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Carbon emissions embodied in Russia's trade

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Abstract

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JEL: F18, F64, Q65

Keywords: global climate change, carbon emissions, virtual carbon, carbon intensity of trade, Russia's trade, input-output analysis, Kyoto protocol

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In this paper emissions embodied in exports and imports of Russia were calculated with the use of inter-country input-output tables. It was revealed that Russia is the second largest exporter of emissions embodied in trade and the large portion of these emissions is directed to developed countries. The reasons for high carbon intensity of Russia's exports are obsolete technologies (in comparison to developed economies) and the structure of commodity exports.

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1. Introduction

Climate change is one of the acute global issues extensively damaging the world economy. According to Intergovernmental Panel on Climate Change (IPCC), anthropogenic GHG emissions, primarily CO₂, are the main cause of climate change (IPCC, 2013).

International climate cooperation that started in 1990s made necessary to account emissions associated with separate countries. The key issue is how to define, which country is responsible for emissions. In order to fulfill obligations under the Kyoto protocol countries prepare national inventories containing information about the emissions that take place “within national territory and offshore areas over which the country has jurisdiction” (IPCC, 2006).

This approach is most transparent and feasible but has some drawbacks, because it ignores international trade flows. Meanwhile, around 30% of global CO₂ emissions are released during the production of internationally traded goods (Sato, 2013). Therefore, an increase in the consumption of carbon intensive goods in one country may not lead to an increase in its emissions, but will contribute to an increase in emissions in other countries, suppliers of carbon intensive products.

This is aggravated by the fact that most of carbon intensive trade flows are directed from developing to developed countries. Developing countries are not listed in Annex I of the UNFCCC and therefore haven't taken quantitative commitments for emissions reduction. This means that the growth in carbon intensive products consumption in developed countries, which is related to imports from developing countries, is not regulated by the current international climate change regime. Moreover, it induces “emission (carbon) leakage”, that is the increase in emissions outside developed countries due to rising imports of carbon intensive products from developing countries (as a result of the policy to cap emission).

There is an alternative approach to emission accounting, based on consumption, not production (as it is stated by UNFCCC) of a particular country. According to this approach, emissions, occurred abroad due to imports are accounted along with emissions from domestic final consumption. In this case preconditions for “emission leakage” disappear and additional incentives for reducing consumption (but not production and exports) of carbon intensive products arise.

Global production-based and consumption-based emissions are equal. However, they vary in different countries. According to Peters and Hertwich (2008) in 2001 total consumption-based emissions of Annex I countries were 5% higher than their production-based emissions. In particular, consumption-based emissions of the USA in 2001 exceeded its production-based emissions by 7.3%. Unlike the USA, the production-based emissions of China and Russia were 17,8% and 21,6% higher than consumption-based emissions.

The difference between production-based and consumption-based emissions is the net emissions exports:

$$(1) \quad E_{prod} = E_{cons} + E_{exp} - E_{imp}$$

where E_{prod} – production-based emissions, E_{cons} – consumption-based emissions, E_{exp} – emissions embodied in exports, E_{imp} – emissions embodied in imports.

The gaps between national production-based and consumption-based emissions are defined by the geographical structure of international trade flows of intermediate and final goods. The generally used assessment method for carbon content of trade (“virtual carbon”²) is input-output analysis (IOA), which allows taking the whole supply chain into account.

2. Main approaches to assessment of embodied emissions and literature review

Environmental input-output analysis has been implemented since 1970s, after a publication of Leontief (1970), who considered an economy with two sectors (agriculture and industry) and showed the implications of input-output analysis for accounting environmental externalities. Similar approach was used for accounting energy, water, material use and pollution at different stages of production of final goods. The first significant empirical study using input-output analysis for accounting interregional CO₂ flows was conducted for 38 industries of the United Kingdom. Currently the main databases, containing input-output (IO) tables³ contain information, that link output by industry and by country and associated GHG emissions.

Earlier carbon emissions estimates were based on assumption of equal technologies in different countries (primarily because of data shortage). In other words, bilateral trade was analyzed and national input-output table formed the basis for accounting emissions embodied in exports and imports. For example, Wykoff and Roop (1994) using this assumption, estimated total emissions embodied in imports of the six largest OECD economies (Canada, France, Germany, Japan, Great Britain and United States). They found that the policy of these countries to cap emission may be ineffective if the imports share in consumption is high. However, technology assumption leads to biased estimates of “virtual carbon” volumes, especially if trade partners have substantially different technologies and/or energy balance structures.

In order to eliminate such inaccuracies the use of *multi-regional input-output (MRIO)* tables has started to analyze emissions embodied in exports and imports. These tables extended the concept of W. Leontief and allowed taking inter-country technological differences into account. Although this type of analysis was applied since 1950s for interregional comparisons,

² The term originated from «virtual water» (Atkinson et al., 2011), the amount of water, used for production of a particular good.

³ In particular, bases: World Input-Output Database (WIOD, <http://www.wiod.org/>), Global Trade Analysis Project (GTAP, <http://www.gtap.agecon.purdue.edu>), Eora Database (<http://www.worldmrio.com>)

its application to “virtual carbon” flows has started only recently (Ahmad and Wykoff, 2003; Lenzen, 2004).

Currently there are two main approaches to embodied emissions assessment: *environmentally extended bilateral trade (EEBT)* and *multi-regional input-output analysis (MRIO)* (Peters, 2007). These approaches differ not only in data source (national IO tables for EEBT and MRIO tables for MRIO), but also in assessing emissions on different stages of final goods production.

The difference between two approaches can be illustrated with the following example. Assume country A imports a car from country B. Using EEBT approach, emissions embodied in imports include only emissions related to production of a car itself, whereas emissions from mining of iron ore in country C and smelting of the steel in country D would be imports of country B from countries C and D (The Carbon Trust, 2011).

Using MRIO approach, CO₂ emissions associated with the production of the car – mining of iron ore for the steel, smelting of the steel and the assembly of the car – would be considered as imports of the country A from countries B, C, D. MRIO approach, therefore allows analyzing the whole life cycle of a good and most complete assesses “virtual carbon” volumes.

There are more and more studies using IO analysis for accounting emissions embodied in exports of a particular country (primarily for China – the largest emitter and exporter of CO₂ emissions (Peters et al., 2007; Xu, Allenby, and Chen, 2009; Liu et al., 2010; Lin and Sun, 2010; Dietzenbacher, Pei, and Oosterhaven, 2012, Su, Ang, and Low, 2013)) and emissions embodied in global exports⁴.

Ahmad and Wykoff (2003) found that total CO₂ emissions embodied in exports is comparable with (and in many cases exceeds) total emissions of particular countries. Most developed countries are net importers of emissions, whereas developing countries are primarily net exporters of emissions. Net exports of China and Russia in 1995 was almost equal to net imports of OECD region (Ahmad and Wykoff, 2003). Nevertheless, some studies revealed that some developing countries with energy intensive exports are net exporters of emissions – Australia (Lenzen, 1998), Norway (Peters and Hertwich, 2006) and Sweden (Kander and Lindmark, 2006).

Peters and Hertwich (2008) estimated CO₂ emissions embodied in trade of 87 countries in 2001. Global emissions embodied in exports accounted for 5.3 GtCO₂. The authors pointed out that current international climate change regime is inefficient, because mainly net importers of emissions have taken quantitative commitment under the Kyoto protocol. They suggested including trade effects in national emission inventories and allocating responsibility in

⁴ For an overview see: Wiedmann (2009), Sato (2013)

accordance to regional groups, not countries, which could lessen the influence of trade on CO₂ increase (Peters and Hertwich, 2008).

Davis and Caldeira (2010) calculated CO₂ emissions embodied in exports for 113 countries and 57 industries. In 2004 they were around 6.2 GtCO₂ (later the result was corrected to 6.4 GtCO₂ (Davis, Caldeira and Peters, 2011)), and most emissions embodied in trade occurred as exports from China and other developing countries to OECD countries. In Switzerland, Sweden, Austria, United Kingdom and France more than 30% of consumption-based emissions were embodied in imports and in China 22.5% production-based emissions were embodied in exports. The authors conclude that the allocation of responsibility between producers and consumers of emissions is important for developing an effective climate agreement (Davis and Caldeira, 2010).

Boitier (2012) used MRIO method in order to calculate emissions embodied in trade for 40 countries and 35 industries based on *WIOD* data from 1995 to 2009. The author distinguished “CO₂-consumers” (OECD countries, especially EU-15, where consumption-based emissions exceed production-based emissions) and “CO₂-producers” (developing countries – BRIC and “Rest of the World”). The author suggests implementing not only production-based, but also consumption-based CO₂ accounting, which would allow to elaborate more objective targets for climate change mitigation policy. Moreover, it is assumed that for most countries, that didn't sign Annex I UNFCCC, using consumption-based CO₂ accounting for determining national reduction targets would be preferable and probably stimulated taking quantitative commitments for emission reductions (Boitier, 2012).

Most studies devoted to calculation of emissions embodied in trade include assessment of emissions embedded in exports and imports of Russia (Boitier, 2012; Peters and Hertwich, 2008; Davis, Caldeira, and Peters, 2011). But there are few studies discussing in depth carbon content of Russia's trade (apart from indicating total values).

Emissions embodied in Russia's exports and imports were estimated in 2011 by Russian-Indian research group that used *EEBT* method and IO tables of Rosstat (2002), trade statistics and carbon intensities of industries. Emissions embodied in exports in 2002 accounted for 373 Mt, emissions embodied in exports were about 203 Mt. The authors concluded that the largest importers of emissions from Russia are European countries and China, which is related to high value of exports of mineral resources (Mehra et al., 2011). It was assumed that the technology (and hence carbon intensity) of Russian exports is equal to the imports technology, which lead to some bias.

Piskulova, Kostyunina and Abramova (2013) analyzed exports of Russian regions concerning possible changes in Russian trade partners' climate policies. The authors showed that

carbon intensity of a large number of Russian regions is quite high and the implementation of border carbon adjustment (BCA) by Russian trade partners could be damaging. This study did not include quantitative assessment of emissions embodied in Russian exports.

3. Data description

For estimation of emissions embodied in exports we use *World Input-Output Database* (*WIOD*), which contains national and world IO tables. World IO tables are constructed using national IO tables and/or supply-and-use tables, *UN COMTRADE* trade statistics, OECD, Eurostat, IMF and WTO for services trade data and others (Timmer, 2012).

Russian IO tables in *WIOD* database are constructed using detailed national tables in 1995. For extrapolation to further years developers of the database used Russia's national account system (NAS). Russian statistical service (Rosstat) has changed methodology of the accounting NAS and IO since 1995. This along with high inflation rates during the period of reference lead to biased industry proportions and decreases reliability of Russian IO tables in *WIOD* database (Baranov et al., 2014). However these limitations cannot be avoided and accompany all the dynamic series of Russian IO tables.

Inter-country IO tables in *WIOD* database cover 35 industries and 40 countries (over 85% of the world's GDP), other countries are reflected as "Rest of the world". The tables have the following (simplified) structure: rows contain data about monetary outflows of resources and goods (for domestic consumption and exports) by country and by industry; columns represent inflows of resources and goods (domestically produced and imported) by country and by industry (see Table 1).

WIOD database includes data about CO₂ emissions by country divided into 35 industries and – separately – emissions from final consumption of households. Data is available for 40 countries and "Rest of the world" from 1995 to 2009. This study uses total volumes of emissions received from official national inventories (for Annex I countries)⁵ and World Resource Institute (for non-Annex I countries)⁶. Since the classification of industries in UNFCCC data differs from classification in *WIOD* IO tables, we assume that structure of emissions by industry (each industry's shares in total emissions) is equal to *WIOD* structure. Moreover, due to lack of data for 2010 and 2011 the same structure of emissions as in 2009 was used.

⁵ UNFCCC – http://unfccc.int/ghg_data/items/3800.php

⁶ WRI, CAIT 2.0. 2014. Climate Analysis Indicators Tool: WRI's Climate Data Explorer. Washington, DC: World Resources Institute. <http://cait2.wri.org>

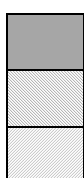
Table 1 – The structure of MRIO tables in *WIOD* database

		Intermediate consumption						Final consumption*			Output (row total)	
		C ₁			...	C ₄₁			C ₁	...		C ₄₁
		O ₁	...	O ₃₅	...	O ₁	...	O ₃₅				
C ₁	O ₁											
	...											
	O ₃₅											
...	O ₁											
	...											
	O ₃₅											
C ₄₁	O ₁											
	...											
	O ₃₅											
GVA at basic prices												
Output at basic prices (column total)												

Value of production of industry 1 country *m* for consumption of industry 35 country 1

O_{*i*} industry *i* = 1, ..., 35.

C_{*m*} country *m* = 1, ..., 41; C₁, ..., C₄₀ – countries, C₄₁ – Rest of the world



Domestic production of country *m* for domestic consumption of country *m*

exports (country *m* to country *v*)

imports (country *m* from country *v*)

*Final consumption includes: Final consumption expenditure by households, Final consumption expenditure by non-profit organisations serving households (NPISH), Final consumption expenditure by government, Gross fixed capital formation. Changes in inventories and valuables assumed to be 0.

Source: authors, based on *WIOD*

4. Methodology

This study employs standard *MRIO* methodology for estimation of emissions embodied in exports. *MRIO* adapted for *WIOD* tables is described in Boitier (2012) and is the basis for this study.

The key idea of assessing emissions embodied in exports using IO tables is combining of (monetary) data about flows of resources and goods (between countries and industries) and CO₂ emissions data (in physical units).

An IO table for MRIO analysis can be represented by:

$$(2) \quad x = Ax + f$$

$$(3) \quad \begin{pmatrix} x_1 \\ \vdots \\ x_m \\ \vdots \\ x_N \end{pmatrix} = \begin{pmatrix} A_{11} & \cdots & A_{1v} & \cdots & A_{1N} \\ \vdots & & \ddots & & \vdots \\ A_{m1} & \cdots & A_{mv} & \cdots & A_{mN} \\ \vdots & & \vdots & \ddots & \vdots \\ A_{N1} & \cdots & A_{Nv} & \cdots & A_{NN} \end{pmatrix} \begin{pmatrix} x_1 \\ \vdots \\ x_m \\ \vdots \\ x_N \end{pmatrix} + \sum_{m=1}^N \begin{pmatrix} f_{1m} \\ \vdots \\ f_{vm} \\ \vdots \\ f_{Nm} \end{pmatrix}$$

where x_m – is the vector of total output in country m , $m = v = 1, \dots, N$; A_{mv} – the inter-industrial matrix between country m and country v , where the elements are measured per unit of output; f_{vm} is a vector of the final demands in country m addressed to country v .

The output x can be calculated in terms of final consumption:

$$(4) \quad x - Ax = \sum_m f_m$$

$$(5) \quad x(I - A) = \sum_m f_m$$

где I – identity matrix, f_m – a vector of the final demands in country m .

$$(6) \quad x = \sum_m (I - A)^{-1} f_m$$

$$(7) \quad x = \sum_m y_m$$

where y_m is a vector of output of country m , necessary to meet the final demands in country m and its trade partners.

Breaking down y_m into domestic output used for domestic final consumption of country m ($y_{m,m}$) and domestic output of country m used for foreign final consumption of country v ($y_{m,v}$) (при $m \neq v$):

$$(8) \quad y_m = y_{m,m} + y_{m,v}$$

$$(9) \quad y_{m,m} = (I - A_{m,m})^{-1} f_{m,m}$$

$$(10) \quad y_{m,v} = (I - A_{m,v})^{-1} f_{m,v}$$

Total output in country m is:

$$(11)$$

$$x_m = \sum_{v=1}^N y_{m,v}$$

In order to calculate the CO₂ emissions related to the production of y_m , it is multiplied by the following coefficient:

$$(12) \quad e = \frac{\text{industry CO}_2 \text{ emissions}}{\text{industry output}}$$

where industry output is the row total in IO table. Thereafter, matrix E represents intercountry flows of “virtual carbon”. In particular, CO₂ emissions of country m for domestic consumption:

$$(13) \quad E_{m,m} = e_m y_{m,m} = e_m (I - A_{m,m})^{-1} f_{m,m}$$

CO₂ emissions embodied in exports from country m :

(14)

$$E^{exp} = \sum_{v \neq m} E_{m,v} = e_m y_{m,v} = e_m (I - A_{m,v})^{-1} f_{m,v}$$

CO₂ emissions embodied in imports to country m :

(15)

$$E^{imp} = \sum_{m \neq v} E_{v,m} = e_v y_{v,m} = e_v (I - A_{v,m})^{-1} f_{v,m}$$

Production-based CO₂ emissions are calculated the following way:

$$(16) \quad E^{prod} = E_{m,m} + E^{exp} + E^H$$

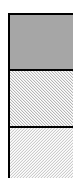
and consumption-based CO₂ emissions:

$$(17) \quad E^{cons} = E_{m,m} + E^{imp} + E^H$$

where E^H – emissions from final consumption of households (for example, from burning car fuel in country m) (see Table 2).

Table 2 – Structure of the table reflecting inter-industry and inter-country flows of “virtual carbon”

		Final consumption				
Production		C ₁	...	Russia	...	C _N
C ₁	O ₁₋₃₅			CO ₂ imports		
...	...			CO ₂ imports		
Russia	O ₁₋₃₅	CO ₂ exports	CO ₂ exports	CO ₂ from production of Russia for final consumption in Russia	CO ₂ exports	CO ₂ exports
...				CO ₂ imports		
C _N				CO ₂ imports		



CO₂ from production of Russia for final consumption in Russia

CO₂ exports (from country 1 to country m)

CO₂ imports (from country m to country 1)

Source: authors, based on *WIOD*

5. Results

5.1 Emissions embodied in Russia’s exports

Currently Russia ranks fourth in the world according to carbon emissions, after China, United States and India⁷, and if taking into account land use, land-use change and forestry (LULUCF) it is probably behind Brazil and Indonesia. The Soviet industrialization 1930-1980s was accompanied by an rapid GHG emissions growth. For 70 years Soviet Union has increased annual CO₂ emissions more than 1000-fold (from 11.2 Mt in 1922 to 1.1 Gt in 1988), and before its collapse, the volume of its emissions was very close to that of the United States (Marland et al., 2011). After the collapse of the USSR Russia experienced painful transitional crisis that resulted in sharp GDP fall by 42.5%⁸, many enterprises were dissolved. One of external effects of the crisis was the reduction of CO₂ emissions (see Figure 1). By 1998 CO₂ emissions (not including LULUCF) decreased by 42.5% in comparison to 1990. Economic recovery since 1999 has not returned Russia to its previous level of emissions, as it has been accompanied by industry restructuring: the carbon-intensive industries that dominated in the Soviet era in the structure of the economy have been replaced by the service sector (Grigoryev, Makarov, and Salmina, 2013).

⁷ According to UNFCCC

⁸ According to World Development Indicators

During the first decade of 21st century carbon emissions have slightly increased and in 2012 they were 33.9% lower than in 1990⁹.

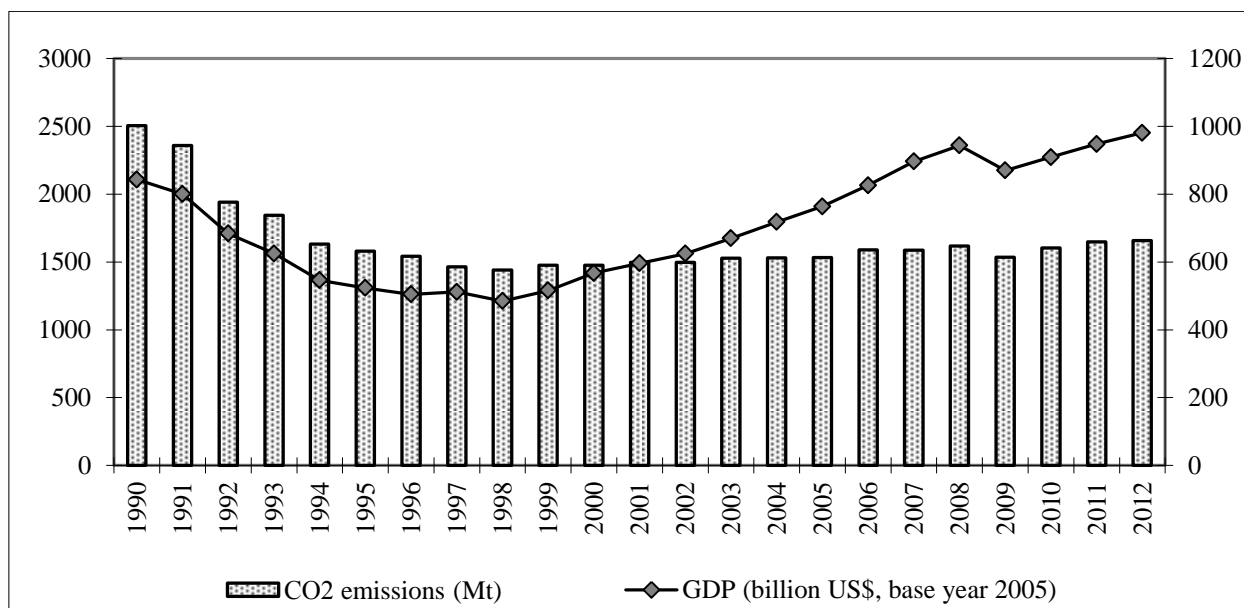


Figure 1 – CO₂ emissions (left axis) and GDP (right axis) in Russia in 1990-2012.

Source: UNFCCC, World Developments Indicators

It could be expected that dynamics of emissions embodied in Russia’s exports coincides with dynamics of total emissions. However, it was revealed that it is not true. In 2011 Russia exported 541 Mt of CO₂ (Figure 2). It is the highest value since 2007, but it is 18% lower than in 2000. In 2000 Russia exported 45% of total emissions, in 2011 – only 32%.

This tendency could seem odd, because the export value (US dollar, current prices) rose 5-fold from 2000 to 2011 and production-based emissions (according to UNFCCC national inventories) increased by 11%¹⁰. However, export volume index¹¹, reflecting real export volumes, reached only 140% by 2011 (base year 2000)¹². 40%-increase of commodity exports was compensated, on the one hand, by technological improvement and on the other hand by simplification of export structure (production of final goods, which requires burning large volumes of domestic fossil fuel, is associated with higher emissions volumes than selling raw mineral fuels).

⁹ According to UNFCCC

¹⁰ According to UNFCCC

¹¹ The ratio of export value index and national currency value index

¹² According to World Development Indicators

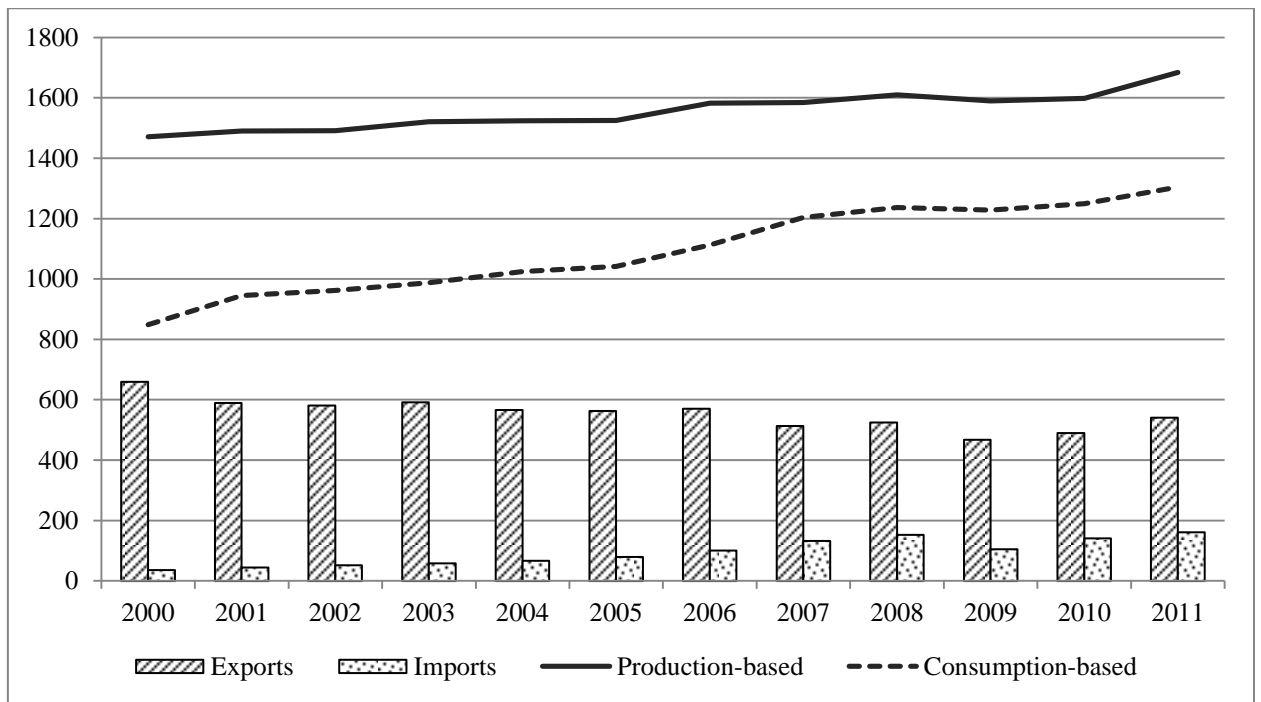


Figure 2 – Production-based and consumption-based emissions, CO₂ exports and imports, Mt, 2000-2011)

Source: authors' calculations, based on UNFCCC and *WIOD*

Our estimates of emissions embodied in Russia's exports are comparable with the results of other studies that employed MRIO method, excluding the studies based on *GTAP* database (see Table 3). This database has several differences from *WIOD* and *Eora*. Firstly, *GTAP* includes only CO₂ from fuel combustion, whereas other bases include also emissions from industrial processes. Secondly, *GTAP* uses world average emission coefficients for industry analysis (12)¹³. Since emission coefficients for most Russian industries are higher than the world average, *GTAP* data analysis leads to underestimation of emissions embodied in exports. As it was expected our estimates of emissions embodied in exports are higher than estimates based on the use of *EEBT* method (this method initially covers narrower range of trade flows).

¹³ Limitations of *GTAP* are described in detail in Peters and Hertwich (2007)

Table 3 – Estimates of emissions embodied in Russia’s exports in 2000-2011.

	Data source	Method	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
This study	WIOD	MRIO	659	590	581	592	567	563	571	513	525	468	490	541
Lenzen et al. (2013)	Eora	MRIO	604	596	649	631	568	504	557	522	506	483	414	-
Boitier (2012)	WIOD	MRIO	703	625	615	635	606	604	614	555	558	469	-	-
Mehra et al. (2011)	Input-output, Russia	EEBT	-	-	372	-	-	-	-	-	-	-	-	-
Peters and Hertwich (2008)	GTAP	MRIO simpl*	-	413	-	-	-	-	-	-	-	-	-	-
Davis, Caldeira, and Peters (2011)	GTAP	MRIO	-	-	-	-	422	-	-	-	-	-	-	-

*Within simplified version of *MRIO* traded goods are not divided into intermediate and final consumption. Therefore *MRIO* results are close to *EEBT*.

Source: authors’ calculations, based on *UNFCCC* and *WIOD*; (Lenzen et al., 2013); (Boitier, 2012); (Mehra et al., 2011); (Peters and Hertwich, 2008); (Davis, Caldeira, and Peters, 2011).

5.2 Structure of emissions embodied in Russia’s exports

Emissions embodied in exports, are represented primarily (42%) by industry “Electricity, Gas and Water Supply” (related to emissions associated with electricity, water and heat production for manufacturing exported goods). 16% of emissions embodied in exports occur in “Basic Metals and Fabricated Metal” sector, 14% – in “Mining and Quarrying” (mainly oil), 13% falls on transport. The structure of emissions embodied in exports remains stable – emissions associated with electricity, gas and water supply decreased by several percentage points, substituted by increase in transport (see Figure 3).

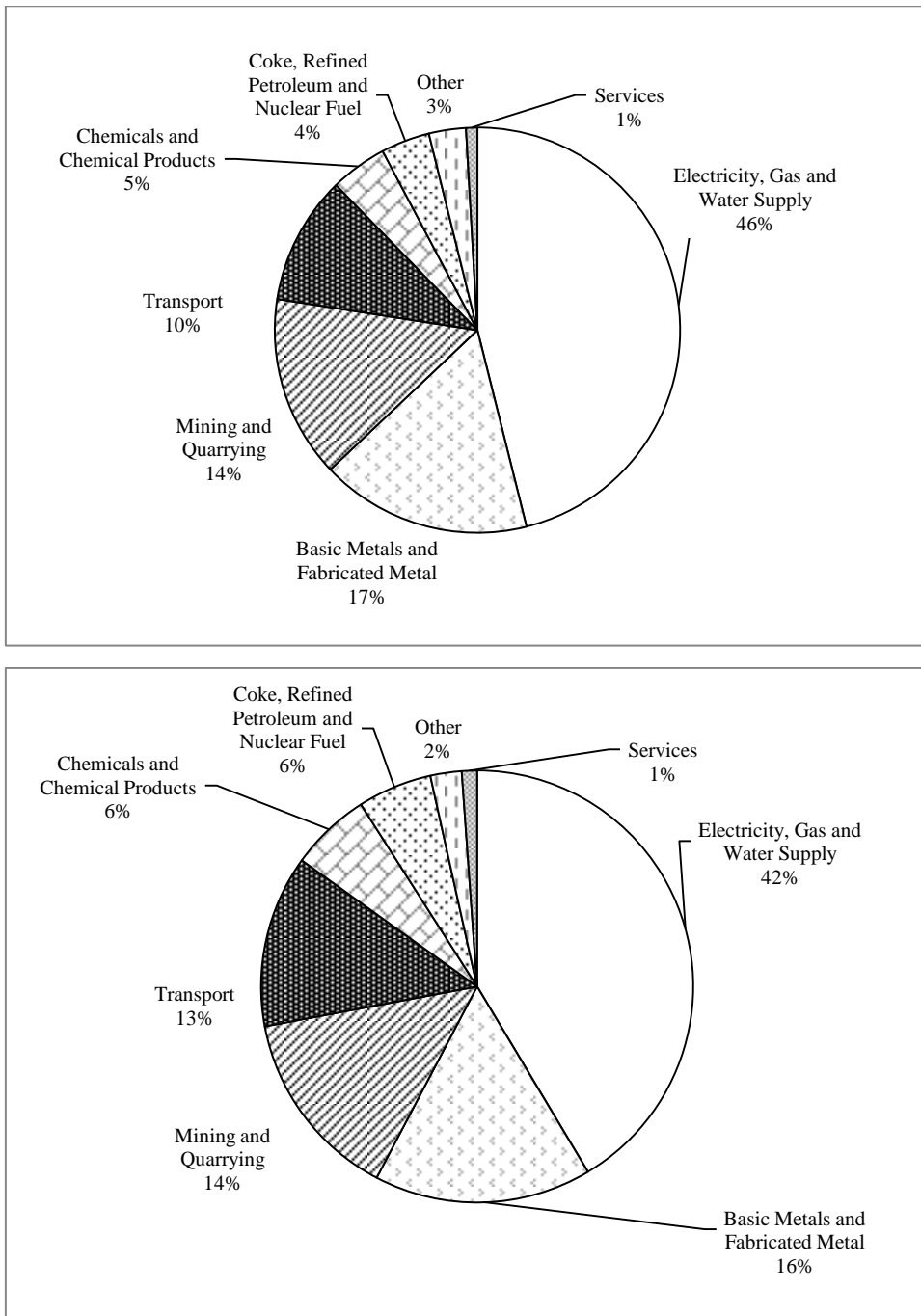


Figure 3 – Industrial structure of emissions embodied in Russia’s exports in 2000 (above) and 2011 (below)

*"Other" includes: Rubber and Plastics; other Non-Metallic Mineral; Agriculture, Hunting, Forestry and Fishing; Pulp, Paper, Paper, Printing and Publishing; Machinery & Equipment; Construction; Food, Beverages and Tobacco; Leather, Leather and Footwear; Wood and Products of Wood and Cork; Textiles and Textile Products; Manufacturing, Nes; Recycling.

Source: authors’ calculations, based on UNFCCC and *WIOD*.

Large part of emissions embodied in Russia’s exports in 2011 was directed to the USA (see Figure 4). It could seem odd because of low volume of export from Russia to the United

States. The reason lies methodology features. The MRIO method considers as emissions embodied in exports from Russia to the USA not only emissions associated with manufacturing of exported final products, but also the emissions associated with mining of resources, exported to China, the EU and other countries and then used there for production of goods, exported to the USA. Therefore, directions of Russian emission exports using MRIO method are defined not by directions of Russian commodity exports, but by global trade flows. Comparing emissions export data in 2000 and 2011, the share of China significantly increased (from 4% to 10%) and the share of Germany declined (from 16% to 6%). The share of the EU countries decreased from 59% to 40%.

5.3 Emissions embodied in Russia's imports

Emissions embodied in Russia's imports increased 4.4-fold from 2000 to 2011 (see Figure 2). The reasons were rising commodity imports volume and substitution of imports of European goods by more carbon intensive Chinese goods. However, emissions embodied in imports in 2011 accounted for only 161 MtCO₂ – 3.4 times less than emissions embodied in exports.

Industrial structure of emissions embodied in imports is more differentiated than that of emissions embodied in exports, which is determined by more complicated structure of Russian imports in comparison to exports. Emissions embodied in imports are represented by “Electricity, Gas and Water Supply” (41%), “Basic Metals and Fabricated Metal” (10%) and “Transport” (9%), large part of emissions is associated with “Chemicals and Chemical Products” (9%), “Rubber and Plastics; other Non-Metallic Mineral” (7%), and “Agriculture, Hunting, Forestry and Fishing” (4%). Emissions from mining and quarrying, representing a large part of emissions embodied in exports, have a small share in imports (see Figure 5).

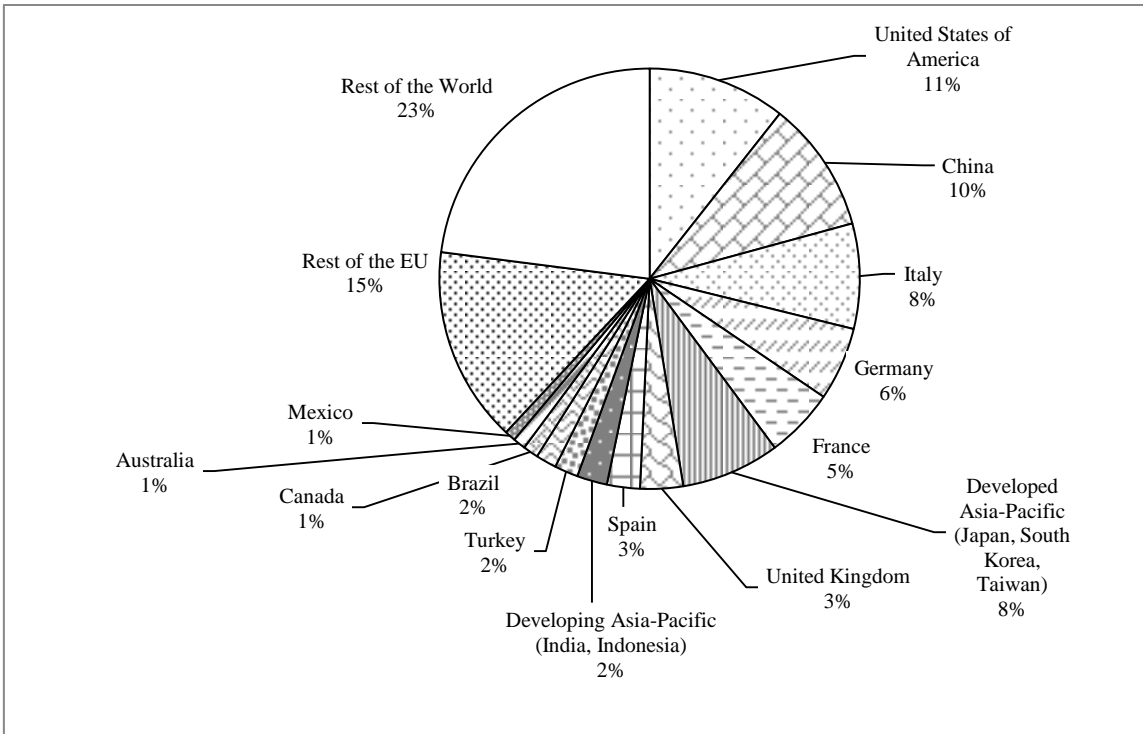
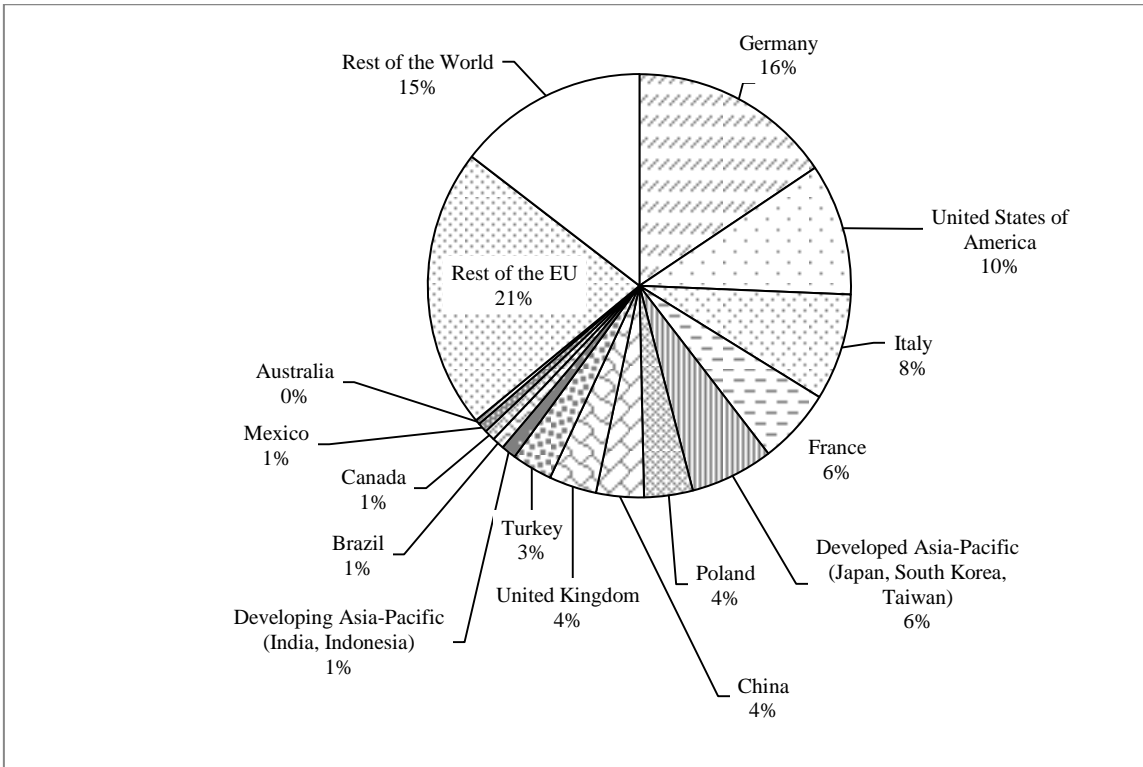


Figure 4 – Structure of emissions embodied in Russia’s exports in 2000 (above) and 2011 (below) by partner

* Due to lack of data we had to include a range of large trade partners of Russia in the category “Rest of the world” (Ukraine, Belarus, Kazakhstan)

Source: authors’ calculations, based on UNFCCC and *WIOD*.

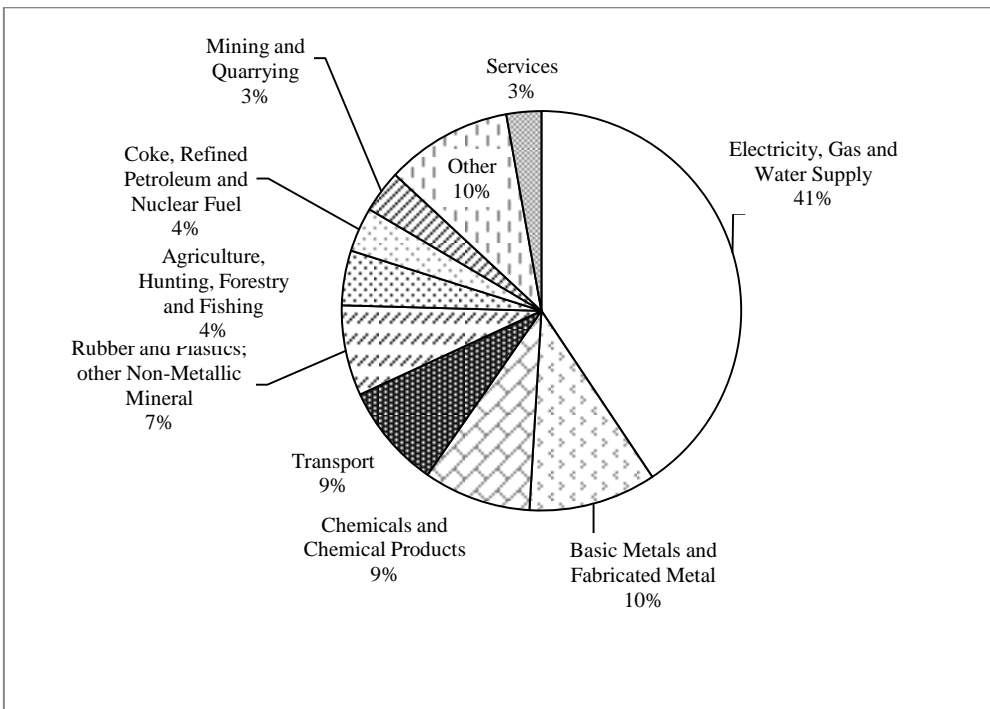
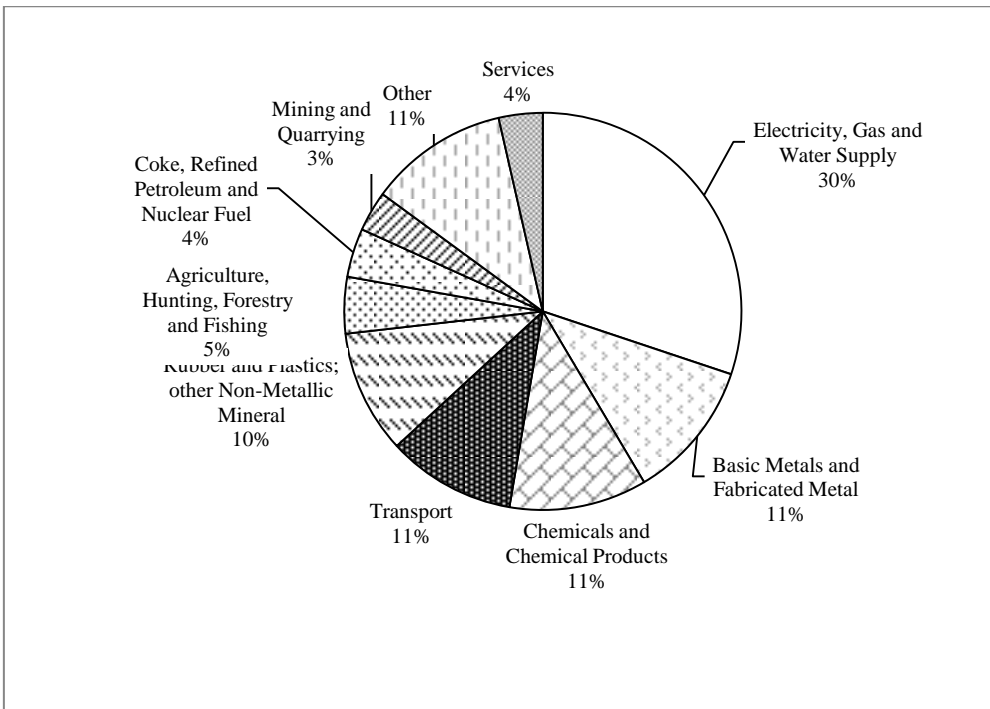


Figure 5 – Industrial structure of emissions embodied in Russia's imports in 2000 (above) and 2011 (below)

Other includes: Textiles and Textile Products; Machinery & Equipment; Food, Beverages and Tobacco; Pulp, Paper, Paper, Printing and Publishing; Leather and Footwear; Wood and Products of Wood and Cork; Manufacturing, Nec; Recycling; Construction.

Source: authors' calculations, based on *UNFCCC* and *WIOD*.

It is worth pointing out that the share of "Electricity, Gas and Water Supply" in emissions embodied in imports increased from 30 to 41% from 2000 to 2011. On the one hand, it can be explained by the growth of the share of final industrial goods in imports, on the other hand –

increased share of imports from China, characterized by lower energy efficiency than European countries.

Geographical structure of imports changed drastically for 10 years (see Figure 6). In 2000 China represented only 10% of emissions embodied in Russian imports; in 2011 it was already 39%. Six leading Asia-Pacific countries (China, India, Indonesia, Japan, South Korea, and Taiwan) represent now more than a half of emissions embodied in Russian imports, while the share of the USA and the EU (previously dominating Russian import structure) has decreased. In general, structure of emissions embodied in imports reflects current structure of production-based emissions on the whole world with some corrections determined by the geographical proximity of Russia to Asia-Pacific.

5.4 Comparison of emissions embodied in trade in Russia and other countries

Accounting of production-based and consumption-based CO₂ emissions reveals different results. For example, share of China in global production-based CO₂ emissions in 2011 is 30%, whereas its share in global consumption-based CO₂ emissions is only 25%. The USA demonstrates the opposite tendency: its share in global production-based CO₂ emissions is 19%, while its share in consumption-based CO₂ emissions accounts for 21% (see Table 4).

In Russia production-based and consumption-based CO₂ emissions also significantly differ. Russia is the fourth largest emitter (production-based approach) and its share in global production-based emissions is 6%. Under the consumption consumption-based Russia is responsible to only 4% of global emissions and cedes the fourth place to Japan.

The gap between production-based and consumption-based CO₂ emissions is determined by large Russian emission exports (even larger than the US exports, despite the huge difference in commodity export volumes) and by extremely low emission imports (Russia isn't even listed among top 10 countries).

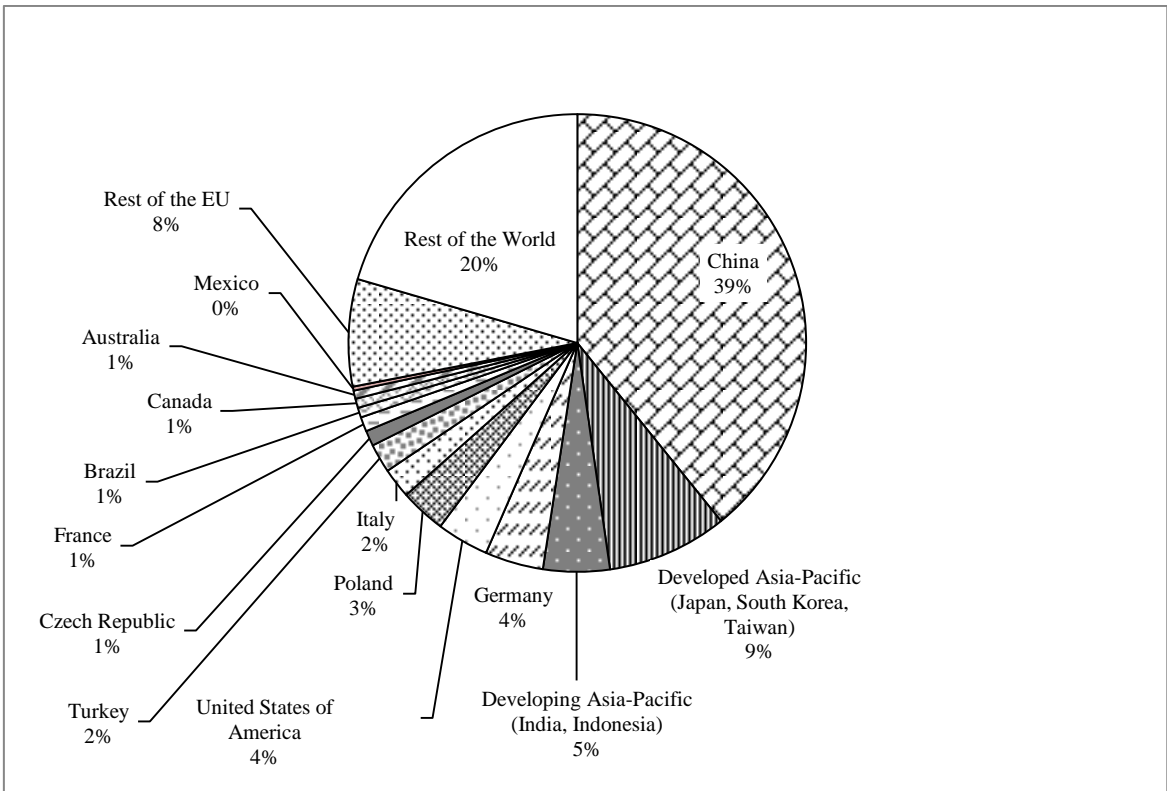
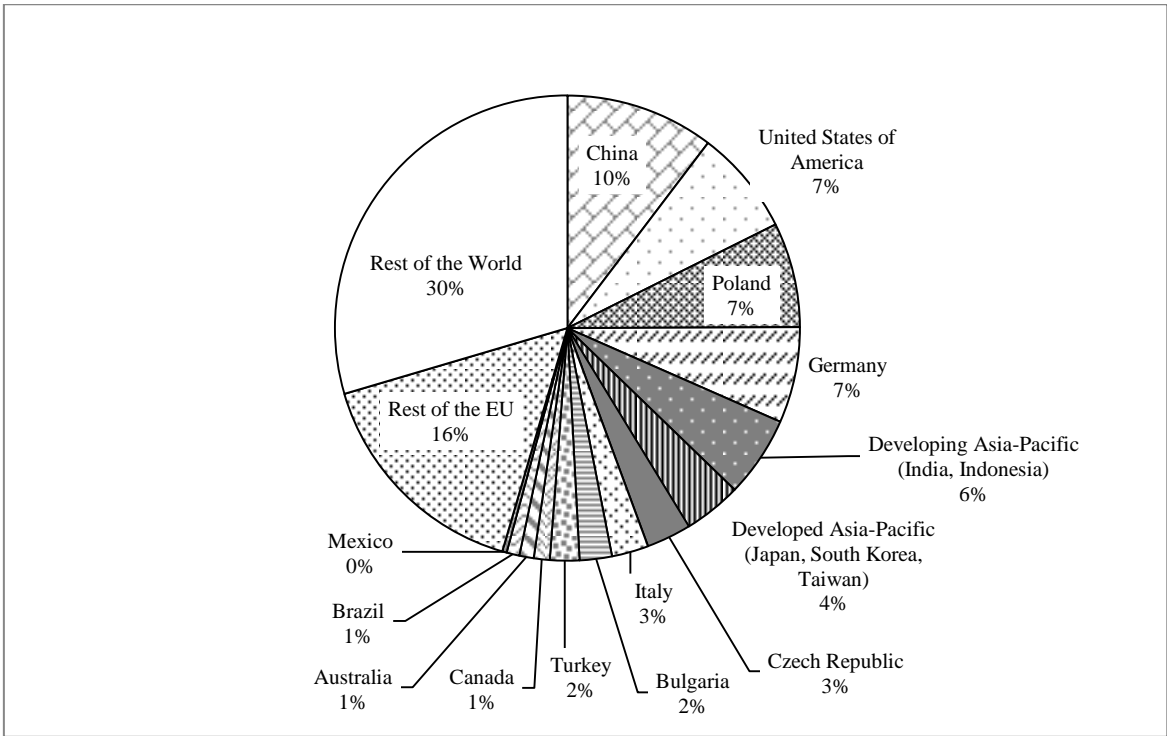


Figure 6 – Structure of emissions embodied in Russia’s imports in 2000 (above) and 2011 (below) by partner

* Due to lack of data we had to include a range of large trade partners of Russia in the category “Rest of the world” (Ukraine, Belarus, and Kazakhstan).

Source: authors’ calculations, based on UNFCCC and *WIOD*.

Table 4 – Emissions embodied in exports and imports of the main CO₂ emitters in 2000 and 2011

No	Country	Production-based emissions, Mt	Consumption-based emissions, Mt	Emissions embodied in exports, Mt	Emissions embodied in imports, Mt	Net emission exports, Mt	Share in production-based emissions, %	Share in consumption-based emissions, %
2000								
1	United States of America	5962,7	6643,2	486,6	1167,1	-680,5	27%	30%
2	China	3607,5	3093,2	696,7	182,3	514,3	16%	14%
3	Russian Federation	1471,3	848,6	659,4	36,7	622,8	7%	4%
4	Japan	1251,5	1496,1	190,5	435,1	-244,6	6%	7%
5	India	1023,8	922,3	174,9	73,4	101,6	5%	4%
6	Germany	891,4	1101,5	212,4	422,5	-210,1	4%	5%
7	Canada	564,6	503,5	208,6	147,5	61,1	3%	2%
8	United Kingdom	555,2	685,6	126,8	257,2	-130,4	3%	3%
9	South Korea	463,3	434,3	147,5	118,6	29	2%	2%
10	Italy	462,3	577,5	103,9	219,1	-115,2	2%	3%
11	France	415,8	532,5	103,9	220,5	-116,7	2%	2%
12	Mexico	376,3	412,1	68,3	104,2	-35,9	2%	2%
13	Australia	349,4	339,7	88,6	78,9	9,7	2%	2%
14	Brazil	326,9	348,3	40,9	62,3	-21,4	1%	2%
15	Rest of the World	4294,3	3934	1102,6	742,3	360,4	20%	18%
2011								
1	China	9034,7	7503,4	2116,4	585	1531,4	30%	25%
2	United States of America	5603,8	6303,6	522,5	1222,3	-699,8	19%	21%
3	India	1860,9	1782,2	319	240,3	78,7	6%	6%
4	Russian Federation	1684,4	1304,9	540,7	161,2	379,6	6%	4%
5	Japan	1240,7	1475,1	249,9	484,3	-234,4	4%	5%
6	Germany	798,1	981,3	243,4	426,7	-183,3	3%	3%
7	South Korea	611,7	555,8	236,8	181	55,9	2%	2%
8	Canada	555,6	593,2	180,3	217,8	-37,6	2%	2%
9	United Kingdom	464,6	604,4	118,5	258,3	-139,8	2%	2%
10	Mexico	458,1	505	87,5	134,4	-46,9	2%	2%
11	Indonesia	447,2	457,2	103,2	113,2	-10	1%	2%
12	Brazil	443,2	524,7	66,6	148,1	-81,5	1%	2%
13	Italy	414,2	548,7	98,9	233,4	-134,5	1%	2%
14	Australia	406,6	503,3	87	183,7	-96,7	1%	2%
15	Rest of the World	6254,4	6215	1401,5	1362,1	39,4	21%	21%

Source: authors' calculations, based on UNFCCC and WIOD.

Russia was the global leader by net emissions exports as far back as in 2000. However, its net emissions exports have declined by 40% and the figures for China have increased almost threefold. As a result, currently Russia is the second largest exporter of CO₂ emissions after China. The gap between Russia and China is fourfold. However, Russia's net emissions exports are 4.8 times higher than that of the third largest emitter – India.

There are not so many countries showing positive net emissions exports. Among countries, included in *WIOD*, positive net emission exports are attributable to China, Russia, India, some Asian countries (South Korea and Taiwan), and several countries of Eastern Europe. But even in countries of Eastern Europe (except Poland) net emission exports are not far from zero.

Russia is one of the leaders by export share in production-based emissions. 32.3% of emissions within national borders are exported. It is much higher than in China (23.4%) and the USA (9.3%). Export share in production-based emissions is higher than in Russia only in South Korea (38.7%) and Canada (32.5%). Comparable volumes are shown by Germany (30.5%) (see Table 4).

On the contrary, Russia's imports share in consumption-based emissions is low in comparison to other large economies – China (7.8%), India (13.5%) and the USA (19.4%). This figure for leading European countries – Germany, United Kingdom and Italy – exceeds 40%.

5.5 Reasons for large volumes of emissions embodied in Russia's exports

On the one hand, large volumes of emissions embodied in Russia's exports are explained by its commodity structure of exports, which is primarily represented by fuels and energy intensive industries. Countries with high export share in production-based emissions are South Korea, Canada, Russia and Germany. In case of South Korea and Germany it is explained by high export quota, and in case of Russia and Canada the only explanation is distortion of the structure of exports towards energy intensive products.

On the other hand, net exporters of emissions are mainly Asian countries and countries of Eastern Europe. These countries have high carbon intensity of exports (and Russia is the leader), which is defined as ratio of emissions embodied in exports to the value of commodity exports (see Figure 7). This allows us to presume that large volumes of emissions embodied in exports are determined by relative technological backwardness, typical for developing countries and economies accomplishing a transition from a command-and-control to a market economy.

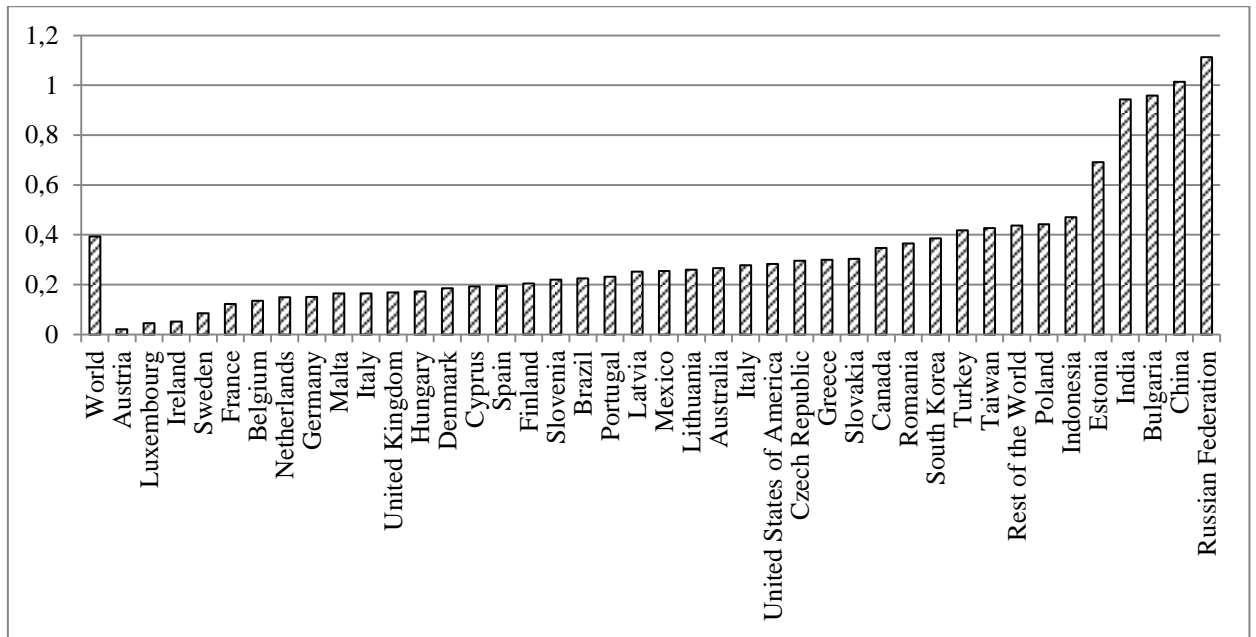


Figure 7 – Carbon intensity of exports in 2011, tCO₂/thousand US\$

Source: authors' calculations, based on UNFCCC and WIOD.

One opportunity to assess the influence of technological factor on Russia's emission exports is to calculate CO₂ emissions embodied in exports of Russia making the assumption that for the given volumes and structure of exports it uses technologies, identical to technologies of developed countries. Though there is no universal standard of a country with clean technologies, we take Germany as an example. In order to get comparable results, assume then that technologies that are used in Germany are used globally.

For this purpose we substitute matrices A in equation (3) for Russia and other countries by matrix A for Germany (for example, $A_{RUS,RUS} = A_{DEU,DEU}$, $A_{RUS,m} = A_{DEU,m}$; $m = 1, \dots, N$)¹⁴. The data about national output and final consumption of goods and services remain unchanged.

Thus the initial inter-country IO table (3) turns into:

(18)

$$\begin{pmatrix} x_1 \\ \vdots \\ x_{RUS} \\ \vdots \\ x_N \end{pmatrix} = \begin{pmatrix} A_{1,1} & \cdots & A_{1,RUS} & \cdots & A_{1,N} \\ \vdots & \ddots & \vdots & & \vdots \\ A_{RUS,1} & \cdots & A_{RUS,RUS} & \cdots & A_{RUS,N} \\ \vdots & & \vdots & \ddots & \vdots \\ A_{N,DEU} & \cdots & A_{N,RUS} & \cdots & A_{NN} \end{pmatrix} \begin{pmatrix} x_1 \\ \vdots \\ x_{RUS} \\ \vdots \\ x_N \end{pmatrix} + \sum_{m=1}^N \begin{pmatrix} f_{1,m} \\ \vdots \\ f_{RUS,m} \\ \vdots \\ f_{Nm} \end{pmatrix} =$$

¹⁴ This method is described by Lenzen (2004)

$$= \begin{pmatrix} A_{DEU,DEU} & \cdots & A_{DEU,RUS} & \cdots & A_{DEU,N} \\ \vdots & \ddots & \vdots & & \vdots \\ A_{DEU,1} & \cdots & A_{DEU,DEU} & \cdots & A_{DEU,N} \\ \vdots & & \vdots & \ddots & \vdots \\ A_{N,DEU} & \cdots & A_{DEU,v} & \cdots & A_{DEU,DEU} \end{pmatrix} \begin{pmatrix} x_1 \\ \vdots \\ x_{RUS} \\ \vdots \\ x_N \end{pmatrix} + \sum_{m=1}^N \begin{pmatrix} f_{1,m} \\ \vdots \\ f_{RUS,m} \\ \vdots \\ f_{N,m} \end{pmatrix}$$

Assume that carbon intensity coefficients of different industries (12) are equal to corresponding coefficients of Germany ($e_m = e_{DEU}$). Then, taking into account (14), emissions embodied in exports of Russia are:

(19)

$$E_{RUS}^{exp} = \sum_{v \neq RUS} E_{RUS,v} = e_{DEU} y_{RUS,v} = e_{DEU} (I - A_{DEU,v})^{-1} f_{RUS,v}$$

And emissions embodied in imports of Russia, taking into account (15) are:

(20)

$$E_{RUS}^{imp} = \sum_{v \neq RUS} E_{v,RUS} = e_{DEU} y_{v,RUS} = e_{DEU} (I - A_{v,DEU})^{-1} f_{v,RUS}$$

Calculation results according to (19) and (20) are shown in Figure 8. Under the assumption that Russia uses the same technologies as Germany, Russia's emissions exports in 2011 would decline 3.1-fold (from 541 to 175 MtCO₂). Thus only the third of Russian emission exports are determined by volume and commodity structure of Russian exports, and the rest two thirds are determined by technological lagging (behind Germany).

Using the assumption that German technologies are used in all Russia's trade partners, Russia's emission imports would also decline – 2.8-fold (from 157 to 61 MtCO₂ in 2011). Therefore, under the assumption of global implementation of clean technologies (equal to German ones) Russia would still be a net exporter of emissions and the ratio of exports to imports would hardly change: from 3,4:1 to 3,1:1.

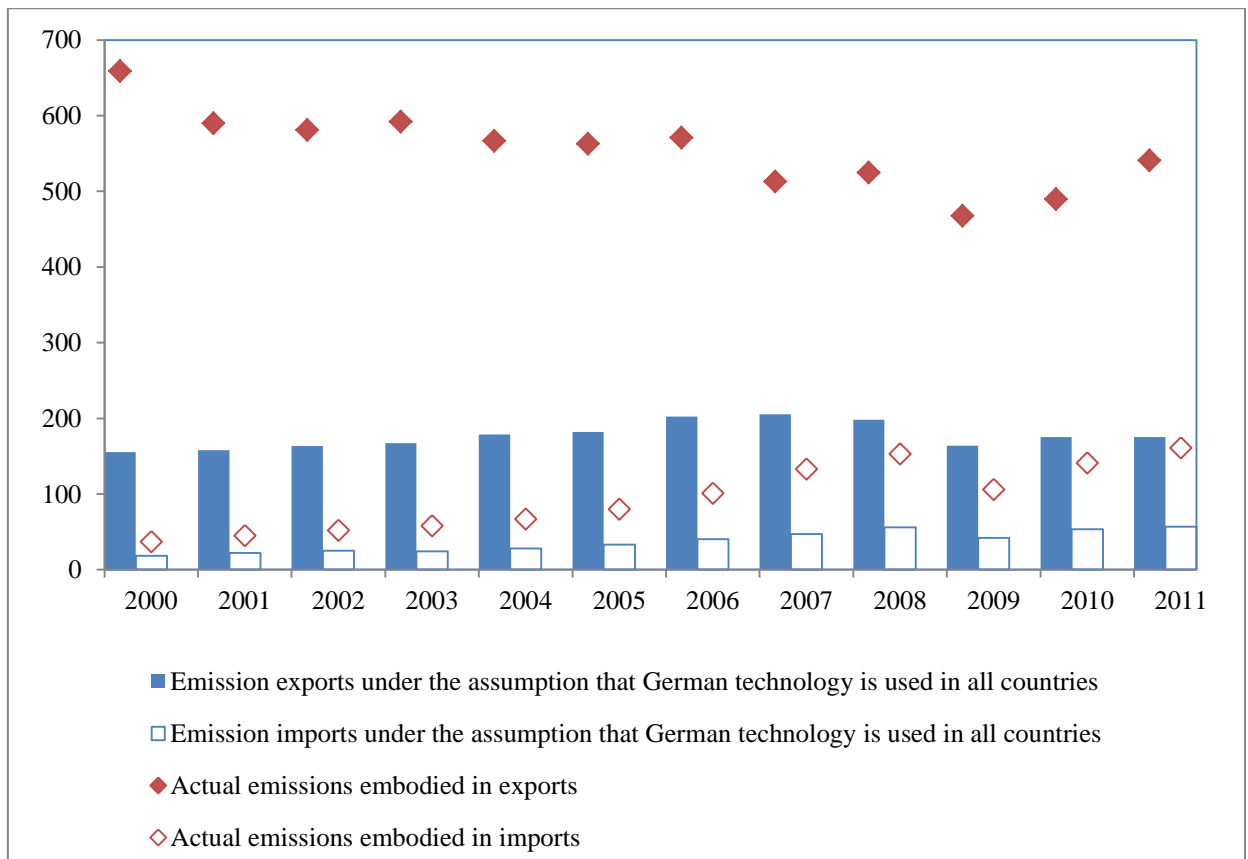


Figure 8 – Emissions embodied in exports and imports of Russia in 2011 – actual values and those under the assumption that German technologies are used all over the world

Source: authors' calculations, based on UNFCCC and *WIOD*.

Moreover, in case if the world implements technology of Germany, Russia would become the largest net exporter of emissions (see Figure 9) and the fourth largest exporter of emissions (after China, Germany and the USA). Hence, large net exports of emissions cannot be explained only by technological backwardness – current ratio of exports to imports and existing structure of foreign trade a priori make Russia one of the largest net emission exporters.

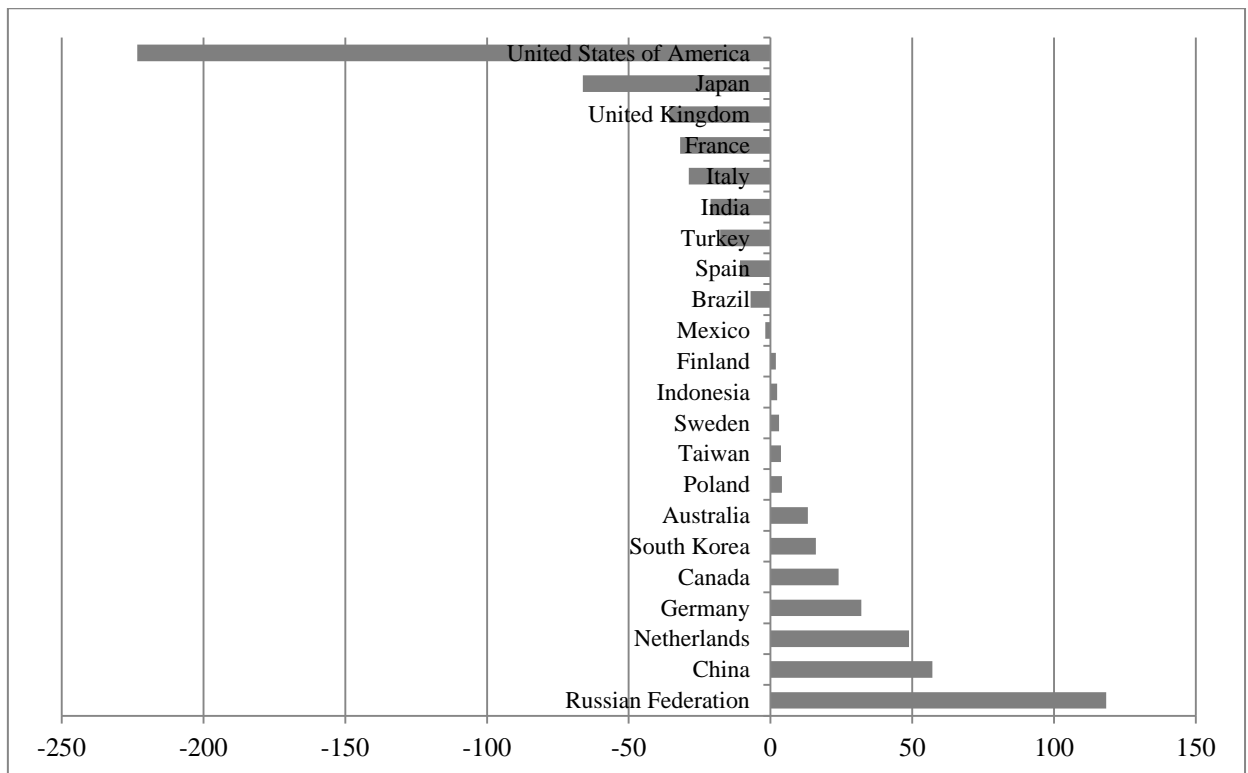


Figure 9 – Net emission exports in 2011 under the assumption that all countries use technologies as in Germany

Source: authors' calculations, based on *UNFCCC* and *WIOD*.

6. Discussion

Analysis conducted in this paper shows that flows of emissions embodied in international trade are too large to ignore them within international climate change regime. Taking into account that most emissions are exported from leading developing to developed countries, neither exporters (leading developing countries, non-Annex I) nor importers (developed countries, obliged to reduce domestic emissions only) undertake obligations to reduce these emissions. New climate agreement that should be adopted by 2015 and come into effect beyond 2020, presumes participation of developing countries. In this case they will take responsibility for most emissions embodied in exports. However, it is exactly the reason why it does not work to convince developing countries to join binding agreement.

Before the end of the first commitment period of the Kyoto protocol Russia found itself in a situation, which presumably threatens leading developing countries after 2020. Russia did not take any quantitative commitments within the second commitment period. Currently Russia is the only Annex I UNFCCC party with large net exports of emissions. Substantial part of its emissions is associated with consumption of developed countries, but Russia is solely responsible for these emissions.

Hence, the reallocation of responsibility for CO₂ emissions embodied in exports towards the joint responsibility between exporters and importers corresponds Russia's interests. An importer should be responsible, because its demand forms the precondition for emissions. At the same time, shifting all the responsibility to the importer is not correct, because an exporter, releasing emissions by producing an exported good, receives a payment from an importer (Sato, 2013).

There can be different forms of joint responsibility. For example, commitments for emissions reduction under a new agreement can be corrected considering emissions embodiment in trade (net exporters could take a smaller commitment and net importers – a higher commitment in comparison to that based on production-based emissions only). Another option is a mechanism of compensation from net importers to net exporters for taking full responsibility for emissions. It is also possible to implement flexibility mechanisms, giving an opportunity to developed countries to finance (on account of their emissions reduction obligations) projects located in other countries aimed at reducing emissions embodied in exports.

At the same time demand for allocation of responsibility for exported emissions between exporters and importers are justified only in relation to that part of emissions which is determined by large volumes and/or peculiarities of commodity structure of exports, and not by application of “dirty” technologies. The analysis conducted in this study shows that this share of Russian emissions exports accounts for about one third. The rest two thirds¹⁵ of emissions embodied in Russian exports result from technological lagging behind developed countries and the responsibility for these emissions lies with Russia.

Moreover, exactly this part of emissions makes Russia vulnerable to implementation of border carbon adjustment (carbon tax). In some measure they can also be treated as a mechanism of allocating responsibility for exported emissions between exporters and importers. One part of costs associated with implementation of border carbon adjustment falls on consumers of importing country, who have to pay higher prices for imported goods, on which carbon tax is imposed. Another part of costs falls on exporters because of declining competitiveness of their products in importing country.

Obvious drawbacks of “carbon protectionism” lie in welfare losses in exporting and importing countries and initial conflictness of such measures (that is why they called “carbon protectionism”). Finding a compromise while allocating responsibility for emissions reduction, which implies mutual consideration of interests by net exporters and net importers, elaboration of cooperation mechanisms for exported emissions reduction (as technology transfer or as

¹⁵ Both estimates should be taken as approximate, while Germany was chosen as a representative of developed countries, and its representativeness is hard to assess.

economic flexibility mechanisms) are more appropriate measures for enhancement of international climate change regime in the future.

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Appendix

1. Industries in *WIOD* database

#	Industry
1	Agriculture, Hunting, Forestry and Fishing
2	Mining and Quarrying
3	Food, Beverages and Tobacco
4	Textiles and Textile Products
5	Leather, Leather and Footwear
6	Wood and Products of Wood and Cork
7	Pulp, Paper, Paper , Printing and Publishing
8	Coke, Refined Petroleum and Nuclear Fuel
9	Chemicals and Chemical Products
10	Rubber and Plastics
11	Other Non-Metallic Mineral
12	Basic Metals and Fabricated Metal
13	Machinery, Nec
14	Electrical and Optical Equipment
15	Transport Equipment
16	Manufacturing, Nec; Recycling
17	Electricity, Gas and Water Supply
18	Construction
19	Sale, Maintenance and Repair of Motor Vehicles and Motorcycles; Retail Sale of Fuel
20	Wholesale Trade and Commission Trade, Except of Motor Vehicles and Motorcycles
21	Retail Trade, Except of Motor Vehicles and Motorcycles; Repair of Household Goods
22	Hotels and Restaurants
23	Inland Transport
24	Water Transport
25	Air Transport
26	Other Supporting and Auxiliary Transport Activities; Activities of Travel Agencies
27	Post and Telecommunications
28	Financial Intermediation
29	Real Estate Activities
30	Renting of M&Eq and Other Business Activities
31	Public Admin and Defence; Compulsory Social Security
32	Education
33	Health and Social Work
34	Other Community, Social and Personal Services
35	Private Households with Employed Persons

2. Countries in *WIOD* database

EU-27		
Austria	Germany	Netherlands
Belgium	Greece	Poland
Bulgaria	Hungary	Portugal
Cyprus	Ireland	Romania
Czech Republic	Italy	Slovakia
Denmark	Latvia	Slovenia
Estonia	Lithuania	Spain
Finland	Luxembourg	Sweden
France	Malta	United Kingdom
North America	Latin America	Asia-Pacific
Canada	Brazil	China
United States of America	Mexico	India
		Japan
		South Korea
		Australia
		Taiwan
		Turkey
		Indonesia
		Russian Federation