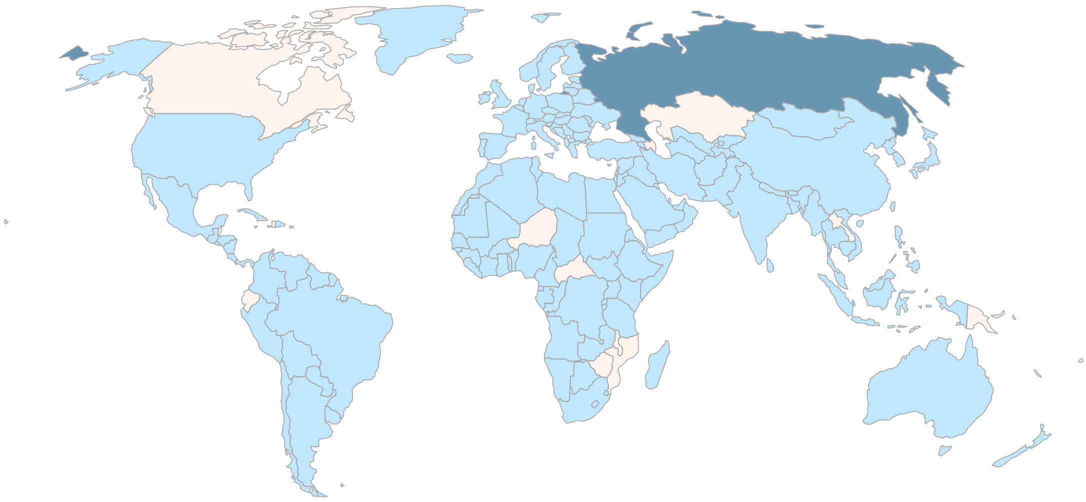
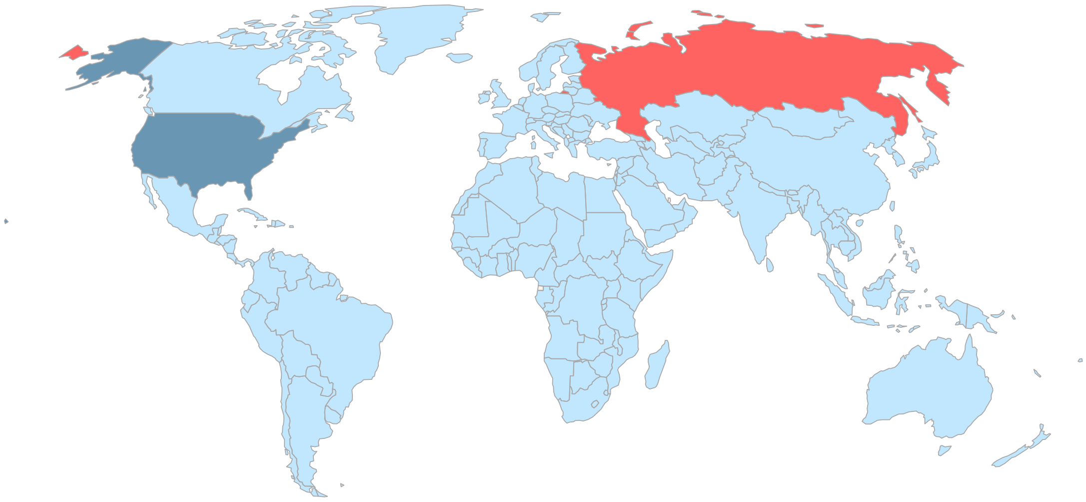


Figure B3: Percentage Changes in Carbon Emissions, Russia Balanced

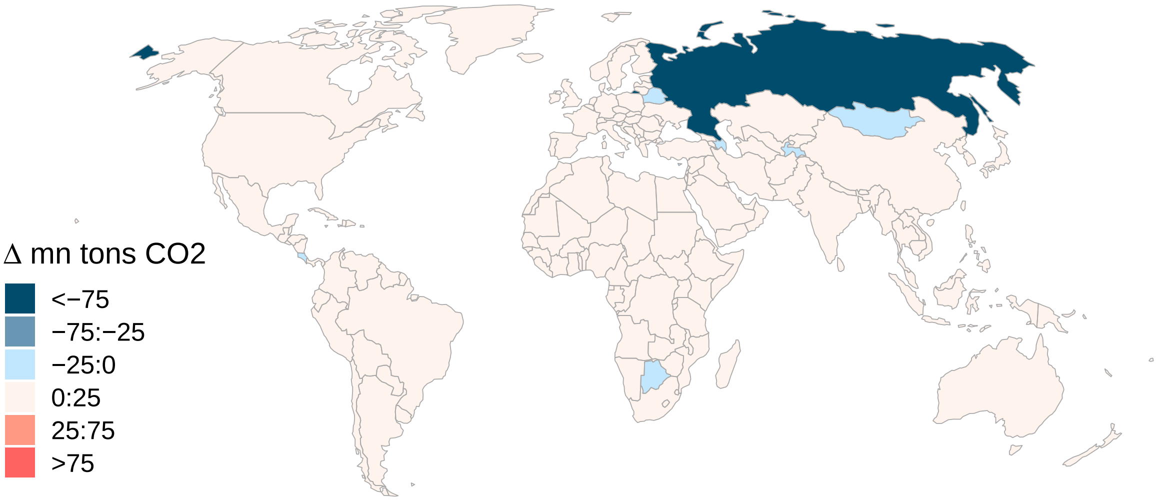
**Production footprint**



**Consumption footprint**



**Extraction footprint**



## B.2 Tables

Table B1: Countries' corresponding emission changes, each countries balanced individually

| Country | Countries' footprint change | | | Global emission change |
|---|---|---|---|---|
| | Production | Consumption | Extraction | |
| | | in mn tons CO2 | | |
| AFG | 0.33 | -9.79 | 2.49 | -1.37 |
| ALB | -0.17 | -1.67 | 0.20 | -0.81 |
| ARE | -4.14 | -24.88 | 14.03 | -4.79 |
| ARG | -0.26 | -7.17 | 3.32 | -2.37 |
| ARM | -0.12 | -1.80 | 0.00 | -0.34 |
| AUS | -5.16 | 22.95 | -56.53 | -26.25 |
| AUT | 0.13 | 4.47 | -0.08 | 0.55 |
| AZE | 2.49 | 6.30 | -11.70 | -3.40 |
| BEL | 0.10 | -26.00 | 0.04 | -15.47 |
| BEN | -1.92 | -5.73 | 0.01 | -3.37 |
| BFA | -0.02 | -0.41 | 0.00 | -0.27 |
| BGD | -0.65 | -16.42 | 1.05 | -7.55 |
| BGR | 0.01 | 0.15 | -0.01 | 0.03 |
| BHR | 0.09 | -0.52 | 0.21 | 0.05 |
| BLR | -0.80 | -4.74 | 0.20 | -0.42 |
| BOL | -0.49 | -1.55 | 1.94 | -0.39 |
| BRA | 0.21 | 18.25 | -13.03 | -3.53 |
| BRN | 0.06 | 0.27 | -0.69 | -0.24 |
| BWA | 0.04 | 0.92 | -0.12 | 0.06 |
| CAF | 0.02 | -0.07 | 0.00 | -0.00 |
| CAN | 3.91 | -12.87 | 20.32 | 1.76 |
| CHE | 0.05 | 0.91 | -0.00 | 0.04 |
| CHL | -0.11 | 5.87 | -0.19 | 0.76 |
| CHN | 25.43 | 263.40 | -74.90 | 17.43 |
| CIV | 0.03 | 0.25 | -0.06 | 0.03 |
| CMR | 0.19 | -1.45 | 1.49 | 0.13 |
| COD | 0.02 | 0.98 | -0.20 | 0.52 |
| COG | 1.00 | 2.98 | -3.05 | -0.53 |
| COL | -0.33 | -4.98 | 13.10 | 2.63 |
| COM | -0.12 | -0.32 | 0.00 | -0.20 |
| CRI | 0.04 | 0.22 | 0.00 | 0.04 |
| CYP | -0.44 | -1.69 | -0.00 | -0.32 |
| CZE | 1.48 | 19.60 | -1.70 | 1.86 |
| DEU | 7.57 | 113.34 | -6.71 | 9.12 |
| DNK | 0.23 | -3.64 | 0.76 | -1.84 |
| DOM | -0.22 | -0.84 | 0.00 | -0.49 |
| DZA | 0.47 | 1.05 | -2.17 | -0.69 |
| ECU | 0.04 | 0.19 | -0.29 | -0.08 |
| EGY | -6.31 | -39.98 | 20.78 | -5.13 |
| ESP | -0.11 | 8.62 | -0.10 | 0.30 |
| EST | 0.06 | -1.08 | 0.08 | -0.31 |
| ETH | -0.35 | -12.99 | 0.13 | -7.90 |
| FIN | 0.02 | -0.14 | 0.01 | -0.07 |
| FRA | -0.40 | -14.35 | 0.06 | -9.78 |

Continued on next page

Table B1: Countries' corresponding emission changes, each countries balanced individually

| Country | Countries' footprint change | | | Global emission change |
|---|---|---|---|---|
| | Production | Consumption | Extraction | |
| | | in mn tons CO2 | | |
| GAB | 0.10 | 0.74 | -3.02 | -1.15 |
| GBR | -5.36 | -52.15 | 8.87 | -24.14 |
| GEO | -0.95 | -4.35 | 0.06 | -1.62 |
| GHA | -0.31 | -2.34 | 2.60 | -0.60 |
| GIN | 0.18 | 1.18 | 0.00 | 0.32 |
| GNQ | 0.18 | 1.91 | -9.72 | -3.38 |
| GRC | 0.39 | -9.69 | 0.63 | -3.44 |
| GTM | -0.18 | -1.76 | 0.06 | -0.96 |
| HKG | -0.19 | -6.94 | 0.01 | -2.40 |
| HND | -0.35 | -1.49 | 0.00 | -0.85 |
| HRV | -0.11 | -1.33 | 0.08 | -0.68 |
| HTI | 0.01 | -0.09 | 0.00 | -0.01 |
| HUN | 0.15 | 7.34 | -0.31 | 0.73 |
| IDN | 4.06 | 29.70 | -40.46 | -10.71 |
| IND | -6.48 | -127.41 | 48.61 | -15.13 |
| IRL | 5.51 | 24.89 | 0.00 | 1.89 |
| IRN | -0.73 | 11.04 | -18.11 | -7.23 |
| IRQ | 10.36 | 25.19 | -93.52 | -31.70 |
| ISR | -0.34 | -4.80 | 0.36 | -2.22 |
| ITA | 2.25 | 25.16 | -0.41 | 2.40 |
| JAM | -0.63 | -3.77 | 0.01 | -1.38 |
| JOR | -4.21 | -11.10 | 0.02 | -5.47 |
| JPN | 0.17 | 6.10 | -0.02 | 0.39 |
| KAZ | -0.08 | 15.03 | -22.44 | -8.83 |
| KEN | -0.60 | -8.89 | 0.12 | -3.79 |
| KGZ | -3.32 | -10.64 | 0.10 | -4.61 |
| KHM | -0.24 | -0.84 | 0.00 | -0.40 |
| KOR | -8.16 | 68.09 | -0.24 | 0.96 |
| KWT | 3.11 | 12.86 | -32.86 | -11.87 |
| LAO | 0.31 | -0.34 | 0.36 | -0.06 |
| LBN | -3.56 | -13.45 | 0.02 | -5.53 |
| LKA | -1.28 | -5.50 | 0.01 | -2.75 |
| LTU | 0.02 | -2.11 | 0.01 | -0.98 |
| LUX | -0.24 | -1.59 | 0.00 | -1.06 |
| LVA | -0.05 | -2.48 | 0.01 | -0.86 |
| MAR | -2.18 | -8.97 | 0.01 | -4.72 |
| MDG | 0.00 | 0.02 | -0.00 | 0.01 |
| MEX | 2.58 | 14.86 | -4.17 | 1.26 |
| MLI | 0.05 | -0.90 | 0.01 | -0.63 |
| MLT | -0.23 | -2.70 | 0.00 | -1.15 |
| MNG | 4.32 | 8.69 | -7.67 | 0.38 |
| MOZ | 0.42 | -3.54 | 3.66 | -0.58 |
| MUS | -0.31 | -1.59 | 0.01 | -0.72 |
| MWI | 0.07 | -1.42 | 0.07 | -0.47 |
| MYS | 8.27 | 45.46 | -10.69 | 3.56 |
| NAM | -0.13 | -1.29 | 0.00 | -0.47 |
| NER | 0.01 | -0.23 | 0.05 | -0.14 |

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Table B1: Countries' corresponding emission changes, each countries balanced individually

| Country | Countries' footprint change | | | Global emission change |
|---|---|---|---|---|
| | Production | Consumption | Extraction | |
| | | in mn tons CO2 | | |
| NGA | -0.86 | -3.42 | 9.17 | 2.16 |
| NIC | -0.15 | -0.47 | 0.00 | -0.28 |
| NLD | 0.64 | -4.94 | 0.69 | -2.30 |
| NOR | -0.21 | 0.73 | -3.15 | -1.30 |
| NPL | -1.12 | -14.12 | 0.04 | -6.23 |
| NZL | -0.26 | 3.31 | -0.68 | -1.10 |
| OMN | -0.80 | -3.20 | 5.84 | 0.92 |
| PAK | -19.56 | -46.19 | 2.78 | -25.46 |
| PAN | 3.47 | -3.95 | 0.06 | 1.37 |
| PER | 1.13 | 6.18 | -1.07 | 0.98 |
| PHL | -5.15 | -22.61 | 1.11 | -10.55 |
| POL | 0.08 | 0.47 | -0.05 | 0.07 |
| PRI | -0.47 | -2.14 | 0.00 | -1.27 |
| PRT | 0.05 | -1.49 | 0.00 | -0.77 |
| PRY | -0.64 | -1.89 | -0.00 | -2.05 |
| PSE | -0.85 | -2.91 | 0.02 | -1.80 |
| QAT | -1.53 | 35.32 | -136.36 | -52.89 |
| ROU | -0.35 | -4.27 | 0.65 | -2.14 |
| RUS | -33.37 | 104.52 | -248.51 | -113.14 |
| RWA | -0.05 | -0.39 | 0.01 | -0.31 |
| SAU | 0.49 | 56.64 | -117.01 | -45.58 |
| SDN | -0.53 | -2.82 | 0.62 | -1.77 |
| SEN | -0.87 | -4.49 | 0.01 | -2.40 |
| SGP | 1.71 | -19.86 | 0.04 | -7.18 |
| SLV | -0.22 | -1.60 | 0.00 | -0.99 |
| SRB | 0.07 | -1.92 | 0.25 | -0.43 |
| SVK | 0.48 | 7.27 | -0.02 | 1.55 |
| SVN | 0.09 | -1.45 | 0.14 | -0.63 |
| SWE | -0.09 | 2.68 | -0.01 | -0.11 |
| SWZ | 0.01 | 0.08 | -0.00 | 0.03 |
| SYR | -4.23 | -15.03 | 1.40 | -4.22 |
| TCD | 0.06 | 0.49 | -4.44 | -1.76 |
| TGO | -0.22 | -2.58 | 0.00 | -1.34 |
| THA | 3.20 | 33.73 | -2.36 | 3.35 |
| TJK | 0.03 | -3.11 | 0.21 | -0.74 |
| TTO | -1.05 | 1.44 | -4.16 | -1.63 |
| TUN | -0.78 | -2.96 | 0.35 | -1.02 |
| TUR | -5.34 | -32.17 | 2.06 | -12.58 |
| TWN | -4.62 | 21.33 | -0.04 | -1.72 |
| TZA | -0.15 | -3.25 | 0.20 | -1.66 |
| UGA | -0.15 | -2.27 | 0.01 | -1.27 |
| UKR | -0.39 | -2.89 | 0.56 | -0.50 |
| URY | -0.00 | 0.21 | -0.00 | -0.01 |
| USA | -26.78 | -324.43 | 140.59 | -78.49 |
| UZB | -0.89 | -4.98 | 4.34 | -1.26 |
| VEN | -1.09 | 5.35 | -17.58 | -7.02 |
| VNM | -1.55 | -6.15 | 0.17 | -2.43 |

Continued on next page

Table B1: Countries' corresponding emission changes, each countries balanced individually

| Country | Countries' footprint change | | | Global emission change |
|---|---|---|---|---|
| | Production | Consumption | Extraction | |
| | in mn tons CO2 | | | |
| XAC | 1.54 | 6.47 | -28.41 | -9.78 |
| XCA | -0.01 | -0.58 | 0.02 | -0.17 |
| XCB | -1.05 | -8.82 | 0.50 | -3.75 |
| XEA | 0.11 | 1.15 | -0.43 | -0.08 |
| XEC | -0.54 | -5.60 | 4.55 | -0.39 |
| XEE | -0.80 | -2.90 | 0.01 | -0.97 |
| XEF | 0.01 | -0.17 | 0.00 | -0.10 |
| XER | 0.58 | -6.67 | 1.30 | -1.62 |
| XNA | 2.13 | 10.19 | -0.00 | -1.79 |
| XNF | 3.14 | 6.81 | -15.12 | -4.22 |
| XOC | 1.46 | -7.66 | 1.59 | -1.32 |
| XSA | -0.01 | -0.06 | 0.00 | -0.05 |
| XSC | -0.27 | -1.15 | 0.00 | -0.43 |
| XSE | -0.71 | -4.47 | 13.29 | 0.72 |
| XSM | -0.00 | -0.02 | 0.00 | -0.01 |
| XSU | 0.11 | 5.72 | -17.75 | -3.05 |
| XTW | 0.00 | -0.01 | 0.00 | -0.00 |
| XWF | -0.66 | -7.17 | 0.05 | -2.29 |
| XWS | -1.28 | -5.37 | -0.07 | -2.48 |
| ZAF | -4.95 | 28.96 | -17.99 | -7.60 |
| ZMB | -0.28 | 1.02 | -0.10 | 0.21 |
| ZWE | 0.45 | -1.90 | 0.58 | -0.02 |

Table B2: Countries' corresponding emission changes, all countries balanced simultanously

| Country | Countries' footprint change | | |
|---|---|---|---|
| | Production | Extraction | Consumption |
| | in mn tons CO2 | | |
| AFG | 0.03 | -10.26 | 2.51 |
| ALB | -0.24 | -1.69 | 0.26 |
| ARE | -6.80 | -28.01 | 28.41 |
| ARG | -1.68 | -9.09 | 5.17 |
| ARM | -0.21 | -1.97 | 0.00 |
| AUS | -7.52 | 18.06 | -35.95 |
| AUT | -0.63 | 3.55 | 0.03 |
| AZE | 2.14 | 5.74 | -10.50 |
| BEL | -1.30 | -27.72 | 0.08 |
| BEN | -2.09 | -5.92 | 0.01 |
| BFA | -0.11 | -0.53 | 0.00 |
| BGD | -1.06 | -17.38 | 0.98 |
| BGR | -0.88 | -0.33 | 0.04 |
| BHR | -0.39 | -0.60 | 0.15 |
| BLR | -1.62 | -5.69 | 0.18 |
| BOL | -0.56 | -1.68 | 3.82 |
| BRA | -1.56 | 10.67 | 0.27 |

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Table B2: Countries' corresponding emission changes, all countries balanced simultanously

| Country | Countries' footprint change | | |
|---|---|---|---|
| | Production | Extraction | Consumption |
| | in mn tons CO2 | | |
| BRN | -0.03 | 0.20 | 0.18 |
| BWA | 0.10 | 0.69 | -0.01 |
| CAF | 0.02 | -0.07 | 0.00 |
| CAN | 2.74 | -19.27 | 47.81 |
| CHE | -0.57 | -0.92 | 0.03 |
| CHL | 0.26 | 5.25 | -0.17 |
| CHN | -18.74 | 199.27 | -23.64 |
| CIV | -0.16 | -0.06 | 0.06 |
| CMR | -0.02 | -1.60 | 1.87 |
| COD | -0.04 | 0.87 | -0.05 |
| COG | 0.93 | 2.95 | -1.12 |
| COL | -0.41 | -5.65 | 18.47 |
| COM | -0.13 | -0.33 | 0.00 |
| CRI | -0.09 | -0.19 | -0.00 |
| CYP | -0.54 | -1.77 | 0.00 |
| CZE | 1.31 | 18.89 | -1.58 |
| DEU | -1.23 | 93.22 | -4.67 |
| DNK | 0.28 | -4.16 | 1.54 |
| DOM | -0.56 | -1.41 | 0.00 |
| DZA | -1.28 | 0.40 | 2.75 |
| ECU | -0.07 | -0.22 | 1.58 |
| EGY | -9.49 | -42.40 | 26.66 |
| ESP | -5.22 | 4.13 | -0.02 |
| EST | -0.05 | -1.42 | 0.16 |
| ETH | -0.54 | -13.36 | 0.14 |
| FIN | -0.77 | -1.92 | 0.07 |
| FRA | -5.10 | -20.19 | 0.15 |
| GAB | 0.06 | 0.73 | -1.83 |
| GBR | -8.32 | -58.16 | 13.52 |
| GEO | -1.13 | -4.61 | 0.09 |
| GHA | -0.31 | -2.83 | 6.71 |
| GIN | 0.08 | 1.05 | 0.00 |
| GNQ | 0.15 | 1.88 | -9.24 |
| GRC | -1.39 | -11.09 | 0.54 |
| GTM | -0.41 | -2.32 | 0.11 |
| HKG | -0.82 | -9.77 | 0.02 |
| HND | -0.45 | -1.77 | 0.00 |
| HRV | -0.56 | -1.23 | 0.17 |
| HTI | 0.01 | -0.09 | 0.00 |
| HUN | -0.64 | 6.80 | -0.22 |
| IDN | 1.94 | 23.85 | -28.75 |
| IND | -31.32 | -154.37 | 68.74 |
| IRL | 5.04 | 23.39 | 0.19 |
| IRN | -4.20 | 8.77 | -4.62 |
| IRQ | 8.96 | 23.14 | -83.89 |
| ISR | -1.79 | -6.29 | 0.84 |
| ITA | -3.72 | 18.05 | -0.00 |

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Table B2: Countries' corresponding emission changes, all countries balanced simultanously

| Country | Countries' footprint change | | |
|---|---|---|---|
| | Production | Extraction | Consumption |
| | in mn tons CO2 | | |
| JAM | -0.81 | -3.89 | 0.01 |
| JOR | -4.61 | -11.50 | 0.03 |
| JPN | -7.38 | -11.62 | 0.08 |
| KAZ | 1.20 | 12.95 | -16.84 |
| KEN | -1.11 | -9.80 | 0.16 |
| KGZ | -3.37 | -10.80 | 0.11 |
| KHM | -0.39 | -1.15 | 0.00 |
| KOR | -16.38 | 58.25 | -0.16 |
| KWT | 2.06 | 12.77 | -27.08 |
| LAO | 0.88 | -0.41 | 0.94 |
| LBN | -4.01 | -13.85 | 0.03 |
| LKA | -1.52 | -5.83 | 0.01 |
| LTU | -0.23 | -2.60 | 0.01 |
| LUX | -0.31 | -1.80 | 0.01 |
| LVA | -0.25 | -2.86 | 0.01 |
| MAR | -2.92 | -9.91 | 0.01 |
| MDG | -0.06 | -0.12 | 0.00 |
| MEX | -1.19 | 7.75 | 4.45 |
| MLI | 0.03 | -0.99 | 0.01 |
| MLT | -0.44 | -2.81 | 0.00 |
| MNG | 4.22 | 8.43 | -6.95 |
| MOZ | 0.42 | -3.77 | 3.28 |
| MUS | -0.34 | -1.69 | 0.02 |
| MWI | 0.05 | -1.47 | 0.07 |
| MYS | 6.93 | 42.58 | -4.97 |
| NAM | -0.10 | -1.40 | 0.00 |
| NER | 0.01 | -0.28 | 0.07 |
| NGA | -1.89 | -4.78 | 14.67 |
| NIC | -0.22 | -0.65 | 0.00 |
| NLD | -2.94 | -7.92 | 3.66 |
| NOR | -0.50 | 0.30 | 12.03 |
| NPL | -1.19 | -14.17 | 0.04 |
| NZL | -0.48 | 2.52 | -0.43 |
| OMN | -1.49 | -3.67 | 10.64 |
| PAK | -21.53 | -49.36 | 3.39 |
| PAN | 2.20 | -4.21 | 0.06 |
| PER | 1.06 | 5.52 | -0.55 |
| PHL | -6.01 | -24.63 | 1.43 |
| POL | -1.54 | -2.55 | 1.61 |
| PRI | -0.57 | -2.43 | 0.00 |
| PRT | -0.80 | -2.16 | 0.01 |
| PRY | -0.63 | -1.94 | -0.00 |
| PSE | -0.97 | -3.01 | 0.02 |
| QAT | -1.64 | 35.23 | -132.00 |
| ROU | -0.94 | -4.95 | 1.77 |
| RUS | -37.58 | 102.61 | -220.93 |
| RWA | -0.09 | -0.46 | 0.01 |

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Table B2: Countries' corresponding emission changes, all countries balanced simultanously

| Country | Countries' footprint change | | |
|---|---|---|---|
| | Production | Extraction | Consumption |
| | in mn tons CO2 | | |
| SAU | -1.47 | 54.85 | -91.34 |
| SDN | -0.67 | -3.24 | 0.95 |
| SEN | -1.03 | -4.68 | 0.01 |
| SGP | 1.57 | -21.92 | 0.09 |
| SLV | -0.29 | -1.84 | 0.00 |
| SRB | -0.48 | -2.24 | 0.24 |
| SVK | 0.08 | 6.60 | -0.02 |
| SVN | 0.01 | -1.51 | 0.14 |
| SWE | -0.45 | 1.30 | 0.00 |
| SWZ | 0.00 | -0.02 | 0.00 |
| SYR | -4.86 | -15.37 | 1.40 |
| TCD | 0.05 | 0.47 | -3.98 |
| TGO | -0.27 | -2.71 | 0.00 |
| THA | 1.27 | 30.29 | -1.13 |
| TJK | -0.61 | -3.21 | -0.37 |
| TTO | -1.44 | 1.28 | -4.31 |
| TUN | -1.25 | -3.30 | 0.49 |
| TUR | -10.86 | -39.44 | 2.51 |
| TWN | -7.21 | 17.66 | -0.02 |
| TZA | -0.40 | -3.64 | 0.17 |
| UGA | -0.30 | -2.62 | 0.01 |
| UKR | -1.61 | -5.13 | 2.31 |
| URY | -0.00 | 0.06 | 0.00 |
| USA | -39.42 | -343.08 | 155.86 |
| UZB | -3.23 | -6.54 | 11.26 |
| VEN | -1.60 | 4.86 | -12.19 |
| VNM | -2.48 | -8.70 | 1.79 |
| XAC | 1.18 | 6.18 | -20.31 |
| XCA | -0.02 | -0.59 | 0.02 |
| XCB | -1.19 | -9.47 | 0.58 |
| XEA | 0.09 | 0.74 | 0.27 |
| XEC | -0.70 | -5.83 | 6.28 |
| XEE | -0.97 | -3.08 | 0.01 |
| XEF | -0.03 | -0.30 | 0.00 |
| XER | 0.42 | -6.94 | 1.25 |
| XNA | 2.10 | 9.93 | -0.00 |
| XNF | 2.42 | 6.35 | -11.95 |
| XOC | 1.18 | -7.99 | 1.94 |
| XSA | -0.11 | -0.07 | 0.00 |
| XSC | -0.21 | -1.16 | 0.00 |
| XSE | -0.67 | -4.71 | 21.62 |
| XSM | -0.08 | -0.13 | 0.02 |
| XSU | -0.10 | 5.47 | -11.57 |
| XTW | -0.00 | -0.01 | 0.00 |
| XWF | -2.94 | -7.49 | 0.06 |
| XWS | -1.40 | -5.53 | -0.01 |
| ZAF | -6.72 | 26.61 | -24.07 |

Continued on next page

Table B2: Countries' corresponding emission changes, all countries balanced simultanously

| Country | Countries' footprint change | | |
|---|---|---|---|
| | Production | Extraction | Consumption |
| | in mn tons CO2 | | |
| ZMB | -0.28 | 0.79 | -0.09 |
| ZWE | 0.52 | -2.17 | 0.69 |