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On the Interpretation and Measurement of Technology-Adjusted Emissions Embodied in Trade

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Abstract
We propose a new method for standardizing the production technology at the world average level and derive interpretations for the resulting carbon emission concepts. The technology-adjusted emission balance measures net weak carbon leakage defined as the difference between the foreign emissions avoided by exports and the foreign emissions generated by imports. We use global multi-regional input–output tables to document the variable's spatio-temporal variation for 49 economies between 1995 and 2015. There is a positive cross-country correlation between net leakage and per-capita income. Changes in net leakage are generally small and do not account for country-specific emission trends, that is, domestic emission decreases were not offset by foreign emission increases.

Keywords CO2 · Carbon · Climate change · Decoupling · Displacement · Emissions · Global value chains · Leakage · Offshoring · Outsourcing · Input–output · Trade

1 Introduction

International emission transfers are measured by the balance of emissions embodied in trade (BEET), meaning the difference between the emissions embodied in exports (EEX) and the emissions embodied in imports (EEM), which equals the difference between production-based emissions (PBE) and consumption-based emissions (CBE). The analysis of global multi-regional input–output tables has revealed how international emission transfers vary over time, across countries, and by income level (e.g. Peters and Hertwich 2008; Hertwich and Peters 2009; Davis and Caldeira 2010). Between 1990 and 2011, the Kyoto-relevant territorial emissions decreased in the developed (Annex-B) countries while the CBE increased (Kanemoto et al. 2014). In 2008, the Annex-B countries transferred 1.6 GtCO2 to non-Annex-B countries; this amount exceeds the reductions achieved in the Kyoto protocol period until then (Peters et al. 2011). In general, the developed countries are "net importing" emissions ($PBE < CBE$) while the developing countries are "net exporting" emissions ($PBE > CBE$).

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How to interpret these facts? Economic activity and the associated emissions may simply have migrated from the developed to the developing world. Trade liberalization might have encouraged the developing countries to specialize in the production and export of emission-intensive products. “Emission outsourcing” might explain the advanced-economy decoupling success. National emission decreases apparently did not translate into corresponding global emission decreases. Jakob and Marschinski (2013) caution against premature conclusions and emphasize that the interpretation of international emission transfer patterns, and the derivation of climate policy implications, requires better understanding of the underlying driving forces. The size and direction of international emission transfers are determined to a large extent by international technology differences, that is, cross-country differences in the carbon intensity of energy and the energy intensity of production. In the presence of technology differences, exchanging identical products at equal prices would imply emission transfers (Jakob and Marschinski 2013; Jakob et al. 2014). Kander et al. (2015) propose a new scheme to account for the emissions embodied in trade – technology-adjusted accounting – which standardizes the emission intensity at the world average level. Jiborn et al. (2018), Baumert et al. (2019), and Jiborn et al. (2020) implement the technology adjustment in order to appraise competing narratives about the advanced-economy decoupling. These studies seek to evaluate the claim that the developed countries are “systematically outsourcing emissions” to the developing countries, and to assess the extent to which developed-country PBE trends are driven by international trade. The scale of emission outsourcing, it turns out, is much smaller than previously suggested, and the clear divide between the developed world and the developing world disappears. Many developed countries, especially in Europe, are “insourcing” emissions and not “outsourcing” them (Baumert et al. 2019).

How to interpret the new facts revealed by technology-adjusted accounting? We propose a new method for technology-adjusted accounting and develop interpretations for the resulting emission concepts. We interpret the technology-adjusted emission balance as a measure of *net weak carbon leakage*, document how the variable varies across space and over time, analyze its cross-country relationship with per-capita income, and discuss what technology-adjusted accounting implies with respect to the decoupling of emissions and economic growth.

The “technology adjustment” implemented thus far really is an *emission intensity adjustment*: the direct emission intensities (the ratios of emissions to gross outputs) are standardized but not the input intensities (the ratios of intermediate inputs to gross outputs). In input–output analysis (Leontief 1986), the ratios of inputs to outputs are said to represent the production technology (the “production recipes”). This point is not merely a semantic quibble but matters in practice. The observed cross-country differences in the input intensity are non-negligible, e.g. China’s cement, lime, and plaster production requires 0.82 euros worth of inputs per unit worth of output while the same sector in Germany requires just 0.64 euros. On average, Chinese producers require 0.61 euros worth of inputs per euro worth of gross output while German producers require only 0.48 euros.[1] The same demand will generate greater environmental impacts, ceteris paribus, if more inputs are required per unit of output. A comparative standard intended to represent the world average production technology should also eliminate international differences in the

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[1] These are value added-weighted national means based on EXIOBASE3 (Stadler et al. 2018) calculated as follows: for each sector, sum all intermediate input purchases from all sectors and countries and divide the sum by gross output, then form the weighted mean of these ratios using sector values added as weights.

input intensity. In this article we build on the decomposition proposed by Xu and Dietzenbacher (2014) in order to standardize the input intensities across countries. We implement the technology adjustment using EXIOBASE3 (Stadler et al. 2018), which offers finer sector detail than the MRIO tables used by our antecedents.

The emission intensity adjustment has a curious feature: it tends to be inconsequential when the analysis draws on highly dis-aggregated data, i.e. input–output tables with fine sector detail. The intensity adjustment is inconsequential, in particular, when the electricity sector is broken down by green and brown energy sources. The energy mix of the domestic electricity sector is a key driver of embodied emissions. As a rough approximation, the emission intensity of Sweden's aggregate electricity sector is low because Sweden uses hydro power rather than coal, and not because Sweden's hydro electricity production is exceptionally clean. In general, the emission intensity of the aggregate electricity sector varies a lot more across countries than the emission intensities of electricity sub-sectors vary across countries. Therefore, with fine sector detail, standardizing only the emission intensity – substituting a sector's world average value for the sector's country-specific emission intensity – will be relatively inconsequential. Our proposed technology adjustment behaves differently, because the technology adjustment standardizes the direct emission intensities *and* the intermediate input requirements. Standardizing the input requirements implies, for example, that the aluminum sectors of Sweden and China require the same amount of hydro electricity input per unit of output. As a result, the technology adjustment is consequential even when based on highly dis-aggregated data (EXIOBASE3 provides global MRIO tables with 163 sectors per country).

Section 2 discusses related literature and introduces the key concepts used in this study. We explain why we apply the technology-adjustment only to the export side, and why interpret the technology-adjusted emission balance as a measure of net weak carbon leakage. Section 3 introduces the notation for the environmentally-extended MRIO model, describes how the model is used to calculate emissions embodied in trade, and explains the modifications needed for standardizing the production technology. Section 5 discusses the results. The patterns of net weak carbon leakage are quantitatively and qualitatively different from international emission transfers. Emissions in most countries follow country-specific trends, regardless of the emission concept. Weak carbon leakage cannot be considered an important driver of national emission trends.

2 Related Literature and Key Concepts

Kander et al. (2015) first proposed the emission intensity adjustment to address concerns over the incentives implicit in PB and CB accounting. PB accounting does not hold countries responsible for the emissions associated with the production of imported products, while CB accounting does not hold countries responsible for the emissions associated with the production of exported products. In either case, there are no incentives for taking mitigation action with respect to certain emissions attributed to trading partners. The emission-intensity adjustment was designed to serve the principle that national "actions that contribute to reduced global emissions should be credited, and actions that increase them should be penalized" (Kander et al. 2015, p. 431). Kander et al. (2015) propose to hold countries responsible for the emission intensity-adjusted consumption-based emissions (EICBE), calculated as EICBE = PBE − EIEEX + EEM, where EIEEX are the emission intensity-adjusted emissions embodied in exports. Compared to regular CB accounting, this scheme introduces a new mitigation incentive by rewarding countries for cleaning up their export production. As such it contributes to the normative debate about the merit of alternative carbon accounting schemes, which discusses how emission responsibility should be attributed in order to support mitigation incentives, equity and fairness, and other principles (Rodrigues et al. 2010; Afionis et al. 2017; Zhang 2018; Dietzenbacher et al. 2020; Jakob et al. 2021).

The existing empirical implementations of the emission intensity adjustment do not discuss implicit incentive structures and normative principles, but interpret the results of positive ex-post empirical analyses of trade and emission flows. Jiborn et al. (2018) use data for Sweden and the UK to investigate if the decoupling of national emissions and production is a delusion. The decoupling would be a delusion if the emission decreases observed in Sweden and the UK were in fact offset by emission increases in the ROW. The underlying issue, at a general level, is how and to what extent "trade-driven" emission changes in individual countries *are related* to emission changes in the ROW. Baumert et al. (2019) extend the analysis to the global economy and implement the emission intensity adjustment for 40 countries and 35 sectors between 1995 and 2009, drawing on data from the World Input–Output Database, 2013 Release (Timmer et al. 2015). Jiborn et al. (2020) implement the emission intensity adjustment for 43 countries and 56 sectors between 2000 and 2014, drawing on the World Input–Output Database, 2016 Release. These studies ask if the emission trends in the developed countries are in fact driven by trade, and they seek to evaluate the claim that the developed countries are "systematically outsourcing" emissions to the developing countries.

It is important to be clear about the meaning of "emission outsourcing", and about what is being measured for which region when embodied emission flows are adjusted for intensity differences. "Emission displacement means that a country's foreign trade contributes to (i) reduced domestic emissions and (ii) increased emissions abroad compared to a no-trade scenario with the same domestic and foreign consumption" (Jiborn et al. 2018, p. 27). Note that the authors use the terms displacement, outsourcing, and weak leakage interchangeably. As explained below, the intensity-adjusted emission balance does not actually say something about the contribution of trade to *domestic* emissions—it represents the contribution of trade to *foreign* emissions—and therefore we settle on the term (net weak) leakage. Strong carbon leakage refers to policy-driven emission increases in the ROW, the idea being that e.g. more ambitious European climate policy will lead to increased production and emissions in China.[2] Weak carbon leakage refers to "demand-driven" emission increases in the ROW, the idea being that e.g. higher European import demand will lead to increased production and emissions in China (Peters 2008, 2010). The original definitions refer to the relation between Kyoto-constrained Annex-B countries and unconstrained non-Annex B countries, but many later studies simply analyze the relation between a focus country and the ROW. In either case, leakage refers to emission changes outside a focus country. The accounting for emissions embodied in trade was developed largely in response to concerns over weak leakage. Peters (2008) proposed to measure weak leakage by the emissions embodied in imports.

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[2] The evidence for strong leakage effects was always weak to non-existent, and still is. The careful econometric analysis of micro-data can uncover effects of environmental policy on trade and investment flows for certain narrowly defined energy- and pollution-intensive economic activities, but in general international environmental policy differences hardly influence the global production and investment decisions of firms (Cherniwchan et al. 2017; Dechezleprêtre and Sato 2017; Dechezleprêtre et al. 2019).

Jakob and Marschinski (2013) suggest that assessing a *net impact of trade on emissions* requires answering a but-for question: what would emissions be without trade? In this spirit Kander et al. (2015) imagine a counterfactual no-trade scenario that considers "what would be the case if a certain commodity were not to be exported from the country in question" (Kander et al. 2015, p. 432). The counterfactual scenario takes domestic and foreign demand as given, meaning a foreign producer using foreign technology will have to produce the focus country's exports instead. Without further knowledge about the counterfactual producer, "the most plausible, and least demanding, assumption is that a similar good would have been produced at the average emissions intensity on the world market for the relevant sector" (Kander et al. 2015, p. 432). Thus, when the emission intensity adjustment is applied to the emissions embodied in exports, the resulting variable (EIEEX) has to be interpreted as a measure of the *foreign emissions avoided by exports* (i.e. the PBE avoided in the ROW by the focus country's exports).

Kander et al. (2015) and Jiborn et al. (2020) define the intensity-adjusted emission balance as EIBEET = EIEEX − EEM. If applied only to the export side, the intensity adjustment violates scale invariance (Domingos et al. 2016). Scale invariance is a desirable property of carbon accounting schemes (the emission responsibility attributed to an aggregate region must equal the sum of the emission responsibility attributed to its sub-regions). To preserve it, Jiborn et al. (2018) and Baumert et al. (2019) also adjust the emissions embodied in imports. But what the resulting variable measures is not so clear. The emission-intensity adjusted emissions embodied in imports (EIEEM) has no obvious interpretation. There is a conflict between methodological choices that serve the attribution of emission responsibility and methodological choices that serve the ex-post analysis of trade and emission flows. We are performing the latter, we like to preserve clean interpretations of the technology-adjusted emission concepts, and therefore we adjust only the export side.

The intensity-adjusted emission balance (EIBEET = EIEEX − EEM) compares the foreign emissions avoided by exports to the foreign emissions generated by imports; with reversed sign, it can be interpreted as a measure of *net weak carbon leakage*. A positive EIBEET indicates that a country's trade is net avoiding emissions in the ROW, or net avoiding foreign emissions for short. The contribution of trade to domestic emissions would be given by the difference between the observed emissions embodied in exports and the counterfactual emissions avoided by imports, and is typically measured by the *balance of avoided emissions*.[3]

3 Methods

3.1 Emissions Embodied in Trade and the Emission Intensity Adjustment

We use the environmentally-extended MRIO model to calculate carbon dioxide emissions embodied in trade (Leontief 1970; Miller and Blair 2009). For ease of exposition we

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[3] The balance of avoided emissions is given by the difference between the domestic emissions embodied in gross exports and the domestic emissions avoided by gross imports. Both magnitudes are routinely calculated calculated based on the domestic technology assumption and the *emissions embodied in bilateral trade approach* (e.g. Dietzenbacher and Mukhopadhyay 2007; Zhang 2012; López et al. 2013; Zhang et al. 2017).

simplify to the two-country setting and follow the notation of Jiborn et al. (2020) to write the MRIO model in compact form:

$$\begin{bmatrix} e^{11} & e^{12} \\ e^{21} & e^{22} \end{bmatrix} = \begin{bmatrix} \hat{q}^1 & 0 \\ 0 & \hat{q}^2 \end{bmatrix} \begin{bmatrix} L^{11} & L^{12} \\ L^{21} & L^{22} \end{bmatrix} \begin{bmatrix} y^{11} & y^{12} \\ y^{21} & y^{22} \end{bmatrix} \tag{1}$$

Here the global emission matrix E, the global direct emissions intensity vector q (the hat denotes a diagonal matrix formed by the vector), the global Leontief inverse L, and the global final demand matrix Y are partitioned into sub-matrices and sub-vectors for countries 1 and 2. Country 1 can be considered as the focus country and country 2 as the ROW. e^{11} and e^{22} each represent the "domestic-domestic" emissions (DDE^1 and DDE^2), meaning domestic emissions embodied in domestic final demand. From the perspective of country 1, $e^{12} = \hat{q}^1 L^{11} y^{12} + \hat{q}^1 L^{12} y^{22}$ represents the emissions embodied in exports (EEX^1), meaning the domestic emissions embodied in foreign final demand. $e^{21} = \hat{q}^2 L^{21} y^{11} + \hat{q}^2 L^{22} y^{21}$ represents the emissions embodied in imports (EEM^1), meaning the foreign emissions embodied in domestic final demand. Country 1's production-based emissions (PBE^1) are the sum of DDE^1 and EEX^1. Its consumption-based emissions (CBE^1) are the sum of DDE^1 and EEM^1. Country 1's balance of emissions embodied in trade ($BEET^1$), the net emissions transfer, is given by $BEET^1 = EEX^1 - EEM^1 = PBE^1 - CBE^1$. A positive BEET ($EEX^1 > EEM^1$) indicates that country 1 is net transferring, or net exporting, emissions to the ROW.[4]

The emission intensity adjustment replaces country-specific values of the each sector's emission intensity by the respective sector's world average value. We use a gross output-weighted average:[5]

$$\dot{q}_i = \sum_s \frac{x_i^s}{x_i} \cdot q_i^s \tag{2}$$

$\dot{q}_i$ denotes sector i's standardized emission intensity, q_i^s the direct emission intensity of sector i in country s, x_i^s the gross output of sector i in country s, $x_i = \sum_s x_i^s$ sector i's global gross output, and i and s sector and country indices.

The calculation would more accurately capture the target concept (the emissions avoided in the ROW by the focus country's export production) if the world average intensity was calculated excluding the focus country. This calculation would yield country-specific ROW emission intensities, rather than a single global average for each sector. For most countries it will not matter much, but even China and the USA make up only 15% of global GDP each (a rough indication of the average industry weight for these countries). In our view, this is acceptable, especially because there are also benefits to using a single global average: (i) the results are comparable to previous studies and (ii) the comparison of each country to the same global comparative standard has intuitive appeal.

Using the standardized emission intensities, the MRIO system is:

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[4] The equation system (1) does not capture direct household emissions. In the empirical analysis we will always add household emissions to the domestic-domestic emissions, and therefore treat them as part of PBE and CBE.

[5] Jiborn et al. (2020) use gross outputs as weights while Kander et al. (2015) and Baumert et al. (2019) use trade flows as weights. In either case, large economies like the USA and China heavily influence the world average.

$$\begin{bmatrix} \dot{e}^{11} & \dot{e}^{12} \\ \dot{e}^{21} & \dot{e}^{22} \end{bmatrix} = \begin{bmatrix} \hat{\dot{q}}^{1} & 0 \\ 0 & \hat{\dot{q}}^{2} \end{bmatrix} \begin{bmatrix} L^{11} & L^{12} \\ L^{21} & L^{22} \end{bmatrix} \begin{bmatrix} y^{11} & y^{12} \\ y^{21} & y^{22} \end{bmatrix} \tag{3}$$

The domestic-domestic emissions should be ignored, only the emissions embodied in trade are relevant in what follows. From the perspective of country 1, $\dot{e}^{12} = \hat{\dot{q}}^{1}L^{11}y^{12} + \hat{\dot{q}}^{1}L^{12}y^{22}$ represents the emission intensity-adjusted emissions embodied in exports ($EIEEX^{1}$), and $\dot{e}^{21} = \hat{\dot{q}}^{2}L^{21}y^{11} + \hat{\dot{q}}^{2}L^{22}y^{21}$ the emission intensity-adjusted emissions embodied in imports ($EIEEM^{1}$). The no-trade scenario assumes foreign sectors produce country 1's exports using the world average emission intensity, so the EIEEX measure the foreign emissions avoided by country 1's exports. We follow Kander et al. (2015) and Jiborn et al. (2020) and define country 1's emission intensity-adjusted balance of emissions embodied in trade as $EIBEET^{1} = EIEEX^{1} - EEM^{1}$. Only the exports are adjusted. The EIBEET therefore compares the hypothetical foreign emissions avoided by exports to the observed foreign emissions generated by imports. A positive EIBEET implies a net decrease in foreign emissions.

3.2 The Technology Adjustment

We propose to adjust not only the direct emission intensity but also the intermediate input intensity, the quantity of inputs per unit of output. The technology-adjusted MRIO system is:

$$\begin{bmatrix} \ddot{e}^{11} & \ddot{e}^{12} \\ \ddot{e}^{21} & \ddot{e}^{22} \end{bmatrix} = \begin{bmatrix} \hat{\dot{q}}^{1} & 0 \\ 0 & \hat{\dot{q}}^{2} \end{bmatrix} \begin{bmatrix} \dot{L}^{11} & \dot{L}^{12} \\ \dot{L}^{21} & \dot{L}^{22} \end{bmatrix} \begin{bmatrix} y^{11} & y^{12} \\ y^{21} & y^{22} \end{bmatrix} \tag{4}$$

The equations for embodied emissions are the same as before: from the perspective of country 1, $\ddot{e}^{12} = \hat{\dot{q}}^{1}\dot{L}^{11}y^{12} + \hat{\dot{q}}^{1}\dot{L}^{12}y^{22}$ represents the technology-adjusted emissions embodied in exports ($TEEX^{1}$), and $\ddot{e}^{21} = \hat{\dot{q}}^{2}\dot{L}^{21}y^{11} + \hat{\dot{q}}^{2}\dot{L}^{22}y^{21}$ represents the technology-adjusted emissions embodied in imports ($TEEM^{1}$). The only difference to system (3) is the appearance of the technology-adjusted Leontief inverse $\dot{L}$, which is derived from adjusted technical coefficients. The adjustment is inspired by Xu and Dietzenbacher (2014) and explained in the remainder of this section.

Consider the aluminum sector in Sweden and its intermediate input purchases of nuclear electricity. We so adjust the technical coefficients that Sweden's aluminum sector directly requires as much nuclear electricity per unit of output as the world average aluminum sector. To this end we calculate the *technological* coefficients, which represent direct sector-by-sector intermediate input requirements regardless which country supplies the inputs. Let a_{ij}^{sr} be an element of the global technical coefficient matrix A representing country-sector pair rj's intermediate input purchases from the country-sector pair si. Summing over all supplying countries s gives the technological coefficient:[6]

$$h_{ij}^{r} = \sum_{s=1}^{m} a_{ij}^{sr} \tag{5}$$

Country r's technological coefficient matrix H^{r} (size $n \times n$) collects these coefficients:

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[6] The term *technological* coefficient is from Xu and Dietzenbacher (2014). It needs to be distinguished from the *technical* coefficients in A, which are common to any input–output analysis.

$$H^r = \sum_{s=1}^{m} A^{sr} \tag{6}$$

where A^{sr} is a $n \times n$ sub-matrix of the global technical coefficient matrix A.

The *trade structure matrix* T reflects the origin (geographical composition) of the intermediate inputs:

$$T = \begin{bmatrix} T^{11} & \cdots & T^{1m} \\ \vdots & \ddots & \vdots \\ T^{m1} & \cdots & T^{mm} \end{bmatrix} \tag{7}$$

Its elements represent the share of all inputs i (required per unit of output by sector j in country r) that originates in country s, calculated as:

$$t_{ij}^{sr} = a_{ij}^{sr} / h_{ij}^{r} \tag{8}$$

The sum over all countries s necessarily adds up to one: $\sum_{s=1}^{m} t_{ij}^{sr} = 1$.

We have introduced all the objects needed to decompose the global technical coefficients matrix:

$$A = \begin{bmatrix} T^{11} \otimes H^{1} & \cdots & T^{1m} \otimes H^{m} \\ \vdots & \ddots & \vdots \\ T^{m1} \otimes H^{1} & \cdots & T^{mm} \otimes H^{m} \end{bmatrix} \tag{9}$$

where $\otimes$ represents the Hadamard product (element-wise multiplication). The technology adjustment replaces country-specific values of the technological coefficients by world average values. The standardized coefficients are calculated as gross output-weighted averages:

$$\dot{h}_{ij} = \sum_{s} \frac{x_i^s}{x_i} \cdot h_{ij}^{s} \tag{10}$$

where $x_i = \sum_s x_i^s$ is sector i's global gross output. Using the same technological coefficients for all countries, $\dot{H} = H^1 = H^2 = \ldots$, the new technical coefficients matrix is:

$$\dot{A} = \begin{bmatrix} T^{11} \otimes \dot{H} & \cdots & T^{1m} \otimes \dot{H} \\ \vdots & \ddots & \vdots \\ T^{m1} \otimes \dot{H} & \cdots & T^{mm} \otimes \dot{H} \end{bmatrix} \tag{11}$$

$\dot{A}$ defines the technology-adjusted Leontief inverse, $\dot{L} = (I - \dot{A})^{-1}$, which is used to calculate the technology-adjusted emissions embodied in trade per system (4).

The regular emission balance is defined as BEET = EEX − EEM and the technology-adjusted balance as TBEET = TEEX − EEM. The BEET compares *domestic* emissions generated by foreign demand and *foreign* emissions generated by domestic demand. The BEET measures international emission transfers; when it is positive, we say the country is net exporting emissions or net transferring emissions to the ROW. The TBEET focuses on *foreign* emissions only, comparing hypothetical foreign emissions avoided by exports and observed foreign emissions generated by imports. The TBEET measures net weak carbon leakage; when it is positive, we say the country is net avoiding emissions in the ROW or simply net avoiding foreign emissions. When the TBEET is negative, we say the country is net generating foreign emissions or net leaking emissions.

4 Data

Our source for the annual MRIO tables are the monetary industry-by-industry tables from EXIOBASE3 (Stadler et al. 2018). The main inputs to EXIOBASE3 are macroeconomic data from the UN National Accounts Main Aggregates Database, goods trade data from BACI (Gaulier and Zignago 2010), services trade data from the UN Service Trade Database, product and industry output data from the Detailed Tables of the UN National Accounts Statistics and national statistical offices, as well as supply- and use tables from national statistical offices. Stadler et al. (2018) describe the principles guiding the relations between different classification systems, the filling of gaps, and the reconciliation and balancing needed for the MRIO table construction. The resulting MRIO tables, covering 44 countries and five ROW aggregate regions between 1995 and 2015, stand out for their detailed sector classification dividing economic activity into 163 sectors per country. Notably, electricity production is not merely part of some larger utilities sector but is dis-aggregated by energy source (in total there are 12 different electricity sectors: coal, nuclear, hydro, etc.).

EXIOBASE3 includes environmental satellite accounts matching the sector classification of the MRIO tables. We select total CO2 emissions (kg) as the environmental stressor variable. Only up to 2015 does EXIOBASE3 use detailed emissions data as input to the values of the environmental stressor; we prioritize data quality and restrict our analysis to the period 1995–2015.

EXIOBASE3 covers mostly developed countries with the exceptions of Brazil, China, Indonesia, India, Mexico, and South Africa. The five ROW aggregates are largely composed of developing countries, though the average per-capita income of the Middle East ROW aggregate is at the same level as Greece and Hungary. EXIOBASE3 fills input data gaps for single countries and the ROW regions, so that the final database is exhaustive in that it covers the global economy. Values in the economic transactions tables are estimated in a way that global totals from the UN National Accounts Main Aggregates Database are preserved. The construction of exhaustive environmental satellite accounts involves the estimation of emission factors for the ROW regions (using weighted averages of all available countries) (Stadler et al. 2018, Supporting Information S3). The appendix gives the complete list of countries and country codes (Table 1).

We supplement the environmentally-extended IO tables with country-level population and national accounts data from the Penn World Table Version 10 (PWT10, Feenstra et al. 2015). As an indicator of income per capita, we use output-side real GDP at chained PPPs in 2017US$ divided by population.

5 Results and Discussion

5.1 The Technology-Adjusted Balance of Emissions in Trade

We plot the technology-adjusted balance of emissions embodied in trade (TBEET) for two big developed countries with trade deficits and relatively large service sectors (the USA and the UK), two big developed countries with export orientation and relatively large manufacturing sectors (Germany and Japan), and the two biggest developing countries (China and India, Fig. 1). For comparison and contrast we also plot the regular emission balance

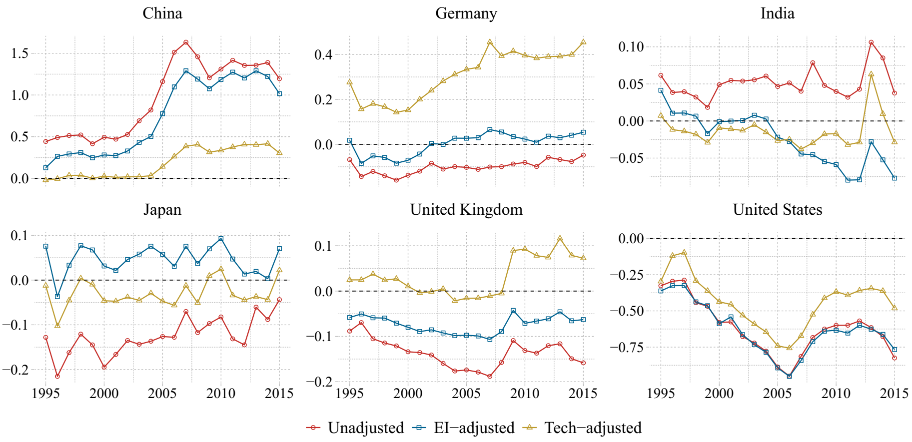

Fig. 1 Balance of Emissions Embodied in Trade, GtCO2

(BEET) and the emission intensity-adjusted emission balance (EIBEET). The USA records a negative TBEET, meaning the USA avoids less emissions in the ROW than it generates in the ROW, in other words, the USA net generates foreign emissions (or is net leaking emissions). No region in the whole sample net generates more foreign emissions than the USA (0.5 GtCO2 in 2015).[7] China net avoids foreign emissions, that is, China's participation in global value chains helps countries in the ROW to reach their climate targets—the "Factory of the World" provides a mitigation service to its trading partners. The amount of foreign emissions net avoided is modest and smaller, by a factor of four, than the amount of emissions transferred (China's TBEET in 2015 is 0.3 GtCO2 and its BEET is 1.2 GtCO2). For the USA, the difference between the TBEET and the BEET is less pronounced (the TBEET is −0.5 GtCO2 and the BEET is −0.8 GtCO2).

For India, Japan, and the UK, the size of the TBEET is relatively modest. These countries do not contribute very much to emissions in the ROW, neither in absolute terms nor relative to national PBE. No single country in the whole sample net avoids more foreign emissions than Germany (0.5 GtCO2 in 2015). Germany, China and other trade-surplus countries are producing more than they are consuming, which helps the ROW to avoid emissions.

There is a well-known negative cross-country relationship between the regular BEET and per-capita income. There is no analogous relationship between the TBEET and per-capita income—in fact there is a positive correlation between the two variables (Fig. 3). Germany, the Netherlands, and many other developed countries are net avoiding foreign emissions while India and Indonesia are net generating foreign emissions. But the strength of the TBEET-income relationship should not be overestimated (see the regression analysis in "Appendix"). The rich USA is net generating foreign emissions while China and South Africa are net avoiding foreign emissions.

The negative cross-country BEET-income relationship is driven to a large extent by international technology differences, as producers tend to generate less emissions per unit of output

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[7] The appendix contains the full set of results for all countries and ROW aggregates. Tables 2, 3, 4, 5, 6 and 7 report emission balances, consumption-based emissions, and the emissions embodied in exports in GtCO2 and also in % of PBE. Figures 4, 5 and 6 show the same variables in line plots by country.

in developed countries than in developing countries (Jakob and Marschinski 2013; Baumert et al. 2019). The EEX depend on the focus country's production technology, but the technology adjustment replaces the country-specific technology by a common global standard, eliminating a key source of variation in EEX. The EEM calculation is based on a mix of production technologies. The more geographically diversified are the import partners, the more will the average import partner technology resemble the world average technology. The role of international technology differences thus dampened, the TBEET will significantly depend on the trade balance, i.e. the scale of exports and imports, and the composition of exports and imports.

Structural decomposition methods could shed light on the TBEET's proximate drivers, and quantify how much certain drivers contribute to the differences between the TBEET and the BEET. That type of analysis is beyond the scope of this study, but some patterns can be inferred from the reported results. First, the monetary trade balance is an important driver of the TBEET. This is evident from the TBEET's variation over time and across countries. For China, Germany, and the USA, the TBEET roughly tracks the trade balance. Prominent surplus countries (China, Germany, and the Netherlands) record positive TBEETs, while the most prominent deficit country (USA) records negative TBEETs (Appendix, Table 3). Second, the trade composition might explain why resource-abundant countries exporting mined raw materials tend to record positive TBEETs. Examples are Canada, Norway, Russia, and the Middle East ROW aggregate (Appendix, Table 3). Trade surpluses may partly explain the pattern, but the trade composition probably plays a role as well, as the cleaning and processing of resources can be quite emission intensive. Composition effects should be most visible in commodity-exporting countries, due to the export concentration. The exports of China, Germany, and the USA are more diversified, thus the trade composition plays a smaller role and trade balance effects are brought to light. Third, the regular BEET depends heavily on international differences in the input intensity. This can be inferred from the difference between the TEEX and the EEX: for most countries this difference is large and larger than the difference between the EIEEX and the EEX (Appendix, Table 7). Standardizing technology is more consequential than standardizing only the direct emission intensity.[8]

The Chinese production technology is browner than the world average, and the technology adjustment roughly halves China's EEX. The American production technology is greener than the world average, and the technology adjustment roughly doubles the USA's EEX (Appendix, Table 7). The technology adjustment triples Germany's EEX, and it is even more consequential for small countries like Austria, Croatia, Finland, Hungary, Slovenia, Sweden, and Switzerland, where the ratios of TEEX to EEX exceed four (Appendix, Table 6). Austria, Germany, and Hungary do not house exceptionally clean electricity sectors, so the energy mix is only part of the story, and the adjustment to the intermediate input intensities of the producing sectors matters as well.

5.2 Technology-Adjusted Consumption-Based Emissions

This section evaluates the national emission trends in the six focus countries. Our main interest rests with the PBE and the TCBE, but we also plot the CBE and EICBE for comparison and contrast (Fig. 2). The TCBE represent the production-based emissions plus the

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[8] We report the emission-intensity adjusted variables for completeness, but the emission intensity adjustment should be implemented with input–output tables that come at a higher level of aggregation. The disaggregated electricity sector in EXIOBASE3 dampens the effects the intensity adjustment would otherwise have.

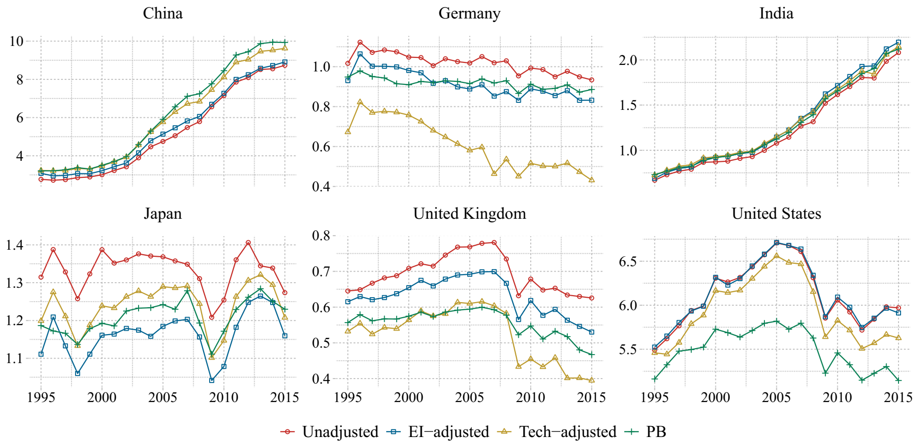

Fig. 2 Consumption-based Emissions, GtCO2

emissions net generated in the ROW. Assuming the economy is growing, decreasing PBE indicates successful decoupling. The decoupling would be a delusion, following Jiborn et al. (2018), if the TCBE increased over the same period, for then the increase in the net generation of foreign emissions was larger than the PBE decrease.

The overall picture is that emissions are increasing in the two big developing countries, are decreasing in Germany, show ups and downs while remaining overall roughly constant in Japan, and are increasing first and then decreasing in the UK and the USA. This picture emerges regardless of which emission concept is being considered. For each country, there are level differences between the PBE and TCBE, but the two variables tend to change in the same direction, following country-specific trends. Changes in the net generation of foreign emissions, as a rule, are too small to cause qualitative divergence between the existing emission concepts.

In much of the developed world, economic growth has decoupled from any of the existing emission concepts. Europe's CBE peaked in 2006 (Karstensen et al. 2018; Wood et al. 2019). Both PBE and CBE decreased in 18 developed countries between 2005 and 2015 (Quéré et al. 2019). Jiborn et al. (2020) analyze the period 2000–2014 and report that 21 countries record decreases in PBE, CBE, and the emission intensity-adjusted CBE. Our sample covers the period 1995–2015 and shows that PBE are decreasing in 24 countries (out of 44), the technology-adjusted CBE are decreasing in 29 countries, and both variables are decreasing in 19 countries (Appendix, Tables 4 and 8). That said, the absolute decoupling of emissions and economic growth in the developed countries is insufficient—reaching climate targets requires far greater mitigation rates (e.g. Quéré et al. 2019).

While most developed countries record decreasing emissions, all the developing countries in our sample record increasing emissions. The proximate drivers are relatively clear. Production-side decompositions based on the Kaya identity show that energy intensity improvements (more than decarbonization) account for the bulk of the emission decreases in the developed countries. Meanwhile in the developing world, income and population growth are pushing emissions up more than decarbonization efforts and energy intensity improvements are pulling them down (Quéré et al. 2019; Xia et al. 2020). The importance of changes in the scale of economic activity is also visible from demand-side decompositions based on the input–output model. Rising domestic demand—more than the increased participation in global supply chains—has driven the emission increases in the developing countries (de Vries and Ferrarini 2017). Alone the increased *domestic production serving domestic final demand in China* accounts for nearly 50% of the increase in *global* emissions between 2000 and 2014 (Jiborn et al. 2020).

Net weak carbon leakage as measured by the technology-adjusted emission balance cannot be regarded as an important driver of national emission trends. To avoid misunderstanding, this does not mean that international trade hardly influences national or global emissions. It may be true that the key proximate determinants of China's rapid emission growth are the (coal-fueled) buildup of the domestic capital stock and the rising consumption demand from the growing middle class, rather than observed trade flows. But this economic development is hard to imagine without the export-oriented growth strategy China was able to pursue in the increasingly integrated world economy. Without technology diffusion and learning spurred by foreign investment, without the foreign demand for manufactured products, China's domestic demand would never have increased as much. The input–output model rules out mechanisms through which trade influences technology and demand.[9] Net weak carbon leakage represents the contribution of a country's trade to foreign emissions, where this contribution is calculated for given technologies and demands. The interpretation is analogous to the balance of avoided emissions, also an input–output based concept that takes technology and demand as given, which represents the contribution of a country's trade to domestic emissions (e.g. Dietzenbacher and Mukhopadhyay 2007; Zhang et al. 2017).

6 Summary and Concluding Remarks

We proposed and implemented a new method for the technology-adjusted accounting for emissions embodied in trade. Following the logic of emission intensity-adjusted accounting (Kander et al. 2015), the standardization should be extended to the production recipes.

Technology-adjusted accounting can be viewed as a contribution to the normative debate about the attribution of emission responsibility, which considers the design of incentive-compatible accounting schemes that would credit countries only for those national mitigation actions that lead to global emission reductions (Kander et al. 2015; Dietzenbacher et al. 2020; Jakob et al. 2021). Such schemes should not ignore international differences in the input intensity. Exploring the merits of alternative accounting schemes, irrespective of political and practical constraints, is a worthwhile enterprise. At the same time, there is little political momentum for adopting an alternative to territorial or PB accounting, and any scheme that depends on accurate input–output tables for all countries faces severe practical challenges (e.g. Liu 2015; Afionis et al. 2017).

The technology adjustment can also be viewed as a tool for the positive analysis of emissions embodied in trade. After examining what the resulting emission concepts measure,

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[9] Standard models in the tradition of the pure theory of trade predict scale, composition, and technique effects of trade on emissions. Econometric methods can quantify these effects (e.g. Antweiler et al. 2001). In decomposition studies, the effects of the proximate drivers often bear the same names, but these "empirical" effects need to be distinguished from the causal effects of trade implied by economic models.

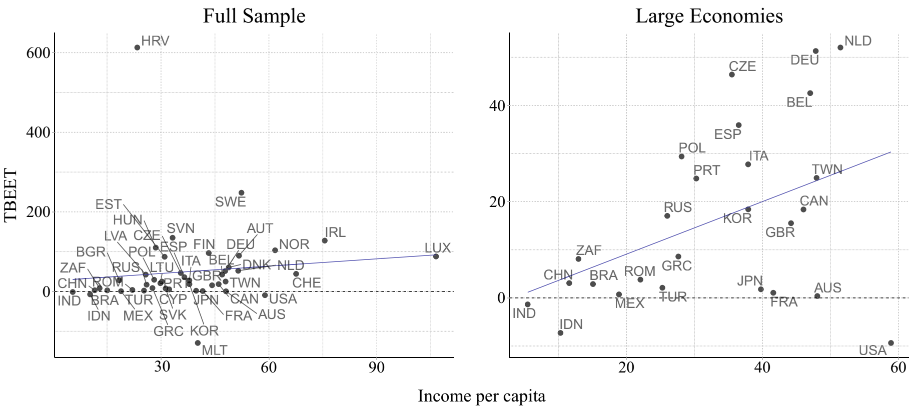

Fig. 3 TBEET vs. Income per Capita, 2015 Snapshot. *Notes* Own calculations based on EXIOBASE3 and PWT10 using data from 2015. The TBEET is measured in % of PBE, income per capita in thousand PPP-adjusted US$. The right panel excludes economies whose 2015 population is lower than 10 million. The lines represent the best linear fit from simple OLS cross-country regressions (see "Appendix")

we interpreted the technology-adjusted emission balance (with reversed sign) as a measure of net weak carbon leakage. A country's imports generate emissions in the ROW, while its exports avoid emissions in the ROW. The technology-adjusted EEX represent a measure of the foreign emissions avoided by exports, and the technology-adjusted BEET represents a measure of the foreign emissions net avoided by trade. The technology-adjusted CBE represent production-based emissions plus emissions net avoided in the ROW.

International emission transfers and net weak carbon leakage show different patterns. In contrast to the regular BEET, the TBEET exhibits a *positive* cross-country correlation with per-capita income. Most developed economies are net avoiding foreign emissions. China helps its trading partners to avoid emissions, though the amounts are modest and much smaller than China's net emission exports. Emissions are decreasing in many developed countries while they are increasing in the developing countries, regardless of the emission concept. The modest decoupling success in the developed countries would be tainted if the PBE decreases had been accompanied by trade-driven emission increases in the ROW. This is not the case, changes in net weak leakage do not account for the decreases.

Appendix: Cross-Country Regressions

To assess the strength of the positive cross-country correlation between the TBEET and per-capita income, we regress the TBEET in % of PBE on per-capita GDP in thousand PPP-adjusted US$ (Table 9). The columns 1 and 2 report simple OLS regressions with heteroskedasticity-consistent standard errors based on the 2015 cross section (Fig. 3 shows the regression lines). The columns 3 and 4 report pooled OLS regressions with country-cluster-robust standard errors based on panel data from 1995–2015. The pooled OLS estimator is consistent for the parameters $\boldsymbol{\beta}$ of the model:

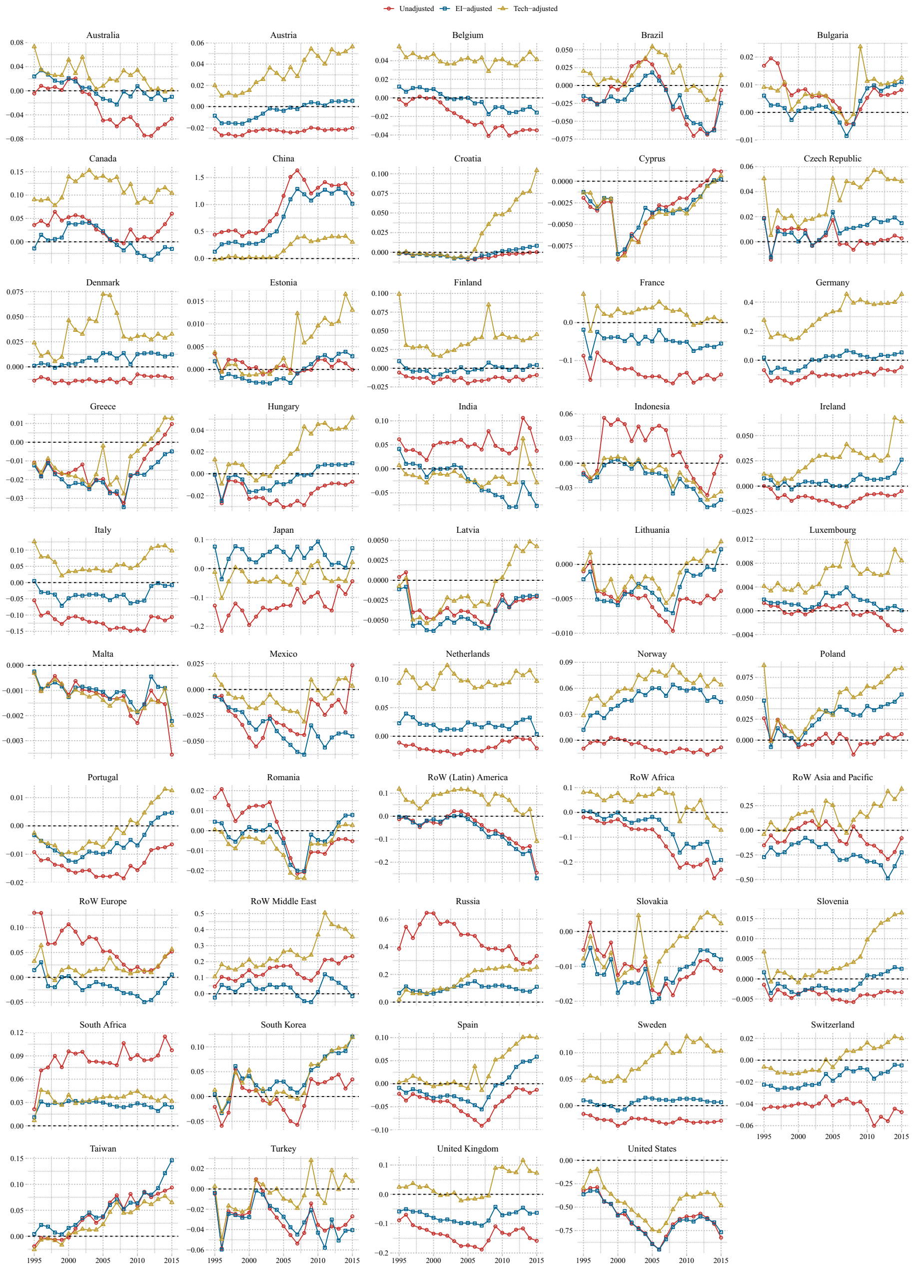

Fig. 4 Balance of emissions embodied in trade 1995–2015, line plots by country

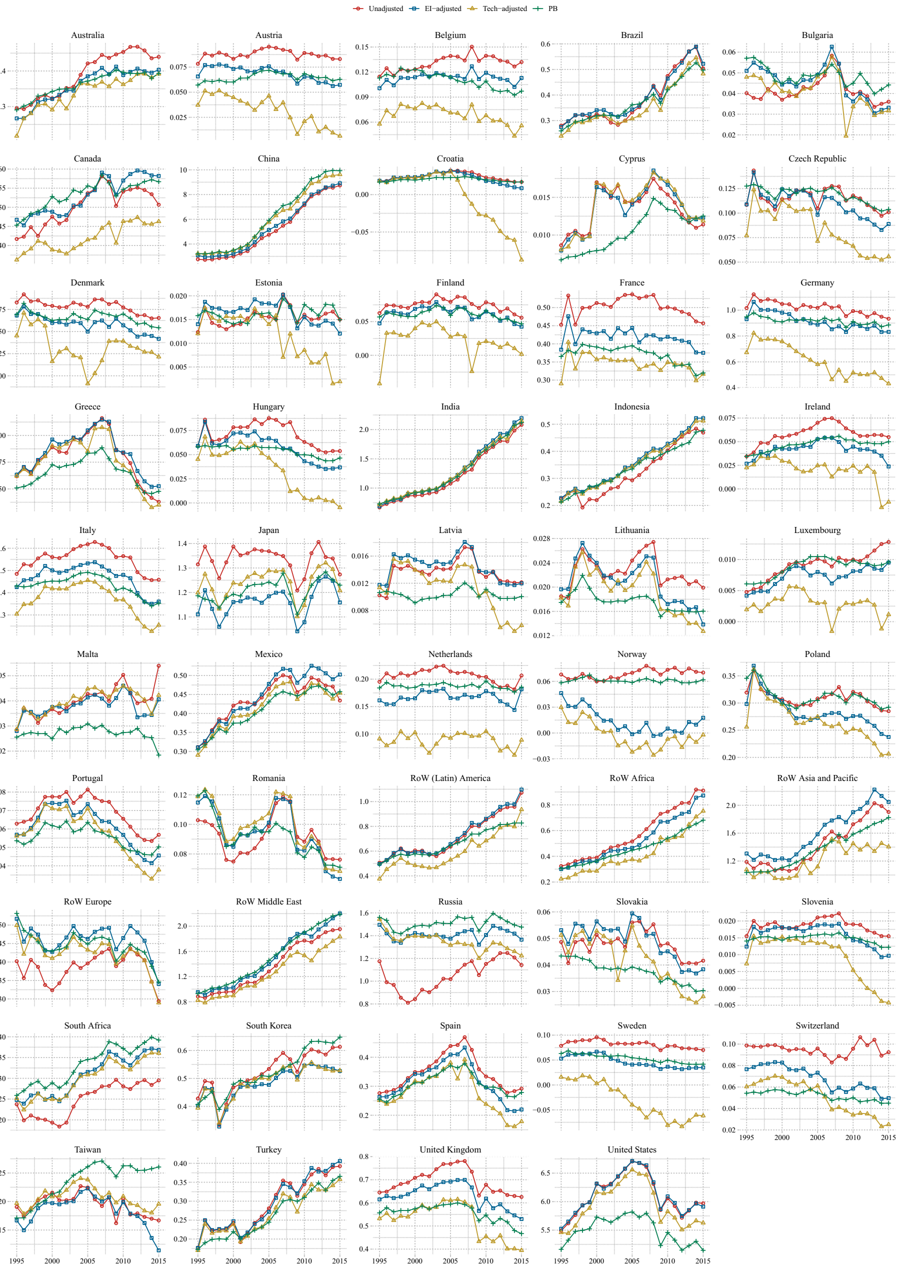

Fig. 5 Consumption-based and production-based emissions 1995–2015, line plots by country

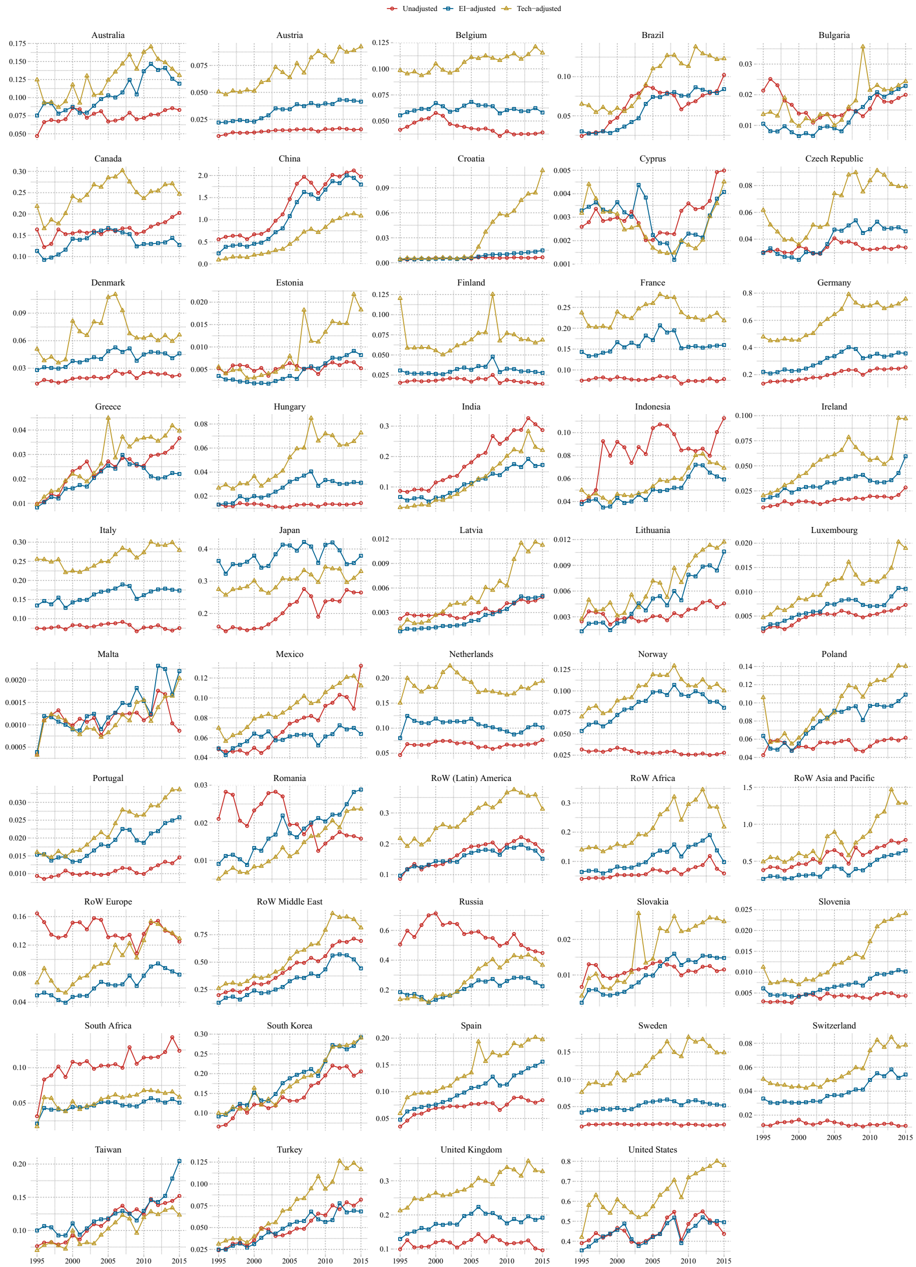

Fig. 6 Emissions embodied in exports 1995–2015, line plots by country

Table 1 Countries in EXIOBASE3

Code	Country	Code	Country
AUS	Australia	KOR	South Korea
AUT	Austria	LTU	Lithuania
BEL	Belgium	LUX	Luxembourg
BGR	Bulgaria	LVA	Latvia
BRA	Brazil	MEX	Mexico
CAN	Canada	MLT	Malta
CHE	Switzerland	NLD	Netherlands
CHN	China	NOR	Norway
CYP	Cyprus	POL	Poland
CZE	Czech Republic	PRT	Portugal
DEU	Germany	ROM	Romania
DNK	Denmark	RUS	Russia
ESP	Spain	SVK	Slovakia
EST	Estonia	SVN	Slovenia
FIN	Finland	SWE	Sweden
FRA	France	TUR	Turkey
GBR	United Kingdom	TWN	Taiwan
GRC	Greece	USA	United States
HRV	Croatia	WWA	RoW Asia and Pacific
HUN	Hungary	WWE	RoW Europe
IDN	Indonesia	WWF	RoW Africa
IND	India	WWL	RoW (Latin) America
IRL	Ireland	WWM	RoW Middle East
ITA	Italy	ZAF	South Africa
JPN	Japan		

$$y_{it} = \boldsymbol{x}_{it}\boldsymbol{\beta} + v_{it} \tag{12}$$

where the regressor vector $\boldsymbol{x}_{it}$, which includes per-capita income and year dummies, does not correlate with the composite error (the unobserved country effect plus the idiosyncratic error $v_{it} = c_i + u_{it}$), i.e. $E(\boldsymbol{x}_{it}v_{it}) = \boldsymbol{0}$. The regressions yield coefficients that measure statistical association and should be viewed as a tool of descriptive analysis. A causal analysis would at the very least address the potential correlation between per-capita income and the unobserved effects (i.e. use the fixed effects estimator), and possibly deal with reverse causality as well. Our goal is merely to show how net weak carbon leakage and per-capita income are related in the cross-section.

The slope coefficient, statistically significant (5%) in one regression (Column 3), is always greater than zero and varies between 0.44 and 0.95. A coefficient of one would indicate that one thousand dollar higher income is associated with one percentage point higher TBEET. The R squares are low, the variation around the best linear fit is large, many factors other than income explain the TBEET.

Table 2 Balance of emissions embodied in trade, GtCO2

Country	1995			2005			2015		
	BEET	EIBEET	TBEET	BEET	EIBEET	TBEET	BEET	EIBEET	TBEET
Australia	– 0.005	0.024	0.073	– 0.049	– 0.013	0.008	– 0.046	– 0.010	0.002
Austria	– 0.021	– 0.009	0.020	– 0.024	– 0.004	0.026	– 0.020	0.005	0.056
Belgium	– 0.002	0.012	0.055	– 0.025	0.000	0.043	– 0.035	– 0.016	0.041
Brazil	– 0.021	– 0.015	0.020	0.030	0.018	0.054	– 0.007	– 0.025	0.014
Bulgaria	0.017	0.006	0.009	0.004	0.000	0.001	0.008	0.011	0.012
Canada	0.036	– 0.014	0.091	0.019	0.023	0.141	0.060	– 0.015	0.104
China	0.442	0.128	– 0.020	1.161	0.776	0.141	1.195	1.016	0.305
Croatia	– 0.002	– 0.002	– 0.001	– 0.009	– 0.009	– 0.008	0.000	0.008	0.104
Cyprus	– 0.002	– 0.001	– 0.001	– 0.004	– 0.004	– 0.004	0.001	0.000	0.001
Czech Republic	0.019	0.019	0.050	0.017	0.024	0.051	0.003	0.015	0.048
Denmark	– 0.014	0.001	0.024	– 0.014	0.014	0.073	– 0.011	0.012	0.033
Estonia	0.003	0.002	0.004	0.001	– 0.002	0.002	0.000	0.003	0.013
Finland	– 0.006	0.009	0.099	– 0.020	– 0.005	0.032	– 0.009	0.004	0.045
France	– 0.087	– 0.019	0.075	– 0.142	– 0.049	0.039	– 0.137	– 0.055	0.003
Germany	– 0.068	0.018	0.276	– 0.103	0.027	0.334	– 0.048	0.054	0.454
Greece	– 0.011	– 0.012	– 0.011	– 0.020	– 0.021	– 0.002	0.010	– 0.005	0.013
Hungary	– 0.001	– 0.001	0.013	– 0.031	– 0.010	0.011	– 0.007	0.010	0.051
India	0.062	0.041	0.007	0.047	– 0.022	– 0.027	0.038	– 0.077	– 0.029
Indonesia	– 0.012	– 0.014	– 0.002	0.042	– 0.012	– 0.009	0.009	– 0.045	– 0.035
Ireland	0.000	0.008	0.012	– 0.017	0.000	0.028	– 0.005	0.026	0.064
Italy	– 0.055	0.005	0.126	– 0.126	– 0.040	0.036	– 0.106	– 0.008	0.098
Japan	– 0.128	0.076	– 0.012	– 0.126	0.058	– 0.047	– 0.044	0.070	0.022
Latvia	0.000	– 0.001	– 0.001	– 0.004	– 0.005	– 0.002	– 0.002	– 0.002	0.004
Lithuania	– 0.001	– 0.002	– 0.001	– 0.006	– 0.004	– 0.002	– 0.004	0.002	0.003
Luxembourg	0.001	0.002	0.004	0.000	0.002	0.008	– 0.003	0.000	0.008
Malta	0.000	0.000	0.000	– 0.001	– 0.001	– 0.001	– 0.004	– 0.002	– 0.002
Mexico	– 0.007	– 0.006	0.014	– 0.034	– 0.047	– 0.019	0.023	– 0.045	0.003
Netherlands	– 0.011	0.023	0.093	– 0.024	0.024	0.097	– 0.021	0.004	0.096
Norway	– 0.010	0.012	0.029	– 0.011	0.060	0.081	– 0.008	0.044	0.064
Poland	0.026	0.047	0.089	– 0.003	0.032	0.030	0.007	0.055	0.086
Portugal	– 0.009	– 0.003	– 0.003	– 0.018	– 0.010	– 0.008	– 0.007	0.005	0.012
Romania	0.016	0.004	0.000	– 0.004	– 0.006	– 0.012	– 0.005	0.008	0.003
RoW (Latin) America	– 0.013	– 0.003	0.118	0.008	– 0.012	0.115	– 0.245	– 0.270	– 0.109
RoW Africa	– 0.019	0.004	0.081	– 0.069	– 0.018	0.072	– 0.231	– 0.192	– 0.071
RoW Asia and Pacific	– 0.152	– 0.272	– 0.040	0.010	– 0.212	0.255	– 0.080	– 0.224	0.419
RoW Europe	0.130	0.015	0.032	0.052	– 0.014	0.016	0.052	0.005	0.056
RoW Middle East	0.045	– 0.024	0.107	0.174	0.057	0.262	0.235	– 0.014	0.355
Russia	0.386	0.065	0.017	0.489	0.133	0.191	0.333	0.110	0.251
Slovakia	– 0.005	– 0.010	– 0.008	– 0.017	– 0.020	– 0.016	– 0.011	– 0.008	0.002
Slovenia	– 0.001	0.002	0.007	– 0.005	– 0.003	0.002	– 0.003	0.003	0.016

Table 2 (continued)

Country	1995			2005			2015		
	BEET	EIBEET	TBEET	BEET	EIBEET	TBEET	BEET	EIBEET	TBEET
South Africa	0.021	0.011	0.007	0.081	0.030	0.037	0.097	0.024	0.032
South Korea	– 0.021	0.005	0.013	– 0.027	0.030	0.009	0.034	0.121	0.119
Spain	– 0.022	– 0.009	0.003	– 0.068	– 0.038	– 0.010	– 0.013	0.059	0.100
Sweden	– 0.016	0.010	0.047	– 0.028	0.014	0.095	– 0.028	0.007	0.103
Switzerland	– 0.045	– 0.022	– 0.006	– 0.041	– 0.019	– 0.007	– 0.048	– 0.005	0.020
Taiwan	– 0.019	0.004	– 0.026	0.036	0.038	0.023	0.094	0.146	0.065
Turkey	– 0.005	– 0.004	0.002	– 0.037	– 0.027	– 0.010	– 0.027	– 0.040	0.008
United Kingdom	– 0.088	– 0.058	0.025	– 0.174	– 0.098	– 0.016	– 0.158	– 0.063	0.073
United States	– 0.326	– 0.362	– 0.296	– 0.888	– 0.894	– 0.741	– 0.825	– 0.767	– 0.482

Own calculations based on EXIOBASE3

Table 3 Balance of emissions embodied in trade, % of PBE

Country	1995			2005			2015		
	BEET	EIBEET	TBEET	BEET	EIBEET	TBEET	BEET	EIBEET	TBEET
Australia	− 1.549	8.196	25.192	− 13.312	− 3.608	2.128	− 11.798	− 2.548	0.385
Austria	− 37.035	− 15.073	34.899	− 32.752	− 5.503	35.529	− 32.144	8.730	89.846
Belgium	− 1.527	10.741	48.814	− 22.278	0.014	37.521	− 35.907	− 16.275	42.547
Brazil	− 7.977	− 5.706	7.736	8.160	5.013	15.019	− 1.335	− 4.971	2.872
Bulgaria	29.588	10.587	15.984	8.345	0.311	2.206	18.330	24.950	28.292
Canada	7.946	− 3.126	19.982	3.446	4.081	25.315	10.602	− 2.671	18.374
China	13.777	3.987	− 0.631	19.641	13.127	2.393	12.037	10.232	3.071
Croatia	− 10.560	− 9.453	− 6.795	− 41.247	− 37.273	− 33.803	0.438	48.953	613.024
Cyprus	− 28.761	− 18.447	− 20.114	− 36.716	− 34.717	− 39.990	8.975	1.689	5.141
Czech Republic	14.997	14.564	39.576	14.163	19.414	41.522	2.594	14.322	46.411
Denmark	− 19.746	1.620	34.638	− 22.546	21.453	113.919	− 20.475	22.943	60.411
Estonia	21.929	11.331	23.895	5.176	− 12.018	14.835	− 0.252	19.519	87.133
Finland	− 10.061	16.625	173.955	− 34.226	− 9.131	53.885	− 19.381	9.220	96.540
France	− 23.958	− 5.147	20.535	− 35.943	− 12.456	9.900	− 42.785	− 17.274	1.059
Germany	− 7.221	1.891	29.084	− 11.247	2.948	36.516	− 5.441	6.065	51.301
Greece	− 7.191	− 8.208	− 7.386	− 10.736	− 11.692	− 1.068	6.571	− 3.332	8.595
Hungary	− 1.339	− 1.424	22.273	− 53.282	− 16.663	18.635	− 15.671	20.765	110.144
India	8.430	5.670	0.975	4.136	− 1.936	− 2.364	1.776	− 3.636	− 1.353
Indonesia	− 5.456	− 6.416	− 0.795	12.492	− 3.498	− 2.678	1.814	− 9.350	− 7.279
Ireland	0.175	22.368	34.604	− 32.843	0.088	53.129	− 9.970	52.471	127.775
Italy	− 12.732	1.130	29.311	− 25.716	− 8.202	7.307	− 30.094	− 2.226	27.753
Japan	− 10.794	6.383	− 1.045	− 10.159	4.638	− 3.814	− 3.555	5.718	1.785
Latvia	3.859	− 10.623	− 6.868	− 38.457	− 47.298	− 19.906	− 20.899	− 19.407	42.325
Lithuania	− 5.835	− 12.401	− 4.218	− 34.132	− 22.747	− 11.421	− 24.061	13.644	20.647
Luxembourg	21.420	31.206	68.045	3.705	23.638	71.752	− 33.866	0.670	88.002
Malta	− 11.644	− 9.499	− 12.207	− 38.578	− 34.130	− 45.108	− 192.948	− 120.416	− 129.373
Mexico	− 2.439	− 2.132	4.556	− 7.969	− 10.959	− 4.377	5.087	− 9.853	0.724
Netherlands	− 6.111	12.342	50.458	− 12.909	12.693	51.247	− 11.419	2.057	52.028
Norway	− 16.511	20.541	48.927	− 19.166	102.293	137.562	− 13.470	71.403	103.512
Poland	7.548	13.660	25.886	− 1.144	10.482	9.796	2.471	18.692	29.386
Portugal	− 17.252	− 6.118	− 4.860	− 27.988	− 15.584	− 11.814	− 13.016	9.323	24.807
Romania	13.814	3.756	0.401	− 4.022	− 6.410	− 12.923	− 7.326	11.073	3.787
RoW (Latin) America	− 2.679	− 0.531	23.907	1.215	− 1.930	17.816	− 29.613	− 32.632	− 13.156
RoW Africa	− 6.342	1.440	26.428	− 15.342	− 4.118	16.100	− 33.898	− 28.189	− 10.496
RoW Asia and Pacific	− 14.730	− 26.307	− 3.908	0.695	− 15.439	18.541	− 4.369	− 12.286	22.970
RoW Europe	24.377	2.763	6.099	11.625	− 3.137	3.488	14.969	1.571	16.241
RoW Middle East	4.885	− 2.550	11.478	11.964	3.906	18.022	10.728	− 0.656	16.222
Russia	24.710	4.188	1.082	32.456	8.846	12.643	22.581	7.466	17.047
Slovakia	− 12.165	− 22.456	− 18.084	− 42.850	− 51.605	− 39.731	− 37.071	− 26.328	7.394
Slovenia	− 10.430	11.678	48.022	− 32.519	− 17.909	15.673	− 27.107	20.569	134.953
South Africa	8.262	4.267	2.646	23.586	8.640	10.602	24.790	6.102	8.092
South Korea	− 5.149	1.147	3.163	− 5.290	5.913	1.747	5.312	18.662	18.408
Spain	− 8.597	− 3.539	1.058	− 18.407	− 10.353	− 2.698	− 4.757	21.062	35.906

Table 3 (Continued)

Country	1995			2005			2015		
	BEET	EIBEET	TBEET	BEET	EIBEET	TBEET	BEET	EIBEET	TBEET
Sweden	– 24.774	15.924	75.051	– 51.281	25.058	173.317	– 68.231	15.846	248.125
Switzerland	– 82.153	– 41.385	– 11.382	– 75.956	– 34.436	– 12.031	– 105.714	– 10.511	44.239
Taiwan	– 11.270	2.532	– 14.941	13.939	14.592	8.676	35.969	56.123	24.933
Turkey	– 2.770	– 2.235	1.422	– 14.997	– 11.207	– 4.057	– 7.379	– 11.072	2.104
United Kingdom	– 15.879	– 10.484	4.421	– 29.291	– 16.405	– 2.657	– 33.903	– 13.478	15.521
United States	– 6.322	– 7.016	– 5.742	– 15.255	– 15.356	– 12.736	– 16.032	– 14.900	– 9.364

Own calculations based on EXIOBASE3

Table 4 Consumption-based emissions, GtCO2

Country	1995			2005			2015		
	CBA	EICBA	TCBA	CBA	EICBA	TCBA	CBA	EICBA	TCBA
Australia	0.295	0.267	0.218	0.421	0.385	0.364	0.440	0.403	0.392
Austria	0.078	0.066	0.037	0.095	0.076	0.046	0.083	0.057	0.006
Belgium	0.115	0.101	0.058	0.139	0.114	0.071	0.132	0.113	0.056
Brazil	0.280	0.275	0.240	0.332	0.344	0.307	0.504	0.522	0.483
Bulgaria	0.040	0.051	0.048	0.045	0.049	0.048	0.036	0.033	0.032
Canada	0.417	0.467	0.362	0.537	0.533	0.415	0.507	0.582	0.463
China	2.768	3.083	3.231	4.750	5.135	5.769	8.734	8.914	9.625
Croatia	0.019	0.019	0.018	0.032	0.031	0.031	0.017	0.009	– 0.087
Cyprus	0.009	0.008	0.008	0.014	0.014	0.015	0.011	0.012	0.012
Czech Republic	0.108	0.109	0.077	0.105	0.098	0.071	0.101	0.089	0.056
Denmark	0.083	0.068	0.045	0.078	0.050	– 0.009	0.065	0.042	0.021
Estonia	0.012	0.014	0.012	0.016	0.018	0.014	0.015	0.012	0.002
Finland	0.063	0.047	– 0.042	0.079	0.065	0.027	0.056	0.042	0.002
France	0.453	0.384	0.290	0.537	0.444	0.356	0.457	0.375	0.316
Germany	1.017	0.930	0.672	1.018	0.888	0.581	0.934	0.832	0.431
Greece	0.162	0.163	0.162	0.203	0.205	0.185	0.138	0.153	0.135
Hungary	0.059	0.059	0.045	0.088	0.067	0.047	0.054	0.037	– 0.005
India	0.669	0.689	0.723	1.078	1.146	1.151	2.081	2.195	2.147
Indonesia	0.225	0.227	0.215	0.293	0.346	0.344	0.469	0.522	0.512
Ireland	0.034	0.027	0.023	0.070	0.053	0.025	0.055	0.024	– 0.014
Italy	0.485	0.425	0.304	0.618	0.532	0.456	0.458	0.360	0.255
Japan	1.315	1.111	1.199	1.368	1.185	1.290	1.274	1.159	1.208
Latvia	0.010	0.012	0.011	0.014	0.015	0.012	0.012	0.012	0.006
Lithuania	0.018	0.020	0.018	0.024	0.022	0.020	0.020	0.014	0.013
Luxembourg	0.005	0.004	0.002	0.010	0.008	0.003	0.013	0.010	0.001
Malta	0.003	0.003	0.003	0.004	0.004	0.004	0.005	0.004	0.004
Mexico	0.312	0.311	0.290	0.465	0.478	0.449	0.434	0.502	0.454
Netherlands	0.195	0.161	0.091	0.214	0.166	0.092	0.207	0.182	0.089
Norway	0.068	0.046	0.030	0.070	– 0.001	– 0.022	0.070	0.018	– 0.002
Poland	0.319	0.298	0.256	0.308	0.273	0.275	0.285	0.238	0.206
Portugal	0.063	0.057	0.056	0.081	0.073	0.071	0.057	0.046	0.038
Romania	0.103	0.115	0.119	0.099	0.101	0.107	0.076	0.063	0.068
RoW (Latin) America	0.507	0.496	0.376	0.636	0.657	0.529	1.072	1.097	0.936
RoW Africa	0.324	0.301	0.224	0.516	0.466	0.375	0.911	0.872	0.752
RoW Asia and Pacific	1.188	1.307	1.076	1.364	1.585	1.119	1.904	2.048	1.405
RoW Europe	0.402	0.517	0.499	0.396	0.463	0.433	0.294	0.340	0.290
RoW Middle East	0.884	0.953	0.822	1.281	1.398	1.192	1.954	2.203	1.834
Russia	1.175	1.495	1.544	1.018	1.374	1.317	1.142	1.365	1.224
Slovakia	0.049	0.053	0.051	0.056	0.059	0.055	0.042	0.038	0.028
Slovenia	0.016	0.012	0.007	0.021	0.019	0.013	0.015	0.010	– 0.004
South Africa	0.237	0.248	0.252	0.264	0.315	0.309	0.295	0.368	0.360

Table 4 (continued)

Country	1995			2005			2015		
	CBA	EICBA	TCBA	CBA	EICBA	TCBA	CBA	EICBA	TCBA
South Korea	0.428	0.402	0.394	0.534	0.477	0.498	0.613	0.527	0.528
Spain	0.276	0.263	0.252	0.439	0.409	0.381	0.292	0.220	0.178
Sweden	0.079	0.053	0.016	0.083	0.041	– 0.040	0.070	0.035	– 0.062
Switzerland	0.099	0.077	0.060	0.096	0.073	0.061	0.092	0.050	0.025
Taiwan	0.190	0.167	0.197	0.225	0.223	0.238	0.167	0.114	0.196
Turkey	0.177	0.176	0.170	0.281	0.272	0.254	0.393	0.406	0.358
United Kingdom	0.645	0.615	0.532	0.769	0.692	0.610	0.626	0.530	0.395
United States	5.489	5.525	5.459	6.706	6.712	6.560	5.970	5.912	5.627

Own calculations based on EXIOBASE3

Table 5 Consumption-based emissions, % of PBE

Country	1995			2005			2015		
	CBA	EICBA	TCBA	CBA	EICBA	TCBA	CBA	EICBA	TCBA
Australia	101.55	91.80	74.81	113.31	103.61	97.87	111.80	102.55	99.61
Austria	137.03	115.07	65.10	132.75	105.50	64.47	132.14	91.27	10.15
Belgium	101.53	89.26	51.19	122.28	99.99	62.48	135.91	116.28	57.45
Brazil	107.98	105.71	92.26	91.84	94.99	84.98	101.33	104.97	97.13
Bulgaria	70.41	89.41	84.02	91.65	99.69	97.79	81.67	75.05	71.71
Canada	92.05	103.13	80.02	96.55	95.92	74.68	89.40	102.67	81.63
China	86.22	96.01	100.63	80.36	86.87	97.61	87.96	89.77	96.93
Croatia	110.56	109.45	106.79	141.25	137.27	133.80	99.56	51.05	− 513.02
Cyprus	128.76	118.45	120.11	136.72	134.72	139.99	91.03	98.31	94.86
Czech Republic	85.00	85.44	60.42	85.84	80.59	58.48	97.41	85.68	53.59
Denmark	119.75	98.38	65.36	122.55	78.55	− 13.92	120.48	77.06	39.59
Estonia	78.07	88.67	76.11	94.82	112.02	85.17	100.25	80.48	12.87
Finland	110.06	83.37	− 73.95	134.23	109.13	46.12	119.38	90.78	3.46
France	123.96	105.15	79.47	135.94	112.46	90.10	142.78	117.27	98.94
Germany	107.22	98.11	70.92	111.25	97.05	63.48	105.44	93.93	48.70
Greece	107.19	108.21	107.39	110.74	111.69	101.07	93.43	103.33	91.41
Hungary	101.34	101.42	77.73	153.28	116.66	81.36	115.67	79.23	− 10.14
India	91.57	94.33	99.03	95.86	101.94	102.36	98.22	103.64	101.35
Indonesia	105.46	106.42	100.79	87.51	103.50	102.68	98.19	109.35	107.28
Ireland	99.82	77.63	65.40	132.84	99.91	46.87	109.97	47.53	− 27.78
Italy	112.73	98.87	70.69	125.72	108.20	92.69	130.09	102.23	72.25
Japan	110.79	93.62	101.05	110.16	95.36	103.81	103.55	94.28	98.22
Latvia	96.14	110.62	106.87	138.46	147.30	119.91	120.90	119.41	57.68
Lithuania	105.83	112.40	104.22	134.13	122.75	111.42	124.06	86.36	79.35
Luxembourg	78.58	68.79	31.96	96.29	76.36	28.25	133.87	99.33	12.00
Malta	111.64	109.50	112.21	138.58	134.13	145.11	292.95	220.42	229.37
Mexico	102.44	102.13	95.44	107.97	110.96	104.38	94.91	109.85	99.28
Netherlands	106.11	87.66	49.54	112.91	87.31	48.75	111.42	97.94	47.97
Norway	116.51	79.46	51.07	119.17	− 2.29	− 37.56	113.47	28.60	− 3.51
Poland	92.45	86.34	74.11	101.14	89.52	90.20	97.53	81.31	70.61
Portugal	117.25	106.12	104.86	127.99	115.58	111.81	113.02	90.68	75.19
Romania	86.19	96.24	99.60	104.02	106.41	112.92	107.33	88.93	96.21
RoW (Latin) America	102.68	100.53	76.09	98.79	101.93	82.18	129.61	132.63	113.16
RoW Africa	106.34	98.56	73.57	115.34	104.12	83.90	133.90	128.19	110.50
RoW Asia and Pacific	114.73	126.31	103.91	99.30	115.44	81.46	104.37	112.29	77.03
RoW Europe	75.62	97.24	93.90	88.38	103.14	96.51	85.03	98.43	83.76
RoW Middle East	95.11	102.55	88.52	88.04	96.09	81.98	89.27	100.66	83.78
Russia	75.29	95.81	98.92	67.54	91.15	87.36	77.42	92.53	82.95

Table 5 (continued)

Country	1995			2005			2015		
	CBA	EICBA	TCBA	CBA	EICBA	TCBA	CBA	EICBA	TCBA
Slovakia	112.16	122.46	118.08	142.85	151.60	139.73	137.07	126.33	92.61
Slovenia	110.43	88.32	51.98	132.52	117.91	84.33	127.11	79.43	– 34.95
South Africa	91.74	95.73	97.35	76.41	91.36	89.40	75.21	93.90	91.91
South Korea	105.15	98.85	96.84	105.29	94.09	98.25	94.69	81.34	81.59
Spain	108.60	103.54	98.94	118.41	110.35	102.70	104.76	78.94	64.09
Sweden	124.77	84.08	24.95	151.28	74.94	– 73.32	168.23	84.15	– 148.13
Switzerland	182.15	141.39	111.38	175.96	134.44	112.03	205.71	110.51	55.76
Taiwan	111.27	97.47	114.94	86.06	85.41	91.32	64.03	43.88	75.07
Turkey	102.77	102.23	98.58	115.00	111.21	104.06	107.38	111.07	97.90
United Kingdom	115.88	110.48	95.58	129.29	116.40	102.66	133.90	113.48	84.48
United States	106.32	107.02	105.74	115.26	115.36	112.74	116.03	114.90	109.36

Own calculations based on EXIOBASE3

Table 6 Emissions embodied in exports, GtCO2

Country	1995			2005			2015		
	EEX	EIEEX	TEEX	EEX	EIEEX	TEEX	EEX	EIEEX	TEEX
Australia	0.047	0.075	0.125	0.067	0.103	0.124	0.083	0.119	0.131
Austria	0.009	0.022	0.051	0.015	0.034	0.064	0.016	0.041	0.092
Belgium	0.042	0.055	0.098	0.043	0.068	0.111	0.039	0.058	0.115
Brazil	0.024	0.030	0.065	0.086	0.074	0.110	0.102	0.084	0.123
Bulgaria	0.021	0.011	0.014	0.013	0.009	0.010	0.020	0.023	0.024
Canada	0.164	0.113	0.218	0.164	0.167	0.285	0.203	0.127	0.247
China	0.555	0.241	0.093	1.466	1.081	0.447	1.976	1.797	1.086
Croatia	0.004	0.004	0.004	0.005	0.006	0.007	0.007	0.015	0.111
Cyprus	0.003	0.003	0.003	0.002	0.002	0.002	0.005	0.004	0.005
Czech Republic	0.030	0.030	0.062	0.041	0.047	0.074	0.034	0.046	0.079
Denmark	0.013	0.028	0.051	0.021	0.049	0.107	0.022	0.046	0.066
Estonia	0.005	0.004	0.006	0.006	0.004	0.008	0.005	0.008	0.018
Finland	0.016	0.031	0.120	0.017	0.032	0.069	0.014	0.028	0.069
France	0.075	0.143	0.237	0.079	0.172	0.260	0.078	0.160	0.218
Germany	0.134	0.220	0.478	0.206	0.336	0.643	0.254	0.356	0.757
Greece	0.010	0.008	0.010	0.027	0.025	0.045	0.037	0.022	0.040
Hungary	0.013	0.013	0.027	0.011	0.032	0.052	0.014	0.031	0.073
India	0.087	0.067	0.033	0.181	0.113	0.108	0.287	0.172	0.221
Indonesia	0.040	0.038	0.050	0.104	0.050	0.053	0.113	0.059	0.069
Ireland	0.008	0.016	0.020	0.016	0.033	0.061	0.028	0.059	0.097
Italy	0.075	0.134	0.256	0.087	0.173	0.249	0.075	0.173	0.279
Japan	0.159	0.363	0.275	0.227	0.411	0.306	0.265	0.379	0.331
Latvia	0.002	0.001	0.001	0.003	0.002	0.005	0.005	0.005	0.011
Lithuania	0.002	0.001	0.003	0.003	0.005	0.007	0.005	0.011	0.012
Luxembourg	0.002	0.002	0.005	0.005	0.007	0.012	0.007	0.011	0.019
Malta	0.000	0.000	0.000	0.001	0.001	0.001	0.001	0.002	0.002
Mexico	0.048	0.049	0.070	0.074	0.061	0.090	0.132	0.064	0.112
Netherlands	0.046	0.080	0.150	0.070	0.119	0.192	0.076	0.101	0.194
Norway	0.032	0.053	0.070	0.027	0.098	0.119	0.028	0.080	0.100
Poland	0.043	0.064	0.106	0.056	0.091	0.089	0.062	0.109	0.140
Portugal	0.009	0.015	0.016	0.010	0.018	0.020	0.015	0.026	0.034
Romania	0.021	0.009	0.005	0.019	0.017	0.011	0.016	0.029	0.024
RoW (Latin) America	0.086	0.097	0.218	0.191	0.171	0.298	0.176	0.152	0.313
RoW Africa	0.040	0.064	0.140	0.073	0.123	0.213	0.059	0.098	0.218
RoW Asia and Pacific	0.381	0.261	0.493	0.650	0.429	0.895	0.789	0.644	1.288
RoW Europe	0.164	0.050	0.067	0.131	0.065	0.095	0.125	0.079	0.129
RoW Middle East	0.200	0.131	0.262	0.444	0.327	0.533	0.693	0.444	0.813
Russia	0.506	0.185	0.137	0.586	0.230	0.287	0.449	0.226	0.367
Slovakia	0.007	0.002	0.004	0.013	0.010	0.015	0.012	0.015	0.025
Slovenia	0.003	0.006	0.011	0.004	0.007	0.012	0.004	0.010	0.024
South Africa	0.031	0.021	0.017	0.103	0.051	0.058	0.124	0.051	0.058
South Korea	0.066	0.092	0.100	0.131	0.188	0.167	0.206	0.292	0.291

Table 6 (continued)

Country	1995			2005			2015		
	EEX	EIEEX	TEEX	EEX	EIEEX	TEEX	EEX	EIEEX	TEEX
Spain	0.035	0.048	0.059	0.077	0.107	0.135	0.084	0.156	0.197
Sweden	0.013	0.039	0.076	0.018	0.059	0.140	0.017	0.052	0.149
Switzerland	0.012	0.034	0.050	0.014	0.037	0.049	0.011	0.054	0.079
Taiwan	0.076	0.100	0.070	0.116	0.118	0.103	0.152	0.205	0.123
Turkey	0.024	0.025	0.031	0.044	0.054	0.071	0.082	0.068	0.117
United Kingdom	0.099	0.129	0.212	0.127	0.203	0.285	0.096	0.192	0.327
United States	0.390	0.355	0.420	0.427	0.421	0.574	0.437	0.495	0.780

Own calculations based on EXIOBASE3

Table 7 Emissions embodied in exports, % of PBE

Country	1995			2005			2015		
	EEX	EIEEX	TEEX	EEX	EIEEX	TEEX	EEX	EIEEX	TEEX
Australia	16.126	25.871	42.867	18.023	27.727	33.462	21.093	30.343	33.276
Austria	16.606	38.568	88.540	20.640	47.889	88.921	24.990	65.863	146.979
Belgium	36.898	49.166	87.239	37.662	59.954	97.462	40.232	59.863	118.685
Brazil	9.293	11.564	25.006	23.644	20.498	30.504	20.546	16.910	24.753
Bulgaria	37.438	18.437	23.834	26.451	18.417	20.312	45.210	51.829	55.172
Canada	36.110	25.038	48.146	29.424	30.058	51.293	35.738	22.466	43.511
China	17.291	7.501	2.882	24.806	18.292	7.559	19.904	18.100	10.939
Croatia	20.741	21.848	24.506	21.568	25.541	29.012	38.456	86.971	651.042
Cyprus	38.620	48.934	47.267	19.441	21.440	16.168	39.831	32.546	35.998
Czech Republic	23.760	23.327	48.339	33.326	38.577	60.685	32.493	44.222	76.310
Denmark	19.032	40.398	73.416	32.296	76.295	168.761	41.424	84.842	122.310
Estonia	32.861	22.263	34.827	38.631	21.437	48.289	34.962	54.734	122.348
Finland	27.273	53.959	211.289	28.412	53.507	116.523	30.687	59.288	146.609
France	20.427	39.238	64.919	19.992	43.479	65.836	24.446	49.957	68.290
Germany	14.132	23.244	50.437	22.527	36.722	70.291	28.717	40.224	85.460
Greece	6.516	5.499	6.321	14.809	13.852	24.476	24.800	14.897	26.824
Hungary	22.441	22.357	46.054	19.364	55.984	91.282	30.597	67.033	156.412
India	11.908	9.148	4.453	16.096	10.024	9.596	13.551	8.138	10.421
Indonesia	18.745	17.786	23.407	31.055	15.066	15.886	23.578	12.414	14.486
Ireland	24.561	46.754	58.989	30.227	63.158	116.199	56.737	119.178	194.482
Italy	17.403	31.265	59.446	17.697	35.211	50.720	21.375	49.243	79.223
Japan	13.424	30.602	23.173	18.290	33.087	24.635	21.541	30.814	26.880
Latvia	21.208	6.727	10.482	28.246	19.405	46.798	48.814	50.306	112.038
Lithuania	14.078	7.512	15.695	16.816	28.202	39.527	28.405	66.110	73.113
Luxembourg	30.744	40.530	77.368	50.864	70.797	118.911	76.196	110.732	198.064
Malta	13.187	15.332	12.624	33.318	37.766	26.788	47.120	119.653	110.695
Mexico	15.920	16.227	22.915	17.249	14.258	20.841	28.914	13.973	24.551
Netherlands	25.122	43.575	81.690	36.982	62.583	101.137	41.191	54.668	104.638
Norway	54.286	91.338	119.723	46.304	167.763	203.032	45.081	129.955	162.064
Poland	12.321	18.433	30.659	18.363	29.989	29.304	21.087	37.309	48.002
Portugal	17.471	28.605	29.863	15.561	27.964	31.735	28.965	51.303	66.787
Romania	17.644	7.586	4.231	20.487	18.099	11.586	22.224	40.624	33.337
RoW (Latin) America	17.493	19.640	44.079	29.683	26.538	46.285	21.337	18.317	37.794
RoW Africa	13.134	20.916	45.904	16.268	27.492	47.710	8.653	14.362	32.056
RoW Asia and Pacific	36.829	25.252	47.651	47.350	31.216	65.196	43.243	35.325	70.582
RoW Europe	30.943	9.329	12.665	29.234	14.472	21.097	36.139	22.740	37.411
RoW Middle East	21.578	14.143	28.171	30.552	22.494	36.611	31.670	20.286	37.164
Russia	32.395	11.873	8.767	38.871	15.262	19.058	30.405	15.290	24.871
Slovakia	15.371	5.080	9.452	33.892	25.137	37.011	37.943	48.686	82.408
Slovenia	21.336	43.444	79.788	26.356	40.967	74.548	35.670	83.346	197.730
South Africa	12.150	8.155	6.534	29.792	14.846	16.808	31.607	12.919	14.909

Table 7 (continued)

Country	1995			2005			2015		
	EEX	EIEEX	TEEX	EEX	EIEEX	TEEX	EEX	EIEEX	TEEX
South Korea	16.287	22.583	24.599	25.921	37.124	32.958	31.795	45.145	44.891
Spain	13.720	18.778	23.376	20.824	28.877	36.532	30.215	56.033	70.877
Sweden	21.349	62.048	121.175	32.097	108.436	256.695	40.781	124.858	357.137
Switzerland	21.630	62.398	92.401	25.801	67.321	89.726	24.739	119.942	174.693
Taiwan	44.599	58.401	40.928	44.577	45.230	39.314	58.372	78.525	47.335
Turkey	13.851	14.387	18.043	18.108	21.898	29.048	22.425	18.731	31.908
United Kingdom	17.862	23.257	38.162	21.343	34.229	47.977	20.595	41.020	70.019
United States	7.560	6.866	8.141	7.338	7.238	9.857	8.490	9.623	15.159

Own calculations based on EXIOBASE3

Table 8 Production-based emissions, GtCO2

Country	1995	2005	2015
Australia	0.291	0.372	0.393
Austria	0.057	0.072	0.063
Belgium	0.113	0.114	0.097
Brazil	0.260	0.362	0.497
Bulgaria	0.057	0.049	0.044
Canada	0.453	0.556	0.567
China	3.211	5.910	9.930
Croatia	0.017	0.023	0.017
Cyprus	0.007	0.010	0.013
Czech Republic	0.128	0.122	0.104
Denmark	0.069	0.064	0.054
Estonia	0.016	0.016	0.015
Finland	0.057	0.059	0.047
France	0.365	0.395	0.320
Germany	0.948	0.915	0.886
Greece	0.151	0.183	0.148
Hungary	0.058	0.057	0.046
India	0.730	1.125	2.118
Indonesia	0.213	0.335	0.478
Ireland	0.034	0.053	0.050
Italy	0.430	0.492	0.352
Japan	1.187	1.242	1.230
Latvia	0.011	0.010	0.010
Lithuania	0.017	0.018	0.016
Luxembourg	0.006	0.010	0.010
Malta	0.003	0.003	0.002
Mexico	0.304	0.431	0.457
Netherlands	0.184	0.190	0.185
Norway	0.058	0.059	0.062
Poland	0.345	0.305	0.292
Portugal	0.054	0.064	0.050
Romania	0.119	0.095	0.071
RoW (Latin) America	0.494	0.644	0.827
RoW Africa	0.305	0.447	0.681
RoW Asia and Pacific	1.035	1.373	1.824
RoW Europe	0.532	0.448	0.346
RoW Middle East	0.929	1.455	2.189
Russia	1.561	1.507	1.475
Slovakia	0.043	0.039	0.030
Slovenia	0.014	0.016	0.012
South Africa	0.259	0.345	0.392
South Korea	0.407	0.507	0.647
Spain	0.254	0.371	0.278
Sweden	0.063	0.055	0.042
Switzerland	0.054	0.055	0.045
Taiwan	0.171	0.261	0.261
Turkey	0.173	0.244	0.366

Table 8 (continued)

Country	1995	2005	2015
United Kingdom	0.557	0.594	0.467
United States	5.163	5.819	5.145

Own calculations based on EXIOBASE3

Table 9 TBEET vs. income per capita: cross-country regressions

	(1) 2015, all	(2) 2015, pop > 10 m	(3) Pooled, all	(4) Pooled, pop > 10 m
Income	0.612	0.546	0.947**	0.441
	(0.639)	(0.266)	(0.303)	(0.227)
Constant	26.91	− 1.822	14.32	1.626
	(36.02)	(6.722)	(21.07)	(5.800)
Year effects	No	No	Yes	Yes
N	44	26	924	559
R squared	0.012	0.192	0.151	0.182

Own calculations based on EXIOBASE3 and PWT10. $^{*}p < 0.1$; $^{**}p < 0.05$; $^{***}p < 0.01$. Regressions of the TBEET in % of PBE on per-capita income in thousand PPP-adjusted US$. Column 1 reports a simple OLS regression with heteroskedasticity-consistent standard errors based on the 2015 cross-section. Column 2 repeats the OLS regression but excludes countries whose 2015 population is lower than 10 million. Column 3 reports a pooled OLS regression with year fixed effects and cluster-robust standard errors based on the 1995–2015 panel. The regression constant represents the intercept for the year 2015. Column 4 repeats the pooled OLS regression but excludes countries whose 2015 population is lower than 10 million

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Declarations

Conflict of Interests The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this article.

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