



# An environmentally extended global multi-regional input–output analysis of consumption-based and embodied import-based carbon emissions of Turkey

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## Abstract

Understanding the consumption-based accounting (CBA), production-based accounting (PBA), and emissions embodied in trade is an important prerequisite for designing climate mitigation policies. Environmentally extended input–output (EEIO) models have been developed to evaluate the linkages between economic activities and environmental impacts as well as the embodied emissions in goods and services that are traded between countries. In this study, an environmentally extended global multi-regional input–output (EE GMRIO) analysis is performed to calculate Turkey’s CBA emissions and import-based embodied emissions for the year 2015 using the Eora26 database, which is a simplified version of the Eora database adapted to 26 economic sectors. The key sectors and sectoral carbon intensities of countries are determined in terms of embodied emissions in imports for household consumption. Our results indicate that Turkey was a net importer of greenhouse gas (GHG) emissions in 2015 and about 10% of total emissions of the final consumption in Turkey have occurred in other countries. The dominant contributing sectors to a nation’s GHG emissions can be quite different for the CBA and PBA approaches and the efforts to reduce GHG emissions requires a holistic approach. Import-based household emissions are assessed in terms of countries, sector and GHG intensities. Our results indicate that Turkey was a net importer of GHG emissions in 2015 with its approximately 10% of the total and 7.7% of household final consumption emissions having occurred in other countries. This also suggests that imported goods and services for household consumption have been produced in those countries with relatively low emission intensities. Considering Turkey’s emissions reduction targets, these results provide methodological benefits that will enhance national efforts by giving invaluable inputs about the emission intensity of imported and exported goods and better guidance to policy makers about future strategies for low-carbon manufacturing and shifting consumption patterns.

**Keywords** EEIO · CBA · Turkey · Eora26 · Greenhouse gas emissions

## Introduction

Scientific evidence indicates that climate change is a serious and urgent issue (Stern 2007) that is defining our time as the greatest challenge to sustainable development (UN 2019). Science shows with 95% certainty that human activities are the dominant cause of increasing the greenhouse gas (GHG)

concentrations in the atmosphere, leading to a changing climate (IPCC 2013). The international community put into force the Kyoto Protocol in 1997 and the Paris Agreement in 2015 under UNFCCC to reduce and monitor GHG emissions as well as to increase the global ambition towards achieving the paradigm shift decoupling economic growth and GHG emissions. Paris Agreement calls for climate action to be undertaken by all countries, taking into account their common but differentiated responsibilities and respective capabilities, in the light of different national circumstances (UNFCCC 2015). Over the past two decades, the international community has been dealing with the question of how to assign responsibilities for reducing GHG emissions (Lenzen et al. 2007; Afionis et al. 2017). These efforts are often

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hampered due to methodological challenges for calculating GHG emissions.

There are mainly, two types of emission accounting approaches in the literature: the production-based accounting (PBA) and the consumption-based accounting (CBA). In the PBA framework, the producer is responsible for the emissions from the production of energy, goods and services (Munksgaard and Pedersen 2001). PBA, also known as territorial emission accounting framework, is employed by the United Nations Framework Convention on Climate Change (UNFCCC) (2019) and follows the guidelines of the Intergovernmental Panel on Climate Change (IPCC). International climate negotiations and national climate policies are determined based on this framework. The main difference between PBA and CBA is the allocation of global emissions. At a national scale, GHG inventory calculated with CBA can be defined as the inventory calculated with PBA plus the net GHG emissions embodied in trade (i.e., exports minus imports) (C40 2018; Khan et al. 2020).

Although the PBA has been used for many years in accounting national GHG emissions, it has certain methodological gaps mainly due to the fact that it neglects the connections between economies and the implications of carbon leakage (Peters and Hertwich 2008a; Davis and Caldeira 2010; Aichele and Felbermayr 2012; Naegele and Zaklan 2019). Ignoring these linkages can result in a misleading analysis of global, regional and national emission trends and mitigation policies (Peters et al. 2011). Another disadvantages of PBA is that it does not account for the emissions stemming from international air and sea transportation since their attribution to specific countries is difficult (Franzen and Mader 2018).

These methodological gaps of PBA and the rapidly expanding share of international trade in global emissions have led to the development of CBA among others (Ramaswami et al. 2008, 2011; Barrett et al. 2013; Lin et al. 2013; Onat et al. 2014). CBA can successfully address many of these challenges, as consumers are the eventual drivers of natural resource extraction, production and distribution, instead of the original producers of those GHG emissions (Munksgaard and Pedersen 2001; Wiedmann 2009; Clarke 2017; Afionis et al. 2017; C40 2018). Principally, both the PBA and CBA calculate the same total amount of anthropogenic GHG emitted into the atmosphere each year. However, key advantages of CBA include; increased emissions coverage, taking carbon leakage into account, encouragement of cleaner production practices, consistency between consumption and environmental impacts, political acceptability and equity and justice (Peters and Hertwich 2008b; Peters 2008; Steininger et al. 2014; Afionis et al. 2017). Despite its strengths, CBA also has some disadvantages. These include its data-intensive nature, necessity for complex calculations, higher transaction costs than PBA, increased uncertainty,

measurement from one extreme to the other extreme and the need to transcend the arena of geographical politics to make political decisions (Peters 2008; Jakob and Marschinski 2013; Liu 2015; Fan et al. 2016). Nevertheless, CBA can help better understand the driving forces of trends and patterns in global emission levels to reduce emissions (Liu 2015; Afionis et al. 2017; OECD 2019a; Karakaya et al. 2019). It can give invaluable inputs to emissions-importing countries about the emission intensity of imported goods, as well as to emissions-exporting countries about future strategies for low-carbon manufacturing and financial and technological transfer programs (Wiedmann 2009; Barrett et al. 2013; Afionis et al. 2017; Chandrakumar et al. 2020).

International trade has been increasingly characterized not only by the exchange of goods, services and capital across international borders or territories but also by the energy consumption and GHG emissions that occurred during their production. Products and services consumed in a country inevitably cause environmental impacts in many other countries due to complex supply chains (Hertwich and Peters 2009; Tukker et al. 2016). Although sharp declines have been observed due to financial crises and the COVID-19 pandemic more lately, the volume of the world trade in goods and services has been dramatically increasing over the last decade (UNCTAD 2021). Along with the expansion of international trade, global carbon emissions associated with the production and distribution of traded goods and services, reached 8 Gigatonnes (Gt), which was nearly a quarter of global carbon emissions of approximately, 32 Gt, in 2015 (BDF 2020). In terms of individual countries, in 2015 the largest net importers of CO<sub>2</sub> were the USA (0.79 Gt), Japan (0.16 Gt), the UK (0.14 Gt) and France (0.13 Gt), while the largest net exporters of CO<sub>2</sub> were China (1.3 Gt), Russia (0.32 Gt), India (0.12 Gt) and South Africa (0.1 Gt) (Yamano and Guilhoto 2020). There is a recent boom in the literature investigating the flows of carbon emissions embodied in international trade and identifying the factors affecting the change of these emissions (Sato 2014; Zhang et al. 2017, 2020; Beylot et al. 2019; Wang et al. 2019; Najibullah et al. 2021; Weber et al. 2021; Adebayo and Rjoub 2021).

Understanding the magnitude of GHG emissions embodied in international trade and its implications is important for consumers, policy makers, as well as producers. IO analysis is a well-established analytical tool within economics and systems of national accounts (Suh 2009; Athanassiadis et al. 2018; Miernyk 2020). Regional IO models (RIO) deal with a single or more regions and their interconnections (Miller and Blair 2009). RIO models can be classified into single-region input–output (SRIO) models and multi-region input–output MRIO models. SRIO models use the so-called domestic technology assumption (DTA), which assumes that imported goods are produced with the same production recipe as domestic goods and services (EEA 2013; Owen

2017). Although SRIO models are widely used in sustainability analyses, there has been an increase in recent years in the use of the global multi-regional input–output (GMRIO) analysis in the field of global policy-making on sustainable production and consumption (Onat 2018). Use of such models can eliminate the truncation errors and cut-offs that are present in conventional life cycle assessment (LCA)-based approaches because of their comprehensiveness and completeness (Suh et al. 2004; Pomponi and Lenzen 2018; Tukker et al. 2020).

Improved computational tools and a wider availability of economic and environmental accounts have enabled such models to be implemented on a wider scale (Wiedmann 2009). This has enabled the development of MRIO databases containing data for hundreds of countries (Malik et al. 2018). Among these databases, the most known and used are EXIOBASE, global trade analysis project (GTAP), world input–output database (WIOD), OECD inter-country input–output (OECD ICIO) and Eora (Dietzenbacher et al. 2013; Lenzen et al. 2013; Timmer et al. 2015; OECD 2016; Aguiar et al. 2016; Stadler et al. 2018). The main properties of these databases are summarized in Table 1.

Although the basic principles underlying the calculation methods used in all these databases are essentially the same, several studies show differing results (Arto et al. 2014; Moran and Wood 2014; Steen-Olsen et al. 2014; Owen et al. 2016; Wieland et al. 2018; Dawkins et al. 2019). In the

process of developing these models, the modelers need to make some choices about the structure and data components that influence the results. Different MRIO approaches (e.g., different aggregation levels, territorial or residential allocation, transit trade and emission data) and reconciliation of domestic and trade blocks can lead to different results at different levels (Tukker et al. 2020).

Turkey's national GHG emission inventory, similar to many others, is annually prepared and submitted to the UNFCCC (NIR 2020) at the basis of international carbon accounting systems (UNFCCC 2008). There are many studies about forecasting and calculating Turkey's sectoral and total GHG emissions using different methods, as studied by Ari and Aydinalp Koksak (2011), Arıoğlu Akan et al. (2017), Halicioglu (2009), Ozcan (2016), Şahin (2019), Sözen et al. (2007, 2009). Table 2 provides a non-exhaustive list, focusing on environmental RIO studies in Turkey.

This short review of the literature suggests that different databases are used so far, while SRIO and MRIO analyses are quite limited for Turkey. Previous studies have almost exclusively focused on sector or scope-based carbon emissions and used pre-2010 data. As far as we know, no previous research has investigated Turkey's CBA emissions including all sectors with the Eora26. This paper differentiates from others by studying the embodied GHG emissions in imports for final household consumption calculating those emissions for the first time with the Eora26 database for

**Table 1** Characteristics of existing GMRIOs

Name of database	Countries/regions	Total number of sectors	Time series	References
Eora	190	26 to ~500 industries/products	1990–2015	(EORA 2015)
WIOD	28 EU + 15 major countries + RoW (rest of world)	56 sectors	2000–2014	(Dietzenbacher et al. 2013)
EXIOBASE	28 EU + 16 major countries + RoW	163 industries/ 200 products	1995–2011	(Stadler et al. 2018)
GTAP	141	65 sectors	2004, 2007, 2011, 2014	(GTAP 2019)
OECD ICIO	36 OECD countries + 28 non-OECD countries + 5 RoW	36 sectors	1995–2015	(OECD 2019b)

**Table 2** Environmental studies based on RIO analysis in Turkey

Reference	RIO	Base year	Database	Sector	Environmental pressure
(Tunç et al. 2007)	SRIO	1996	State Institute of Statistics	5 aggregated sectors	CO <sub>2</sub>
(Kucukvar et al. 2015)	MRIO	2000–2009	WIOD	Manufacturing	Scope-based carbon footprint
(Kucukvar and Samadi 2015)	MRIO	2000–2009	WIOD	Food production	Carbon and energy footprints
(Kucukvar et al. 2016)	MRIO	2000–2009	WIOD	Manufacturing	Carbon and energy footprints
(Kucukvar et al. 2017)	MRIO	2050 Scenario	EXIOBASE	Electricity production	GHGs, wages, taxes
(Aydın 2018)	MRIO	Scenario	WIOD	Electricity generation	GHGs and air pollutants
(Onat 2018)	MRIO	2000–2009	WIOD	Construction industry	Global carbon footprint
(Sajid et al. 2019)	MRIO	2009	WIOD	Block-wise sectoral aggregation	Inter-sectoral carbon linkages

2015, which is the latest year available on the database. This study's objective is to estimate Turkey's CBA and import-based embodied GHG emissions for 2015 for bridging the gap between policy-making and model-based scientific approach to mitigate national emissions, making policy recommendations to policy makers and contributing to the state-of-the-art.

## Materials and methods

Different environmentally extended input–output (EEIO) models are available in the literature to evaluate the linkages between economic activities and environmental impacts as well as the embodied emissions in goods and services that are internationally traded between countries. In this study, an EE GMRIO analysis is performed using the Eora26 database, a simplified version of the Eora database harmonized to 26 sectors, to determine the economic sectors and countries with the largest shares by calculating the GHG emissions embodied in Turkey's 2015 imports.

### EEIO analysis

First developed by Wassily Leontief (1936), IO models are used to describe and analyze forward and backward economic linkages between different economic sectors or industries. IO tables are the foundation of IO analyses and include a series of rows and columns of data that quantify the supply chain for all sectors of an economy. EEIO analysis (Leontief 1970; Suh 2009) is based on IO analysis (Miller and Blair 2009) and is a simple and robust method that can be used to evaluate environmental impacts embodied in traded goods as well as environmental impacts associated with economic consumption (Kitzes 2013). EEIO has long been used to calculate carbon footprint. By converting monetary flows into GHG emissions, the emissions embodied in traded goods and services can be successfully estimated (Caro 2019).

In brief, the EEIO method can be described as follows.

The vector of total outputs  $X$  can be expressed as the sum of intermediate inputs  $Z$  and the vector of final demands  $Y$ . The matrix  $A$ , known as the 'technical coefficient' matrix, reveals the total direct input requirements for each industry per unit of output. Matrix notations below are taken from Miller and Blair (2009).

$$Z = \begin{bmatrix} Z_{11} & \dots & Z_{1n} \\ \vdots & \ddots & \vdots \\ Z_{n1} & \dots & Z_{nn} \end{bmatrix} A = \begin{bmatrix} Z_{11}/X_1 & \dots & Z_{1n}/X_n \\ \vdots & \ddots & \vdots \\ Z_{n1}/X_1 & \dots & Z_{nn}/X_n \end{bmatrix} Y = \begin{bmatrix} Y_1 \\ \vdots \\ Y_n \end{bmatrix} X = \begin{bmatrix} X_1 \\ \vdots \\ X_n \end{bmatrix}$$

The relationship consisting of  $Z$ ,  $A$ ,  $Y$  and  $X$  for the whole economic system can be expressed as follows:

$$X = AX + Y \quad (1)$$

Equation (1) can be further transformed into Eq. (2) to obtain total output matrix:

$$X = (I - A)^{-1} Y = LY \quad (2)$$

where  $I$  is the identity matrix and  $L = (I - A)^{-1}$  is the Leontief inverse matrix, which captures both direct and indirect inputs to satisfy one unit of final demand in monetary values.

We can obtain the total GHG emissions from each product sector in CO<sub>2</sub>eq unit by using national and international reports. This vector can be divided by the economic total output vector  $X$  to calculate the vector of the direct GHG emissions intensity,  $q$ , in tCO<sub>2</sub>eq/\$ unit. To calculate the CBA and embodied GHG emissions in goods and services, the GMRIO table was extended with the matrix of the direct GHG emissions intensity,  $q$ , as expressed in Eq. (3), which can be used to calculate the embodied carbon footprint of a given final consumption:

$$C = qLY \quad (3)$$

### Data sources

Tukker and Dietzenbacher identify an ideal GMRIO "as detailed as possible in terms of sectors and products, with a set of socio-economic and environmental extensions as extensive as possible, covering the globe and discerning as many as possible countries and regions, including long time series, and cost-effective to build" (2013).

In this study, the Eora26 database is preferred thanks to its publicly available large amount of data set covering 189 countries for 2015, the focus year of this study. This was the latest year available on the database at the time of the analysis. The Eora26 database, which is a simplified version of the full Eora database harmonized to 26 sectors, is utilized here (EORA 2015). Although the simplified Eora26 model is slightly less accurate, it is much easier to work with and more comparable across countries than the full version. In this simplified model, all countries have been aggregated to a common 26-sector classification and the supply-use tables from the full Eora MRIO have been converted to symmetric product-by-product IO tables using the Industry Technology Assumption. Eora provides the MRIO in basic prices, recommended for use for EEIO analysis (EORA 2015).

### GHG satellite accounts

In the past, Eora had used the constrained optimization approach to combine multiple data sources on GHG

emissions to create the GHG satellite account rows. However, this has led to a situation where the Eora GHG territorial emissions inventory may not fully agree with other data providers. To address this issue, the current version of Eora provides CO<sub>2</sub> and GHG emissions inventory satellite account rows from three different data providers; i.e., EDGAR, CDIAC and the PIK PRIMAPHIST models. The sectoral allocation of emissions follows Eora’s original pattern. This enables users to take the territorial emissions inventory from EDGAR, CDIAC or PRIMAPHIST as the starting point for their analysis. However, Eora recommends the PRIMAPHIST dataset, as this already includes EDGAR and CDIAC data and includes interpolation and smoothing as needed (EORA 2015). This study, therefore, makes use of the PRIMAP-HISTCR datasets which combines several published datasets to create a comprehensive set of GHG emission records for every country between the years 1850 to 2017. This applies to all UNFCCC member states, as well as many non-UNFCCC territories (Gütschow et al. 2016). PRIMAPHIST country-reported data form the highest priority category as it can benefit from detailed knowledge about the specific situation in a country and is well accepted in the context of the UNFCCC negotiations. IPCMOEL National Total excluding LULUCF category and Kyoto GHG (GgCO<sub>2</sub>eq) entity is used.

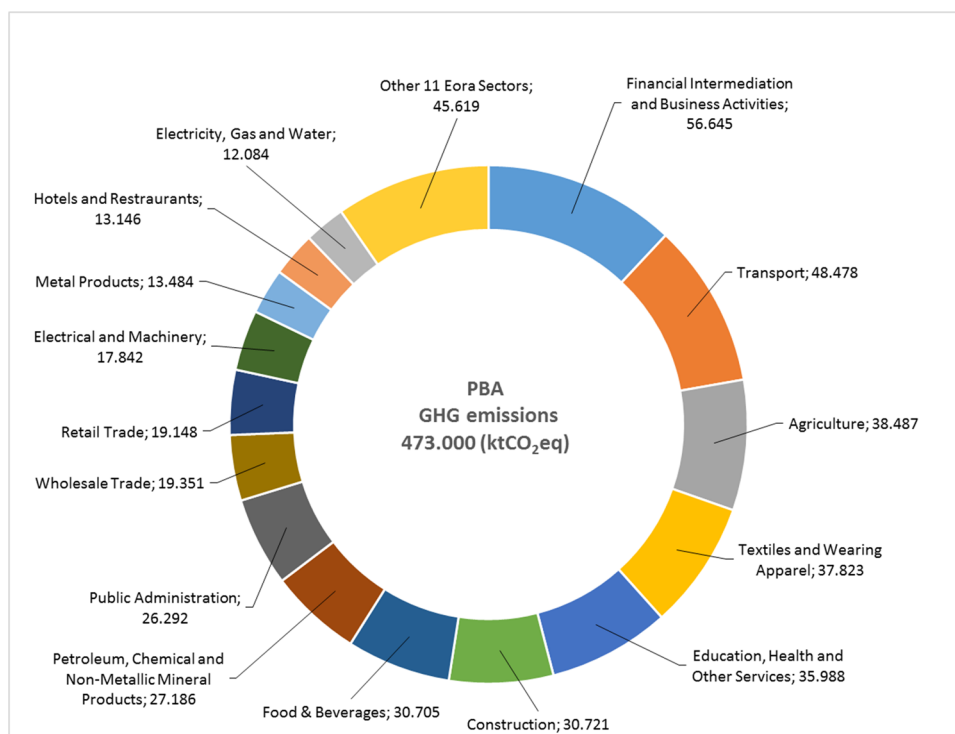
## Results and discussion

### GHG emissions of Turkey

According to the Eora26-based MRIO analysis, Turkey’s GHG emissions for 2015 are calculated as 473,000 ktCO<sub>2</sub>eq (Fig. 1) and 545,873 ktCO<sub>2</sub>eq (Fig. 2), with the PBA and CBA approaches, respectively. In CBA accounting, not only the Household Final Consumption but also other Eora26 final demand categories are included, such as the Non-profit institutions serving households, government final consumption, gross fixed capital formation, changes in inventories and acquisitions less disposals of valuables. Given that the CBA GHG emissions of Turkey are approximately 15% higher than the PBA emissions, the country was a net importer of GHG emissions in 2015. A study conducted for Turkey with 1996 data found that CBA emissions are 14% higher than PBA emissions (Tunç et al. 2007). The net imported GHG emissions of Turkey are found as 9.67% of CBA GHG emissions in 2015. According to another study for the same year, which used the GTAP database, the net imported CO<sub>2</sub> emissions represented 8.34% of CBA CO<sub>2</sub> emissions of Turkey (Peters et al. 2011, 2012; Friedlingstein et al. 2020). The difference between the two studies likely comes from differences in the database and GHG gases included.

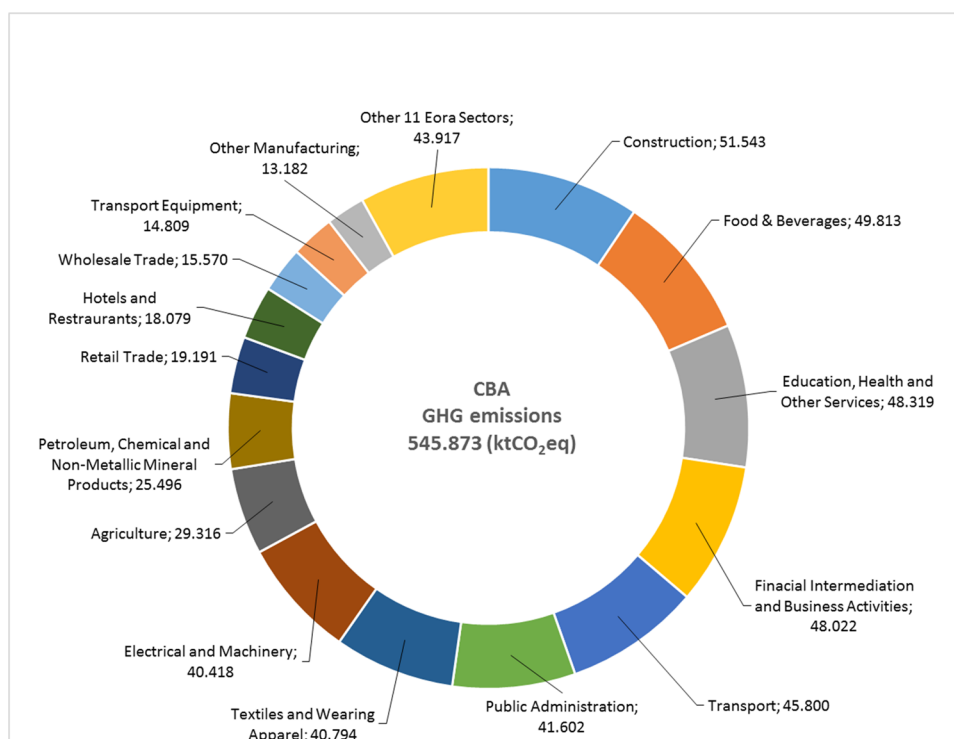
According to our analysis, Turkey’s PBA and CBA GHG emissions are 6.01 tCO<sub>2</sub>eq per capita and 6.93

**Fig. 1** Contribution of the key sectors to Turkey’s PBA GHG emissions for the year 2015





**Fig. 2** Contribution of the key sectors to Turkey's CBA GHG emissions for the year 2015



**Table 3** CBA per capita GHG emissions in Turkey

CBA tCO <sub>2</sub> eq per capita	Data year	Method	Reference
4.6	2001	GTAP	Hertwich and Peters (2009)
6.904	2007	EXIOBASE 2.1	Tukker et al. (2014)
6.67	2011	PAS 2070 and GTAP	C40 (2018)
6.93	2015	Eora26	This study

tCO<sub>2</sub>eq per capita, respectively for 2015. Global per capita GHG emissions was 6.66 tCO<sub>2</sub>eq for the same year (Crippa et al. 2019). While Turkey's per capita PBA GHG emissions are below the global average, the per capita CBA GHG emissions are above the global average. Table 3 provides a list of different studies calculating CBA per capita GHG emissions in Turkey.

For OECD countries, total CBA emissions amount to 13.8 Gt and the per capita CBA emissions amount to 10.8 t of CO<sub>2</sub> in 2015. These figures are 374.9 Mt and 4.8 t of CO<sub>2</sub> for Turkey, respectively (OECD 2016). OECD's ICIO model includes only CO<sub>2</sub> emissions and only those emissions that come from burning fossil fuels. Therefore, one must expect that the results from the OECD model would be smaller than from those models that cover all GHG gasses and CO<sub>2</sub> emissions from other sources (Jensen 2017).

Figure 1 and Fig. 2 show Turkey's GHG emissions calculated using the PBA and CBA approaches at the Eora26 sector level in 2015. In the PBA approach (Fig. 1), the dominant contributors are found to be the *Financial Intermediation and Business Activities* (12%); *Transport* (10.2%); *Agriculture* (8.1%); *Textiles and Wearing Apparel* (8%); and *Education, Health and Other Services* (7.6%). In the CBA approach (Fig. 2), the dominant contributors were *Construction* (9.4%); *Food and Beverages* (9.1%); *Education, Health and Other Services* (8.9%); *Financial Intermediation and Business Activities* (8.8%); and *Transport* (8.4%).

Similar to our study, Tunç et al. (2007) employed an EEIO with 1996 data for Turkey and compared the total PBA and CBA CO<sub>2</sub> emissions in five aggregated sub-sectors. PBA CO<sub>2</sub> emissions in that study suggested that the *Manufacturing Industry* has the highest share (32%), followed by *Energy and Mining* (30%); *Transportation* (16%), *Other Services* (16%) and *Agriculture and Husbandry* (6%). CBA CO<sub>2</sub> emissions were distributed among the same sectors with 35% for *Manufacturing Industry*, 33% for *Energy and Mining*, 14% for *Other Services*, 12% for *Transportation* and 6% for *Agriculture and Husbandry*. In another study (Kucukvar et al. 2015), the average sectoral GHG contributions were calculated for manufacturing sectors in Turkey between 2000 and 2009. Accordingly, the *Agriculture, Hunting, Forestry and Fishing* sector has the highest share (17.6%), followed by *Food, Beverages and Tobacco* (13.5%) and *Textile and Textile Products* (12.9%). The Sectoral GHG emissions differ in each study due to the calculation methodology, time

period, sectoral aggregation and the change in the production and consumption profile of the country over the years. This study contains the most up-to-date data for 2015.

These numbers suggest a misperception that the environmental impacts of service sectors are smaller compared to industrial sectors (Zhang et al. 2015). This overgeneralization may be due to geographically less concentrated service sector with minimal directly observable pollution, compared to industrial sectors (Suh 2006; Alcántara and Padilla 2009; Zhang et al. 2015). The results of our study, however, indicate that Turkey’s emissions from the service sector were (e.g., *Education, Health and Other Services; Financial Intermediation and Business Activities, Transport, Public Administration*) considerably high in PBA and CBA.

### Embodied emissions of Turkey’s trade for final household consumption

In this study, the total net imported GHG emissions of Turkey are found as 52.761 ktCO<sub>2</sub>eq in 2015. According to (Yamano and Guilhoto 2020), net CO<sub>2</sub> embodied of Turkey in the final demand was 38.1 Mt CO<sub>2</sub> in 2015. In this study, in contrast, the GHG emissions embodied in imports for the final household consumption are studied. Consumption activities of other final demand actors in Eora, i.e., private and public entities, are out of scope of this study. Turkey’s GHG emissions from household consumption are found to be 338.305 ktCO<sub>2</sub>eq of which 312.186 ktCO<sub>2</sub>eq was due to domestic emissions and 26.119 ktCO<sub>2</sub>eq was due to embodied emissions in net imports. In other words, approximately

7.7% of Turkey’s household CBA GHG emissions occurred in other countries in 2015.

The distribution of GHG emissions due to household consumption from domestic production and imports is shown in Fig. 3. The sectors in which imported emissions are more dominant are the *Textiles and Wearing Apparel; Petroleum, Chemical and Non-Metallic Mineral Products; Electrical and Machinery; Transport Equipment; and Other Manufacturing* sectors. In terms of share, *Transportation Equipment* has the highest imported emissions intensity and consists of approximately 57% of all imported emissions. In terms of the total amount, *Petroleum, Chemical and Non-Metallic Mineral Products* is the sector with the highest net embodied GHG imports (7.495 ktCO<sub>2</sub>eq). Accordingly, more than 95% of household consumption-related GHG emissions of service sectors originate from domestic emissions.

Turkey’s imports data (Fig. 4a) and embodied emissions from household consumption in imports (Fig. 4b) from the top 20 countries and RoW in 2015 are presented in Fig. 4. The imports data are obtained from the Turkish Statistical Institute (TURKSTAT 2015). According to Fig. 4, the top five countries with the highest share of total imports for 2015 are China (11.8%), Germany (10.6%), Russia (9.7%), USA (5.4%) and Italy (5.3%). For the emissions embodied from household consumption in imports, this ranking changes to China (17%), Germany (12%), India (8%), Italy (6%) and Russia (4%). One of the reasons for the difference between the ranking of imports and embodied GHG emissions of Turkey’s trade partner countries can be related to the carbon intensity of import sectors. Another reason can be the disagreement of imports data given in Eora’s national

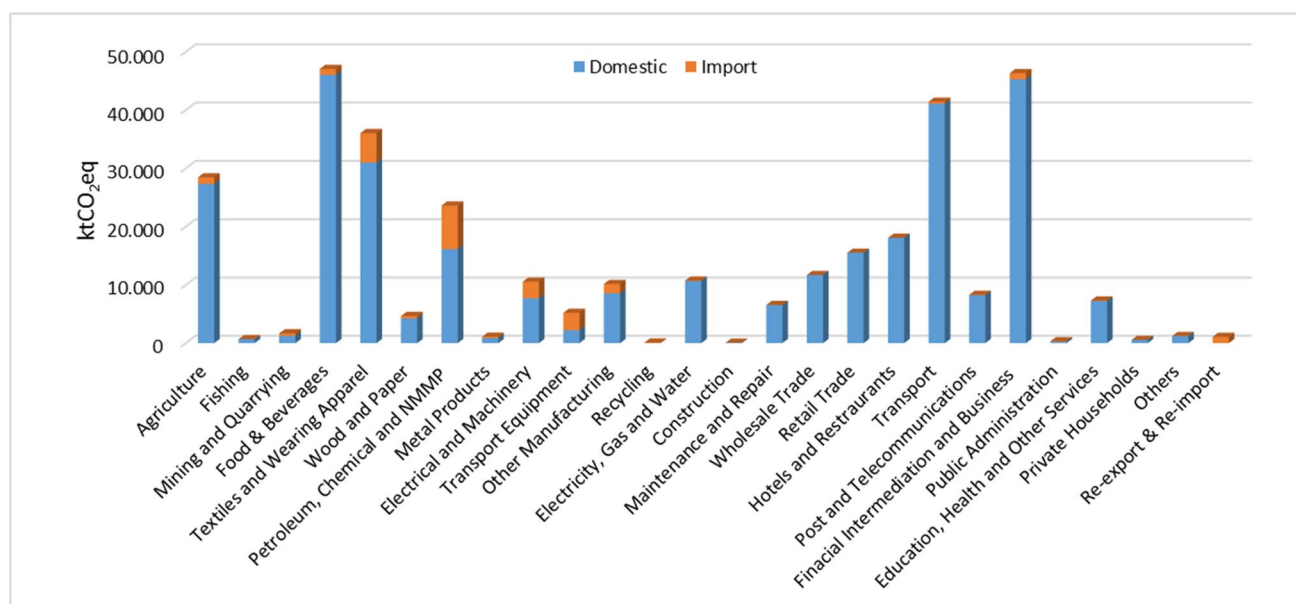
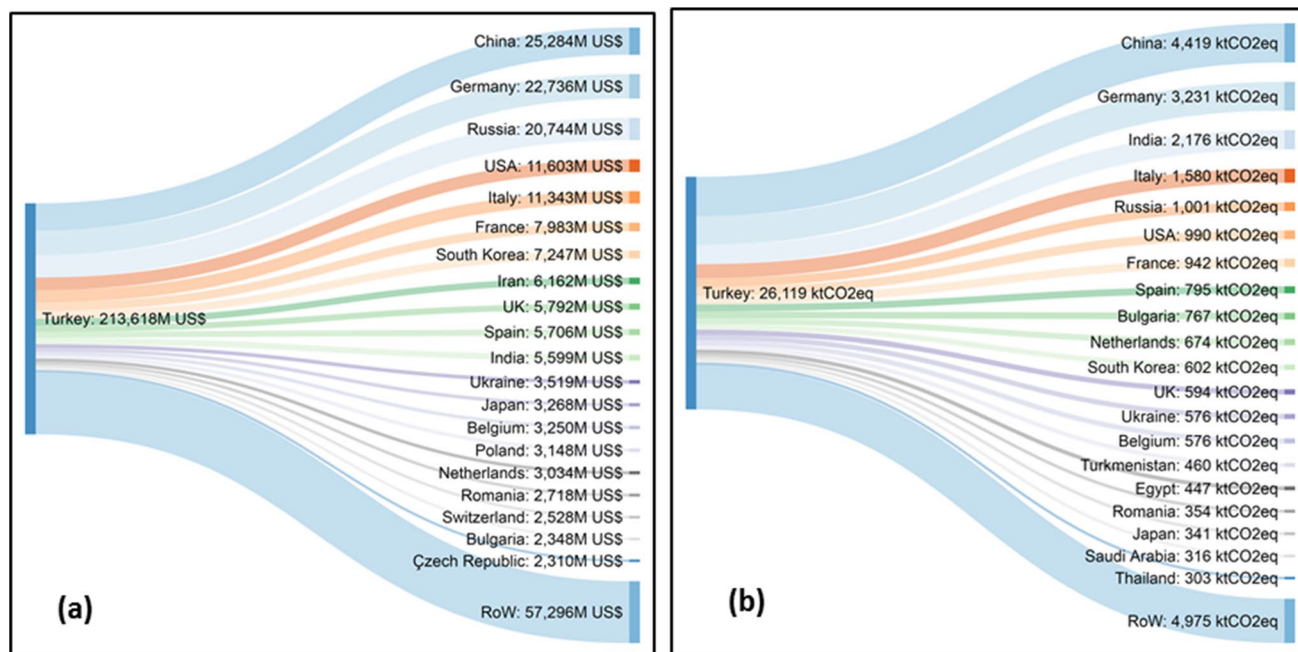


Fig. 3 Distribution of Turkey’s GHG emissions from household consumption according to domestic and imported emissions in the year 2015



**Fig. 4** Top 20 countries in Turkey's import and embodied emissions from household consumption in imports

account balances and the imports data given in the United Nations' Main Aggregates database or bilateral trade data. This is important both in terms of demonstrating that emissions are linked to financial flows in international trade, as well as in emission-intensive sectors and countries.

The 5 key sectors within 26 Eora sectors account for approximately 77% of embodied emissions from household consumption in imports. These industries are *Textiles and Wearing Apparel*; *Petroleum, Chemical and Non-Metallic Mineral Products*; *Electrical and Machinery*; *Transport Equipment*; and *Other Manufacturing*. Therefore, this study focuses on these top key sectors and countries, with the remaining countries shown as RoW as presented in Fig. 5.

China has the highest share in embodied emissions from household consumption in the *Textiles and Wearing Apparel*, *Electrical and Machinery*, and *Other Manufacturing* sectors with 35%, 27%, and 53% share respectively. On the other hand, Germany has the highest share (27%) in embodied emissions in the *Transport Equipment* sector, followed by South Korea (8%) and India (8%). Approximately 33% of the emissions in the *Petroleum, Chemical and Non-Metallic Mineral Products* sector originate from India, Germany, and China.

Turkey has 97 chapters in 2015 import and the ratio of the 20 most imported chapters to total import is 82% (TURKSTAT 2015). However, Eora26 contains only 26 sectors and as such may differ from sectors in which Turkey's import. Although this disaggregation makes it difficult to assess the relationships between import figures and emissions at

a sector level, there are comparable sectors that are compatible. For example, in Turkey's import in the chemical industry, which has quite a large range products, the top five countries with the highest share are Germany, Russia, Italy, India and China in 2015 (Ministry of Trade 2020). In this study, the top five countries with the highest share in embodied emissions from the *Petroleum, Chemical and Non-Metallic Mineral Products* sector are India, Germany, China, Italy and Russia. In *Petroleum, Chemical and Non-Metallic Mineral Products* sector, India and China takes the fourth and fifth place in the import ranking while first and third places in emissions ranking, respectively. This indicates high carbon intensity imports from these markets as in total emissions.

Figure 6 illustrates the distribution of Turkey's 2015 household consumption-related imports from selected countries. The countries and sectors are selected such that they represent the majority in imported emissions both in terms of sectoral breakdown and country of origin. The emissions intensity is calculated by dividing the Eora26 import data by the embodied emissions in imports. These graphical visualizations illustrate that the carbon intensities in imports from developed European countries is lower than those from developing countries. Emerging markets such as China, Russia and India export goods and services with a relatively higher carbon intensity due to the use of carbon-intensive fuels such as coal and low value of energy-intensive exports (Davis and Caldeira, 2010). Emissions intensities are well known to vary among



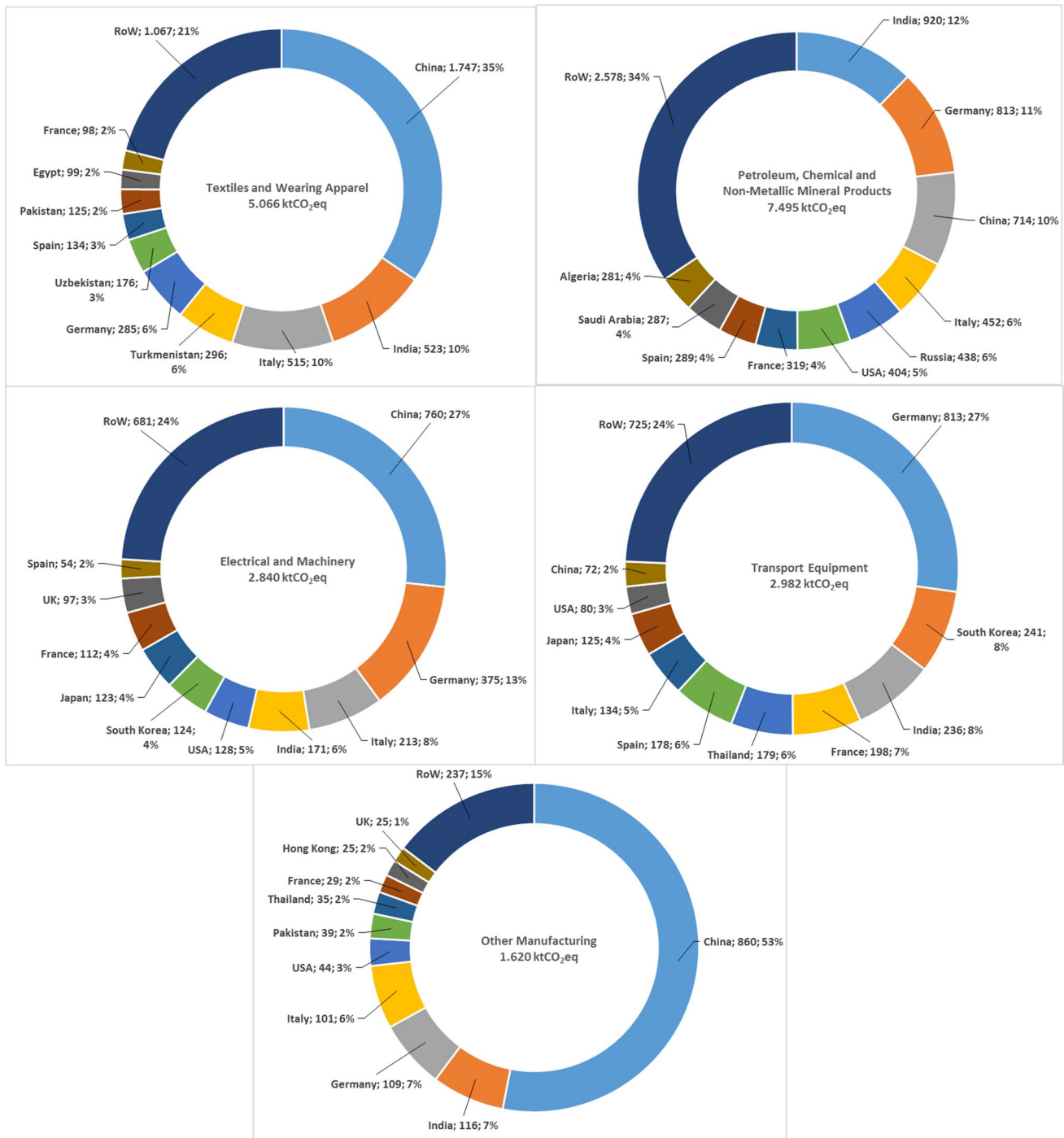


Fig. 5 Top key sectors and countries in embodied emissions from household consumption in imports of Turkey in 2015

sectors and countries, depending on energy systems, production technologies, experience, and skills (Moran et al. 2018). Results also indicate that Turkey has a higher carbon intensity from developed European countries such as Germany, France and Italy and a lower carbon intensity from developing countries such as China, Russia and India.

Imports in the *Textiles and Wearing Apparel*, *Electrical and Machinery* and *Other Manufacturing* sectors are dominated by China with a higher emissions intensity. Nonetheless, the Fig. 6 shows that Turkey’s majority of imports in value stem from European countries with lower emissions intensity, leaving little room for decreasing imported emissions by changing suppliers.

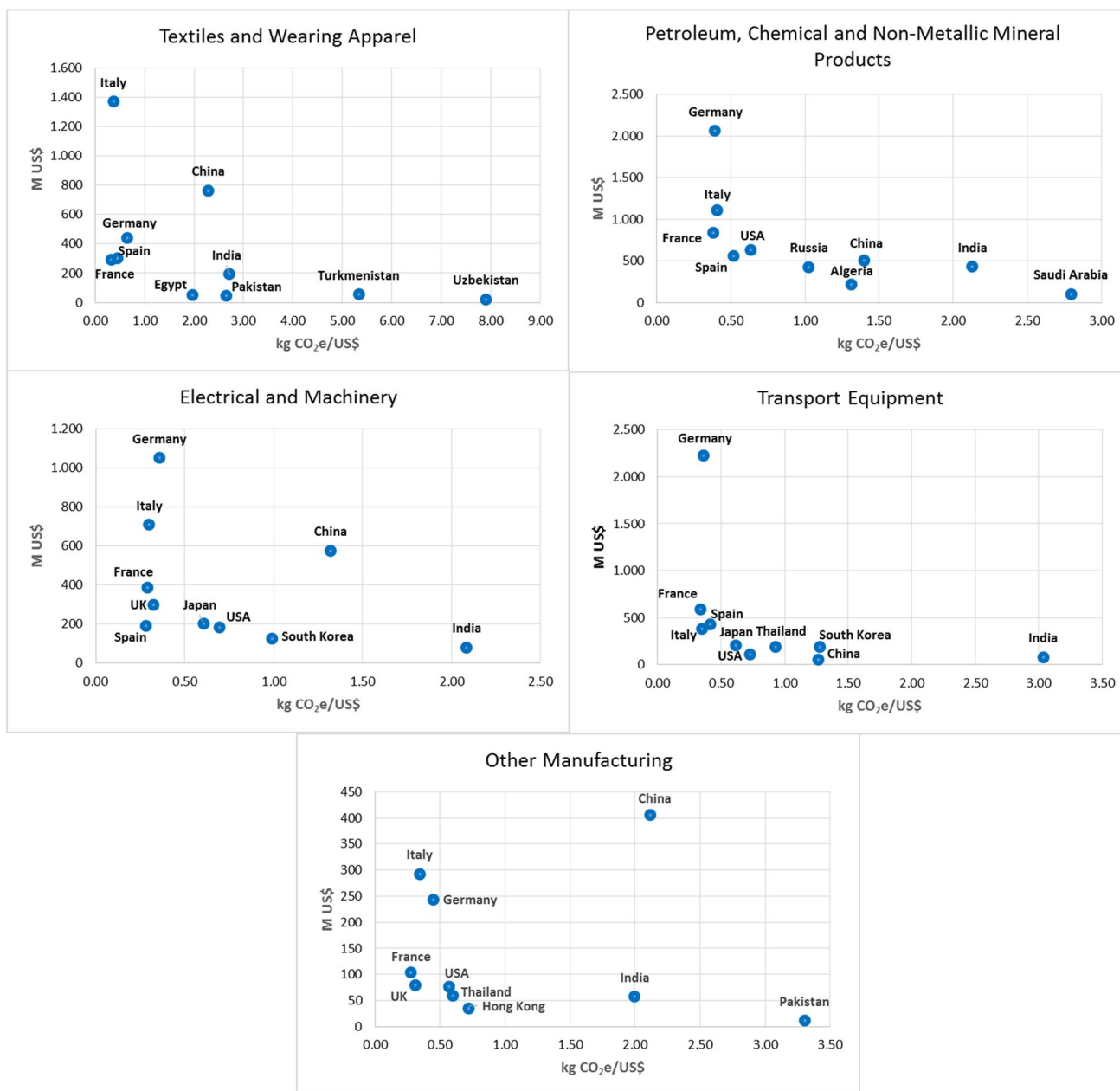


Fig. 6 Turkey’s 2015 household consumption-related imports and embodied emissions for top key sectors and countries

Export-based GHG emissions and re-exported emissions, which represent the emissions that are imported but later exported, are also gaining importance for climate action. The carbon border adjustment mechanism (CBAM), a form of carbon pricing on imports into the EU market according to the carbon content of the imported goods, proposed by the European Commission as a part of the European Green Deal (EU 2019). Turkey is highly trade-exposed to Europe and the existing trade co-operation may be dependent on implementation of

the Paris Agreement (MoEU 2018). According to TIBA (2020) report, CBAM would increase the costs of Turkish exports to the EU market and the total carbon cost of Turkish exports will be 1.1 or 1.8 billion euro annually. Aşıcı (2021) points out that CBAM can be an opportunity for transforming the Turkish economy rather than a risk. Our analysis can give insights to policy makers if Turkey wishes to consider carbon pricing in order to protect itself against a potentially high-cost possibility.

## Conclusions

In this study, an EE GMRIO analysis is performed using the Eora26 database, to determine CBA GHG emissions and emissions embodied in Turkey's imports for the year 2015 for the first time in the literature. The results suggest that Turkey imports GHG emissions at approx. 9.67% of its total GHG inventory and 7.7% for household consumption and is a net carbon importer in the given year. The results indicate that the dominant contributing sectors to Turkey's GHG emissions are quite different for the CBA and PBA approaches, with considerably high emissions from the service sector (e.g., Education, Health and Other Services, Financial Intermediation and Business Activities, Transport, Public Administration).

Results indicate that the overall carbon intensity of imported consumption goods for Turkey are relatively low, which can be further improved up to a certain extent by discouraging imports from countries with high emission intensities. Furthermore, Turkey's per capita PBA GHG emissions are lower than the global average and the per capita CBA GHG emissions are higher than the global average for the year 2015. However, GHG emissions in both approaches have been increasing. Turkey's imports mainly stem from the EU, which is known for its relatively lower embodied emissions. This limits Turkey's ability to make large reductions in imported emissions in the future. However, ongoing measures in the EU for reducing emissions can help Turkey also reduce its imported emissions. On the other side, Turkey has pledged carbon neutrality in 2053, which is based on PBA. Reducing CBA emissions in parallel can bring co-benefits, making the CBA a useful method for Turkey in shaping its future climate policies. Therefore, Turkey needs to take domestic actions to mitigate emissions and continue to support low-carbon production with more ambitious policies.

Especially, in the eve of the announcement for a CBAM by the European Commission, CBA as complementary to PBA can provide methodological benefits that will enhance national efforts by giving invaluable inputs about the emission intensity of imported and exported goods and better guidance to policy makers about future strategies for low-carbon manufacturing and shifting consumption patterns.

The study is limited by its model. Generally, model limitations to any MRIO analysis include trade and emission data uncertainty, aggregation, allocation and price-based errors and data balancing. Another limitation is the use of only the CBA and embodied import-based GHG emissions of Turkey, instead of all embodied emissions in trade. In future research, the full Eora and other database models can be employed for most robust results. Another limitation of this study is its time frame of one single year,

which does not provide an inter-annual trend analysis for GHG emissions that would have shed more light to future policies. All embodied trade-based GHG emissions of Turkey can be estimated and used in the implementation of CBAM. The employed method can also be extended to other applications beyond GHG emissions, such as resource, energy and water footprints, which are all other important aspects of environmental protection and sustainable development.

**Author contribution** NM developed the conceptual framework and collected the dataset. The introduction and literature review sections were written by NM. NM constructed the methodology section and empirical outcomes in the study. UAS improved interpretations of results and revised introduction and conclusion. UAS has also put her contribution in proof reading. All the authors read and approved the final manuscript.

**Data availability** Data is readily available at <https://worldmrio.com/eora26/>. Lenzen M, Moran D, Kanemoto K, Geschke A (2013) Building Eora: A Multi-region Input–Output Database at High Country and Sector Resolution. *Econ Syst Res* 25: <https://doi.org/10.1080/09535314.2013.769938>

## Declarations

**Competing interests** The authors declare no competing interests.

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