Modeling reductions in the environmental footprints embodied in European Union’s imports through source shifting

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Declarations of interest: none

Abbreviations:

TEF: trade embodied footprint

IEF: import embodied footprint

IECF: import embodied carbon footprint

IEMF: import embodied material footprint

IEWF: import embodied water footprint

IELF: import embodied land footprint

Abstract

The European Union (EU) is responsible for a disproportionately large share of global environmental footprints, in particular those embodied in trade through its imports. Import embodied footprints (IEFs) vary significantly depending on the country of origin, and therefore can be reduced through source shifting. We explore the impacts of shifting imports to the countries with lowest impact intensities per M€ according to four environmental pressures (carbon emissions, materials, water, and land), using Environmentally Extended Multi Regional Input-Output (EEMRIO) analysis. There are significant limitations of EEMRIO analysis (the price and product mix homogeneity assumptions), which we discuss in the paper. We find that a limited set of 13 products, among which food products and chemicals which are not elsewhere classified (n.e.c.), is responsible for more than half of all impacts embodied in imports for each pressure. Except for a few product groups, optimizing sourcing as to minimize impact for one pressure reduces impact in all others. The pressure exhibiting the highest scope for optimization is water. Carbon and material use optimization yields the largest reduction in other environmental pressures. We discuss increasing the policy relevance of EEMRIO in the case of IEFs by disaggregating n.e.c. product groups, and incorporating dynamic effects.

Keywords:

- Input-Output Analysis
- International Trade
- Carbon Footprint
- Material Footprint
- Water Footprint
- Land Footprint

1. Introduction

The fraction of global environmental impacts embodied in trade of goods and services (or trade embodied footprints, TEFs) is growing due to globalization, with the footprints of carbon (CF) reaching levels of 23-30% of total emissions and the corresponding fractions for material use (MF) water use (WF), and land use (LF) being, respectively, 24-68%, 10-30% and 21-37% (Wiedmann and Lenzen, 2018). As such, TEFs have received increasing interest in recent years (Tian et al., 2018).

The share of the EU's footprints in global totals however are much higher than the EU's share in global population, although lower than the EU's share of world GDP, with the share of TEFs as a part of the EU's total footprints being substantial, as we now describe. In 2011 the European Union (EU) accounted for 6.6% of world population[1] but 25% of world GDP[2] and the EU has been at the forefront of environmental legislation for several decades (see e.g. European Parliament and Council of the European Union, 2013). Tukker and colleagues (2016) found that in 2007 the EU's carbon footprint was 8 GtCO_2eq (or 20% of the world total), with 2 GtCO_2eq embodied in trade; the corresponding figures for material use were 12Gt (19%), with 4 Gt in trade; for water 0.2 Mm3 (13%), with 0.09 Mm3 in trade; and for land 11 Gm^2 (13%) with 7 Gm^2 in trade[3]. These results are in agreement with those of Steen-Olsen and colleagues (2012), who found that in 2004 the EU's footprint of carbon was 6.5 GtCO_2eq (or 18% of the world total), with 2.8 GtCO_2eq in trade; water 87 Gm^3 (8%) with 46 Gm^3 in trade, and land 1.23 Ggha (16%) with 0.58 Ggha in trade.

1 https://esa.un.org/unpd/wpp/DVD/Files/1_Indicators\%20(Standard)/EXCEL_FILES/1_Population/WPP2017_POP_F01_1_TOTAL_POPULATION_BOTH_SEXES.xlsx

2 https://unstats.un.org/unsd/snaama/dnltransfer.asp?fID=2

3 Throughout the article we use metric prefixes to signify orders of magnitude: k (10^3), M (10^6), G (10^9), T (10^{12}), and P (10^{15}).

Most global regions including the EU have not yet decoupled environmental pressures from GDP growth (Wiedmann et al., 2015; Wood et al., 2018), although the EU has various policy programs aimed at that goal. These include the Resource Efficiency Roadmap (European Commission, 2011), the Circular Economy Action Plan (European Commission, 2015), and several policy packages focused on climate change, including the endorsement of the Paris agreement (United Nations / Framework Convention on Climate Change, 2015). Most of these policy packages propose production/territorial oriented indicators and policies. This mean that they do not address the problem of emissions embodied in trade, which are quantified in import embodied footprints (IEFs), increasing the risk of e.g. carbon leakage (Sakai and Barrett, 2016). The Resource Efficiency Roadmap, for instance, uses as lead indicator Domestic Material Consumption (DMC) related to GDP growth, supplemented with a dashboard of production-based indicators on material, land, water, and carbon. While this roadmap proposed a set of consumption-based accounting (CBA) dashboard indicators, none of those have been implemented as yet.

Previous studies on the subject of CBA primarily had a conceptual focus. Afionis et al. (2017) provided an overview on the pros and cons of CBA, along with considerations for implementation, in the case of carbon. Generally they concluded that policy uptake of CBA principles will likely be limited, due to technical complexities and political infeasibility. Steininger et al. (2016) placed the concept of CBA in a broader perspective, and contrasted it against other accounting principles. They found that all accounting principles have their own shortcomings in terms of leakages and policy blind spots, which can hamper their goal of achieving effectiveness and justice. Taking these considerations into account, CBA can help policymakers gain insight in IEFs (Afionis et al., 2017).

Environmentally Extended Multi Regional Input-Output (EEMRIO) analysis is currently the method of choice for analyzing TEFs in general, and IEFs specifically, in particular if one wants to cover a large number of environmental pressures. For a general discussion of EEMRIO we refer to Kitzes et al. (2013) and Tukker and Dietzenbacher (2013). While this method offers a comprehensive approach towards capturing TEFs, a main caveat lies in the limited resolution of product groups (de Koning et al., 2015). Products are aggregated in these groups under the assumption that these product mixes are homogeneous throughout the global economy. Moreover, it is assumed that products are homogeneously priced among countries. These assumptions limit the relevance for policy geared towards reducing IEFs, e.g. through shifting sourcing of imports towards cleaner producing countries, as changes in import sourcing could have major implications regarding the imported mix and quantity of products.

To increase the policy relevance of EEMRIO to formulate scenarios aimed at reducing IEFs, there is a clear need to overcome this caveat caused by the homogeneity assumptions. To the best of our knowledge, no studies exist that address this issue. As such, our paper aims to offer a framework that can be used as a stepping stone towards IEF reduction scenarios through EEMRIO, and to prioritize product groups that should be disaggregated to reduce the uncertainty of these scenarios. We employ source shifting to calculate the potential reduction in IEFs of the EU, as this is the underlying mechanism of policies such as border carbon adjustments (BCAs). Put differently, as more polluting imports are taxed more heavily, the resulting price towards the consumer is higher. As such there is an incentive for the consumer to move towards products with lower impacts, i.e. to shift sourcing. This drives down the demand for polluting products, which in turn drives exporting countries to reduce their footprint in order to increase demand.

2. Data and methods

In this study we calculated the reduction potential of the EU IEFs through source shifting. Following the work of Tukker et al. (2016) we focused on four key environmental pressures: carbon emissions (IECF) (Ali, 2017; Malik et al., 2016; Peters et al., 2011; Wood et al., 2018), material use (IEMF) (Giljum et al., 2015; Plank et al., 2018; Pothen and Schymura, 2015; Wood et al., 2018), water use (IEWF) (Ali, 2017; Haqiqi et al., 2016; Lenzen et al., 2013; Wood et al., 2018), and land use (Ali, 2017; Chen and Han, 2015; Weinzettel et al., 2013; Wood et al., 2018). These pressures have shown to be strongly correlated to the many types of indicators that could be used (Steinmann et al., 2017).

To answer our research question we follow a tiered approach:

1. First, we identified which products contribute most to each IEF.
2. Next we calculated the potential improvement in IEFs through source shifting of all EU imports towards countries with lowest impact coefficients.
3. Finally, these reductions were aggregated to establish the overall potential improvements in global environmental impact of EU imports across IEFs.

These steps are discussed in greater detail below, as is the source data.

In the first step IEFs are analyzed with EEMRIO analysis, which is the most frequently used method for that purpose, as it allows to trace environmental impacts throughout global supply chains (Tian et al., 2018; Tukker et al., 2018). In particular, we employ the 2011 tables from the product-by-product representation of EXIOBASE 3.3 based on the industry technology assumption (Stadler et al., 2018). It covers 44 countries, of which 28 are EU member states (EU28), and 5 Rest of Continent (RoC) regions, or n_C = 49 countries and regions; n_P = 200 product groups; and 416 environmental extensions for air emissions, of which 70 relevant for IECF, 227 for IEMF, 103 for IEWF, and 14 for IELF, or n_F = 4 pressures, and n_S = 414 stressors. For brevity we also define n_{CP} = n_C x n_P = 9800 country-product pairs. The method uses the following basic formula to calculate IEFs across products and regions of final sale D (n_F x n_{CP})):

$$D = QR(I - A)^{-1}\hat{y}$$

Where $\hat{y}$ (n_{CP} x n_{CP}) is a diagonal matrix which represents what a given country consumes in M€, across a set of products and regions of final sale. As we only consider impacts in trade, in particular embodied in EU imports, we explicitly do not take into account domestic production. To reflect this, we set the domestic blocks in the final demand matrix to zero. $(I - A)^{-1}$ (n_{CP} x n_{CP}) is the Leontief inverse and reflects the volume of production in a given industry (in rows) that results from the consumption of a monetary unit of a product (in columns), due to supply chains effects across all countries (Miller and Blair, 2009). R (n_S x n_{CP}) represents environmental impacts per M€. Finally, Q (n_F x n_S) contains characterization factors which translate different types of environmental impacts into a common metric, thus defining the IEFs of the four environmental pressures being studied.

In the second step, this assessment is used to sort products from high to low impact for each IEF resulting in 4 lists. From these sorted lists, products are selected up to 50% of total embodied impact in trade for each IEF.

In the final step, sourcing of all 200 imports is shifted to the countries whose exports have the lowest impact intensity per M€, across a given product group. Final demand is fixed, which means that potential reductions in IEFs are only achieved through optimized sourcing of imports. Moreover, we keep exports fixed – the source shifting has no effect on the total volume of exports of countries. In other words, if exports of a best-in-class country to the EU28 increases, then its exports to a third country decreases accordingly. In order to make this calculation, we first identify the impact intensity (embodied impact by M€) and volume (in M€) of the exports of a given product group from a specific country, to all other countries. Afterwards we determine the total volume of import to the EU28 of a given product group. This volume is then shifted to the country with lowest impact intensity, up to current export level of that country, the remainder imports are shifted to the country with the next lowest impact and so on. Put differently, first all exports of a product from the country with lowest impact intensity is redirected to EU28. Then all exports from the country with the second, third, etcetera lowest impact intensity is also redirected until all imports from the EU28 is satisfied. The potential reduction in impact for that product is the difference between current impact and the impact under this shift in sourcing. Finally, potential reductions for all products are aggregated to obtain overall potential improvement for each environmental pressure. Since the aim of this study is to assess overall potential reductions through source shifting of imports, the approach does not discriminate between EU28 trade within and outside its borders. Countries with exports of less than 0.5 M€ for a particular product are excluded from this analysis as they can be considered noise.

The analysis was done with Python3.6. The script is available on 10.5281/zenodo.1475177, including instructions on how to reproduce our results. EXIOBASE 3.3 can be obtained by contacting the authors.

3. Results

3.1 Priority setting

For each IEF, products are sorted in descending order based on their embodied impacts in trade. From this sorted list, the set of products accumulating up to 50% of embodied impact in trade (shown in Figure 1) are selected. Appendix A shows the lists of all 200 products for each pressure, ranked by impact.

Nine products account for 51% of IECF, or 0.7 $PgCO_2eq$. The highest contributions come from chemicals not elsewhere classified (n.e.c.), and motor vehicles (both 0.1 $PgCO_2eq$); machinery n.e.c. (0.08 $PgCO_2eq$); communication products and furniture (both 0.07 $PgCO_2eq$); furs and food products n.e.c. (both 0.06 $PgCO_2eq$); and leather and air transport (both 0.05 $PgCO_2eq$). Similar to IECF, nine products account for 52% of IEMF, or 1 Gt. Again, chemicals n.e.c. have the highest contribution (0.3 Gt). This is followed by food products n.e.c. and motor vehicles (both 0.2 Gt); and vegetables, fruit and nuts, communication products, machinery n.e.c., leather, furs, and furniture (all 0.1 Gt). Just three product groups account for 56% of IEWF (0.03 Tm^3), namely vegetables, fruit, and nuts (0.02 Tm^3), crops n.e.c. (0.01 Tm^3), and food products n.e.c. (0.005 Tm^3). Finally, eight products account for 53% of IELF, or 1 Gm^2. The highest contributions come from food products n.e.c. and forestry (both 0.3 Gm^2); followed by vegetables, fruit, and nuts, meat cattle, and furniture (all 0.2 Gm^2); and chemicals n.e.c., furs, and crops n.e.c. (all 0.1 Gm^2).

A number of products rank highly across multiple IEFs, with food products n.e.c. being among the highest contributors for all four. Chemicals n.e.c., furniture, furs and vegetables, fruit, and nuts span three; communication products, leather, machinery n.e.c., motor vehicles, and crops n.e.c. span two; and air transport, forestry and meat cattle are prioritized for a single IEF. The concatenated set of 13 products accounts for 56% of embodied impact in trade for IECF, 59% for IEMF, 76% for IEWF, and 64% for IELF.

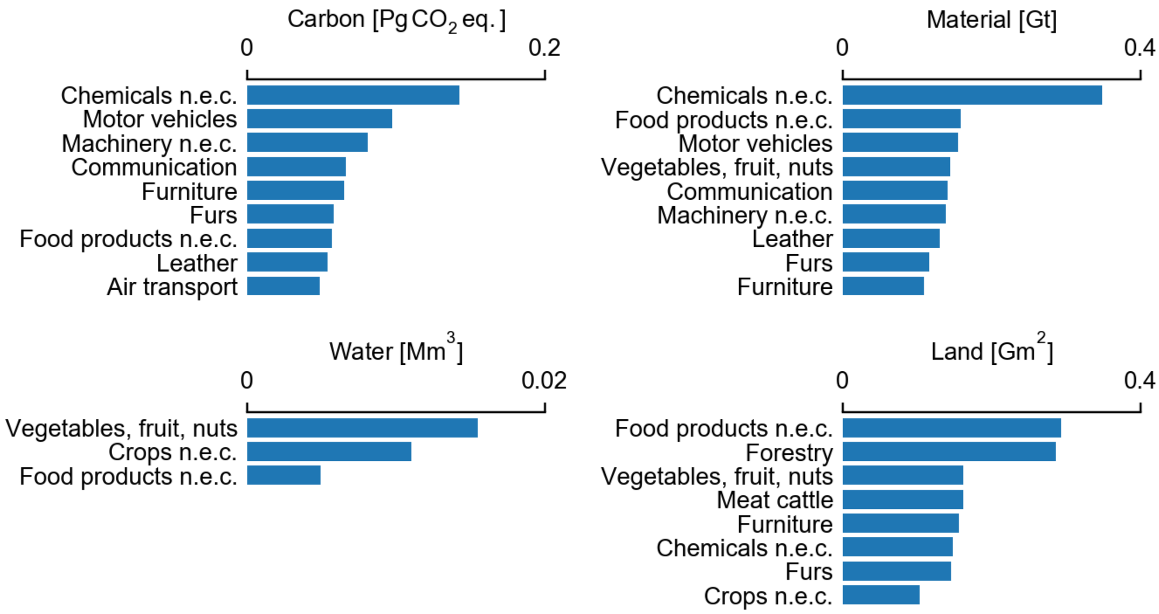

Figure 1 – These plots show product and services groups that contribute most to each import embodied footprint. E.g. the top left plot shows that chemicals n.e.c. contribute most to the carbon footprint, followed by motor vehicles, etc.

3.2 Source shifting

We next explore the benefits of source shifting to optimize the emissions embodied in imports of the EU28. Since the numerical details vary for each environmental pressure and product selected we report here a single case, namely the optimization of IECF for motor vehicles, illustrated in Figure 2. Source shifting for the other IEFs and products can be found in appendix B. This figure plots the volume of global warming impacts (in kgCO_2eq) embodied in exports of every country, sorted from lowest to highest intensity: the vertical axis shows the GHG intensity (in kgCO_2eq per M€) and the horizontal axis shows M€ of exports, so that the area of each rectangle shows the volume of GHG emissions (in kgCO_2eq) embodied in the exports of each country. Put differently, countries exporting motor vehicles with low impact intensity (i.e.

kgCO_2eq per M€) are on the left of the figure, and countries exporting with high impact intensity are on the right side of the figure. Countries with small exports quantities in M€ have rectangles with a small base, while countries with large exports have rectangles with a large base.

The plot shows three colours. Grey rectangles represent current exports whose destination market is not the EU28 and the blue rectangles represent the global warming impact associated with the fraction of each country's export which is imported by EU28 prior to source shifting. The green rectangles show that impact after source shifting. As shown, in the optimized case all imports come from countries with the lowest impact intensity possible.

In this particular case, the EU28 imported 0.2T€ worth of motor vehicles in 2011. As our method does not alter the final demand of products, this amount is the same both before and after optimization. Prior to optimization, the EU28 imported from all 49 countries and regions with a mean global warming impact intensity of 2 GgCO_2eq/M€. The median was 0.7 GgCO_2eq/M€, with the 5th percentile at 0.1 GgCO_2eq/M€ and the 95th at 5 GgCO_2eq/M€. Six regions accounted for 51% of the impact, namely Germany (23%), Spain (8%), France (7%), the United Kingdom (5%), and Poland and Italy (both 4%). After optimization, the number of countries and regions dropped to 13, with a mean and median impact of 0.4 GgCO_2eq/M€, and 5th percentile at 0.3 GgCO_2eq/M€ and the 95th at 0.4 GgCO_2eq/M€, with Germany alone accountable for 56% of the impact.

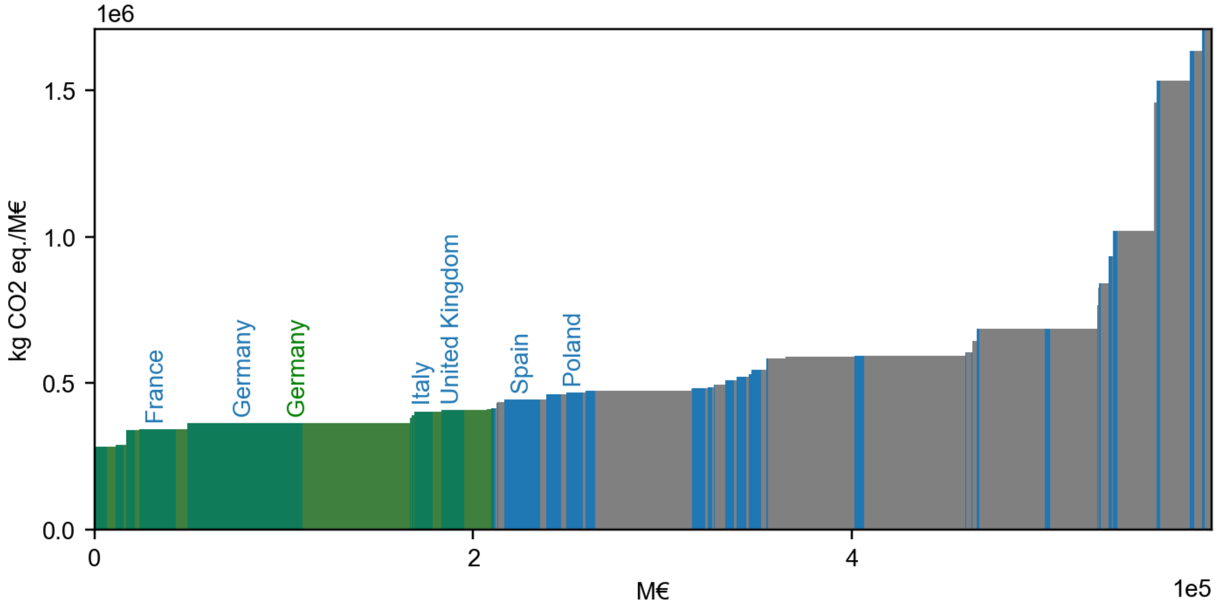

Figure 2 – This figure shows how the carbon emissions embodied in the imports of the EU can change through source shifting. The horizontal axis shows the monetary amount of exported motor vehicles in M€. The vertical axis shows the impact intensity, i.e. the amount of kgCO2eq emitted per M€ of exported motor vehicles. The area of each blue and grey rectangle is the volume of emissions embodied in the exports of each country to the EU28 and to outside the EU28, respectively. Finally, the green plot shows the ex-post carbon footprint of motor vehicles that are imported by the EU28, where imports are sourced from the countries with the lowest impact intensities.

3.3 Potential improvements

Figure 3 shows potential reductions aggregated over all 200 imports through individual IEF optimization. Unsurprisingly, the lowest value for each IEF is achieved by optimizing for itself i.e. a reduction of 46% (0.6 $PgCO_2eq$) for IECF, 53% (1 Gt) for IEMF, 72% (0.04 Tm^3) for IEWF, and 65% (2 Gm^2) for IELF.

IECF and IEMF source optimization are best ranked overall. IECF optimization yields second most reductions for both IEMF (42%, or 1Gt) and IEWF (44%, or 0.02 Tm^3). IEMF optimization achieves second most reductions for IECF (37%, or 0.6 $PgCO_2eq$) and IELF (48%, or 1 Gm^2). IEWF optimization ranks third in reductions of IECF (34% or 0.4 $PgCO_2eq$) and IEMF (41% or 1

Gt), and last for IELF (15% or 0.4 Gm^2). Finally IELF optimization ranks last for all pressures other than itself, namely 30% (0.4 $PgCO_2eq$) for IECF, 38% (1 Gt) for IEMF, and 34% (0.02 Tm^3) for IEWF.

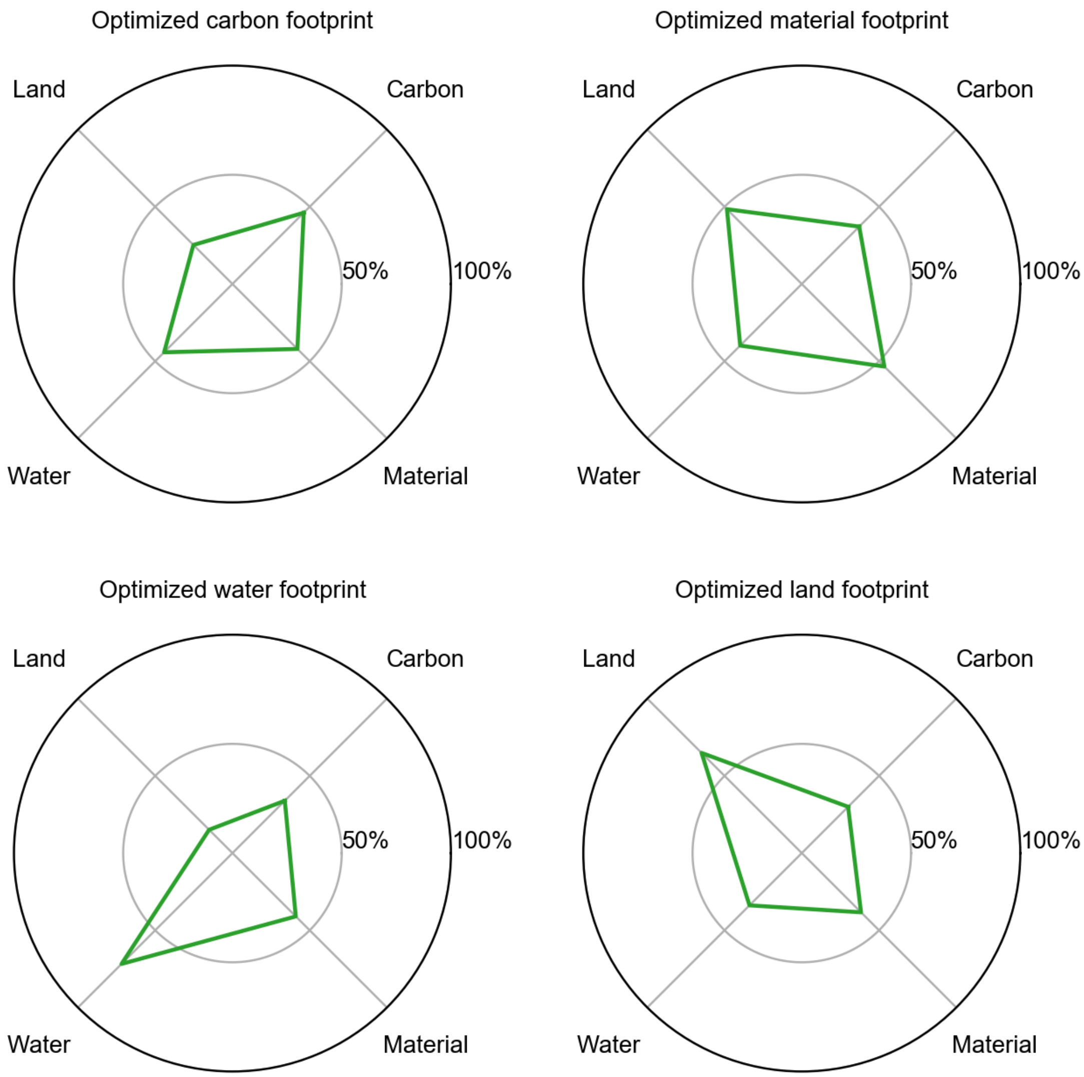

Figure 3 - These plots show the potential reductions in footprints that can be achieved when optimizing reductions for one particular environmental pressure at a time. For instance, the top left graph shows that optimizing for carbon yields a 46% reduction in this footprint, 42% in material use, 44% in water use, and 25% in land use.

3.3.1 Carbon footprint

Figure 4 shows reductions in IEFs of highest contributing products to all four environmental pressures if sourcing would be optimized for IECF. The largest absolute reduction can be observed in chemicals n.e.c. (0.07 PgCO_2eq, or 49% reduction), followed by leather (73%), furniture (59%), communication (54%), and machinery n.e.c. (49%), or 0.04 PgCO_2eq in each product group. Furs show a reduction of 0.03 PgCO_2eq or 50%, and air transport (36%) and motor vehicles (21%) both are reduced by 0.02 PgCO_2eq. Finally, vegetables, fruit, and nuts (47%), crops n.e.c. (46%), meat cattle (29%), and food products n.e.c. (24%) show improvements of 0.01 PgCO_2eq, and forestry of 0.001 PgCO_2eq, or 61% reduction.

Reductions in IECF of these products overall show improvements across all environmental pressures and product categories, save for forestry which shows a sizeable increase in IELF of 0.3 Gm^2. Next to that small increases can be observed in the IELF of air transport and IEWF of meat cattle.

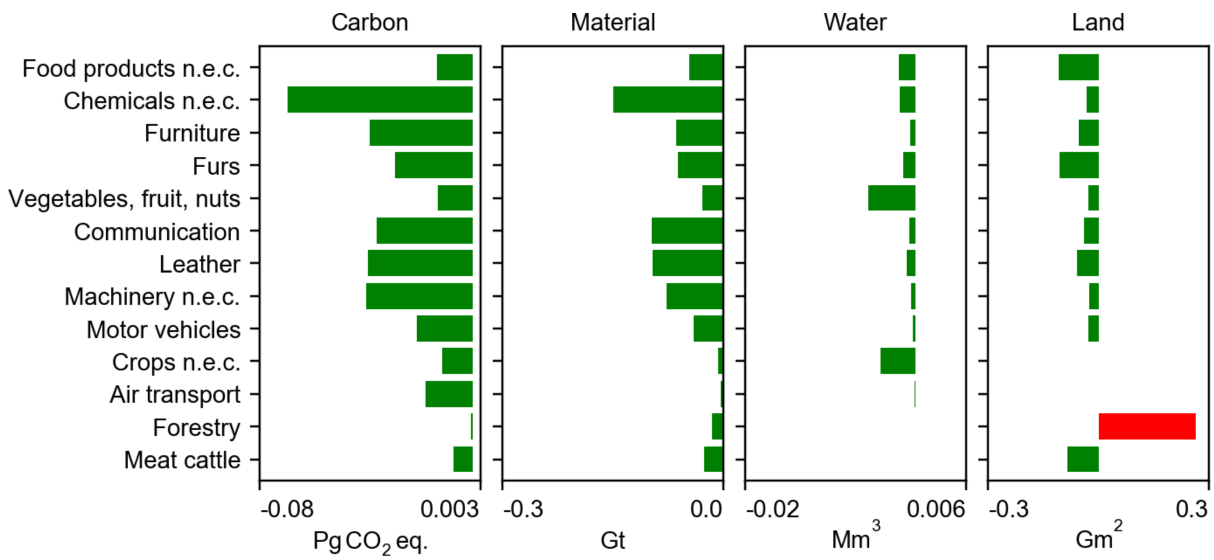

Figure 4 -Potential reduction of embodied impacts in EU28 imports when optimized for carbon footprint.

3.3.2 Material footprint

Figure 5 shows reductions in IEFs of highest contributing imports if sourcing would be optimized for IEMF. Again, chemicals n.e.c. show the largest absolute reductions (0.2 Gt, or 69%). This is followed by leather (76%), communication (69%), furniture (62%), furs (58%), machinery n.e.c. (56%), and food products n.e.c. (35%), namely 0.1 Gt in each product group. IEMF of vegetables, fruit, and nuts (32%) and motor vehicles (31%) are reduced by 0.05 Gt, followed by meat cattle (0.04 Gt, or 36%), forestry (0.02 Gt, or 68%), and air transport (63%) and crops n.e.c. (32%) (both 0.01 Gt). Optimizing for IEMF comes at small tradeoffs in IEWF of crops n.e.c., and IELF of meat cattle.

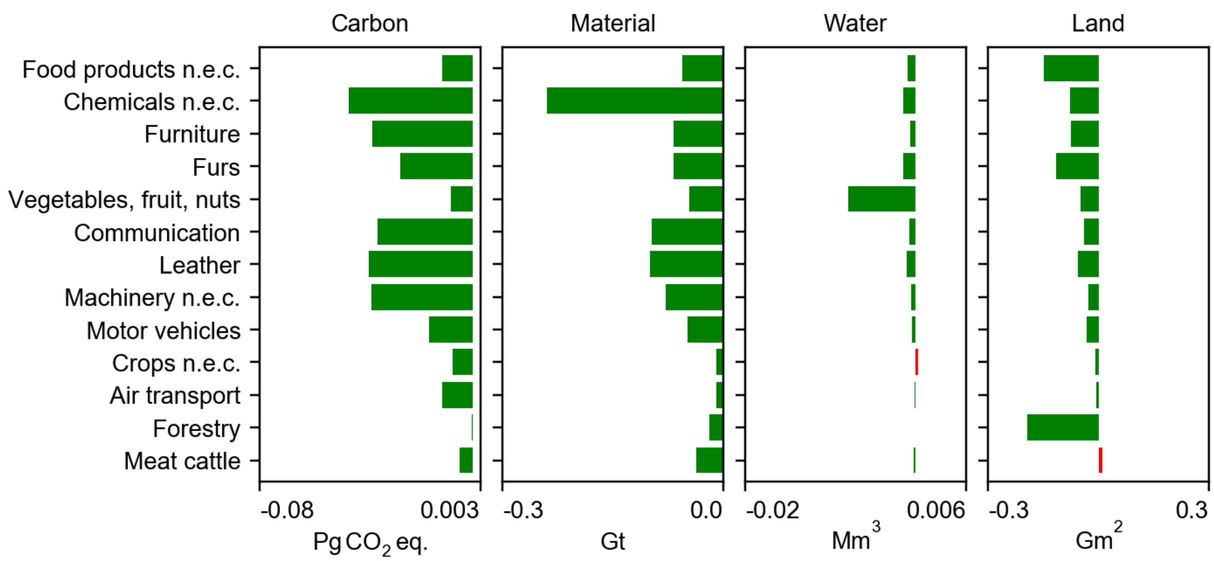

Figure 5 - Potential reduction of embodied impacts in EU28 imports when optimized for material footprint.

3.3.3 Water footprint

Figure 6 shows reductions in IEFs of highest contributing imports when optimized for IEWF.The largest reductions in IEWF are found in vegetables, fruit, and nuts (68% reduction), and crops n.e.c. (85%), namely 0.01 Tm^3 in each product group. This is followed by food products n.e.c. (63%), and chemicals n.e.c. (74%), namely 0.003 Tm^3 in both; and furs (65%), leather (76%), communication (73%), furniture (72%), and machinery (61%) (0.001 Tm^3 in all). Finally, IEWF is reduced for motor vehicles (0.0004 Tm^3 or 38%), meat cattle (0.0002 Tm^3 or 41%), air transport (0.0001 Tm^3 or 73%), and forestry (0.00002 Tm^3, or 78%). The latter product group shows a sizeable increase in IELF (0.3 Gm^2), along with meat cattle (0.1 Gm^2). Next to this, small increases in IELF of crops n.e.c. is observed, and IECF of meat cattle.

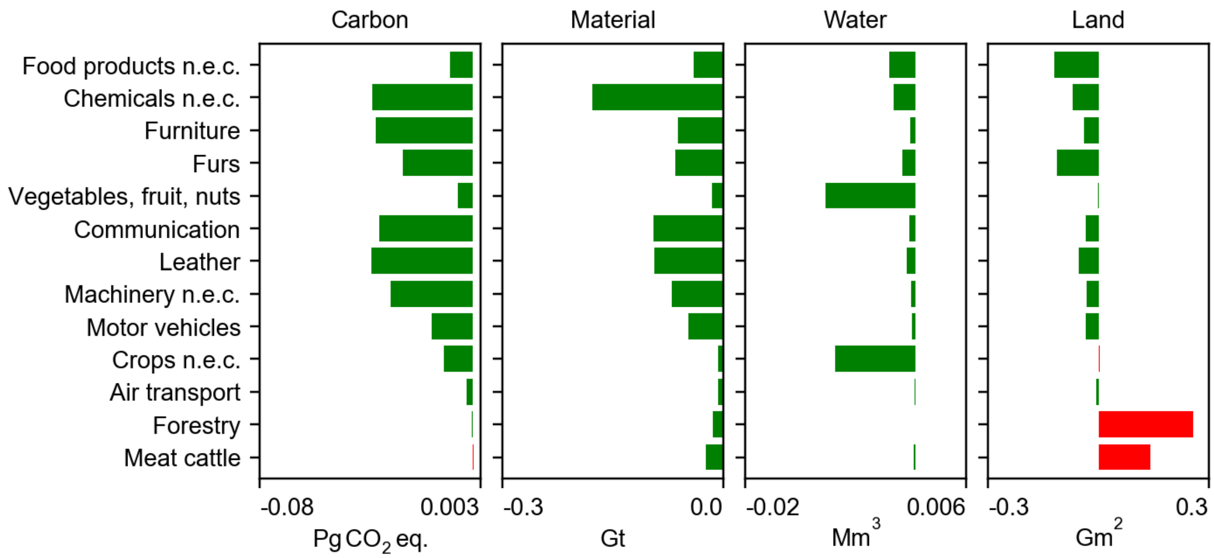

Figure 6 - Potential reduction of embodied impacts in EU28 imports when optimized for water footprint.

3.3.4 Land footprint

Figure 7 shows the potential reductions in the footprint of prioritized products when optimizing IELF. The largest improvements lie with forestry (82% reduction) and food products n.e.c. (60%) (both 0.2 Gm^2), followed by furs (80%), meat cattle (70%), furniture (68%), chemicals n.e.c. (66%), vegetables, fruit, and nuts (48%), and leather(70%) (all 0.1 Gm^2). IELF from communication products is reduced by 0.04 Gm^2 or 70%, motor vehicles (47%), machinery n.e.c. (62%), and crops n.e.c. (25%) by 0.03 Gm^2, and air transport by 0.01 Gm^2 or 73%. The only increase is found in IEWF of crops n.e.c. (0.005 Tm^3).

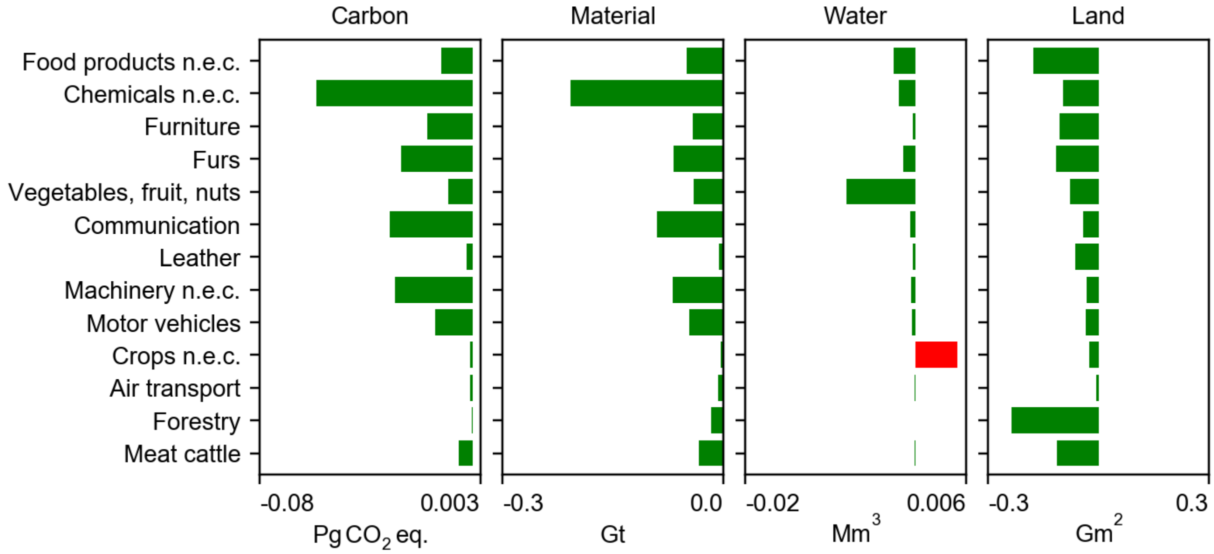

Figure 7 - Potential reduction of embodied impacts in EU28 imports when optimized for land footprint.

4. Discussion and conclusions

The aim of this study was to propose a framework for reducing IEFs by source shifting, and to identify product groups responsible for the highest EU28 IEFs. Over 50% of all IEFs was caused by the imports of just 13 products, where 1 product group was among the highest contributors to all 4 IEFs, 4 product groups to 3 IEFs, 5 product groups to 2 IEFs, and 3 product groups to 1 IEF. This overlap highlights the correlation between pressures which can be used to achieve large reductions in all 4 IEFs by source optimizing a small set of products (Galli et al., 2012; Pascual-González et al., 2015; Simas et al., 2017).

Our analysis highlights that the limitations of the EEMRIO homogeneity assumption is of particular interest when investigating IEFs. Of the 13 product groups responsible for the highest impacts across all IEFs, 4 groups contained products that were not elsewhere classified. As such, shifting sourcing for these groups could have major implications on the actual imported product mix. For instance, chemicals n.e.c. could include anything from fertilizer to pharmaceutical products and source shifting could lead to a strong favor towards one particular product contained in that group. This uncertainty in product mixes captured by product groups, in particular n.e.c. groups, limits the policy relevance of EEMRIO to develop scenarios aimed at reducing IEFS.

In the face of this uncertainty, our framework shows the sizeable potential for reducing IEFs through source shifting and trade-offs between optimizing for different IEFs. The largest scope for optimization was found for water footprint, followed by land, materials and carbon. On average, optimization through source shifting for all 200 products reduced an environmental footprint by 59%, with an upper bound of 72% and lower bound of 46%, depending on the environmental pressure considered. Carbon and materials were the environmental pressures which yielded largest synergies, i.e., optimizing their import source brought largest footprint reduction across all environmental pressures, followed by water and land. Source optimization for all products for a given environmental pressure yielded reduction in the footprints of other environmental pressures of between 48% and 15%, with an average reduction of 43%.

To our knowledge there are no previous studies that we can compare our results to. Jiang et al. (2018) found that CO_2 emissions of global trade in 2011 would have been reduced by 2.8 Gt if the global trade patterns would be shaped like in 1995, 2.0 Gt (2000), 1.3 Gt (2005), and 540 Mt (2008). With the EU's fraction of global GDP and trade roughly 25%, indicatively this would imply a reduction of CO2 emissions of EU28 trade by 0.7 Gt, 0.5, 0.3 and 0.1 Gt respectively. While our studies had a focus of source optimization rather than looking at a past trade structure, the order of magnitude in reduction of IECF is roughly the same (between 0.6 and 0.4 $PgCO_2eq$). We are not aware of studies looking at the other pressures we discussed here.

Our results can be put in perspective by the following reflections. For water impacts we used blue water extraction in volume as an indicator, which does not consider temporal and spatial scarcity. Adding these dimensions would increase the relevance of this pressure (Lenzen et al., 2013). There is a debate whether the distinction between blue and green water is worthwhile, as these essentially are part of the same cycle (See Chenoweth, Hadjikakou, & Zoumides, 2014 for an overview; and Wichelns, 2011 versus Biewald & Rolinski, 2012 for competing views). More generally, we could have included more indicators than the four environmental pressures considered here. We chose to limit the number of pressures for the following reasons. First, due to the correlation between environmental pressures, we believe that these four pressures allow for a reasonably comprehensive picture of IEFs. Second, we chose to adhere to the environmental policy framework of the EU, in particular the Resource Efficiency Roadmap, as to satisfy the RACER (Relevant, Accepted, Credible, Easy and Robust) criteria used to assess the policy relevance of indicators (Eisenmenger et al., 2016; Steinmann et al., 2017). The concept of planetary boundaries offers more dimensions including limits to comprehensively capture environmental impact (Rockström et al., 2009; Steffen et al., 2015). One could also consider including social dimensions, leading to a coverage of the so-called Doughnut Economy concept (Raworth, 2017). However, operationalizing such additional environmental and social targets in measurable indicators can be problematic (Fang et al., 2016, 2015; Lewis, 2012). As such, adding these dimensions to our analysis would be non-trivial and beyond the scope of this paper. Increasing the comprehensiveness of environmental and social impact assessments is of vital importance to reach a safe and just world (Scherer et al., 2018). Finally, by using a consumption perspective in our study we assumed that the EU28 is fully responsible for the global impacts of the EU28's consumption as they take place along global supply chains. This neglects that producer countries have also options to reduce emissions and benefit from exports (compare Tukker et al., 2013). Studies have investigated a middle way between a production- and consumption perspective to develop a footprint considered most fair by all parties involved. Some studies have focused on 'splitting the difference', i.e. taking the average of both footprints, while others have looked at equity and equality measures(Lenzen et al., 2007; Marques et al., 2012; Zhu et al., 2018).

A crucial point is obviously that source shifting of EU28 imports strictly speaking does not reduce environmental impacts globally – the EU28 just uses the exports with lowest impacts and leaves exports with higher impacts to other countries. Our results are hence highlighting the importance of adopting best-in-class production technologies across all countries to lower embodied impacts in trade (Grasso, 2017; Kander et al., 2015; Steininger et al., 2014). Further, source shifting of imports could run into practical barriers which could hamper the applicability in the policy arena. As consumption-based policies, and with them embodied impacts in trade, are becoming more concrete, questions are being raised regarding their policy legitimacy (Afionis et al., 2017; Peters and Hertwich, 2008; Scott et al., 2018). Our analysis suggests that a phenomenon of insourcing may occur, i.e. shifting from importing to domestic production of product groups in the case of EU28 member states. This is due to the fact that we aggregate EU final demand on the one hand, and allow redirecting sourcing to exporting countries residing in the EU on the other. For instance, if the sourcing for a particular product group is shifted primarily to Germany, then part of these exports is redirected to Germany itself. This partly insources German production for this product group. This effect shifts the risks from external production shocks to internal supply chain shocks for this country (Galli et al., 2017). As our model aimed to offer a scope of IEF reduction, rather than advocating for source shifting as a policy tool, we argue that the implications of this shift in risks is limited for our study.

We bring forward several directions for future research. First, increasing the level of detail of n.e.c. product categories in EEMRIOs can help to increase insight into embodied impacts in trade (de Koning et al., 2015). Second, incorporating dynamic effects of import shifting, e.g. through dissemination of best-in-class technologies, can provide a more accurate picture of the implications regarding embodied impacts (Wiedmann et al., 2011). Also, investigating implementation issues regarding import embodied footprints policies can prove to be of vital importance. There is no clear view on how CBA policies regarding other environmental pressures are taking shape. Lessons can be drawn from experience regarding BCA (Afionis et al., 2017).

Acknowledgements

Funding:

This research was carried out as part of the PRINCE project (www.prince-project.se), supported by the Swedish Environmental Protection Agency and the Swedish Agency for Marine and Water Management under a Swedish Environmental Protection Agency research grant (Environmental Research Appropriation 1:5).

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