INTER-COUNTRY COMPARISON OF CARBON FOOTPRINT WITH PURCHASING PRICE INDEX ADJUSTMENT *

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ABSTRACT

Measuring the impact of economic activities in units of carbon dioxide emissions (carbon footprint) is essential information to frame policies addressing the responsibility and behaviour of economic agents towards global warming. Recent analyses based on the OECD's Inter-Country Input-Output (ICIO) database have contributed to provide estimates of country and sector-specific CO2 emissions embodied in domestic and foreign final demand for numerous economies. Such estimations have already improved our understanding on the distribution of CO2 emissions along global value chains. However, these CO2 analyses based on input-output tables in nominal monetary value are heavily biased due to considerable purchasing price differences across countries and sectors. In this paper, we compute CO2 emissions intensity of the final demand adjusted by consumption price differences for the 35 OECD members and major non-OECD economies. Our results show that adjusting CO2 intensity by purchasing price parity (PPP) substantially affects the countries' ranking according to their demand-driven CO2 intensity. Taking a closer look at sectoral results, we observe a particularly high difference in the ranking for the construction, education and communication sectors. High differences between adjusted and non-adjusted final demand prices for the above-mentioned sectors may be attributable to labour-intensive production structures and low degree of market openness

Keywords: Inter-Country Input-Output Table, Carbon footprint, Consumption behaviour
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* This represents views of authors and not necessarily those of the OECD or of its member countries and of Université Paris Dauphine.

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EXECUTIVE SUMMARY

In this paper we calculate CO_2 intensity of the final demand of 9 sectors for 63 countries, among which OECD countries and other major open economies. Beforehand, we show that purchasing price differences between sectors are considerable. These divergences may be largely explained by the sector's degree of market openness (Balassa, 1964; Samuelson,1964). In a second step, we exploit estimations of consumption-based emissions of Wiebe and Yamano (2016) to compute CO_2 intensities of the final demand for our 9 sectors. We adjust the final demand of this indicator by sector-specific PPPs. Our methodology is therefore a way of normalising values toward adjustment by volumes. Potentially, our estimates for developed countries is slightly overvalued as we do not adjust estimations of consumption-based emissions, but only final demand expenditures. Nevertheless, we show that adjusting final demand of the CO_2 intensity indicator by PPP reduces the variability of the CO_2 indicator. This adjustment seems particularly necessary for sheltered sectors, whose purchasing prices are strongly deviating from nominal values. Overall, adjusting by PPPs tend to increase CO_2 intensities of developed countries and vice versa. We show that most CO_2 intensive sectors are, on top of the list, the utility sector, followed by transportation, clothing and food. Thus, our method provides information on the degree of sectoral 'clean consumption' on the one hand and reduces the nominal bias on the other hand. Among other things, we provide detailed graphical analyses which give a clear picture on carbon intensity and its decomposition along global value chains. Finally, we discuss our findings in the light of climate change policies. We place a particular emphasis on fairness in mitigation responsibility. In parallel, we try to think about a feasible and fair implementation of responsibilities on consumption-based emissions and minimisation of CO_2 intensities of consumption.

Dans cette étude, nous calculons l'intensité carbone de la demande finale de 9 secteurs pour 63 pays, dont les pays de l'OCDE et d'autres grandes économies ouvertes. Auparavant, nous montrons que les prix à l'achat varient énormément entre les différents secteurs considérés. Ces différences peuvent vraisemblablement largement s'expliquer par le degré d'ouverture du dit secteur au commerce international (Balassa, 1964, Samuelson, 1964). Dans un second temps, nous utilisons les estimations d'émissions carbones contenues dans la consommation de Wiebe et Yamano (2016) pour calculer les intensités carbones de la demande finale pour 9 secteurs. Nous ajustons la demande finale de notre indicateur par un indice de PPA sectoriel. Notre méthodologie est donc un moyen de normalisation vers un ajustement par les volumes. Potentiellement, nos estimateurs peuvent s'avérer légèrement surévalués pour les pays développés étant donné que nous n'ajustons pas les estimations des émissions contenues dans la demande, mais seulement la demande finale de l'indicateur en elle-même. Néanmoins, nous montrons qu'ajuster la demande finale de notre indicateur d'intensité carbone par la PPA réduit la variabilité de ce même indicateur. L'ajustement nous paraît notamment essentiel pour les secteurs abrités [du commerce international], dont les prix à la consommation sont très éloignés des volumes réels. D'une façon générale, l'ajustement par la PPA a tendance à accroître l'intensité carbone des pays développés et vice versa. Nous trouvons que les consommations les plus intensives en carbone sont celles du secteur de l'énergie, suivi par celui des transports, des habits et l'industrie alimentaire. Notre méthode permet donc d'informer sur le degré de 'consommation propre' d'un secteur d'une part, et de réduire le biais nominal d'autre part. Entre autres, nous nous efforçons de produire des analyses graphiques détaillées, permettant de donner une image claire et concise de l'intensité carbone pour chaque secteur et de sa décomposition dans les chaînes de valeur mondiale. Enfin, nous discutons nos résultats dans le cadre des politiques visant à lutter contre le réchauffement climatique, en mettant particulièrement l'accent sur la notion d'équité dans la responsabilité de réduction des émissions de gaz à effet de serre. Parallèlement, nous essayons de réfléchir à une implémentation équitable d'une prise de responsabilité d'un pays sur ses importations virtuelles d'émissions, et d'une minimisation des intensités de consommation.

1. Introduction

Consumption-based accounting (CBA) of greenhouse gases (GHG) represent essential and complementary information to production-based measures of emissions. Countries may indeed achieve decoupling of production-based emissions from economic growth by offshoring domestic production abroad (Weber and Peters, 2009; OECD, 2014). Alternatively, countries may just cover additional consumption needs by increasing import penetration (OECD, 2014). If imported final and intermediate goods are produced in places where production techniques tend to be more polluting, anthropogenic emissions may globally significantly increase while production-based indicators could exhibit positive results of depollution at the national level (ibid.). CBA is therefore becoming increasingly relevant for policy making related to global warming, as it allows tracking virtual imports of GHG emissions of countries, i.e. emissions generated abroad for the consumption of nationals (Wiedmann, 2009; Peters and Hertwich, 2008a). Discussions are emerging among scholars about net exporting countries of GHG emissions becoming fully or partially responsible for their virtual imports of emissions. Shifting responsibility to the importers would be a way of accelerating the curbing of GHG emissions and bring greater fairness in the battle against climate change (Thomas and Hertwich, 2008b; Wiedmann, 2009). Therefore, it is important to provide fully reliable calculations of such emissions imports.

This paper takes a slightly different but complementary approach of emissions embedded in trade. We aim at providing sector-detailed indicators of carbon dioxide (CO_2) equivalents emissions embedded in final demand in final demand i.e. CO_2 intensity of the final demand at the sector-level. We believe that it is not enough to look at absolute volume of emissions but likewise at "environmental efficiency" of consumption. Our methodology is therefore another way of normalising absolute values (e.g. per capita approach) but with a focus on "clean consumption". If countries want to maintain high levels of consumption while avoiding catastrophic consequences on global climate, minimisation of this indicator is required. In particular, this study points out that what matters when aiming at "cleaning" consumption, is not much national efforts of decarbonisation but rather *the choice of trade partners*, and respectively, their efforts of decarbonisation. Besides, we are very much interested in looking at sectors' particularities rather than solely focusing on countries' net positions. It allows us to spot sectors being particularly carbon-intensive. Besides it helps understanding more in-depth the status of net-importing countries at the sectoral level. Finally, it allows to identify particular distributions of CO_2 along the global chain for the various sectors considered.

Numerous scholars have undertaken accounting of carbon dioxide emissions embodied in trade and in consumption, by either using national input-output tables or multiregional tables (for a review, see Wiedmann, 2009 and Sato, 2014). These studies show the increasing share of emissions embodied in international trade, mostly intended for the consumption of developed countries (Wiedmann, 2009; Sato, 2014). For example, Weber and Matthews (2007) show that the share of production-based emissions in total emissions of the U.S have diminished between 1994 and 2004 but that the share of consumption-based emissions has sharply increased. They attribute this finding to increased trade volume on the one hand, and to shift toward more CO_2 intensive trade partners on the other hand.

The OECD has been particularly active for estimating carbon dioxide emissions embodied in trade, covering a wide range of countries (Ahmad and Wyckoff, 2003; Nakano et al., 2009; Wiebe and Yamano, 2016). Inter-country input-output tables have been used in the recent years to enhance these calculations and increase country coverage up to 63 countries (Wiebe, Yamano, 2016). Wiebe and Yamano (2016) show that consumption-based emissions have increased for OECD countries up to the 2008 financial crisis. OECD countries are on average net importers of CO2 emissions, i.e. consumption-based emissions are higher than production-based emissions. Conversely, non-OECD economies are on average net-exporters. At the same time, their consumption-based emissions have increased faster than OECD-economies, to reach a higher 2011-level than OECD countries.

The use of input-output models for calculating consumption-based emissions presents some caveats (Wiedmann, 2009; Sato, 2014). One of them is the use of nominal values as proxy for physical units. This involves the application of market exchange rates to convert local currencies. Therefore, results of most CBA studies may be strongly biased by differences between nominal values and volumes. We find two exceptions in the literature that show efforts of testing their results' sensitivity toward this issue. Kanemoto and Tonooka (2009) show that when using PPPs instead of market exchange rates (MER), Japan becomes a net exporter of emissions while it was net importer when formerly applying MER. More generally, using PPPs systematically reduce emissions embodied in Japanese imports. Weber and Matthews (2007) also find lower emissions embodied in imports for the United States between 1997 and 2004 when using PPPs as convertors. They argue that adjusting by PPP is particularly relevant for developing countries which exhibit high differences between MER and PPP (also, Weber, 2008). Finally, they qualify their results by stating that PPP-adjusted emissions are likely to be understated. Indeed, each commodity's output in each country includes exports and domestic consumption, where exports are usually higher valued. Thus, adjusting outputs by PPP all alike underestimate volume of exports. Weber (2008) states that multipliers in CO_2 per USD could be as much as 400% different according to the method used (MER vs PPP).

We understand that differential pricing between countries is one of the methodological challenge of multi-region input-output modelling (MRIO; Wiedmann, 2009) and that adjusting by PPP as done by Weber and Matthews (2007) does not completely solve the problem. This adds to all problems relative to getting reliable valuations of purchasing price levels. We add to this argument that between-sectors price differences are considerable and that adjusting all sectors by overall[1] PPP is risky.

In this paper we calculate CO_2 intensity of the final demand of specific sectors for 63 countries, among which OECD countries and other major economies. Beforehand, we show that purchasing prices vary a great deal across sectors. Hence, we argue that adjusting by overall PPP for specific products is hazardous as overall PPP does not reflect sector-specific volumes. We quickly explain inter-sectors divergences by using the well-known seminal properties of Balassa (1964), Samuelson (1964). In a second step, we exploit estimations of Wiebe and Yamano (2016) to compute CO2 intensities of the final demand for 9 sectors that we adjust by sector-specific PPPs. Note that we only adjust the final demand of our CO_2 intensity indicator but not the global final demand matrix used to calculate emissions embodied in trade of Wiebe and Yamano (2016). This would require PPPs indexes for all sectors belonging to our input-output database (ICIO). Our methodology, still, is a way of normalising values toward adjustment by volumes. Also, as argued by Weber and Matthews (2007) adjusting emissions by PPP would underestimate CO_2 emissions embodied in imports of developed countries. But potentially, our CO_2 estimates for developed countries is slightly overvalued. Nevertheless, we show that adjusting final demand of the CO_2 intensity indicator by PPP is particularly necessary, especially for sheltered sectors, whose purchasing prices are strongly deviating from nominal values. Overall, adjusting by PPPs tend to increase CO2 intensities of developed countries and vice versa. We show that most CO_2 intensive sectors are, first and far and away top of the list, the utility sector, followed by transportation, clothing and food. Our method provides information on the degree of clean consumption on the one hand and reduces the nominal bias on the other hand. Among other things, we provide graphical analyses which provide a clear picture on carbon intensity and its decomposition. Finally, we discuss our findings in the light of climate change policies. We place a particular emphasis on fairness in mitigation responsibility, following the work of Rose et al. (1998) and Ringus et al. (2002). We then try to think about feasible and fair implementations of responsibilities on consumption-based emissions and minimisation of CO_2 intensities of consumption.

[1] Country-specific only, GDP- convertor.

2. Model and data for constructing CO_2 intensity of the final demand

2.1. Data

2.2.1. OECD's ICIO database 2016 edition

The data used to build the model are obtained from the 2016 edition of OECD ICIO tables.[2] The tables cover 63 countries, of which all OECD countries and 27 non-member economies (including all G20 countries) and the years from 1995 to 2011. Tables 1 and 2 show the sector and country coverage. The original sector coverage of the ICIO tables is 34 sectors.

2.2.2. IEA CO2 emissions from fuel combustion 2016 edition

We use data from the International Energy Agency (IEA) on emissions from fuel combustion (2016 edition). Complete methodology on calculations of CO_2 emissions can be found on the IEA website.

2.2 Emissions embodied in final demand

We follow the exactly same methodology as in Wiebe an Yamano (2016) to calculate emissions embodied in final demand[3]. We first match sectors of the IEA CO2 data with ICIO industry classification. There are some differences of classification. Most importantly we have to disaggregate the service industries, only available as one aggregate in the IEA database. In parallel, we must aggregate the energy industry, very much detailed in IEA. Besides, we have to re-allocate emissions from road transport to industries according to use by intermediate and final demand.

We then calculate emission factors by country c, industry i and year t as follows:

$$EF_i^c[t] = CO2_i^c[t]/PROD_i^c[t]$$

To get consumption-based emissions (**$CO2^D$**) we multiply our emission factor matrix (**EF**) with a global Leontief inverse matrix (**B**) and global final demand matrix (**Y**), both constructed thanks to ICIO data. In addition, we need to consider direct emissions of final demand (**F**), that is residential emissions (e.g. domestic use of gas oven, stove, water boiler) and emissions from private road transport.

$$\mathbf{CO2^D = (EF \cdot B) \cdot Y + F}$$

2.3 CO2 intensity of sectoral final demand

For each country c, sector i, year t, our sectoral indicator is constructed as follows:

$$CO2\ intensity_{c,i,t} = \frac{co_2{}^D_{c,i,t}}{y_{c,i,t}}$$

With $co_2{}^D_{c,i,t}$ being our country-sector-and time specific estimations of CO2 emissions embodied in final demand; and $y_{c,i,t}$ the final demand expenditures in nominal terms (USD).

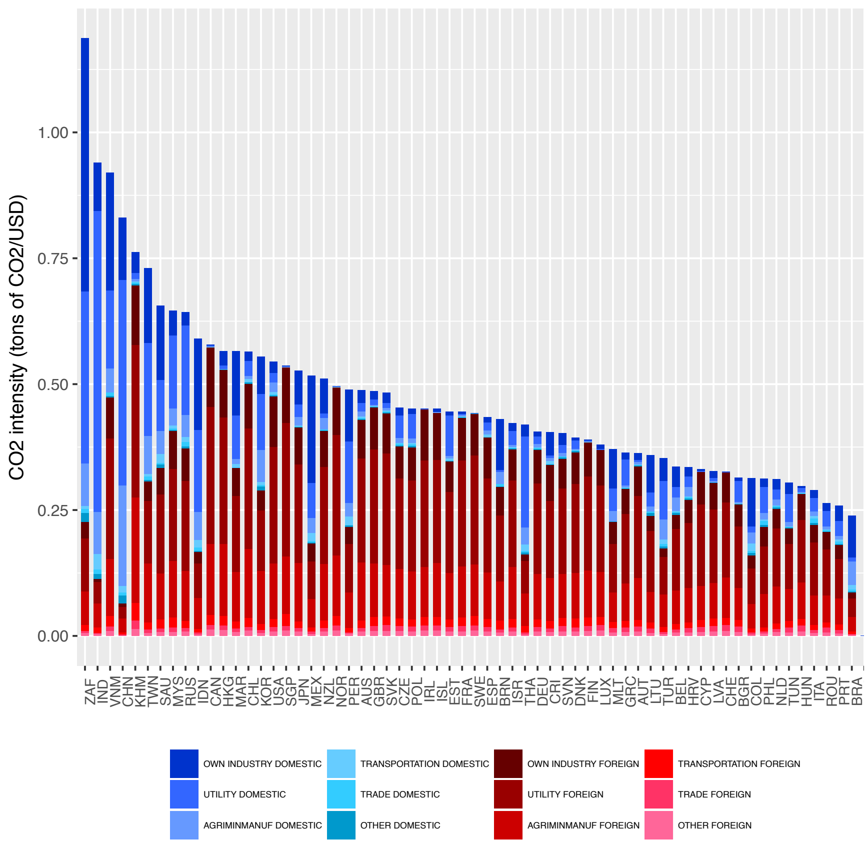
2. See http://www.oecd.org/sti/ind/input-outputtables.htm .

3. For more details on their methodology, please directly refer to Wiebe and Yamano (2016).

Figure 1 displays CO2 intensities of final demand for clothing and footwear, i.e., how CO2-intensive is the consumption of clothing and footwear in one given country. In red are emissions that were emitted abroad and in blue, domestic emissions. The magnitude of domestic CO_2 intensities (blue bar) vary with the importance of domestic use of fossil fuels and national industry size. Our graphical analyses (further available in Appendix) provides a clear picture of distribution of carbon dioxide in international trade. We observe that emissions associated to the consumption of clothing and footwear were emitted abroad for most countries. Only South Africa, India, China, Indonesia, Mexico, Peru, Thailand and Brazil exhibit higher domestic emissions than foreign emissions, as relative to their final demand for cloths. This seems consistent, as these countries are large cotton producers and/or clothing industries. While the relative share of foreign in total emissions seems consistent, the country ranking does less. Indeed, South Africans, Indians buy probably more cloth in volume than what appears in nominal final demand.

Figure 1: CO2 embodied in unit consumption of Textile and apparel product (all countries, 2011)

No adjustment



Nominal values of final demand expenditures in dollars (denominators) are obtained by converting nominal values in local currencies with nominal exchange rates. However, levels of consumption in nominal value tend to be overestimated in developed countries and underestimated in developing countries. This stems from the fact that exchanges rates are formed by international flows of goods and services, i.e. tradable goods (Pancaro, 2011). In turn, it implies that non-tradable goods are not represented in the exchange rate. However, non-tradable sectors usually have closer productivities between countries than tradable sectors, e.g. hair-dressers can cut hairs at similar speed rates. On the contrary developing countries' tradable sectors tend to display lower productivity than in developed countries. Therefore, market exchanges rates will reflect this difference while forgetting productivities in non-tradable sectors.

Hence when computing CO_2 intensities of consumption, not adjusting by PPP will cause underestimations for developed countries versus overestimations for developing countries. Thus, estimations in nominal terms are strongly biased when used for comparison between countries. In parallel, the standard deviation of our indicator is likely to be very inflated due to the use of nominal values. Accordingly, adjusting final demand expenditures by purchasing price differences will able consistent comparisons between countries[4], while decreasing variance of our indicator.

Adjusting by purchasing price differences at the industry-level is a novelty in the input-output literature (for reviews see Wiedmann, 2009 and Sato, 2014). But recall that we only adjust the final demand and not the global final demand matrix used to calculate emissions embodied in trade. Doing so would require having PPP indexes specific to all ICIO sectors and countries. As mentioned above we unfortunately have information on solely 9 sectors. Therefore, it implies that we do not completely erase the nominal bias.

From an environmental point of view, our adjusted CO_2 intensity indicator allows more consistent between-countries comparisons of carbon footprint and could be relevant in global negotiations for climate change.

[4] This approach still contains one weakness: the ICIO data are in basic prices i.e. do not include margins. Further adjustment is therefore needed.

3. Model and data for constructing CO_2 intensity of the PPP-adjusted final demand

Developing countries tend to have undervalued currency and thus higher CO_2 per monetary unit. Weak currency causes our CO_2 intensity indicator to be overvalued. When adjusting by purchasing power parity, final demand expenditures in developing countries will tend to rise, better reflecting actual consumption levels. As a result, the demand-driven CO_2 intensity will decline.

Our adjusted indicator is constructed as follows:

$$CO2\ intensity_{\ c,i,t} = \frac{co_2{}^{D}_{\ c,i,t}}{\rho_{c,i,t} \cdot y_{c,i,t}}$$

With $\rho_{c,i,t}$ a sector-specific index of purchasing price differences

3.1. Data on purchasing price levels

Data on sectoral real expenditures (i.e. PPP adjusted) are issued from the 2005 and 2011 International Comparison Program (ICP) results, conducted by the World Bank. Deaton and Aten (2017) reveal methodological issues in ICP 2005. Thus, we will mainly focus on ICP 2011 throughout the rest of the document.

We match IPC expenditures categories with ICIO industries as follows:

IPC category (World Bank data)	ICIO equivalent (OECD data)
1- Food and non-alcoholic beverages	C15T16 - Food products, beverages and tobacco
2- Clothing and footwear	C17T19 – Textiles, textile products, leather and footwear
3- Housing, water, electricity, gas and other fuels	C40T41 – Electricity, gas and water supply
4- Health	C85 – Health and social work
5- Transport	C60T63 – Transport and storage
6- Communication	C64 – Post and telecommunications
7- Education	C80 – Education
8- Restaurants and hotels	C55 – Hotels and restaurants
9- Construction	C45 – Construction

There can exist slight differences in our matching of IPC categories with ICIO industries, the main one being the ICIO C15T16 industry which includes alcoholic beverages and tobacco while the IPC category does not. We consider that these small differences do not have a significant impact on our estimations results, e.g. alcohol only represents a minor share in total consumption of food and beverages. Also, the ICIO classification is by industry while the IPC categories are expenditures on products so that we have a matching of products from their industry.

Unfortunately, we are only able to match 9 sectors from the IPC dataset with our ICIO classification. This still represents valuable information. To cope with the scarcity of information, an index of overall purchasing price parity will be analysed as well. If relevant, we could adjust sectoral CO_2 intensity with this country-specific index, i.e. if differences among sectors are reasonably low and close to the overall PPP value.

3.2. Indicators of purchasing price differences

We estimate two PPP indicators using the 2005 and 2011 ICP results, one adjusting for overall PPP and one adjusting for sectoral PPP (for the 9 sectors). These indicators are therefore only available for year 2005 and 2011.

1. **Overall PPP**

   For each country i,

$$\rho_{1,i} = \frac{GDP\ in\ PPP_i}{Nominal\ GDP\ _i}$$

2. **Sectoral PPP** (Expenditures approach)

   For each country i and sector s,

$$\rho_{2,i,s} = \frac{Real\ Expenditures\ _{i,s}}{Nominal\ Expenditures\ _{i,s}}$$

Real expenditures are defined by the World Bank as expenditures in international dollars (i.e. nominal USD adjusted by PPP). As $\rho_{1,USA} = 1$ and $\rho_{2,USA,s} = 1\ \forall\ s$, comparisons of indicators will be made relatively to USA.

Statistical analysis of ρ_1 and $\rho_{2,s}$ reveal strong differences among sectors. Price differences between countries are much higher in *sheltered* sectors (particularly health, education, construction) while the PPP index distribution is more concentrated in *open* sectors (food, clothing; see Table 1 and 2). This observation echoes Balassa (1964) and Samuelson (1964), where the authors predict that prices of tradable goods will homogenise thanks to international arbitrage possibilities. As wages equalise between sheltered and open sectors, prices of non-tradable goods will decouple from the sector's productivity. It is therefore more likely that they do not reflect volume of sales and that PPP differences between countries are higher for those sectors. As non-tradable goods have higher purchasing price differences, the need for purchasing price adjustment appears to be stronger for these sectors.

As expected, between-countries variations are much larger than temporal variations. Indeed, a global price convergence was not likely to happen in a period of 6 years. In addition, we reject the null hypothesis of equality of variance of ρ_1 and $\rho_{2,s}$ for all sectors at the 5% level of significance (two-sided test), except for the communication and clothing industries.

So far, we understand the crucial importance of having a sector-specific index, since our sectoral index significantly diverges from our overall index. We conclude that the price adjustments by over PPP figures generate greater biases than the sector-specific adjustments as expected.

Table 1 and 2 display standard deviation of our PPP index respectively for year 2005 and 2011. Highest values are present for health, education and construction. Looking at the inverted distribution in Figure 2 gives us an idea of how values are distributed relative to USA (red horizontal line). We must be careful when using estimations from ICP 2005. Deaton and Aten (2017) show that 2005 per capita consumptions in international dollars (i.e. PPP-adjusted) of most developing countries[5] from the ICP program were understated. In turn, it implies overestimations of our 2005 CO_2 intensity indicators for those same countries. The authors further observe that purchasing prices relative to the United States look more equal in ICP 2011.

Table 1: Standard deviation, t=2005

PPP indicator	Std. Dev.
Food	0.371
Clothing/footwear	0.464
Utilities	0.998
Health	3.196
Transport	0.346
Communication	0.478
Education	5.153
Restaurants/hotels	0.427
Construction	1.361
Overall (GDP)	0.669

Table 2: Standard deviation, t=2011

PPP indicator	Std. Dev.
Food	0.326
Clothing/footwear	0.678
Utilities	1.063
Health	1.787
Transport	0.366
Communication	0.761
Education	3.117
Restaurants/hotels	0.588
Construction	1.314
Overall (GDP)	0.623

[5] Countries in Asia (excluding Japan), Western Asia, Africa (Deaton, Aten, 2017).

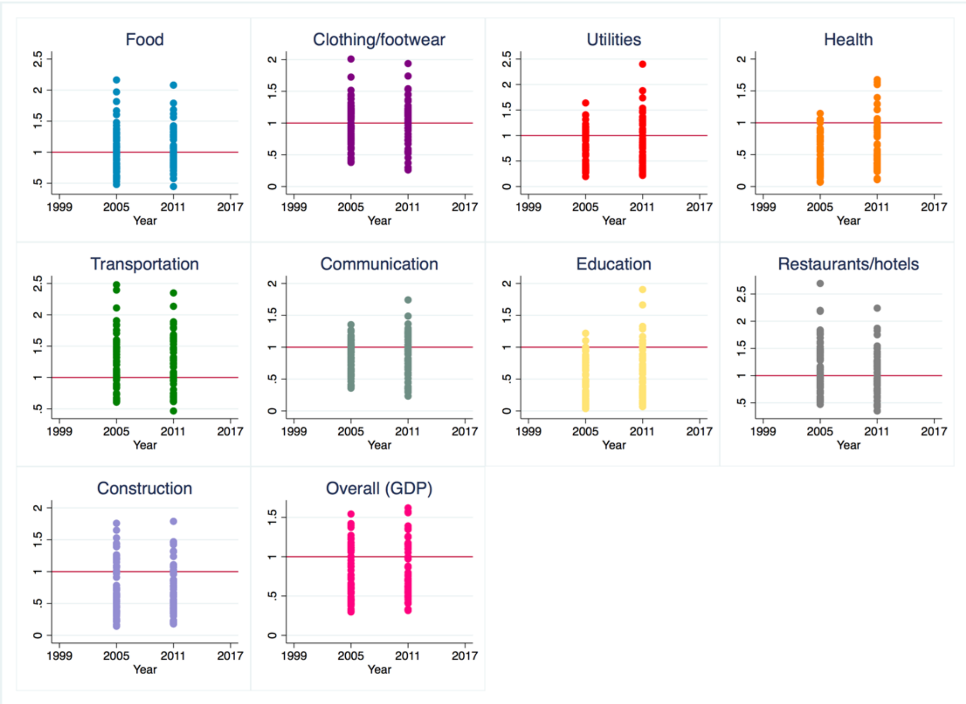
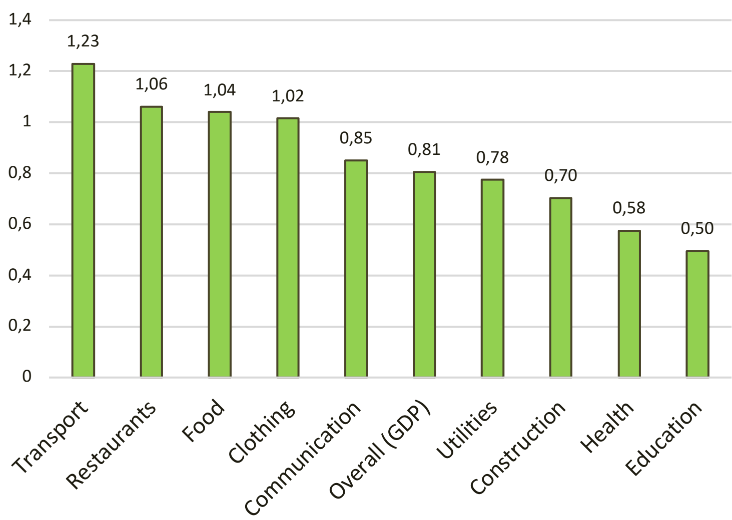


Figure 2: Distribution of the inverted PPP index (overall and sectoral)

On average, American prices seem particularly higher for education, health and construction than in other countries belonging to our sample (Figure 2). We should however not interpret the range of the distribution. As our indicator is inverted in Figure 2, so are the range and variance.

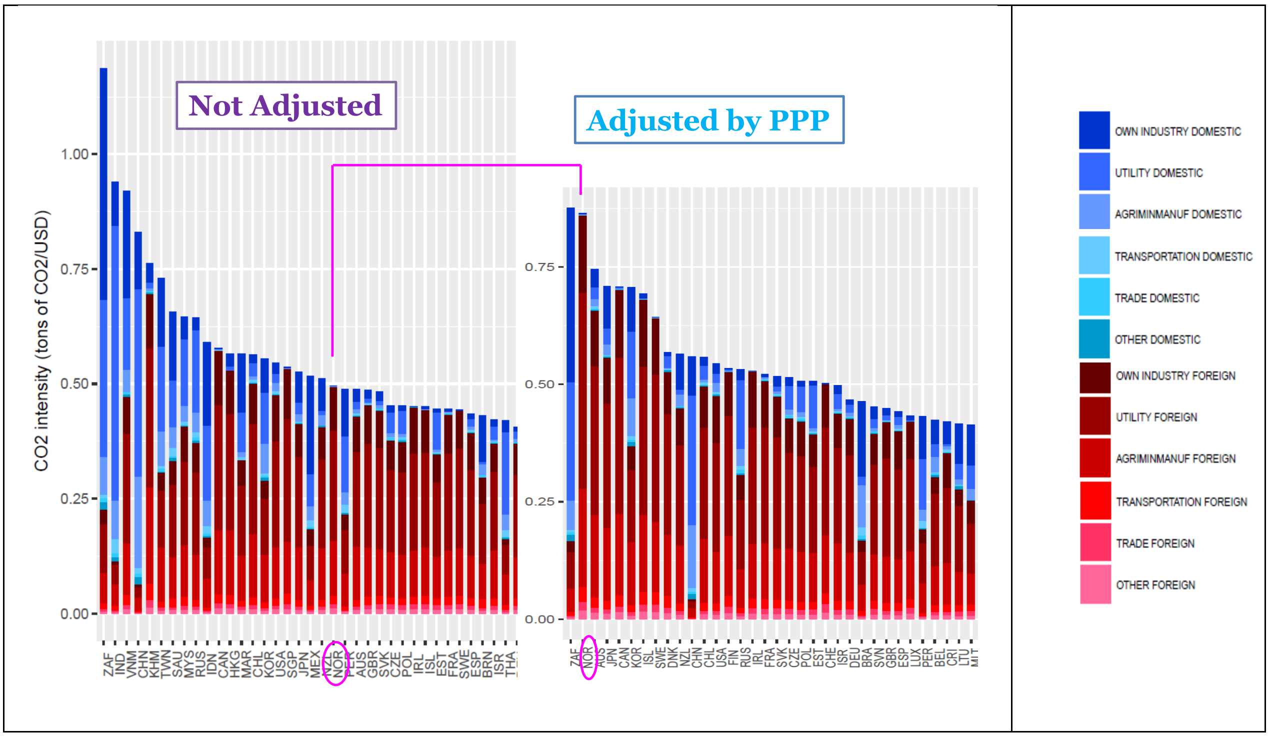
Figure 3 shows that most PPP index are above 1, meaning that on average, adjusting final demand expenditures by PPP will tend to decrease our CO2 intensity indicator.

Figure 3: mean of $1/\rho$, all countries, all years



4. Concrete examples of adjustment

Figure 4: Adjustment by sectoral PPP index for Textiles, textile products, leather and footwear (2011)

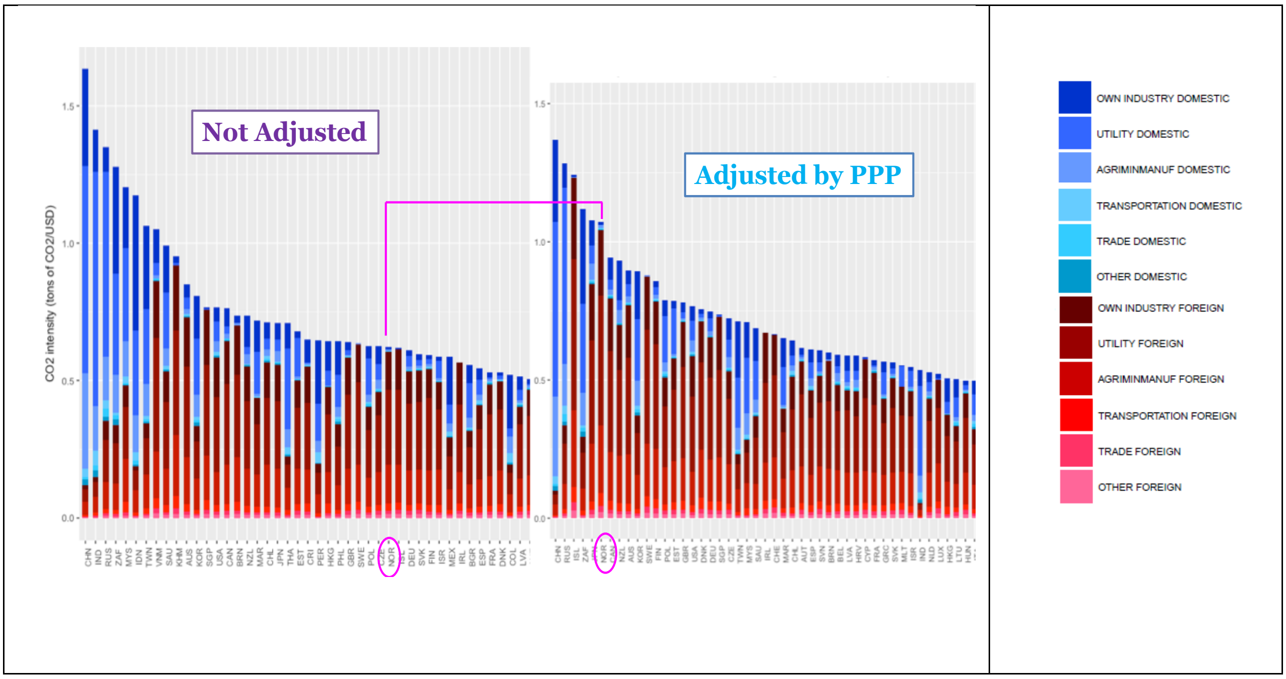


Adjusting by PPP changes the ranking of countries. Developed countries tend to climb in the ranking and vice-versa for developing countries.

As a striking example, Norway becomes second in our ranking due to its strong currency. For clothing prices, it has one of the lowest PPP convertors (around 0.5 relative to USA). We see that almost all of Norwegian emissions stem from abroad, as this country has almost full hydropower (Peters and Hertwich, 2008a) and a small clothing industry.

When having a closer look at the intensity components, we observe that utility (foreign and domestic) represents the lion's share of the CO2 intensity indicator (high share of "utility domestic" for exporting countries, "utility foreign" for importing countries). Again, for internationally traded goods the carbon intensity of consumption often very much relies on the energy mix used by trading partners rather than domestic use of fuels and coal.

Figure 5: Adjustment by sectoral PPP index for Textiles, textile products, leather and footwear (2005)



We obtain similar results for year 2005, but with on average higher CO_2 intensity values than in 2011. This may be due to the methodological issues of ICP 2005 (Deaton and Aten, 2017).

5. Main results

Adjusting by sectoral PPP systematically reduces the variability of our indicator, but also its mean (two exceptions: food and transportation). However, even when controlling for the mean depreciation, we find lower standard deviation in all sectors, all years. Accordingly, we conclude that our adjustment led to some degree of homogenisation of CO_2 intensity indicators among countries. Adjusting by PPP partly erases the nominal bias, where price differences are exacerbated (higher prices in rich countries, lower prices in poorer countries).

Non-tradable goods exhibit the biggest declines in standard deviation (i.e. construction, education, health, communication; Figure 6). The standard deviation of the utility sector also decreases substantially but still remain ten times higher as in other sectors, reflecting very different energy mixes.

Figure 6: Standard deviation of the adjusted CO_2 intensity indicator (t=2011)

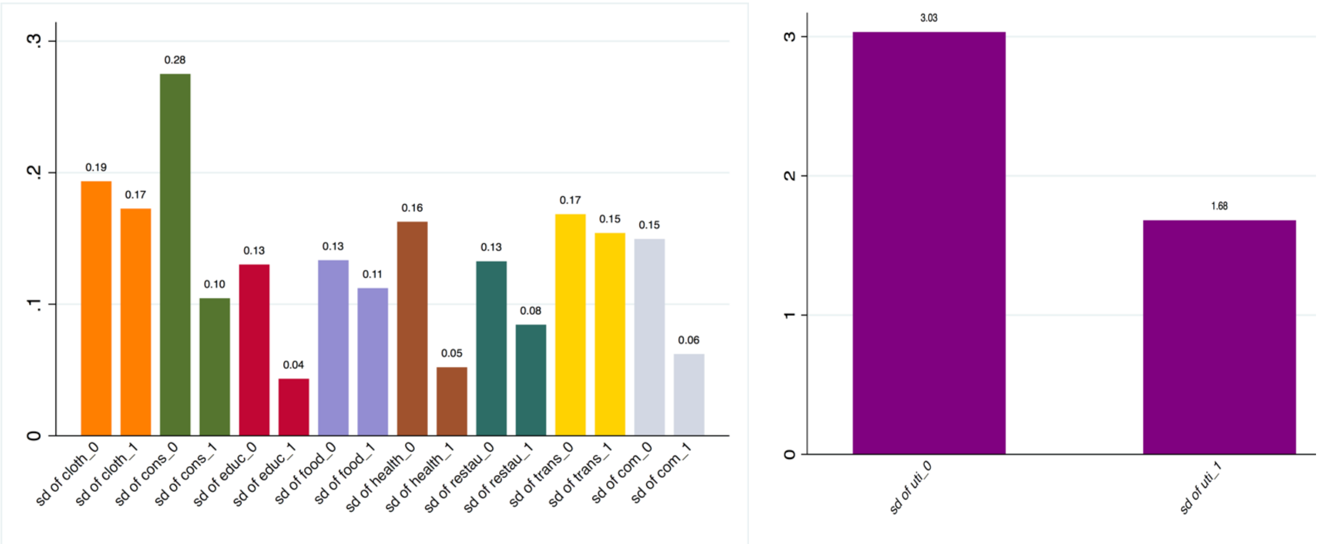


Table 3: Descriptive statistics of adjusted and non-adjusted CO_2 intensity of final demand

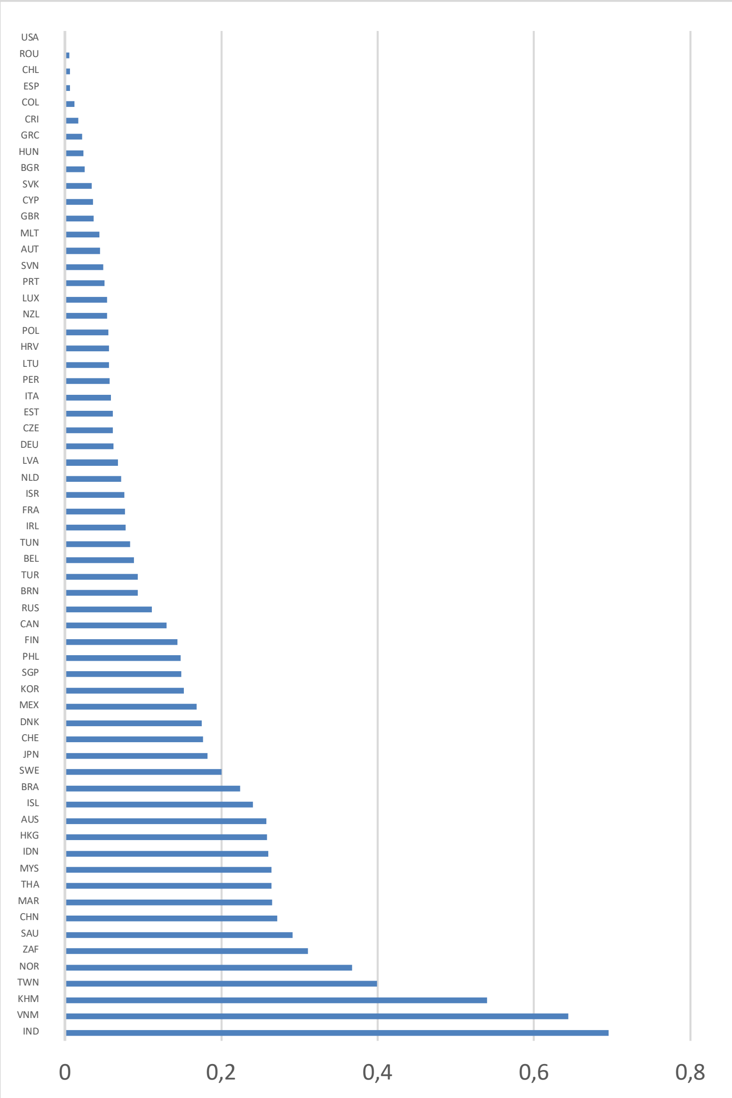
Variable	Mean (2011)	Sd (2011)	Mean (2005)	Sd (2005)
cloth_0	0.46	0.19	0.66	0.29
cloth_1	0.43	0.17	0.63	0.27
cons_0	0.42	0.28	0.67	0.51
cons_1	0.22	0.10	0.36	0.17
educ_0	0.15	0.13	0.24	0.27
educ_1	0.06	0.04	0.06	0.04
food_0	0.33	0.13	0.53	0.25
food_1	0.34	0.11	0.49	0.19
health_0	0.21	0.16	0.34	0.35
health_1	0.10	0.05	0.10	0.05
uti_0	3.43	3.03	5.54	4.86
uti_1	2.16	1.68	3.29	2.80
restau_0	0.25	0.13	0.40	0.23
restau_1	0.22	0.08	0.39	0.20
trans_0	0.42	0.17	0.62	0.30
trans_1	0.48	0.15	0.68	0.25
com_0	0.20	0.15	0.29	0.28
com_1	0.14	0.06	0.22	0.17

Notes: 0 for non-adjusted; 1 for adjusted

Utility industry is on average by far the most CO2-intensive sector, followed by transportation, clothing and food (Table 3). This finding is not surprising as producing goods like cloths and food involve material extraction and energy-intensive process. In parallel, these goods are very much traded, i.e. include emissions from transportation. On top, these goods are labour-intensive and therefore produced where labour is cheaper which is often where energy is less clean.

Note that our analysis focuses only on two years 2005 and 2011. If in these two years there were to be large construction projects in some countries, this could affect the indicator of the construction sector.

Also, strategic sectors are missing to our analysis i.e. mining, material manufacturing, machinery manufacturing. These are very energy-intensive sectors, and it would have been particularly interesting to analyse their CO_2 intensities. Unfortunately, we only have information on gross fixed capital formation of such products in IPC.



We finally would like to check whether tradable sectors of countries with high import intensities are less affected by PPP adjustment. Indeed, we would assume that the greater are countries involved in international trade, the less biased are nominal values. The intuition behind Figure 7, which displays absolute differences between adjusted and non-adjusted indicators for clothing in 2011, is that greatest differences seem to be explained by currencies under or over-valuation. For example, the Norwegian Krone is particularly known for being overvalued and the Indian Rupee undervalued. These two countries exhibit very large absolute differences (Figure 7).

Further investigation should be made to explain differences between adjusted vs. non- adjusted indicators.

Figure 7: Absolute difference between non-adjusted and adjusted intensity for clothing (2011)

6. Policy implications and fairness issues

The 1997 Kyoto Protocol, linked to the United Nations Framework Convention on Climate Change commits its Parties to achieve emission reduction objectives with stricter targets for developed countries. Differentiated responsibilities were agreed after recognition of higher historical responsibility of developed nations for global warming (Rose et al., 1998; Ringus et al., 2002). These two international agreements put particular emphasis on a *fair* burden sharing (Ringus et al., 2002). In those texts, the fairness criteria relate mainly to historical emissions, and to fossil-fuel dependency to a lesser extent. It is said that developed countries have an historical responsibility in global warming. Hence, developing countries should be allowed to pollute more / abate less so as to catch up with developed countries. However, emissions embodied in international trade can substantially affects the efficiency of the Kyoto Protocol through carbon leakage (Peters, Hertwich, 2008a).

Indeed, when looking at volumes of consumption, our results show that developed countries are still very much carbon-intensive. That means, developed countries still enjoy very high levels of consumption while reducing emissions thanks to developing economies producing energy-intensive goods for them. However, this is not a black and white situation. On the one hand, exporting goods encourages economic growth of developing countries, even sometimes lift them out of poverty. On the other hand, developed countries complain from delocalisation of labour-intensive activities, which means important job losses. In parallel, we do not question the fact that developed countries have indeed abated emissions. Consumer countries benefit from products' consumption (utility) but exporters from export revenues and job creation (Csutora and Vetone, 2014, Sato, 2014). For Csutora and Vetone (2014), beneficiary-based shared responsibility should be implemented, meaning that responsibility should be based on each one's benefits (also see Sato, 2014, p.849). GHG of products' value added should therefore be the responsibility of exporting countries while consumer countries should take responsibility for GHG associated to intermediate consumption (Csutora and Vetone, 2014).

We complement this analysis by stating that countries should pay particular attention to CO_2 intensity of consumption and have objectives of sectoral reduction. We thereby refer to the polluter-pays principle, where the polluter is the *consumer*. The polluter-pays principle is a fairness principle very much invoked in international climate negotiations (Ringus et al., 2002). Decreasing CO_2 intensity of the final demand implies either abating CO_2 emissions for a same level of consumption or increasing consumption for a same level of emissions i.e. encourages low-carbon consumption. This said, it implies that countries should target direct and indirect emissions alike, i.e. emissions generated abroad for national consumption. It is however not clear if countries should be fully or partially responsible (e.g. as in Csutora and Vetone, 2014). For Peters and Hertwich (2008a) one way of dealing with emissions embedded in trade would be to assign abatement objectives to a group of countries, preferably having similar environmental objectives and important trade intensity within the region.

However, defining an equity criterion is not enough. There should also exist a feasible and *fair implementation* of this criteria and a way to meet these *equitable* responsibilities. Fairness is indeed a key issue in global climate change negotiations (Rose et al., 1998; Ringus et al., 2002) and should be at all levels. As such international agreements rely on voluntary compliance, a fair burden-sharing is considered a pre-requisite in order that countries agree to abate emissions.

While it is possible to control national emissions, it becomes more difficult to target indirect emissions. Also, developed countries have argued that indirect emissions have partly increased as a result of national environmental policies, through carbon leakage. But deindustrialisation of developed countries due to low labour costs seeking in developing countries is likely to explain most of the leakage[6] (Weber, Peters, 2009). Especially, a large share of imported goods are labour-intensive goods, i.e. activities involving easier delocalisation to developing countries than capital-intensive industries (Cole, Elliott, 2003, Cole, Elliott, 2005). We face several challenges in the implementation of our equity criterion: developed countries should emit less as regards to their volume of consumption. They have two choices doing so: further implementing territory-based abatement policies with the risk of increasing carbon leakage and in turn increase their CO_2 intensity; or implementing environmental policies targeting indirect emissions (e.g. border adjustment) which would negatively impact the economies of developing countries through reduced exports (e.g. see Peters and Hertwich, 2008a). For Weber and Peters (2009) coercive policies such as carbon tariffs are dangerous as it could bring anger from developing countries and unwillingness to cooperate, at a time where cooperation is much needed.

[6] We use the broadest definition of leakage ('weak carbon leakage', see Weber and Peters, 2009), i.e. all emissions shifted from a country to another, be it for escaping environmental regulations or seeking more attractive economic conditions.

Alternatively, developed nations could invest in abatement activities of Southern countries from which they virtually import emissions (Peters, Hertwich, 2008b). Investments could be proportional to the share of the CO_2 intensity stemming from the trading partner (e.g. see the Clean Development Mechanism – CDM - as part of the Kyoto Protocol and the European Trading Emissions Scheme). Weber and Peters (2009) suggest expending the CDM into sectoral approaches, which could match with our approach. Finally, Peters and Hertwich (2008b) point to standards requiring products to meet criteria of energy efficiency. However, this would also negatively impact exports in developing countries. Other instruments could be used e.g. permits applicable to total emissions of a product (brand-specific). At the individual product-level, this requires life cycle analyses (LCA). LCA consists in a very costly method and considered to as not-reliable by some economists. But it seems the most suited and would help raising awareness among manufacturers about their own products' carbon footprint. Our estimations could serve instead as setting abatement targets at the industry-level.

The *compensation principle* (Rose et al., 1998) may be invoked, if developed countries implement policies that penalise exports of developing countries. Financial compensation may be granted to offset these extra costs. In practice, the form of this compensation seems more complicated. Compensating countries over decades to an estimated baseline scenario of what countries would have traded is extremely hazardous while granting constant compensation relative to only past trade volumes is unfair. A potentially fair allocation method would be to allocate pollution permits to developing countries (in the framework of border-adjusted carbon market), e.g. according to current levels of development. This would however not be interpreted as compensation but rather as development aid. The allocation method is therefore debatable. The *compensation principle* could instead be invoked to compensate environmental damages i.e. all countries that import emissions should offset them partly. This goes back to CDM-like approaches.

Finally, Sato (2014) argues that CBA of carbon dioxide emissions has too many serious flaws (in its methodology and data quality) to be directly applicable to climate policy. So far, it should just be used as shadow indicator for countries willing to improve their carbon mitigation strategy (Sato, 2014). Indeed, other limitations than the use of MER exist, such as the decision on the degree of sectoral aggregation and the treatment of the rest of the world as region (Wiedmann, 2009). Data and methodological issues could provoke political impasses and possible abuses (Weber, Peters, 2009).

7. Scope for future research

In a future research, sector-specific PPP convertors could be used in the CO_2 multipliers to enhance estimations of CO_2 emissions embodied in trade. This requires data on price levels for more sectors. Furthermore, more investigations are needed regarding feasible and fair mechanisms of taking emissions embodied in trade into account. Sharing-burden principles have already been much discussed while little is done on how to concretely implement these principles. A "no harm" principle could be at the centre of this mechanism where countries should find ways of offsetting their imports of emissions.

Finally, detailed and reliable data needs to be provided on purchasing price levels in a very broad range of countries such as the ICP program. We would plead for annualization and deepening of this program that would help users of input-output models. In turn, it would allow statisticians from ICP to only have minor revisions each year.

REFERENCES

Ahmad, N. and A. Wyckoff (2003). Carbon Dioxide Emissions Embodied in International Trade of Goods. OECD Science, Technology and Industry Working Papers, 2003/15, OECD Publishing, Paris. http://dx.doi.org/10.1787/421482436815

Balassa, B. (1964). *The Purchasing-Power Parity Doctrine: A Reappraisal*. Journal of Political Economy 72, 584–96.

Cole, M.A. and Elliott, R.J.R. (2003). *Determining the trade–environment composition effect: the role of capital, labor and environmental regulations*. Journal of Environmental Economics and Management, Volume 46, Issue 3, Pages 363-383, ISSN 0095-0696

Cole, M.A. and Elliott, R.J.R. (2005). *FDI and the Capital Intensity of 'Dirty' Sectors: A Missing Piece of the Pollution Haven Puzzle.* Review of Development Economics, Vol. 9, No. 4, pp. 530-548.

Csutora, M. and Mózner, Z. (2014). *Proposing a beneficiary-based shared responsibility approach for calculating national carbon accounts during the post-Kyoto era*. Climate Policy. 14. 10.1080/14693062.2014.905442.

Deaton, A. and Aten, B. (2017). *Trying to Understand the PPPs in ICP 2011: Why Are the Results So Different?* American Economic Journal: Macroeconomics, American Economic Association, vol. 9(1), pages 243-264, January.

Kanemoto, K. and Tonooka, Y. (2009). Embodied CO2 emissions in Japan's international trade. Journal of Japan Society of Energy and Resources. 30. 15-23.

Nakano, S., Okamura, A., Sakurai, N., Suzuki, M., Tojo, Y., and Yamano, N. (2009). The Measurement of CO2 Embodiments in International Trade: Evidence from the Harmonised Input-Output and Bilateral Trade Database. OECD Science, Technology and Industry Working Papers 2009/3, OECD Publishing.

OECD (2014), Green Growth Indicators 2014, OECD Green Growth Studies, Éditions OCDE, Paris, http://dx.doi.org/10.1787/9789264202030-en.

Pancaro, C. (2011). The Balassa-Samuelson and the Penn Effect: Are They Really the Same? Working Paper N°700, National Centre of Competence in Research Financial Valuation and Risk Management ; Available at SSRN: https://ssrn.com/abstract=2275917 or http://dx.doi.org/10.2139/ssrn.2275917

Peters, G. P. and Hertwich, E. G. (2008a). *CO2 Embodied in International Trade with Implications for Global Climate Policy*. Environmental Science & Technology 42 (5), 1401-1407. DOI: 10.1021/es072023k

Peters, G. P. and Hertwich, E. G. (2008b). Trading Kyoto. Nature Reports Climate Change, volume 2.

Ringius, L., Torvanger, A., and Underdal, A. (2002). *Burden Sharing and Fairness Principles in International Climate Policy.* International Environmental Agreements: Politics, Law and Economics, 2: 1. https://doi.org/10.1023/A:1015041613785

Rose, A., Stevens, B., Edmonds, J., and Wise, M. (1998). *International Equity and Differentiation in Global Warming Policy*. Environmental and Resource Economics, 12: 25. https://doi.org/10.1023/A:1008262407777

Samuelson, P. A. (1964). *Theoretical Notes on Trade Problems*. Review of Economics and Statistics 46(1), 145–54.

Sato, M. (2014). *Embodied Carbon in Trade: A Survey of the Empirical Literature*. Journal of Economic Surveys, 28: 831-861. doi:10.1111/joes.12027

Weber, C.L. (2008) Uncertainties in constructing environmental multiregional input-output models. International Input-Output Meeting on Managing the Environment, 9-11 July 2008, Seville, Spain.

Weber, C. L., and Matthews, H. S. (2007) *Embodied Environmental Emissions in U.S. International Trade, 1997−2004.* Environmental Science & Technology 41 (14), 4875-4881. DOI: 10.1021/es0629110

Weber, C.L., and Peters, G. P. (2009) *Climate change policy and international trade: Policy considerations in the US*. Energy Policy, Volume 37, Issue 2, Pages 432-440, ISSN 0301-4215

Wiebe, K. and N. Yamano (2016). Estimating CO2 Emissions Embodied in Final Demand and Trade Using the OECD ICIO 2015: Methodology and Results. OECD Science, Technology and Industry Working Papers, 2016/05, OECD Publishing, Paris, http://dx.doi.org/10.1787/5jlrcm216xkl-en

Wiedmann, T. (2009). *A review of recent multi-region input–output models used for consumption-based emission and resource accounting*. Ecological Economics, Volume 69, Issue 2, Pages 211-222, ISSN 0921-8009.

SUPPLEMENTARY APPENDIX

Supplementary Appendix I: Graphical analyses of 2011 - CO_2 intensities: adjusted versus non-adjusted.

<u>Figure 1:</u> CO2 intensity of final demand for utilities, no adjustment

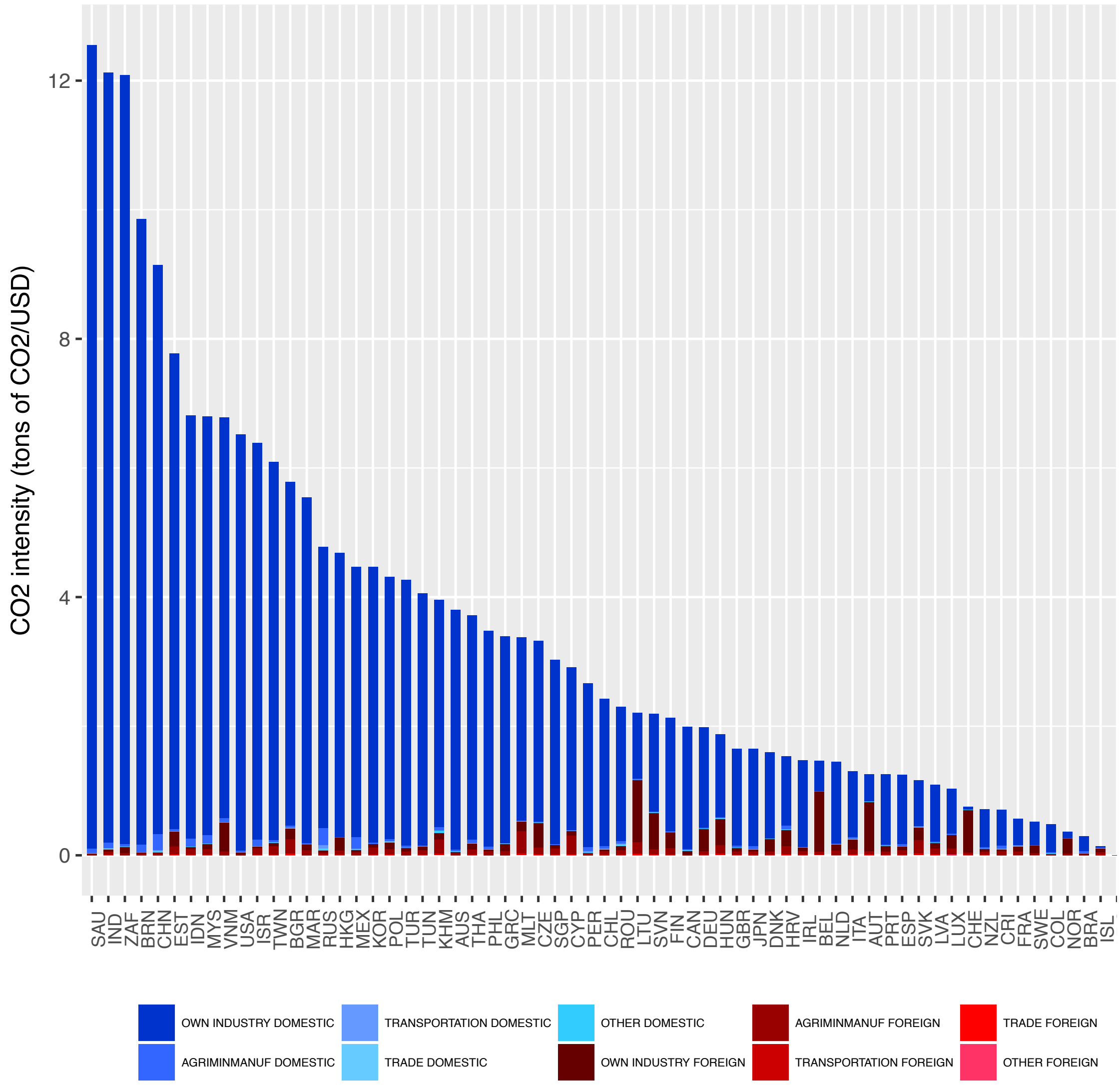


Figure 2: CO2 intensity of final demand for utilities, adjusted by overall PPP

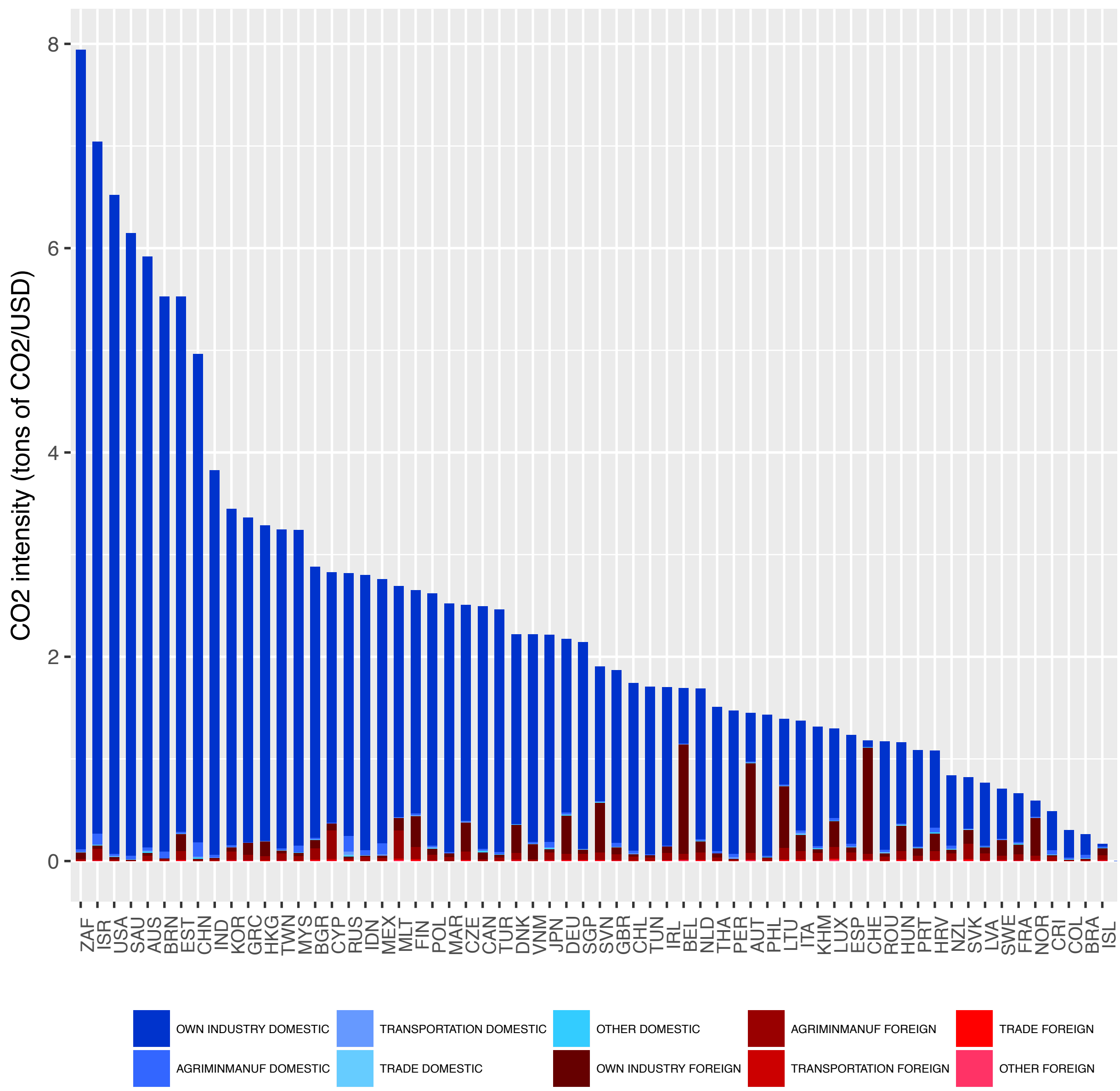


Figure 3: CO2 intensity of final demand for utilities, adjusted by sectoral PPP

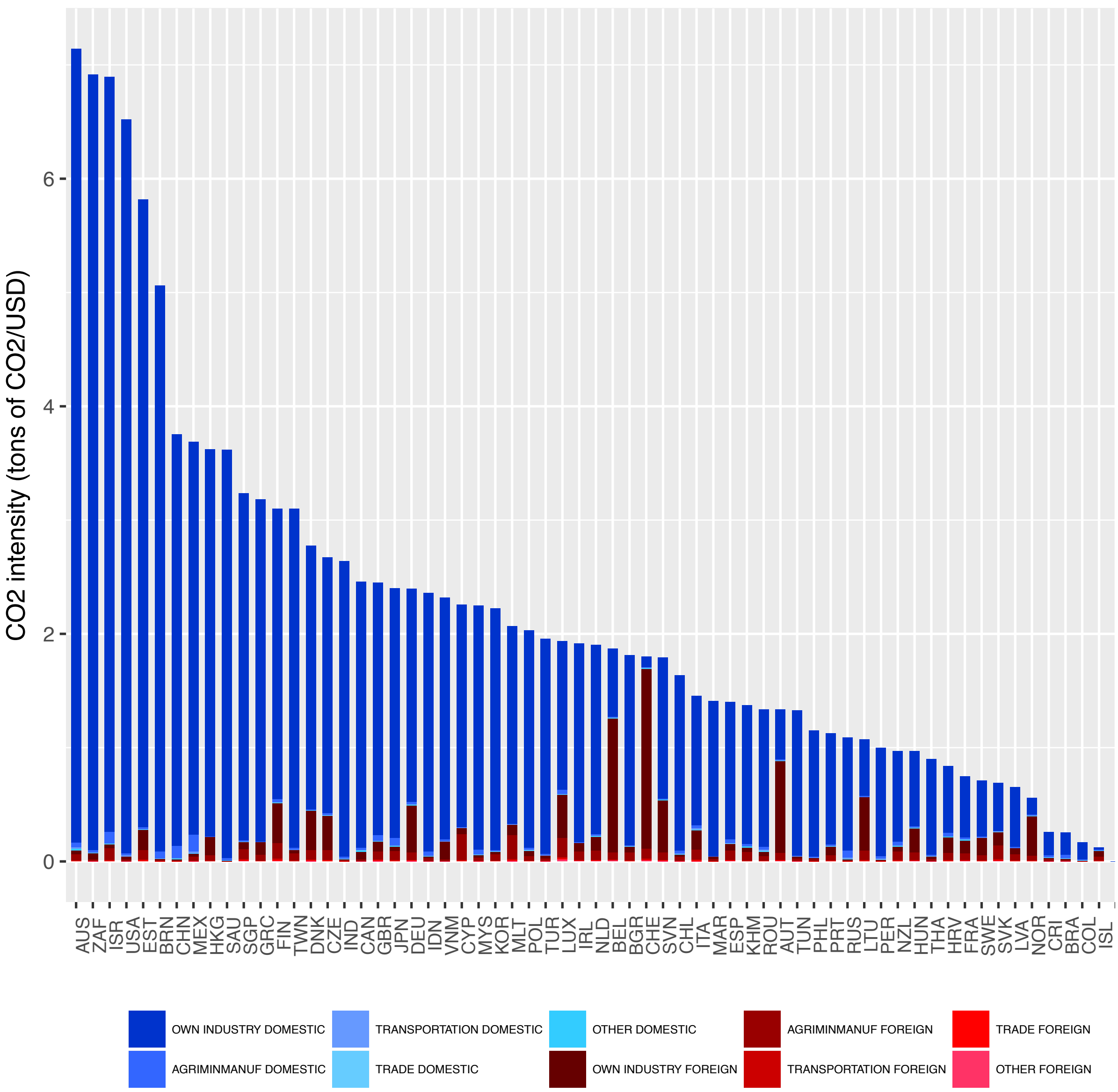


Figure 4: CO2 intensity of final demand for construction, no adjustment

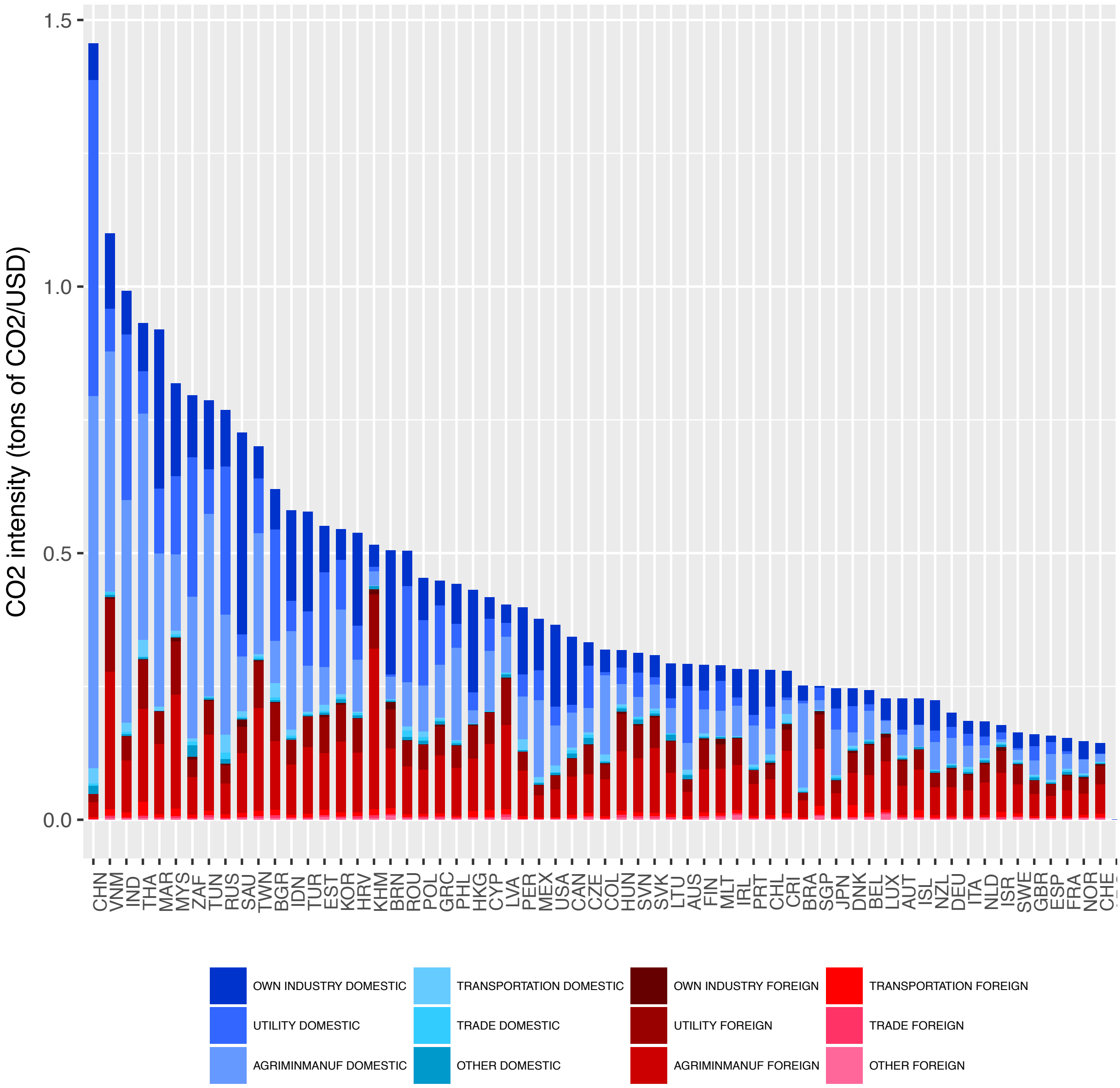


Figure 5: CO2 intensity of final demand for construction, adjusted by overall PPP

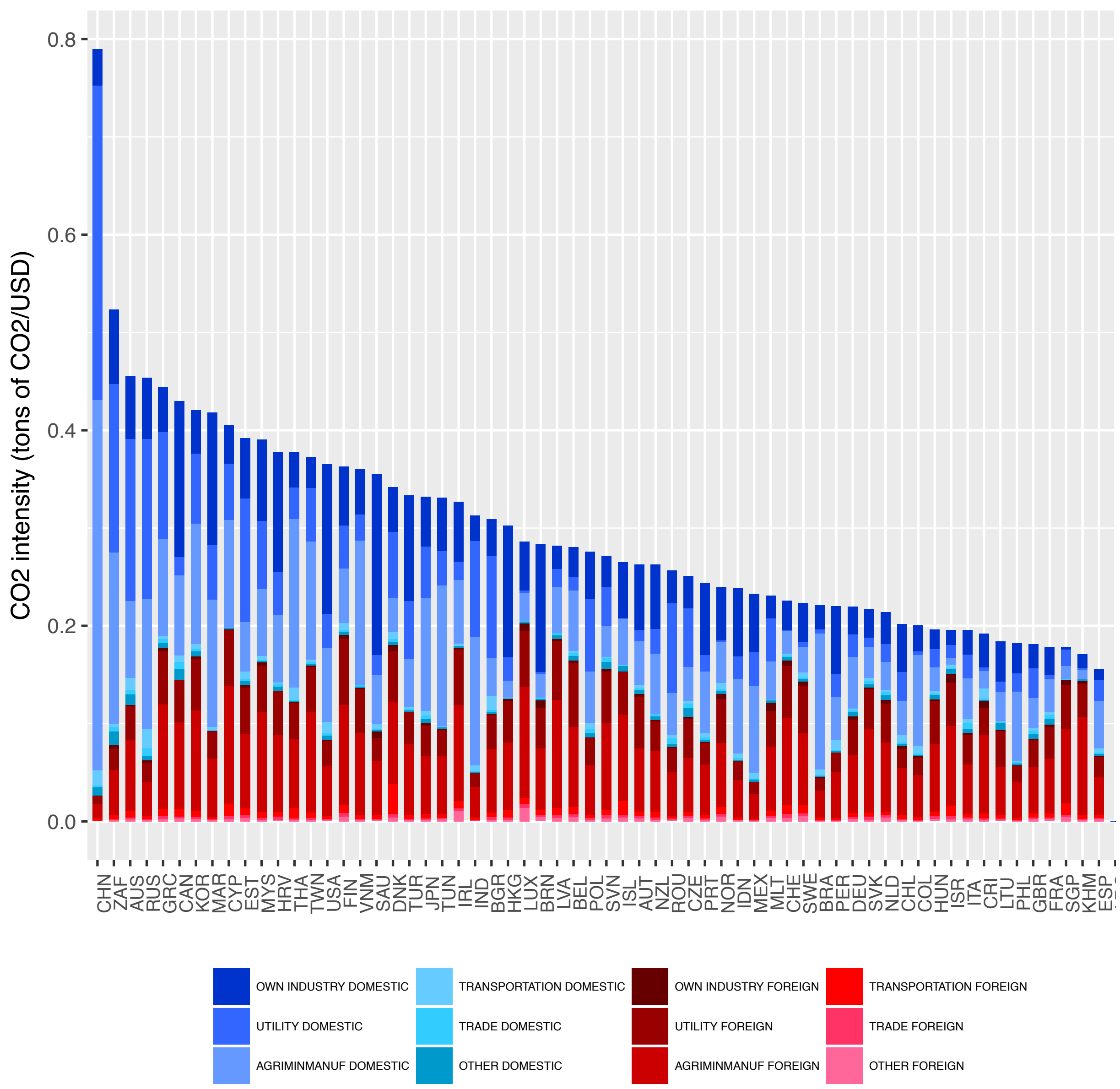


Figure 6: CO2 intensity of final demand for construction, adjusted by sectoral PPP

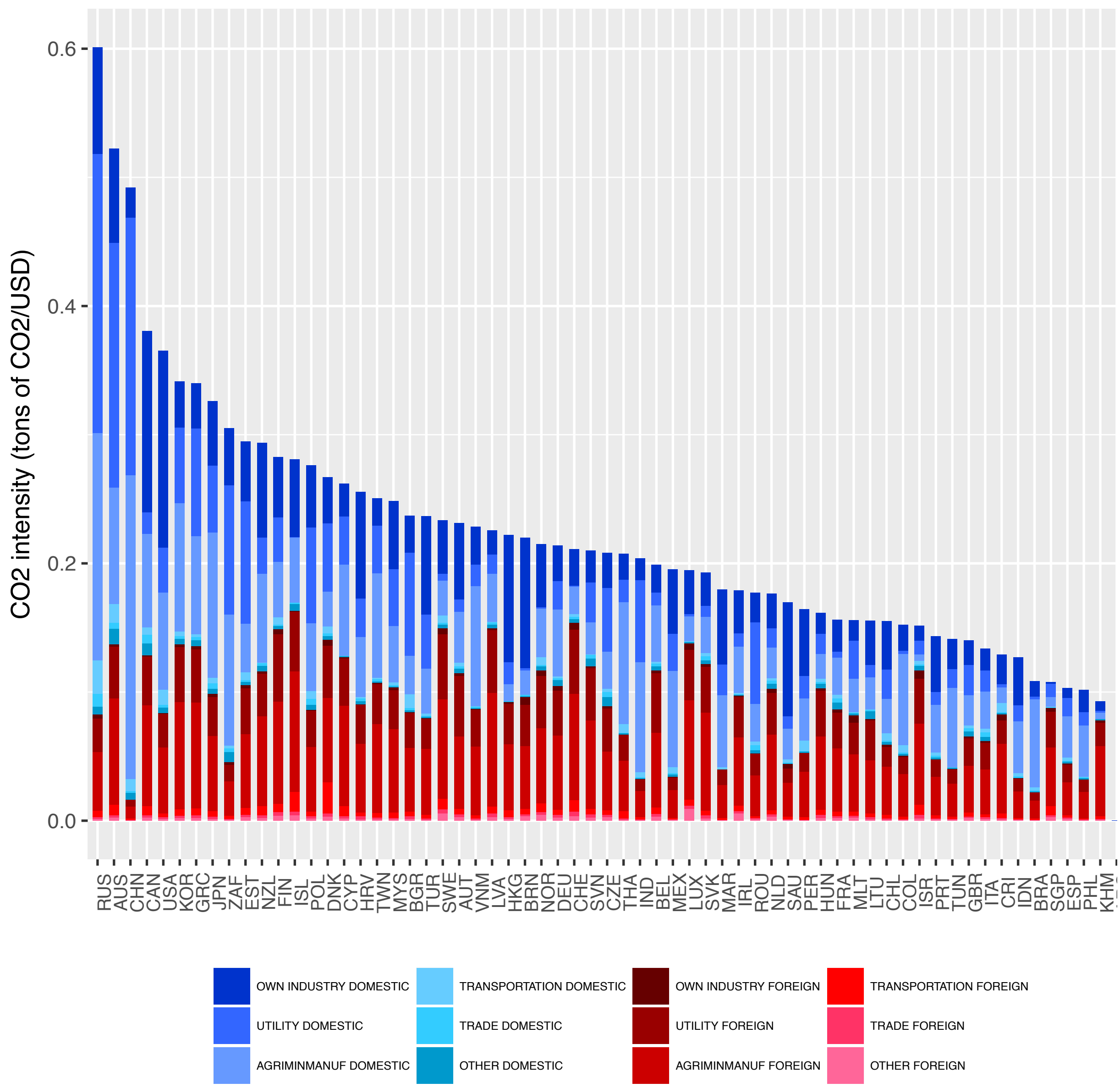


Figure 7: CO2 intensity of final demand for health, no adjustment

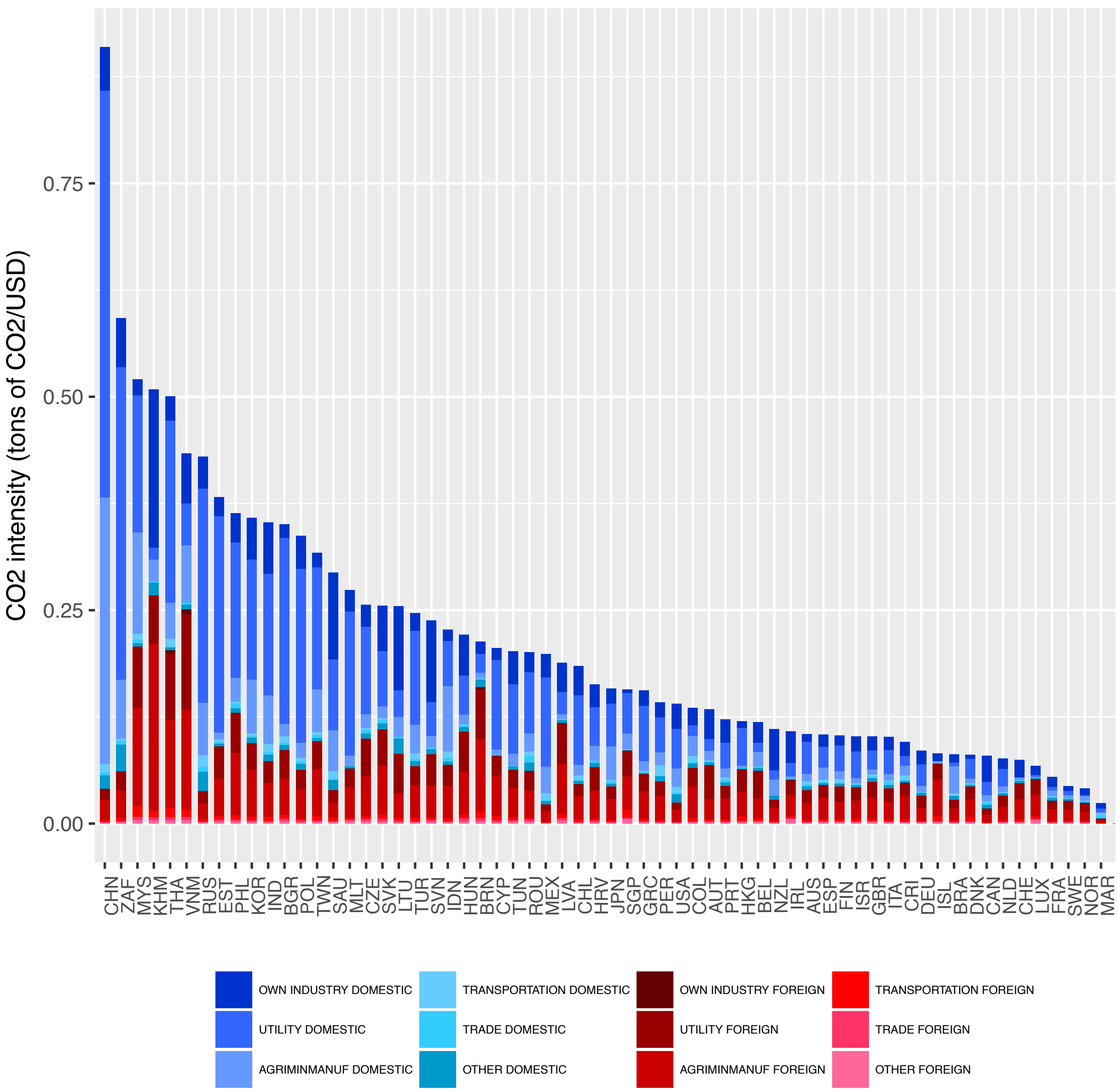


Figure 8: CO2 intensity of final demand for health, adjusted by overall PPP

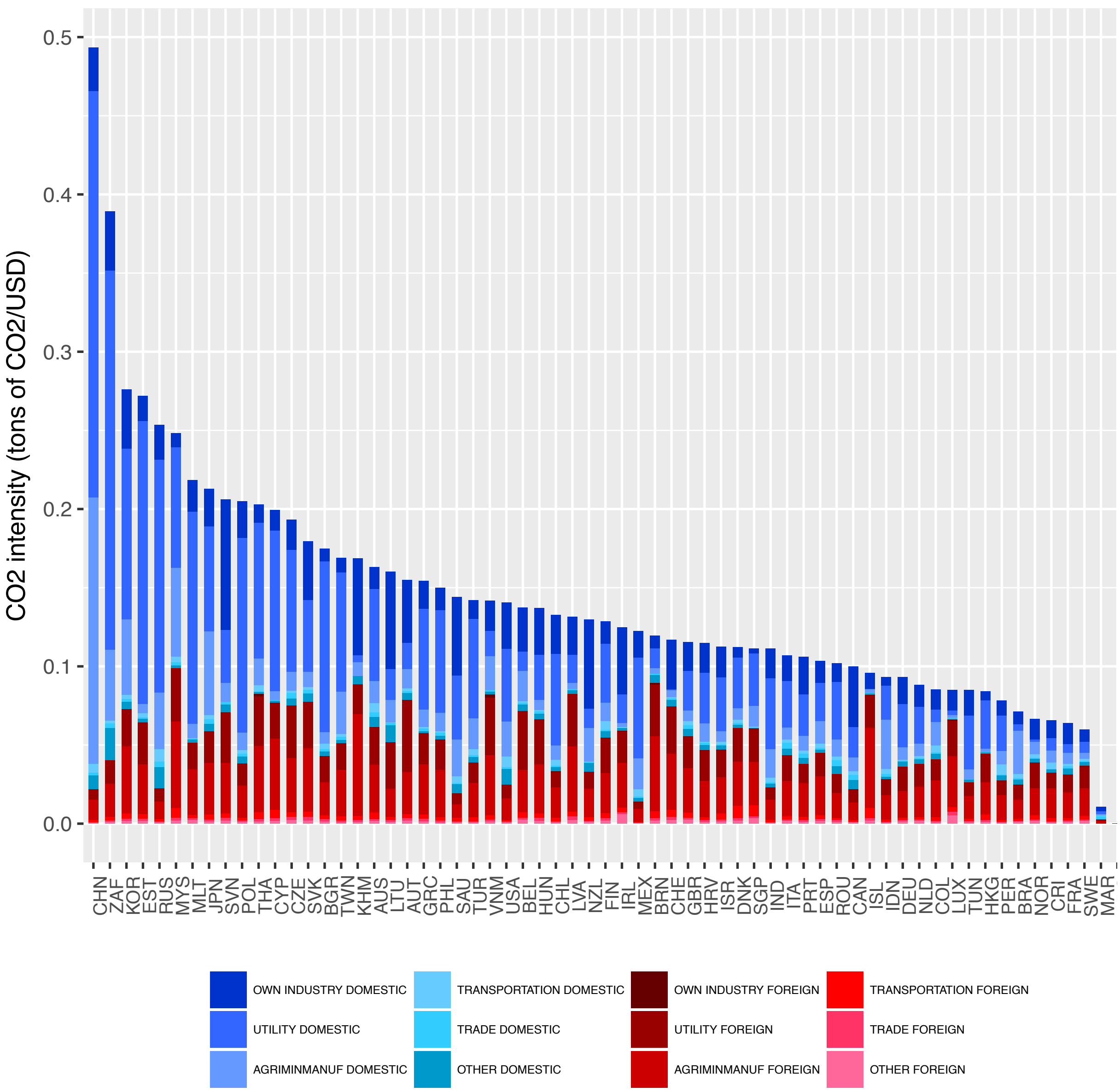


Figure 9: CO2 intensity of final demand for health, adjusted by sectoral PPP

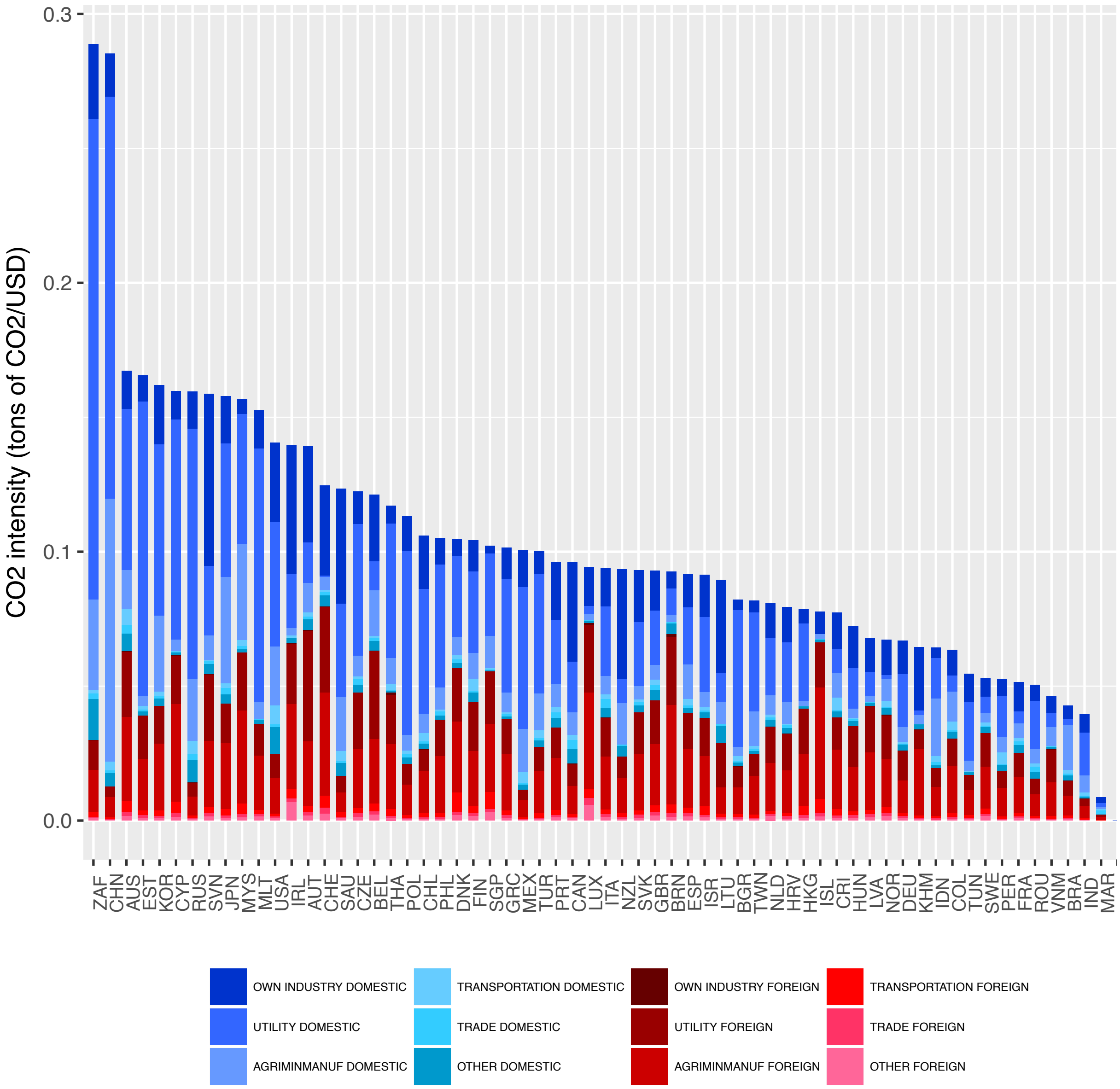


Figure 10: CO2 intensity of final demand for communication, no adjustment

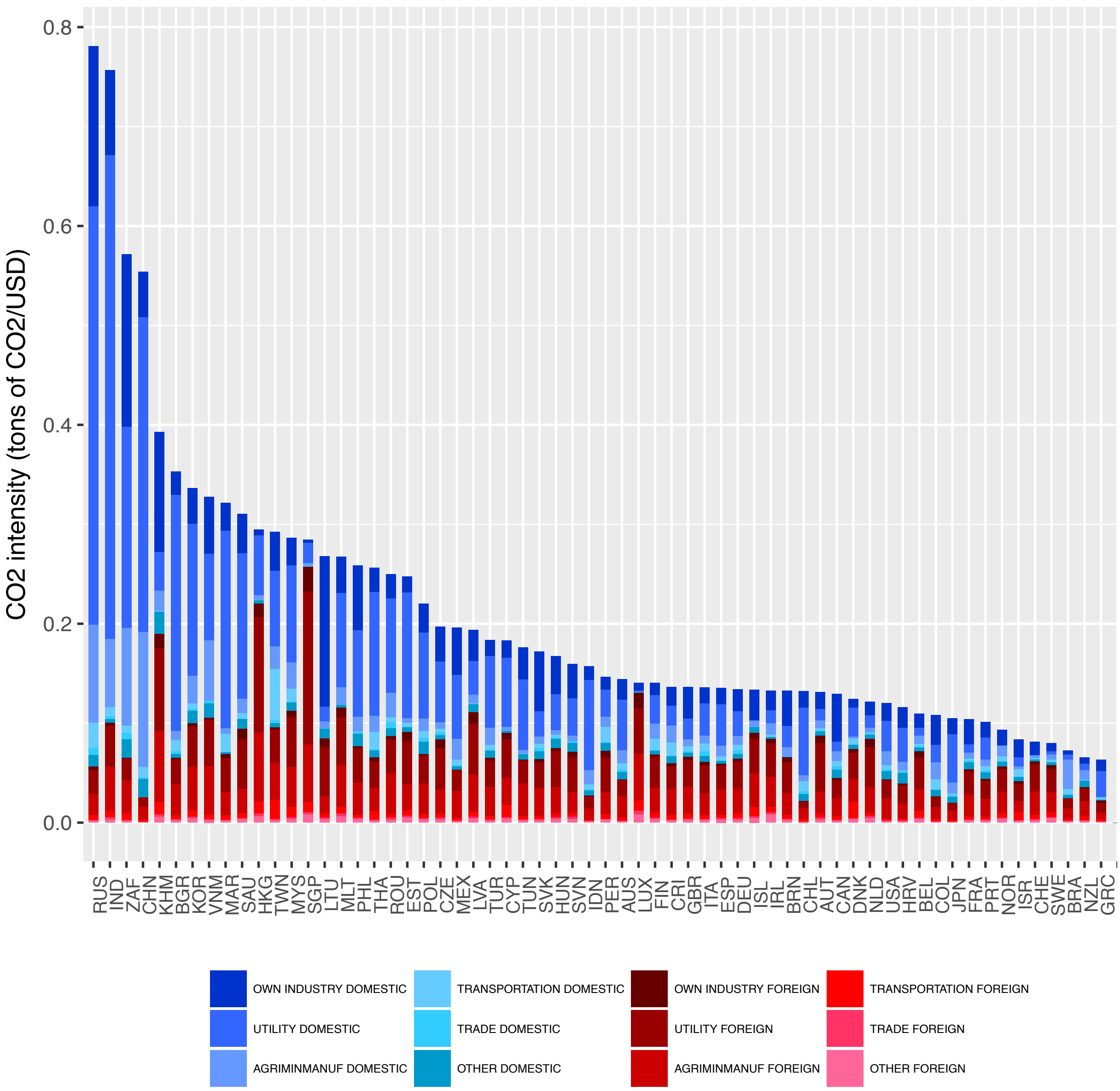
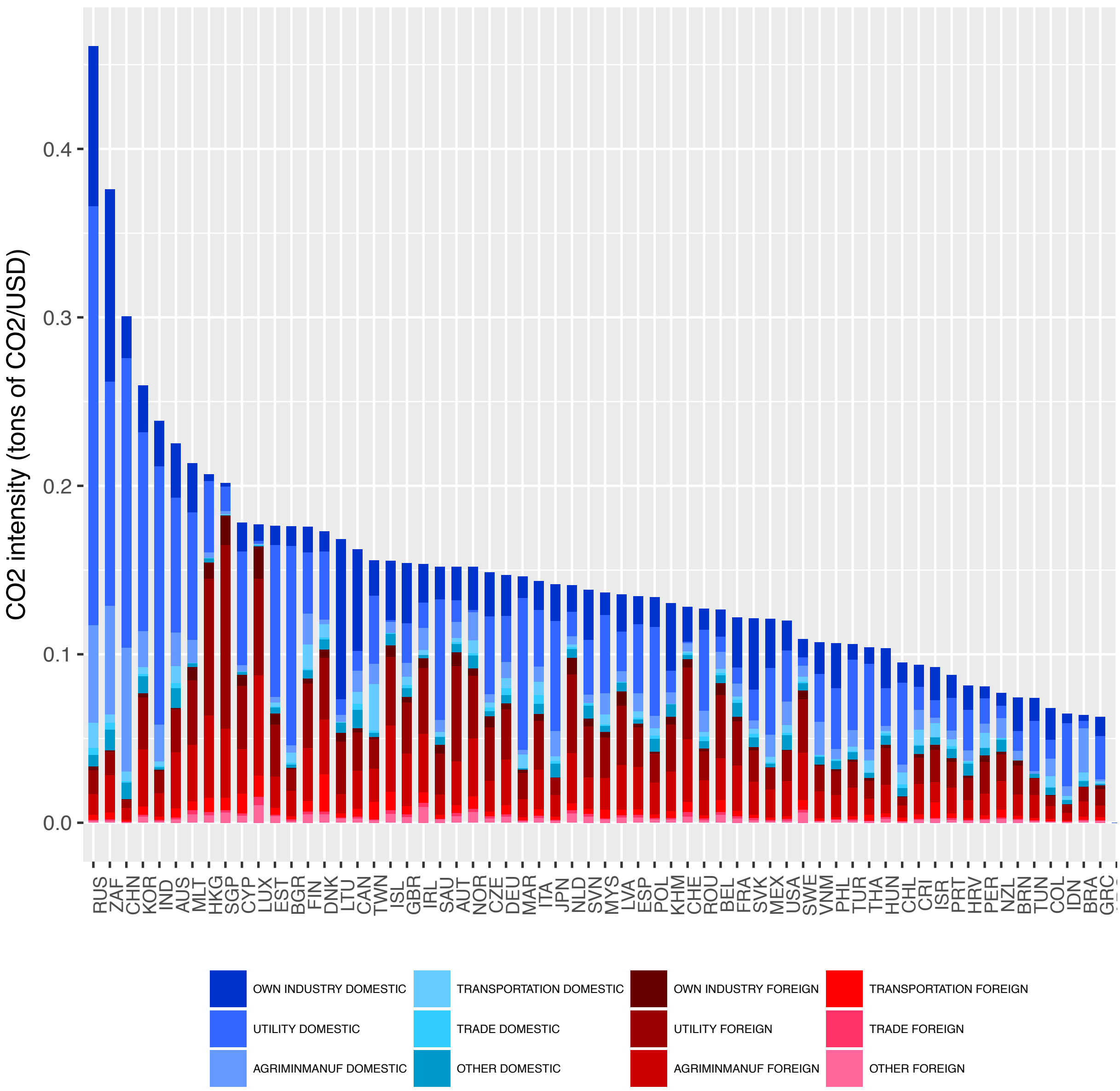
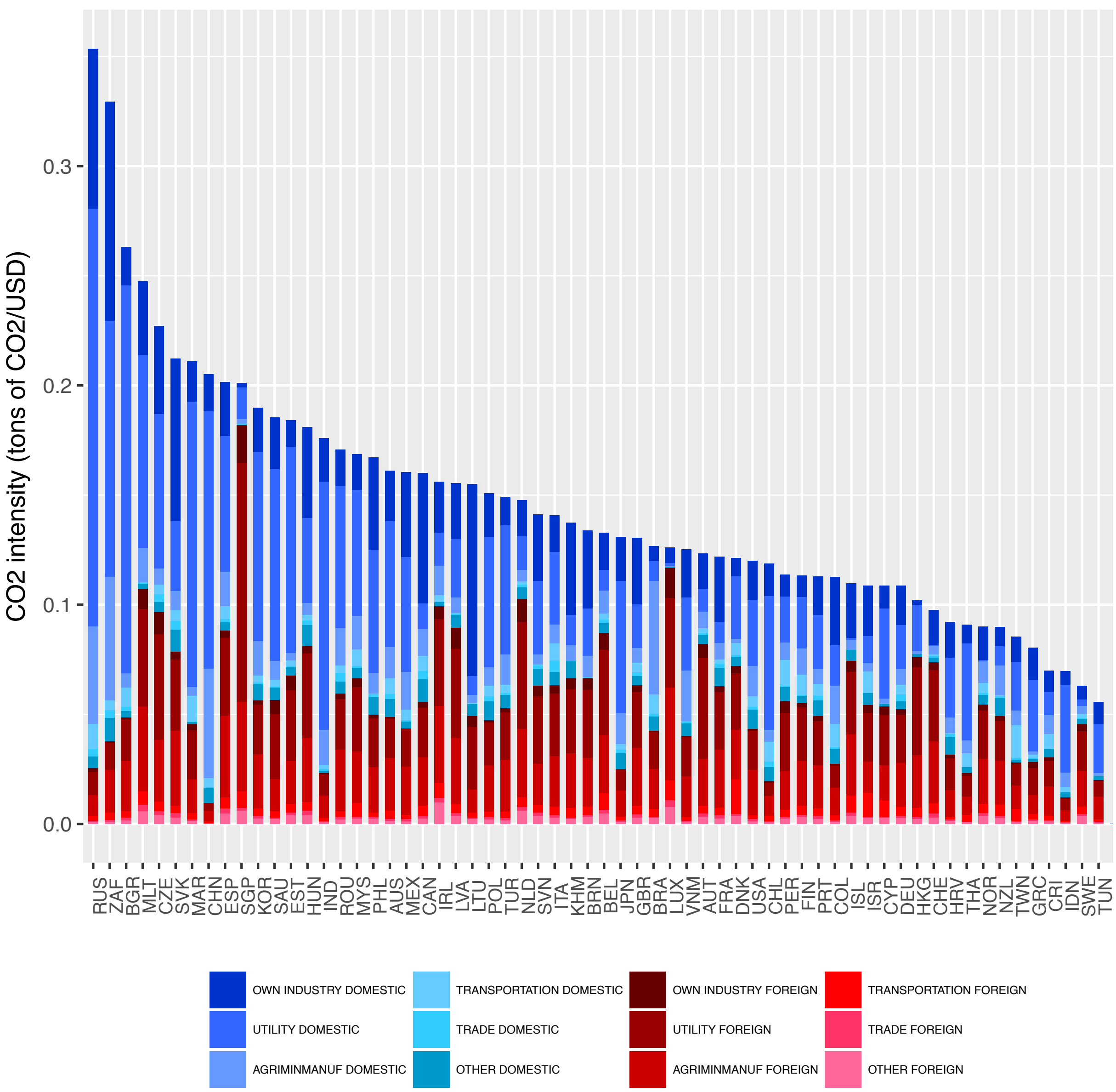


Figure 11: CO2 intensity of final demand for communication, adjusted by overall PPP



<u>Figure 12:</u> CO2 intensity of final demand for communication, adjusted by sectoral PPP



<u>Figure 13:</u> CO2 intensity of final demand for food manufacturing, no adjustment

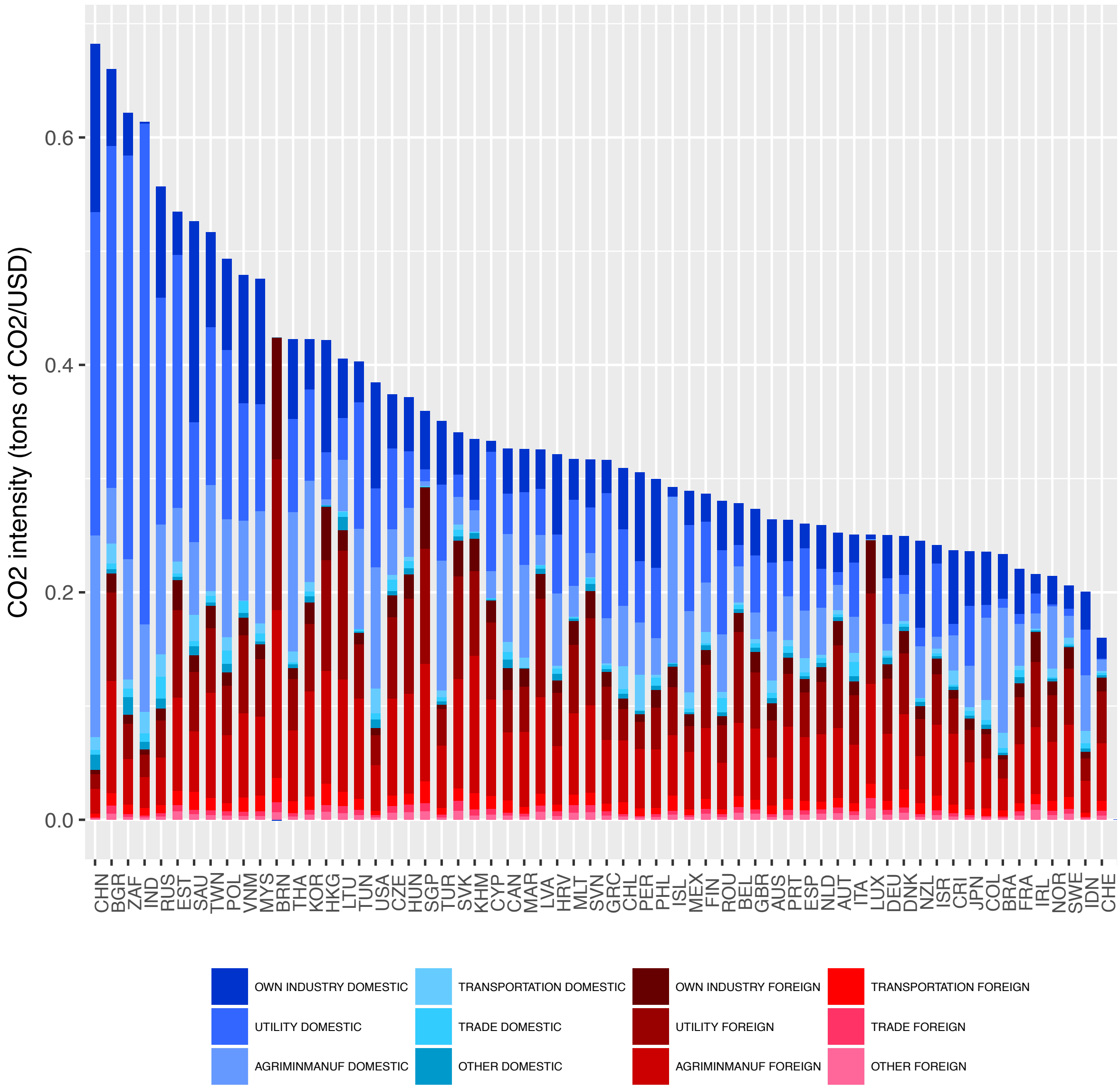


Figure 14: CO2 intensity of final demand for food manufacturing, adjusted by overall PPP

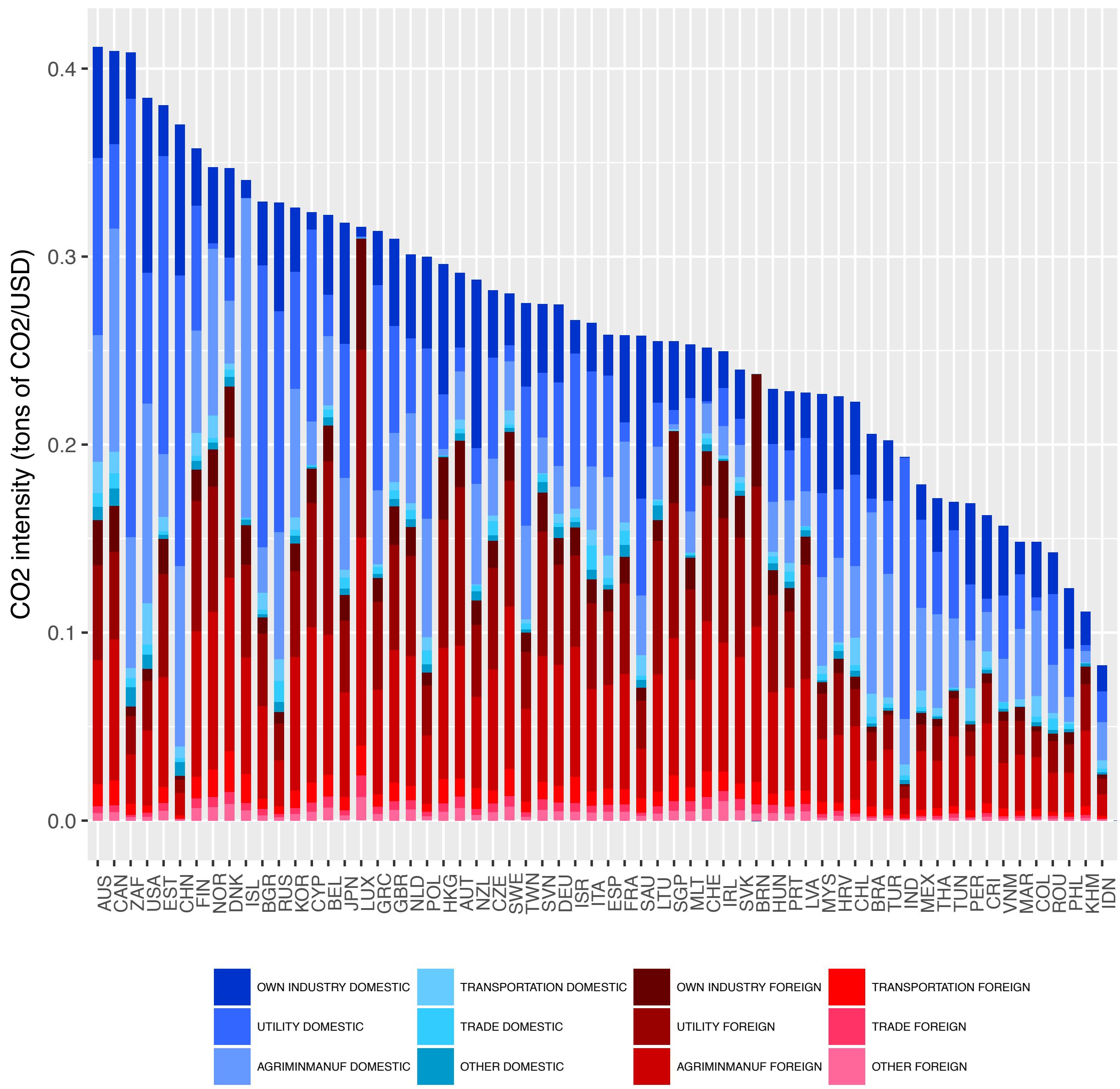


Figure 15: CO2 intensity of final demand for food manufacturing, adjusted by sectoral PPP

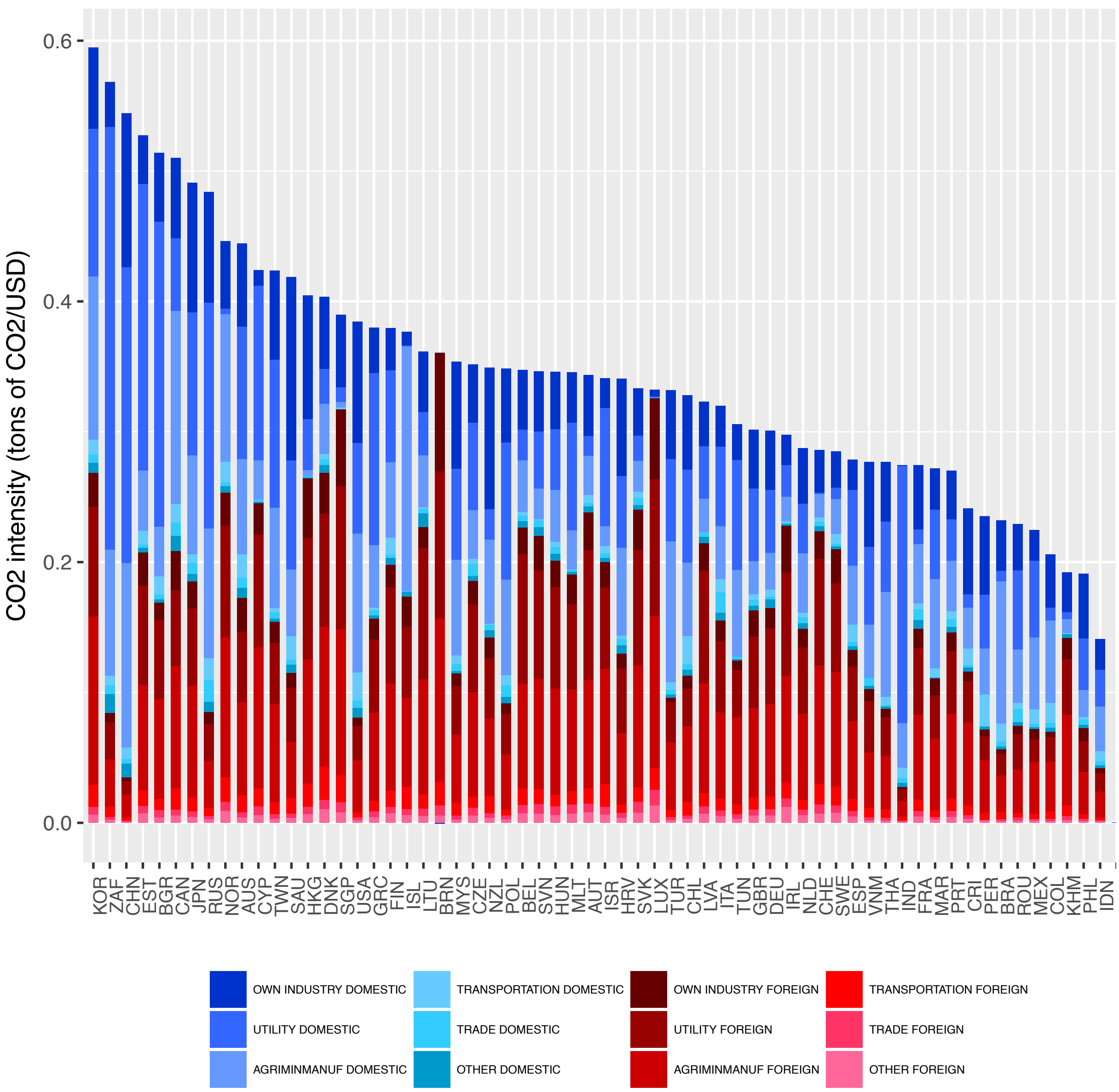


Figure 16: CO2 intensity of final demand for transportation and storage, no adjustment

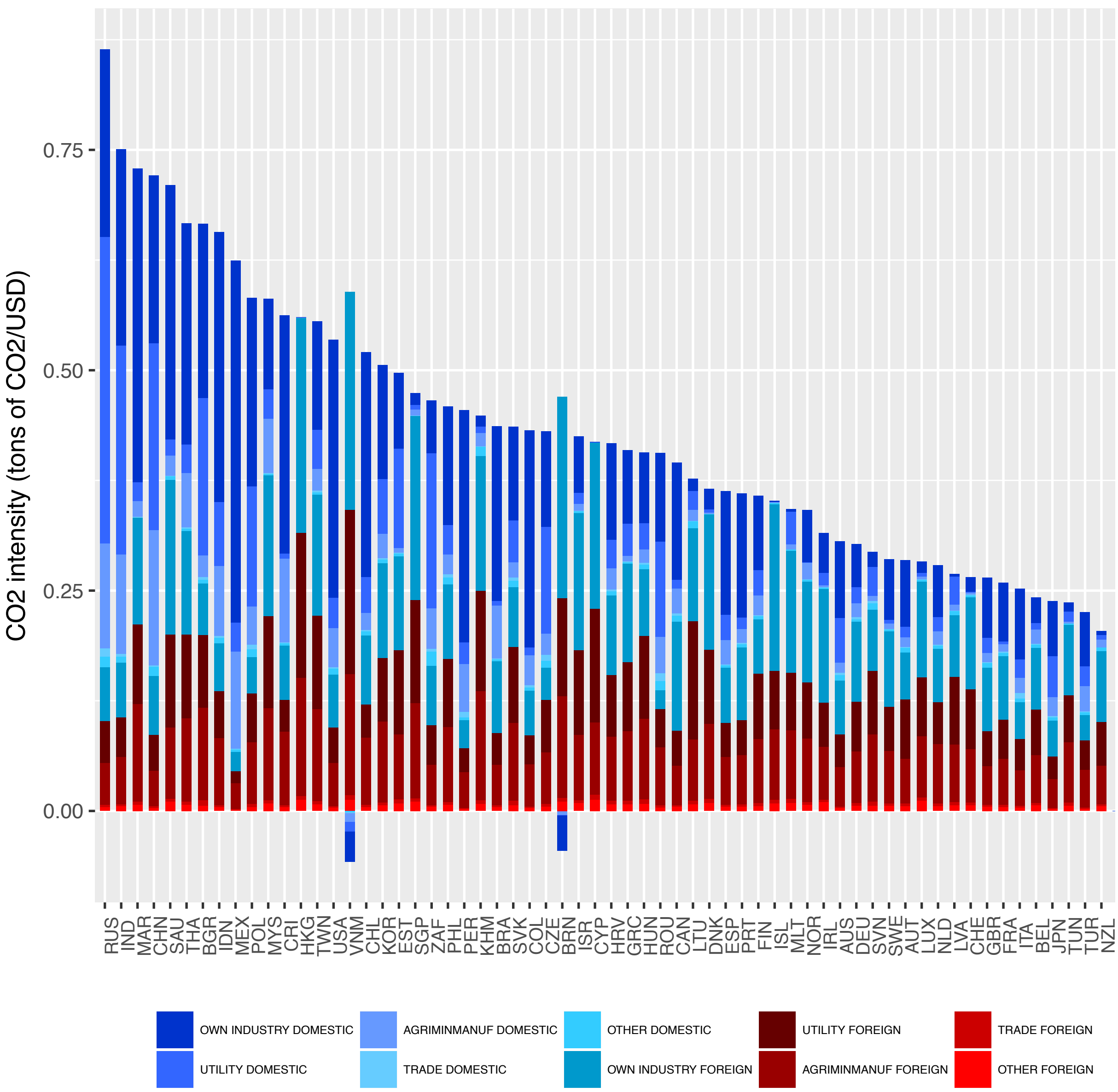


Figure 17: CO2 intensity of final demand for transportation and storage, adjusted by overall PPP

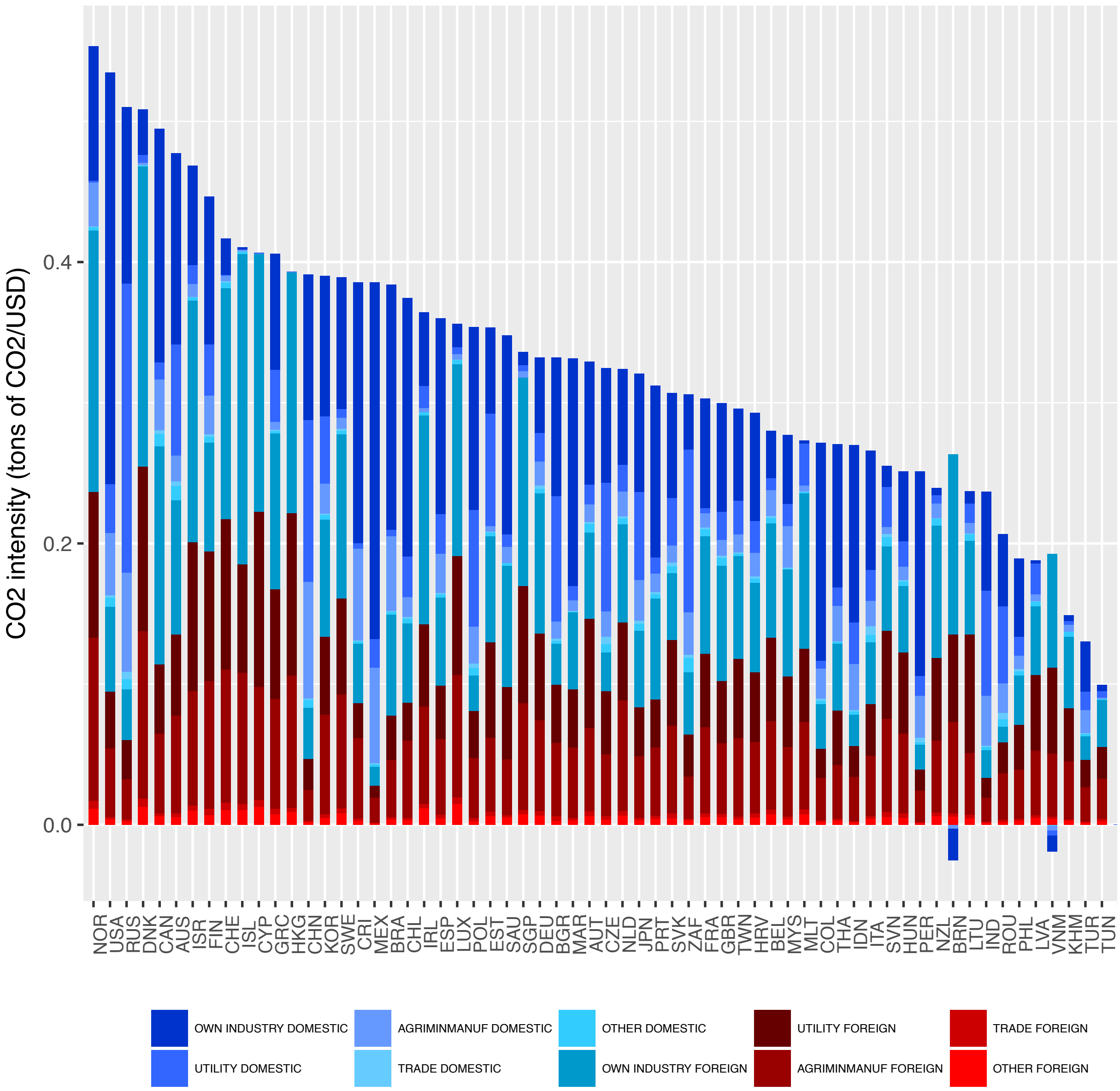


Figure 18: CO2 intensity of final demand for transportation and storage, adjusted by sectoral PPP

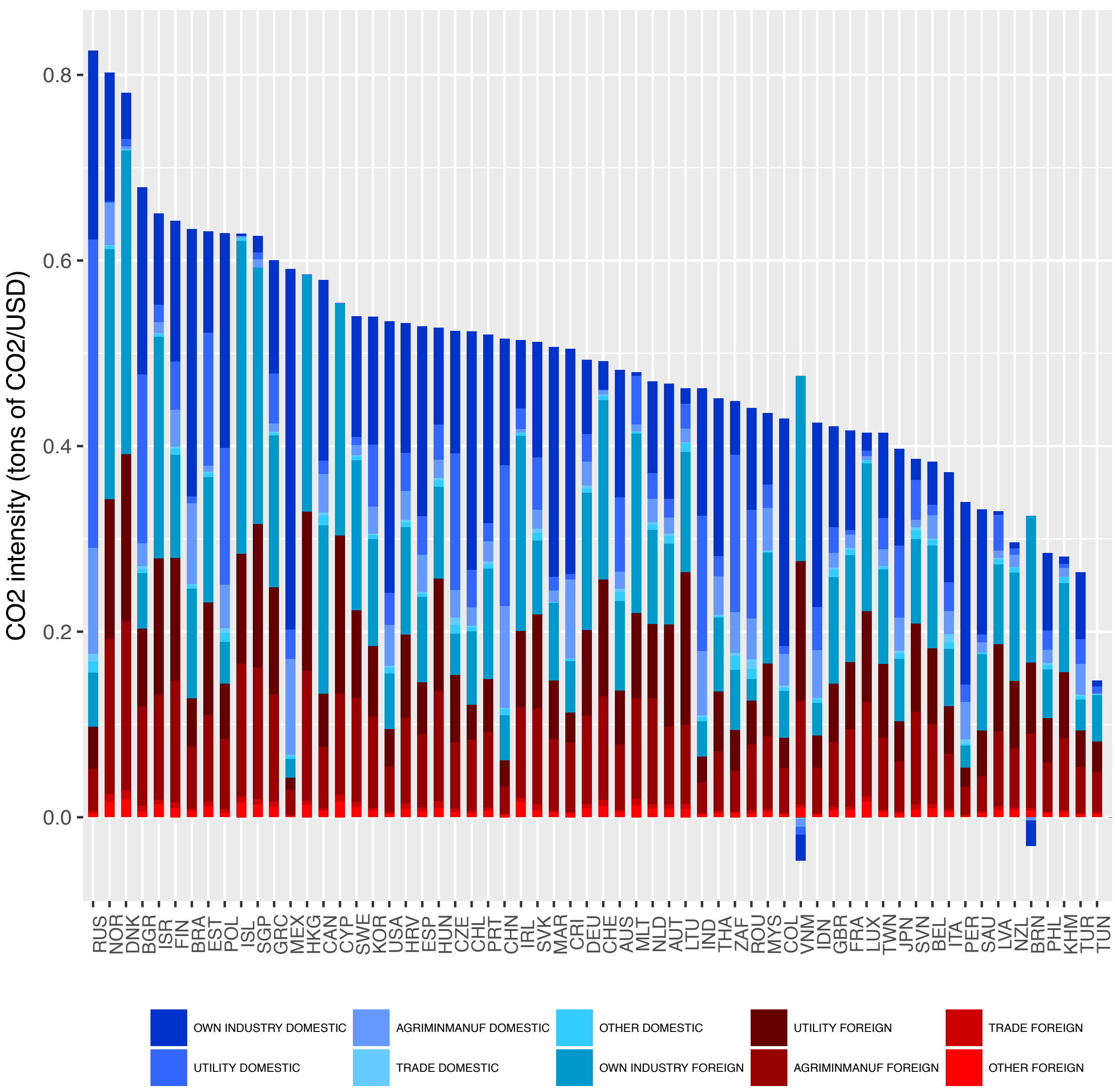


Figure 19: CO2 intensity of final demand for restaurants and hotels, no adjustment

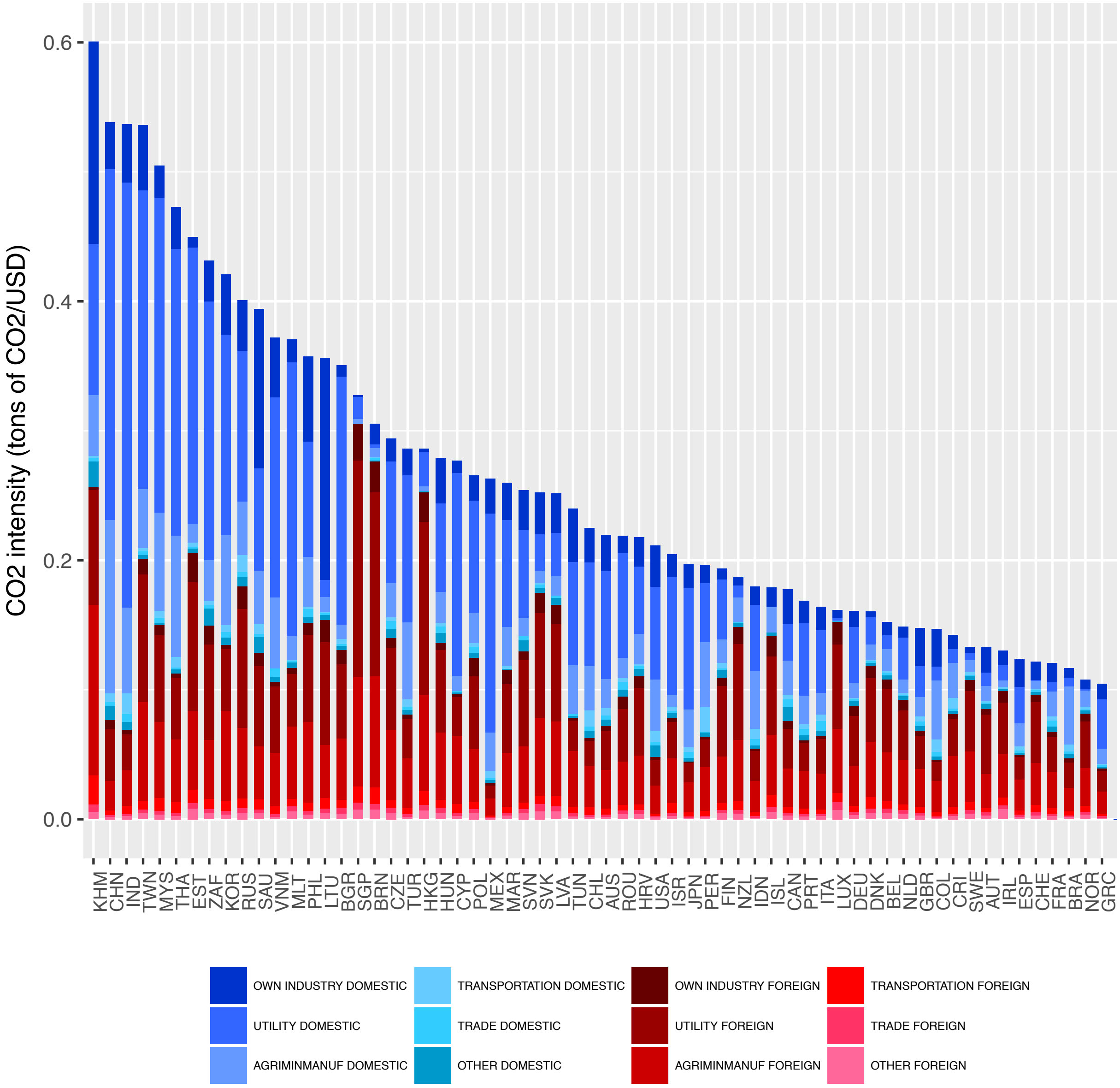


Figure 20: CO2 intensity of final demand for restaurants and hotels, adjusted by overall PPP

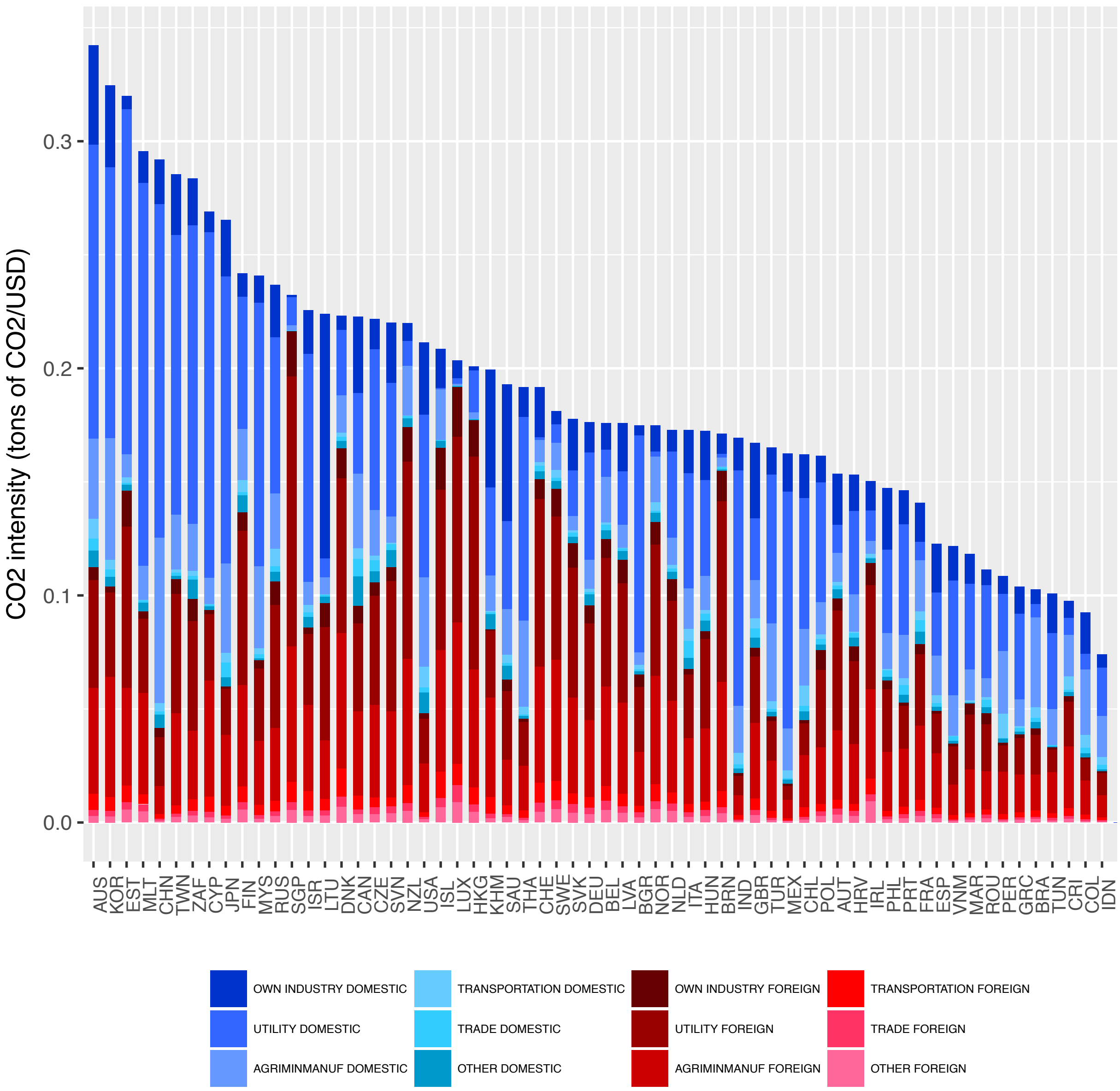


Figure 21: CO2 intensity of final demand for restaurants and hotels, adjusted by sectoral PPP

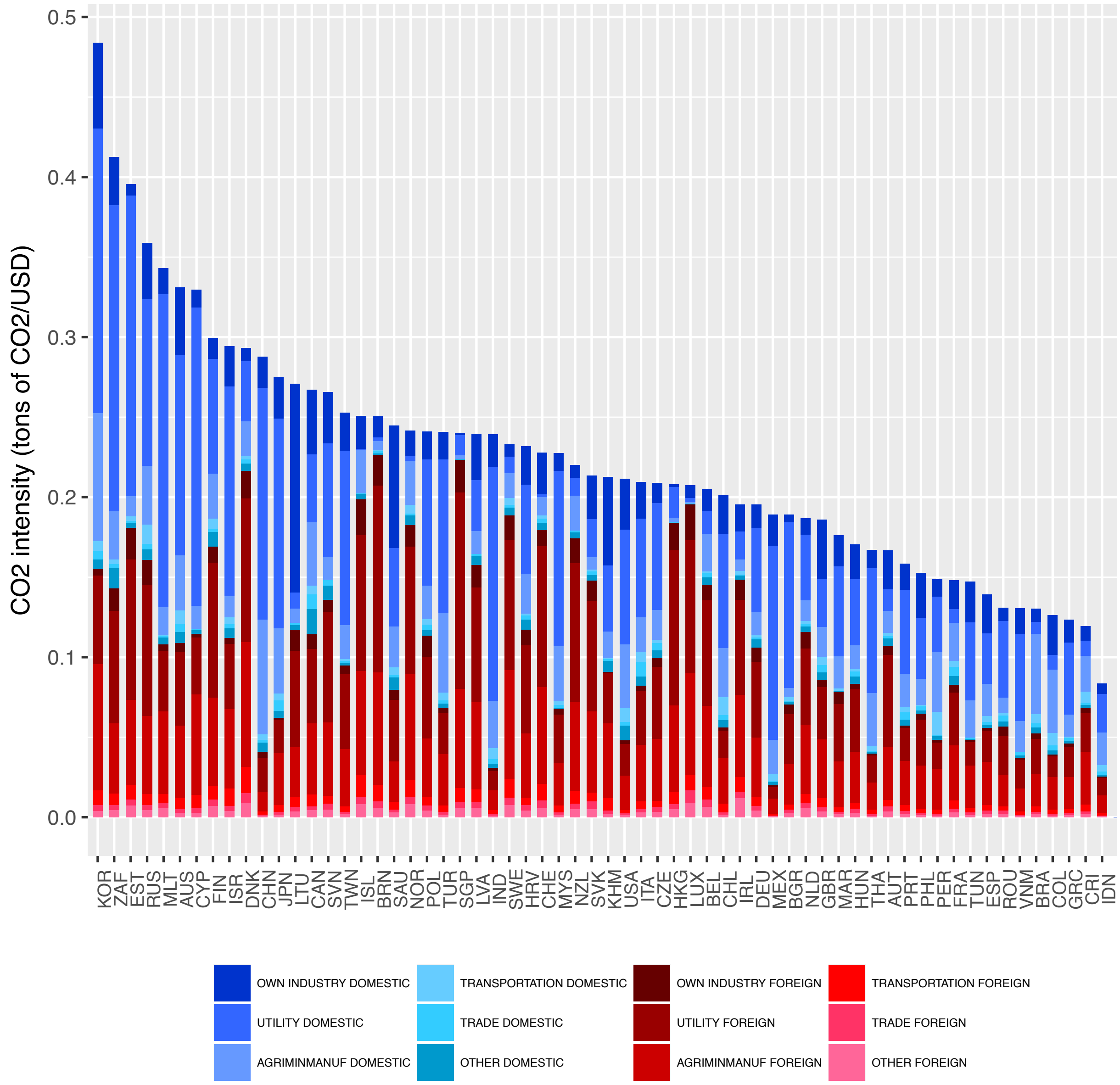


Figure 22: CO2 intensity of final demand clothing and footwear, no adjustment

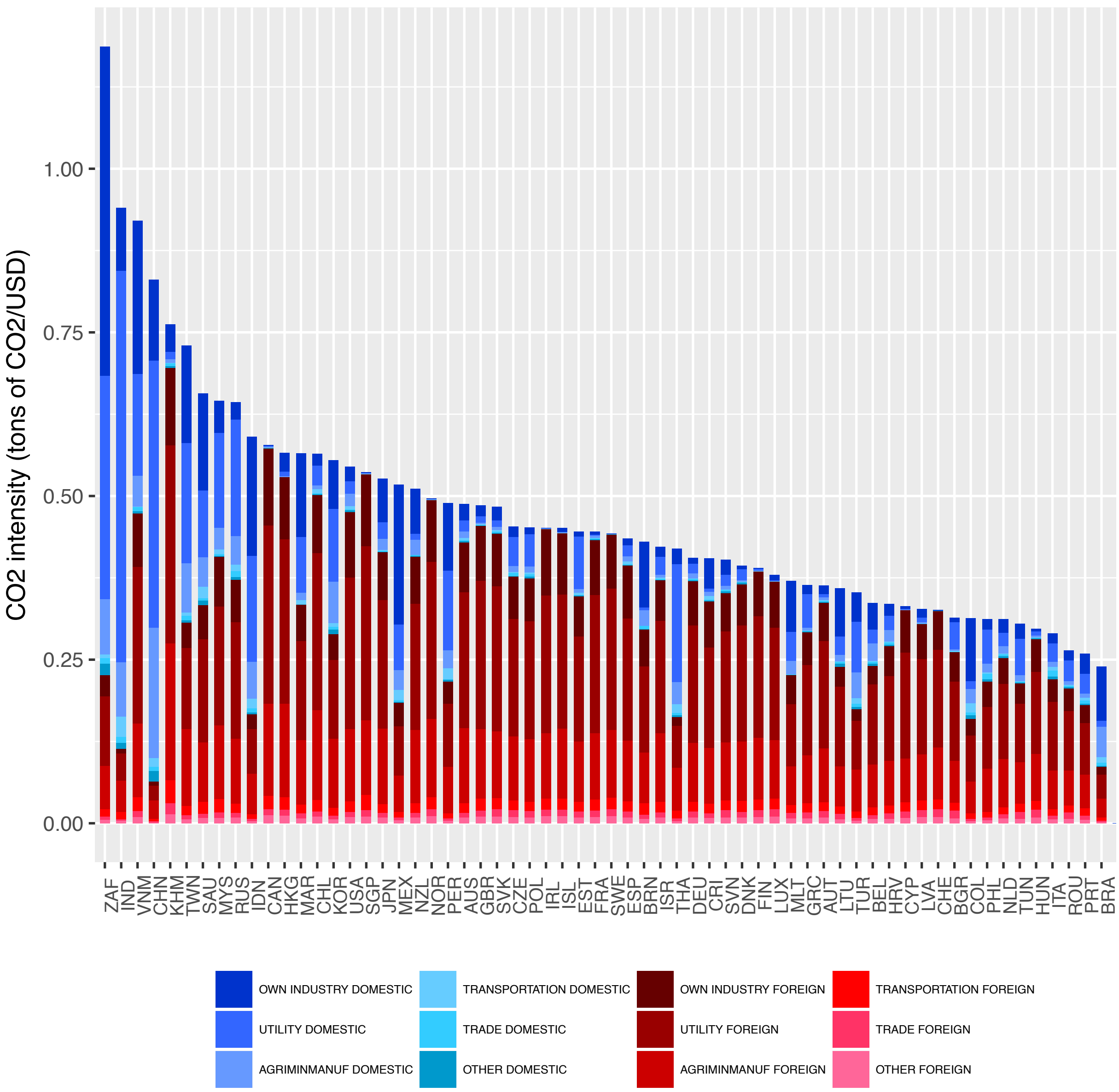


Figure 23: CO2 intensity of final demand clothing and footwear, adjusted by overall PPP

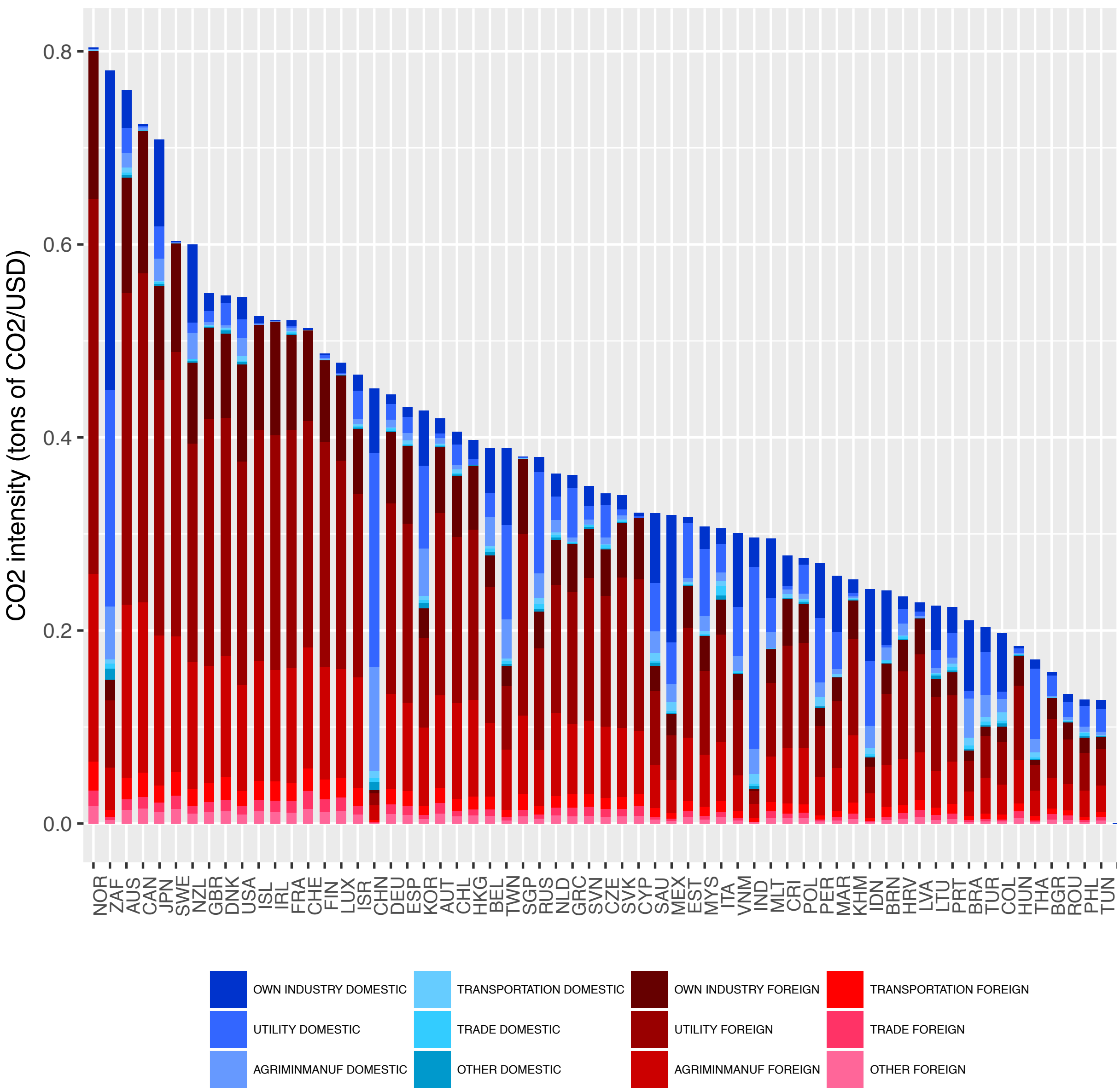


Figure 24: CO2 intensity of final demand clothing and footwear, adjusted by sectoral PPP

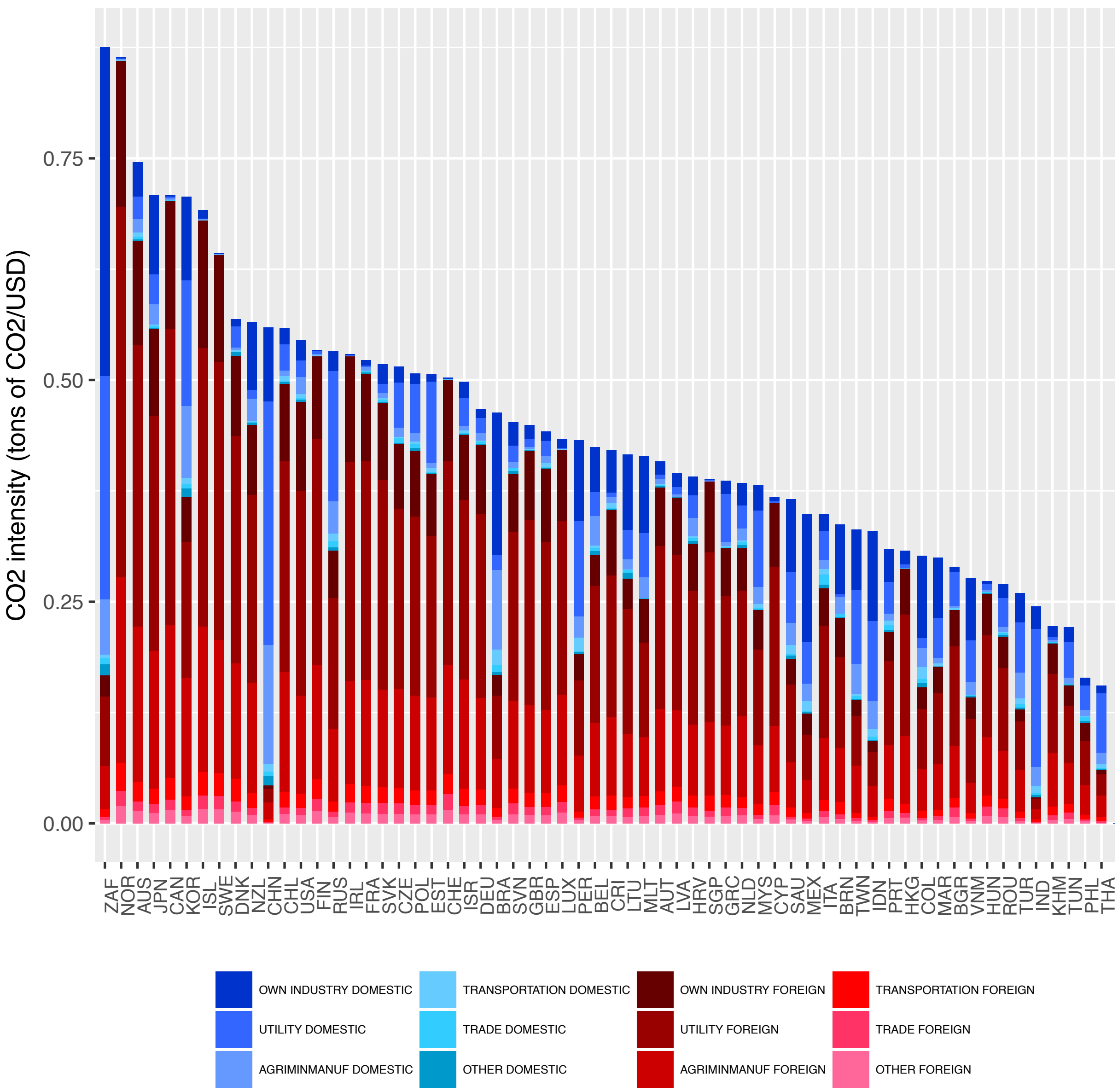


Figure 25: CO2 intensity of final demand for education, no adjustment

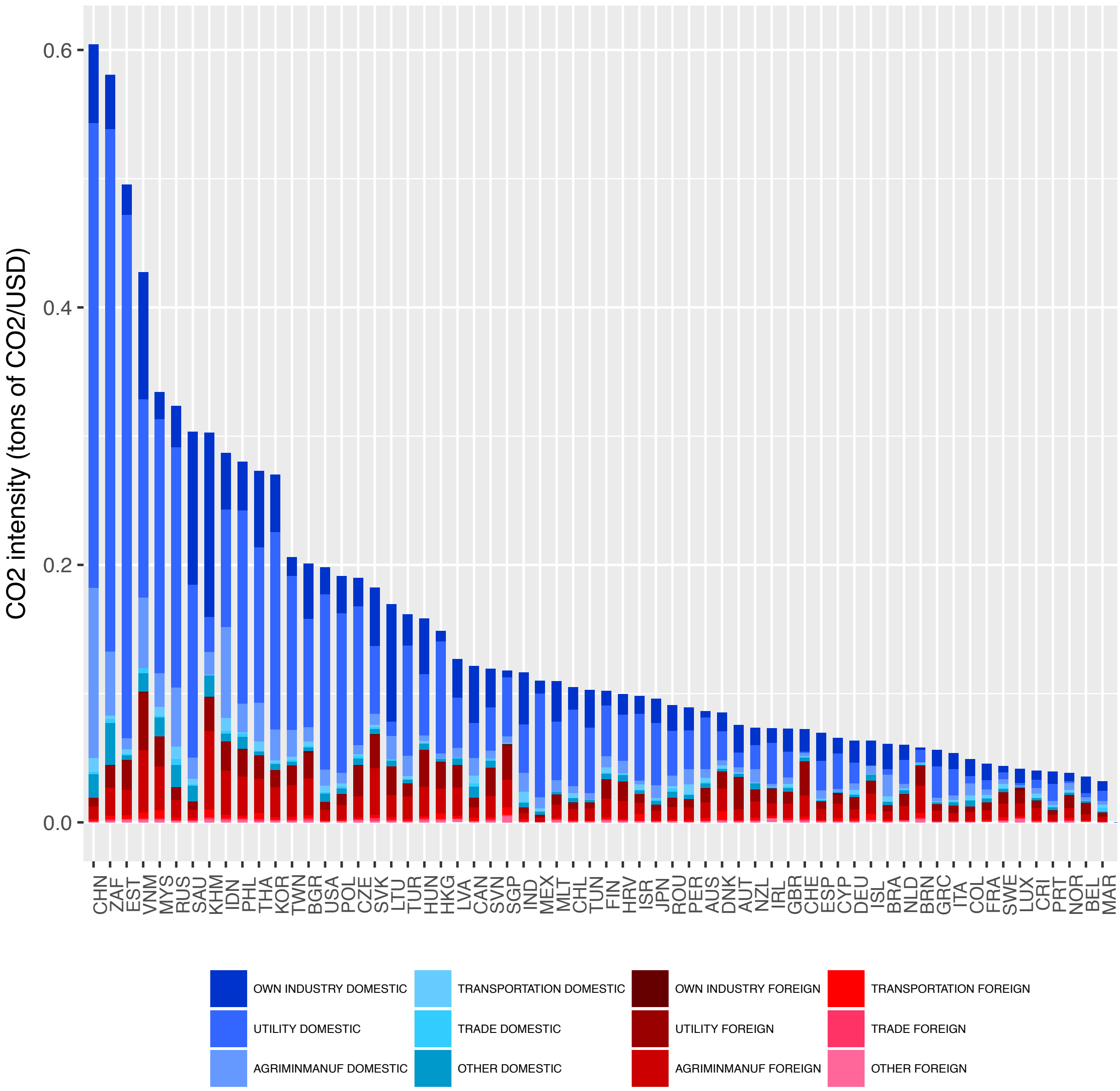


Figure 26: CO2 intensity of final demand for education, adjusted by overall PPP

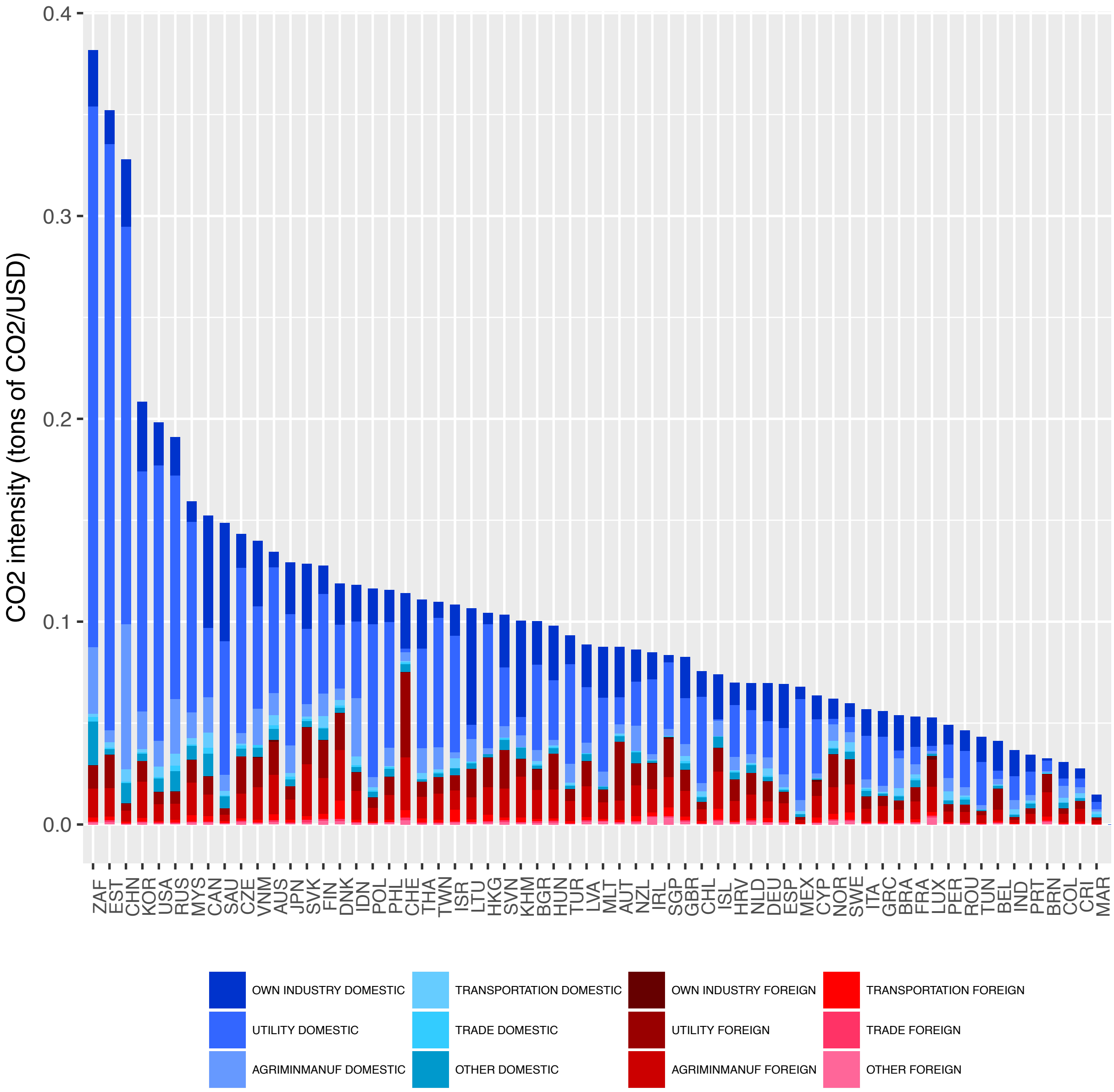
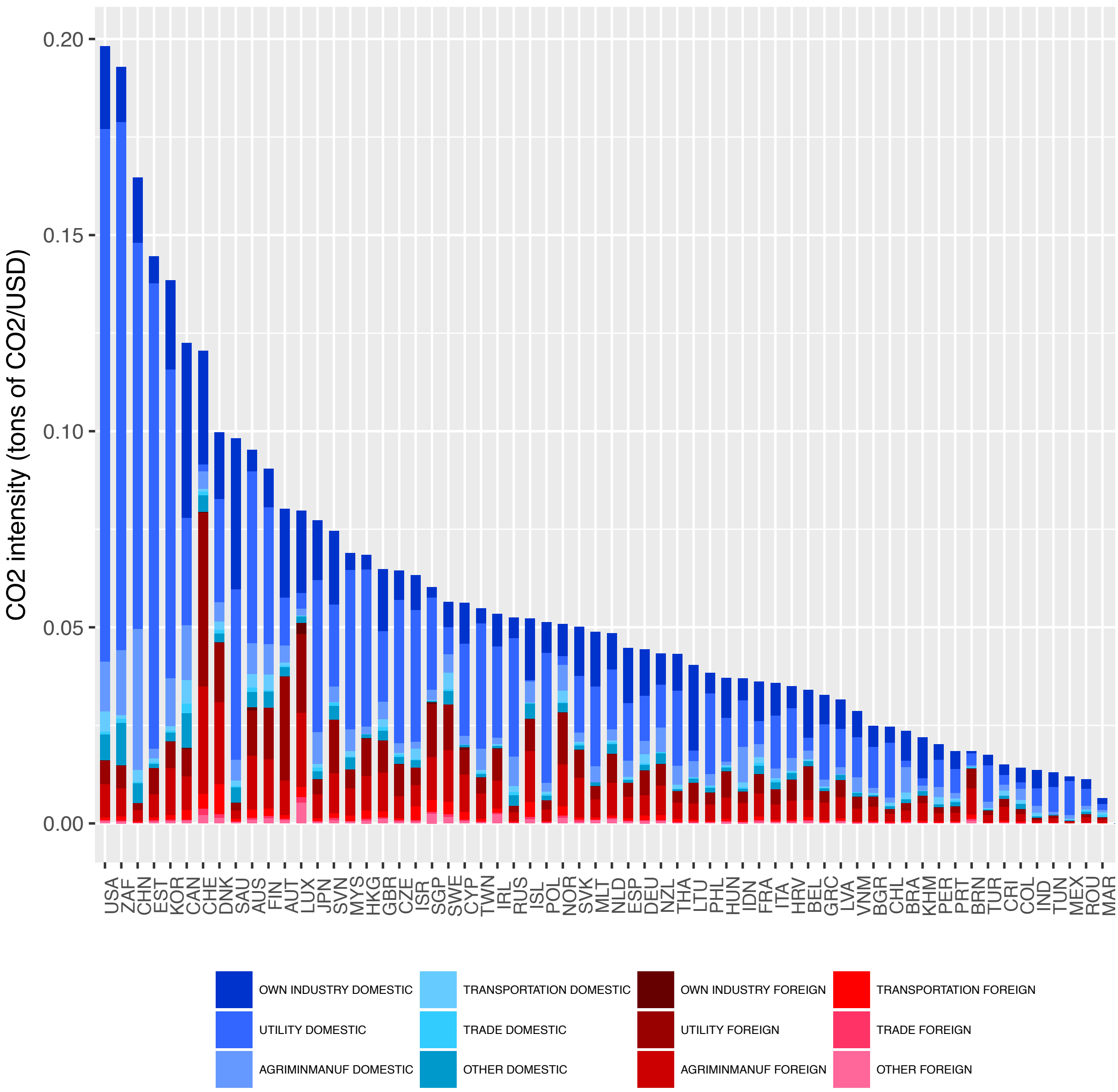


Figure 27: CO2 intensity of final demand for education, adjusted by sectoral PPP



Supplementary Appendix II: Industry and country coverage

Table B1: Industry coverage

	Aggregated code			OECD ICIO tables Original code	
	8-aggregated industry code		Industry Description	Industry Code	Industry Description
Goods sectors	S1	**AGRI**	Agriculture	C01T05	Agriculture, hunting, forestry and fishing
	S2	**MINING**	Mining	C10T14	Mining and quarrying
	S3	**MTR.MF**	Materials manufacturing	C29	Machinery and equipment, nec
				C30T33X	Computer, Electronic and optical equipment
				C31	Electrical machinery and apparatus, nec
				C34	Motor vehicles, trailers and semi-trailers
				C35	Other transport equipment
	S4	**MACH.MF**	Machinery manufacturing	C20	Wood and products of wood and cork
				C21T22	Pulp, paper, paper products, printing and publishing
				C23	Coke, refined petroleum products and nuclear fuel
				C24	Chemicals and chemical products
				C25	Rubber and plastics products
				C26	Other non-metallic mineral products
				C27	Basic metals
				C28	Fabricated metal products
	S5	**OTH.MF**	Other manufacturing	C15T16	Food products, beverages and tobacco
				C17T19	Textiles, textile products, leather and footwear
				C36T37	Manufacturing nec; recycling
Services sectors	S6	**UTL.CSTR**	Utility and construction	C40T41	Electricity, gas and water supply
				C45	Construction
	S7	**BUS.SV**	Business services	C50T52	Wholesale and retail trade; repairs
				C55	Hotels and restaurants
				C60T63	Transport and storage
				C64	Post and telecommunications
				C65T67	Financial intermediation
				C70	Real estate activities
				C71	Renting of machinery and equipment
				C72	Computer and related activities
				C73T74	R&D and other business activities
	S8	**PSN.SV**	Personal services	C75	Public admin. and defence; compulsory social security
				C80	Education
				C85	Health and social work
				C90T93	Other community, social and personal services
				C95	Private households with employed persons

Table B2: Country coverage and definition of four regions

(I) Country coverage of OECD's ICIO tables

Country code	Description (OECD countries)	Country code	Description (Non-OECD countries)
AUS	Australia	ARG	Argentina
AUT	Austria	BGR	Bulgaria
BEL	Belgium	BRA	Brazil
CAN	Canada	BRN	Brunei Darussalam
CHL	Chile	CHN	China
CZE	Czech Republic	CHN.DOM	China Domestic sales only
DNK	Denmark	CHN.PRO	China Processing
EST	Estonia	CHN.NPR	China Non processing goods exporters
FIN	Finland	COL	Colombia
FRA	France	CRI	Costa Rica
DEU	Germany	CYP	Cyprus
GRC	Greece	HKG	Hong Kong SAR
HUN	Hungary	HRV	Croatia
ISL	Iceland	IDN	Indonesia
IRL	Ireland	IND	India
ISR	Israel	KHM	Cambodia
ITA	Italy	LTU	Lithuania
JPN	Japan	LVA	Latvia
KOR	Korea	MLT	Malta
LUX	Luxembourg	MYS	Malaysia
MEX	Mexico	PHL	Philippines
MEX.GMF	Mexico Global Manufacturing	ROU	Romania
MEX.NGM	Mexico Non-Global Manufacturing	RUS	Russian Federation
NLD	Netherlands	SAU	Saudi Arabia
NZL	New Zealand	SGP	Singapore
NOR	Norway	THA	Thailand
POL	Poland	TUN	Tunisia
PRT	Portugal	TWN	Chinese Taipei
SVK	Slovak Republic	VNM	Viet Nam
SVN	Slovenia	ZAF	South Africa
ESP	Spain	RoW	Rest of the world
SWE	Sweden		
CHE	Switzerland		
TUR	Turkey		
GBR	United Kingdom		
USA	United States		

(II) The definition of four regions

Group	Country codes
Americas:	ARG, BRA, CAN, CHL,COL,CRI, MEX, USA
EU+:	EU28, CHE, NOR
East & South East Asia:	JPN, KOR, BRN, CHN, HKG, IDN, KHM, MYS, PHL, SGP, THA, TWN, VNM.
Others:	AUS, ISL, ISR, NZL, TUR, IND, RUS, SAU, TUN, ZAF, RoW