Low-carbon development via greening global value chains

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Low-carbon development via greening global value chains: a case study of Belarus

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Abstract

The ascendancy of global value chains has seen the transfer of carbon emissions embodied in every step of international trade. Building a coordinated, inclusive and green global value chain can be an effective and efficient way to achieve carbon emissions mitigation targets for countries that participate highly in global value chains. In this paper, we firstly account the energy consumption, production and consumption-based carbon emissions of Belarus and its regions from 2010 to 2017. The results show that Belarus has a relatively clean energy structure with 75% of Belarus' energy consumption from imported natural gas. The 'chemical, rubber & plastic products' sector has expanded largely over the past few years; its production-based emissions increased ten-fold from 2011 to 2014, with the 'food processing' sector displaying the largest increase in consumption-based emissions. The analysis of regional emission accounts shows that there is significant regional heterogeneity in Belarus with Mogilev, Gomel and Vitebsk having more energy-intensive manufacturing industries. We then analysed the changes in Belarus' international trade as well as its emission impacts. The results show that Belarus has changed from a net carbon exporter in 2011 to a net carbon importer in 2014. Countries along the 'Belt & Road Initiative', such as Russia, China, Ukraine, Poland, and Kazakhstan, are the main trading partners and carbon emission importers/exporters of Belarus. 'Construction' and 'chemical, rubber & plastic products' are two major emission importing sectors in Belarus, while 'electricity' and 'ferrous metals' are the primary emission exporting sectors. Possible low-carbon development pathways are discussed for Belarus through the perspectives of global supply and value chain.

Key words: Belarus; CO_2 emissions; greening global value chains; input-output

1 Introduction

The ascendancy of global value chains (GVCs) has been a salient feature of the global economy during the last few decades (1). It is a global network, connecting the producing process from the original creation and design to final consumption among the participating countries (regions) (2). The rise of GVCs fragments production procedures internationally, continually raising the ratio of intermediate goods and services in total trade (3). According to De Backer and Miroudot (4), more than half of the world's manufactured imports are intermediate goods, and over 70% of world services imports are intermediate services. GVCs link countries around the world and provide a stepping-stone for developing countries to integrate into the global economy. For many countries, especially emerging economies, it is a vital condition for their development to effectively participate in GVCs (5).

Although there are a range of benefits from taking part in GVCs, the gaps in resource utilization and environmental protection become significant among regions and countries because of their different positions in the global value chains (6). From Shin, Kraemer and Dedrick (7), the high value-added production process is located in both the far upstream and far downstream stages, while the low value-added activities sit in the middle of the value chain (as depicted by a "smile curve"). Those high value-added production processes include basic and applied R&D, design, marketing and brand management, while low value-added activities are mostly within manufacturing and assembly (8). Due to an imbalanced industrial structure, lack of infrastructure, inadequate regional integration, an imperfect business environment and insufficient innovation capabilities, emerging economies remain captive as low value-added members of the GVCs (9). The side effects brought about by GVCs leave emerging economies, especially those with a heavy manufacturing-based industrial structure, in a predicament of high-pollution and high-carbon emission (10). Global value chains have increased the trade of intermediate goods and services, which sees the transfer of "carbon-intensive" production embodied in every step of international trade. The carbon transmission mechanism has become more subtle (6), which leads to great pressure of globally 'common but differentiated responsibilities' to reduce greenhouse gas emissions and keep global warming below 2°C (11). As a result, exploring a coordinated, inclusive and greening global value chain is key to the sustainable development of the world economy.

According to the report from The Donor Committee for Enterprise Development (12), developing a green global value chain means the optimization of outputs within an environmentally sustainable closed-loop system. It aims to enhance the whole natural sustainability of the entire chain through optimization of the links between participants. The greening of GVCs concentrates on the rationalization of the natural inputs into the global value chain and the control of the outputs affecting the environment. In most industries (such as electronics, automotive, agri-food, aerospace, etc.), the typical GVCs are regarded as a sequence of raw materials extraction, components making, assembly, retailing, customer utilization and disposal. Because these activities are complementary, any constraint on one of them will influence the others, no matter whether they are located upstream or downstream in the GVCs (13). For this reason, a systemic approach to greening supply chains is required to integrate the material, information and capital flows for economic and environmental targets via coordination of significant international trade processes (14). What's more, greening GVCs requires traceability. It is necessary to track hazardous products and materials, allocate responsibilities and monitor environmental compliance (13).

Since 2013, 'The Belt & Road Initiative' (the BRI) launched by the Chinese government provides an opportunity for countries to engage in the GVCs. The BRI is regarded as one of the largest infrastructure and investment projects in history (15, 16), covering more than 68 countries and 65% of the world's population, and 40% of the global GDP as of 2017 (17). It is generally believed that the BRI could stimulate international trade and break up the production process (18). According to Zou, Liu, Yin and Tang (19), the countries and regions involved in the BRI are richly endowed with energy resources. However, the geographies of the production and consumption of resources are significantly mismatched (20). With the prioritization on infrastructure development, the BRI is likely to increase energy demand and stimulate the expansion of energy-intensive industries (21, 22). In a word, the BRI could improve the participant extent of involved countries and regions in global value chains, and further alter their positions in the chains. However, its potential two-sided impacts (both negative and positive) on global greenhouse gas (mainly CO_2) emissions will make it a headline focus of global CO_2 mitigation studies (23). Exploring a low-carbon development style via Greening Global Value Chains is especially significant for countries and regions along the BRI.

The Republic of Belarus (referred to as Belarus below) has a unique position among the countries along the "Belt and Road". It is not only the earliest responder and participant of the "Belt and Road" initiative, but also a link between Eurasia and the continent(24). Belarus lies on the 'New Eurasia Land Bridge Economic Corridor' and is a landlocked nation in Eastern Europe, bordering Russia, Poland, Lithuania, Latvia, and Ukraine. Strategically located on the new Eurasia land bridge, there are eight rail container routes on the China-Western European trade route that pass through Belarus (25). In addition, two pan-European Corridors-II (Berlin-Moscow) and IX (Helsinki-Greece) pass through Belarus, strengthening its position as the main trade and transport thoroughfare in the region. The membership of the Eurasian Economic Union (EEU), coupled with the country's geographical proximity to most of the markets in the European Union (EU) and Commonwealth of Independent States (CIS) countries, as well as the forthcoming infrastructure development through the BRI, helps to make Belarus an increasingly important participant of global value chains (26).

Belarus is an export-oriented country with a well-developed manufacturing and services sector as well as agriculture (27). Its economy is greatly affected by neighbouring countries such as Russia and Ukraine. Data from World Development Indicators (WDI) shows that the value-added of agriculture, industry and services in 2017 accounted for 7.77%, 32.13% and 46.94% of GDP respectively. The industries in which Belarus has particular advantages mainly include machinery manufacturing, chemical and petrochemical industries, electronics industry, and radio technology. Belarus depends highly on foreign trade, with trade added value reaching 134% of GDP and ranking it among the top 10 in European countries. Limited by the capacity of the domestic market, around 67% of GDP are realized by exports. At the same time, imports account for 68% of GDP due to shortages of domestic resources and raw materials. Belarus is also regarded as a typical country without abundant fossil fuel reserves (28). Belarus consumed 25.8 million tons (in oil equivalent) of fossil fuels in 2017, with 75% of natural gas, 17% of oil, 5.5% of firewood, 1.3% of coal and 1.2 % of peat. However, less than 15% of the country's energy demand is covered by domestic production and it depends heavily on imports of all types of fossil fuels, especially from Russia (29). In 2017, Belarus was the world's 13th largest importer of natural gas with net imports of 15.3 Mt (in oil equivalent). It imports even larger quantities of crude oil (18.1 Mt) but of that is re-exported in the form of oil products.

The geographical advantage makes Belarus an important trade and transport thoroughfare for products from all over the world and the developed industrial foundation provides its processing and manufacturing industry with export competitiveness in international trade. However, the limited energy resources have intensified its economic dependence (28) and the manufacturing-oriented industrial structure means Belarus stays at a low value-added position in the GVCs. Influenced by geographical location, industrial structure and domestic market, the economic development of Belarus mainly depends on international trade. Under the proceedings of economic transition for sustainable development, Belarus is regarded as an active participant in international economic cooperation and ecological cooperation(24). Although Belarus has promoted the concept of sustainable development through technological, legislative and economic means in recent years, greenhouse gas emissions and environmental pollution caused by industrial production are still serious in this country(30). Under such circumstances, the economic stimulation brought by BRI could lead to both an opportunity to upgrade along the global value chains, and a challenge to mitigate CO_2 emissions for Belarus (25). More importantly, considering the growing significance of GVCs all over the world, tracing the carbon footprint of global intermediate products and service trade and greening the global value chains for countries like Belarus is a fundamental effort to achieve global carbon mitigation targets and environmental sustainability. It can be considered as a microcosm of exploring sustainable global low-carbon growth.

This paper firstly analyses the energy consumption patterns of Belarus. We then follow the Intergovernmental Panel on Climate Change (IPCC) administrative production-based scope to construct time-series emission inventories that span 2010 to 2017 which include 11 fossil fuels and 29 economic sectors for Belarus. By using the environmentally extended input-output (EEIO) analysis, we calculate the consumption-based emissions and trace the embodied carbon emissions of Belarus in international trade. The results of the empirical study provide Belarus with data supporting policies and recommendations for a more sustainable development approach. More importantly, and different from previous research on important economies (countries) or major emitters, we have chosen Belarus to do this analysis as it is a typical manufacturing-based country staying at a low value-added position in the GVCs. Like many other countries, as a participant in GVCs, Belarus needs a clear track of its carbon footprint in order to cooperate and negotiate on CO_2 emissions reduction with its upstream and downstream countries during the global production process. Moreover, Belarus needs to conduct a comprehensive analysis of its industry structure, emission structure and trade structure so as to move up the value chain. The results are believed to be universal and exemplary for countries in the same predicament.

2 Methods and data

2.1 Territorial-based and consumption-based emissions

There are three common methods to allocate greenhouse gas emissions to countries: territorial-based, production-based and consumption-based (31). According to the guidelines from the IPCC, the administrative territorial-based emissions refer to the real human-induced emissions by domestic production and residential activities within the region's boundaries (32, 33). Compiling accurate territorial-based emissions accounting is the basis for implementing carbon mitigation policies (34). The production-based emissions accounting allocates emissions from international aviation, shipping and tourism to the vessel's operator countries and tourists' resident countries(31). From the consumption-based emissions accounting, all the emissions are allocated to the final consumer of the products and service(35). An obvious advantage of consumption-based emissions is that the embodied emissions involved in intermediate production flows would be traced. Since global value chains see the transfer of carbon emissions embodied in every step of international trade (6), consumption-based accounting is believed to provide an alternative perspective to understanding the internal causes that trigger the emissions (36).

In order to trace embodied carbon emissions and allocate responsibilities in GVCs, a significant amount of literature has been developed to evaluate consumption-based accounting (10, 37-39). From the consumption-based scope, the basic territorial-based emissions inventories are adjusted by reducing the CO_2 involved in the products and service exported, and adding the CO_2 associated with the products and service imported (40). Through the comparison between the territorial-based and consumption-based emissions, the net transfer of emissions could be traced (10). According to previous empirical studies, the consumption-based emissions are usually higher than the territorial-based emissions in developed countries, which means that developed countries have more possibilities to become net importers of carbon emissions (41, 42). With the ascendant participation of the emerging economies in GVCs, the net transfer of carbon emissions via international trade increase in quantity year by year (10).

2.2 Territorial emission accounts

We follow the IPCC (43) method to account the administrative territorial-based emissions, see equation (1) below. We estimate the emissions from 11 major fossil fuels combustion within 29 sectors. The fuels and sectors are defined on the basis of the energy statistical system of Belarus, which includes all possible socioeconomic activities in Belarus.

$$CE = \sum_i \sum_j CE_{ij} = \sum_i \sum_j AD_{ij} \times NCV_{ij} \times CC_i \times O_i, i \in [1,11], j \in [1,28] \quad (1)$$

where CE_{ij} refers to the carbon dioxide emissions from fossil fuel i combusted in sector j; AD_{ij} refers to the consumption of fossil fuel i by socioeconomic activities in sector j. NCV_{ij} (net caloric value, $J/$ton fossil fuel consumption), CC_i (carbon content, $ton\ CO_2/J$) and O_i (oxygenation efficiency, %) are emission parameters of different fossil fuels.

We combine the guidance of IPCC (43) and the structure of the energy balance of Belarus, and classify fossil fuels consumed by socioeconomic activities into five categories (see Table 1). Under the territorial-based scope, fossil fuels inputted into heat and electricity transformation are regarded as the total energy consumed by thermal power & heating supply and are allocated into the sub-sector ‘electricity, gas, steam, hot water and air conditioning’ of Belarus.

Table 1 Fossil fuels consumption by socioeconomic activities

Categories	Components
Primary-industry use	Agriculture, forestry, and fisheries
Industrial use	13 sub-sectors + thermal power & heating supply
Construction use	Building sector
Tertiary-industry use	13 sub-sectors
Residential use	Residential use

2.3 Consumption-based emission accounts

Compared with the territorial-based CO_2 emissions that are concentrated on emissions caused by fossil fuels combustion during producing process, the consumption-based accounts of Belarus in 2011 and

2014 were processed in accordance with the Global Trade Analysis Project (GTAP) database of 2011 and 2014.

The environmentally extended input-output (EEIO) analysis was widely used to establish the consumption-based emission accounting (36). In the past few years, environmentally extended multi-regional input-output (MRIO) models were established to measure the embodied CO_2 in international trade (41, 44-47). Through examining the balance table of environmental emissions and resource consumption in physical units for multiple countries and regions (n) each involving m sectors, this model could make the integration of economic connections and ecological endowments (23). We follow the MRIO model to calculate the consumption-based emissions accounting for Belarus in this study.

The traditional MRIO model can be defined as:

$$\mathrm{X} = \mathrm{Z} + \mathrm{F} = \mathrm{AX} + \mathrm{F} \tag{2}$$

we can derivate a basic linear equation of the MRIO model as:

$$\mathrm{X} = (I - A)^{-1}F \tag{3}$$

$$\mathrm{X} = \begin{bmatrix} X^1 \\ X^2 \\ \vdots \\ X^n \end{bmatrix}, \mathrm{Z} = \begin{bmatrix} Z^{11} & Z^{12} & \cdots & Z^{1n} \\ Z^{21} & Z^{22} & & Z^{2n} \\ \vdots & \vdots & \ddots & \vdots \\ Z^{n1} & Z^{n2} & \cdots & Z^{nn} \end{bmatrix}, \mathrm{A} = \begin{bmatrix} A^{11} & A^{12} & \cdots & A^{1n} \\ A^{21} & A^{22} & & A^{2n} \\ \vdots & \vdots & \ddots & \vdots \\ A^{n1} & A^{n2} & \cdots & A^{nn} \end{bmatrix}, F = \begin{bmatrix} f^{11} & f^{12} & \cdots & f^{1n} \\ f^{21} & f^{22} & & f^{2n} \\ \vdots & \vdots & \ddots & \vdots \\ f^{n1} & f^{n2} & \cdots & f^{nn} \end{bmatrix}$$

where $X = (x_i^s)$ is the vector of total output, and x_i^s is the total output of sector i in region s; $Z^{rs} = (z_{ij}^{rs})$ is intersectoral requirement flows from sector i in region r to sector j in region s ; the technical coefficient submatrix $A^{rs} = (a_{ij}^{rs})$ can be calculated by $a_{ij}^{rs} = z_{ij}^{rs}/x_j^s$. I denotes the identity matrix, and $(I - A)^{-1}$ is regarded as the Leontief inverse matrix; $F = (f_i^{rs})$is the final demand matrix, and f_i^{rs} is the final demand of region s for the goods of sector i from region r .

From territorial-based emissions accounting, we can get the environmental indicator, which is emission intensity $\boldsymbol{\epsilon} = [\boldsymbol{\epsilon_1}, \boldsymbol{\epsilon_2}, \cdots \boldsymbol{\epsilon_n}]$ (CO_2 emissions per unit of output in each sector). Assuming that the carbon emission intensity of each sector remains the same under territorial-based and consumption-based emissions accounts, we can calculate the total amount of emissions caused by final demands through following equation:

$$\mathrm{E} = \boldsymbol{\epsilon}(I - A)^{-1}F \tag{4}$$

Where E is the matrix of emissions driven by final demands for each sector. In this way, we can generate the emissions caused by different final demands and sectors.

2.4 Data collection

2.4.1 Energy consumption by sectors and fossil fuel types

There is no energy balance table available in physical quantity for Belarus. In order to accurately measure the carbon dioxide emissions of Belarus, we have established the energy balance table consisting of 28 final consumption sectors and 11 types of fossil energy with real physical quantity for Belarus. The data are collated from the Energy Balance of the Republic of Belarus 2018, which is issued by the National Statistical Committee of the Republic of Belarus.

2.4.2 Emission factors

According to IPCC (43), the default emission factors are suggested only if country-specific factors are not available, and the up-to-date emission factors for Belarus are unavailable at the IPCC emission factors database (EFDB). For this reason, most of the current research has adopted the IPCC default values of emission factors for Belarus. However, the local emission factors of the Former Soviet Union countries (Russia, Ukraine and Kazakhstan) are reported in Gassan-zade (48). As those countries are the major fossil fuels suppliers, and are closely linked in terms of geological features, energy quality, combustion technology and energy efficiency (29), we believe that the emission factors in this report are more applicable than those of the IPCC for Belarus. As a result, we compare the emission factors from the report and IPCC default value for Belarus (see Table 2).

Table 2 Comparison of emission factors and NCV between IPCC and Belarus-specific

	Net caloric values (Tj/Gg)		**Emission factors (Kg/Gj)**		**Oxygenation efficiency (%)**
	IPCC	Belarus	IPCC	Belarus	Belarus
1 Natural gas	48	34.78 ^{CS}	56	55.15 ^{CS}	99.5
2 Oil	42.3	40.12 ^{CS}	73.3	72.53 ^{CS}	99
3 Motor gasoline	44.3	44.21 ^{CS}	69.3	70.14 ^{CS}	99.5
4 Diesel oil	43	43.02 ^{CS}	74.1	72.93 ^{CS}	99
5 Fuel oil	40.4	41.15 ^{CS}	77.4	76.41 ^{CS}	99
6 LPG	47.3	47.31 ^{D}	63.1	63.07 ^{D}	99.5
7 Coal	28.2	24.01 ^{CS}	94.6	91.26 ^{CS}	98
8 Peat	9.76	9.76 ^{D}	106	105.97 ^{D}	99
9 Peat briquettes and semi-briquettes	9.76	9.76 ^{D}	106	105.97 ^{D}	99

10 Firewood	15.6	10.22 [CS]	112	108.09 [CS]	91
11 0ther fuels	11.6	11.6 [D]	100	100.10 [D]	91

Notes: D-IPCC data; CS- country-specific data.

2.4.3 MRIO table

The MRIO tables for the years 2011 and 2014 are collected from the GTAP database. These tables include final demands from household consumption, government consumption and fixed capital investment. It provides sectoral intermediate demand among countries so that we can analyse the CO_2 emissions produced by international trade between 141 countries from 57 sectors. Due to the lack of physical energy consumption data in 2011, we use the territorial-based inventory account in 2010 to match the MRIO table of 2011.

In order to map the territorial-based emissions inventories with the GTAP database, the 28 production sectors in Belarus' energy balance table are divided into 57 GTAP sectors (see Appendix Table 1). We use the original GTAP carbon emission accounts to figure out the specific sectoral emission ratio, and then multiply the total amount by ratios to allocate the specific sectoral consumption after merging and splitting the sectors.

3 Results and discussion

3.1 Energy consumption and the territorial-based CO_2 emissions in Belarus and its regions

Belonging to the groups of countries that have a lack of fossil fuel resources, Belarus is a net importer of oil, gas and electricity. From Figure 1 we can see that fossil fuels related emissions have changed slightly between 52-60 million tons from 2010 to 2017. From the energy structure perspective, the main fossil fuels consumed in Belarus are natural gas (NG), oil, firewood, coal and peat. Among them, natural gas accounts for about 75%, oil occupies around 15%, firewood contributes about 5%, and the percentage of coal and peat are less than 2%. According to Gerasimov (29), due to the poor endowment of fossil resources, as well as the natural conditions which do not allow a large-scale consumption of renewable energy sources such as solar, hydro and water, the forests are regarded as the most significant sources of renewable energy for Belarus. The share of firewood and peat are projected to have a great increase in local energy resources until 2020.

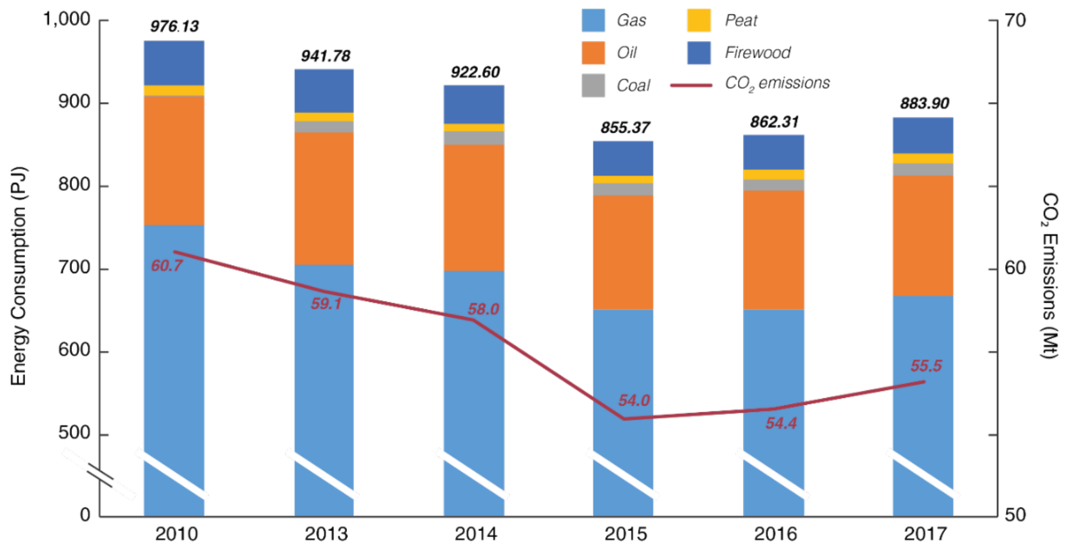

Figure 1 Energy structure and carbon emissions of Belarus

From the regional scope, Belarus is divided into six regions, namely Minsk, Gomel, Vitebsk, Mogilev, Grodno, and Brest. Their industrial structure and resource endowment are closely linked. Minsk (including Minsk city) and Mogilev have a well-developed industry foundation and they are the significant industrial centers of Belarus. The China-Belarus Industrial Park (also called Great Stone) in this state is regarded as a landmark project to promote the 'Belt and Road Initiative'. The major mineral resources in Mogilev are cement and lime while the main industrial sectors of the state are the chemical and petrochemical industries. Gomel and Vitebsk mainly have developed fuel sectors. Gomel has relatively rich fossil fuels renouncement endowment with rich reserves of oil, peat and coal. It also has sectors such as ferrous metallurgy and machinery manufacturing. Vitebsk preserves a wood resource of about 185 million M^3 and has 29% (which is about 1.25 billion tons) of the country's peat resources. Its main industrial sectors are the fuel industry, power industry and petrochemical industry. Grodno's main industry is agriculture. The livestock industry is the most important agricultural sector in the state, accounting for nearly 60% of the country's livestock products. Brest is the gateway from Belarus to Europe with around 80% of the goods exported by the CIS countries to Western European countries transited through here. The main industrial sectors of Brest are light industry, transportation, and the power industry.

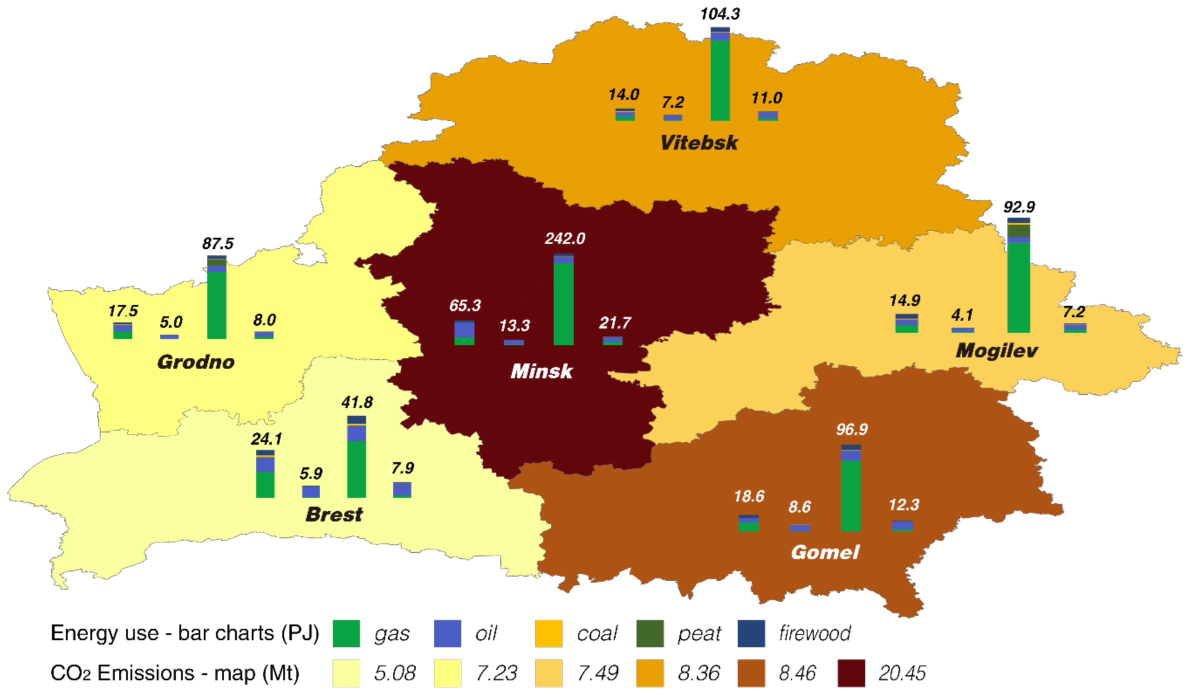

Figure 2 Energy structure and carbon emissions of regions in Belarus (for the year 2014). The columns refer to the energy consumption of household, primary industry, secondary industry, and tertiary industry (from left to right). The colour of the map shows the total CO_2 emissions in the regions.

According to Balezentis (49), the socioeconomic development is a key factor of energy structure and its resulting environmental impacts of a certain region. Besides the industry sector, the residential sector plays an important role as a major consumer of the energy. From Figure 2 we can see that as the economic center of Belarus, as well as the region with the highest population density, Minsk (including Minsk city) is the main carbon emission region. The total CO_2 emissions within this area reached 20.45 Mt, taking up approximately 35.8% of Belarus' national carbon emissions in 2014, followed by Gomel and Vitebsk with carbon dioxide emissions accounting for 14.8% and 14.6% respectively. The carbon intensity is 0.065 t/million Belarusian rouble (mBYN) in Minsk. As the main fuel bases of Belarus, the carbon intensity in the two regions of Gomel and Vitebsk are relatively higher (0.097 t/mBYN and 0.132 t/mBYN, respectively). As the chemical and petrochemical industries base, Mogilev takes up around 13.1% of the total CO_2 emissions of Belarus, with the highest carbon intensity of 0.133 t/m BYN. The economic development of Grodno state is dominated by agriculture and the carbon intensity of this region is 0.108 t/m BYN. As an important railway hub, Brest is an important area for transportation and light industry. Carbon dioxide emissions are much lower than other states, which is only 5.08 Mt, less than a quarter of Minsk. The carbon intensity of this region is 0.067 t/mBYN, and much lower than that of the energy and heavy manufacturing-based regions.

From the energy structure perspective, natural gas is the most significant energy resource for every region in Belarus, which takes up 60%-80% of the total energy consumption. The use of natural gas is mainly concentrated in the secondary industry, and then household consumption. Oil, the second largest source of energy, is the major source of fossil fuels for primary industry and transportation. Coal and peat account for a small share of the energy consumption structure while firewood is mainly used for household consumption and secondary industry. Combining the industrial structure and resource endowments of different regions, due to the development of the transportation industry, oil consumption accounts for 26.5% of the total energy use in Brest, while other regions are below 20%. The percentage of coal, firewood, and peat consumption vary in different regions. The consumption of coal is mainly concentrated in the areas of Mogilev and Brest for households and secondary industry. Minsk is the region with the highest energy consumption. Its household and industry energy use is 2.5-5 times that of other regions.

3.2 Major emission sectors and their trends

Figure 3 compares the top 15 emission sectors and their trends from 2011 (inner pie) to 2014 (outer pie) from the territorial and consumption perspectives separately. Detailed results are shown in the Appendix table 2.

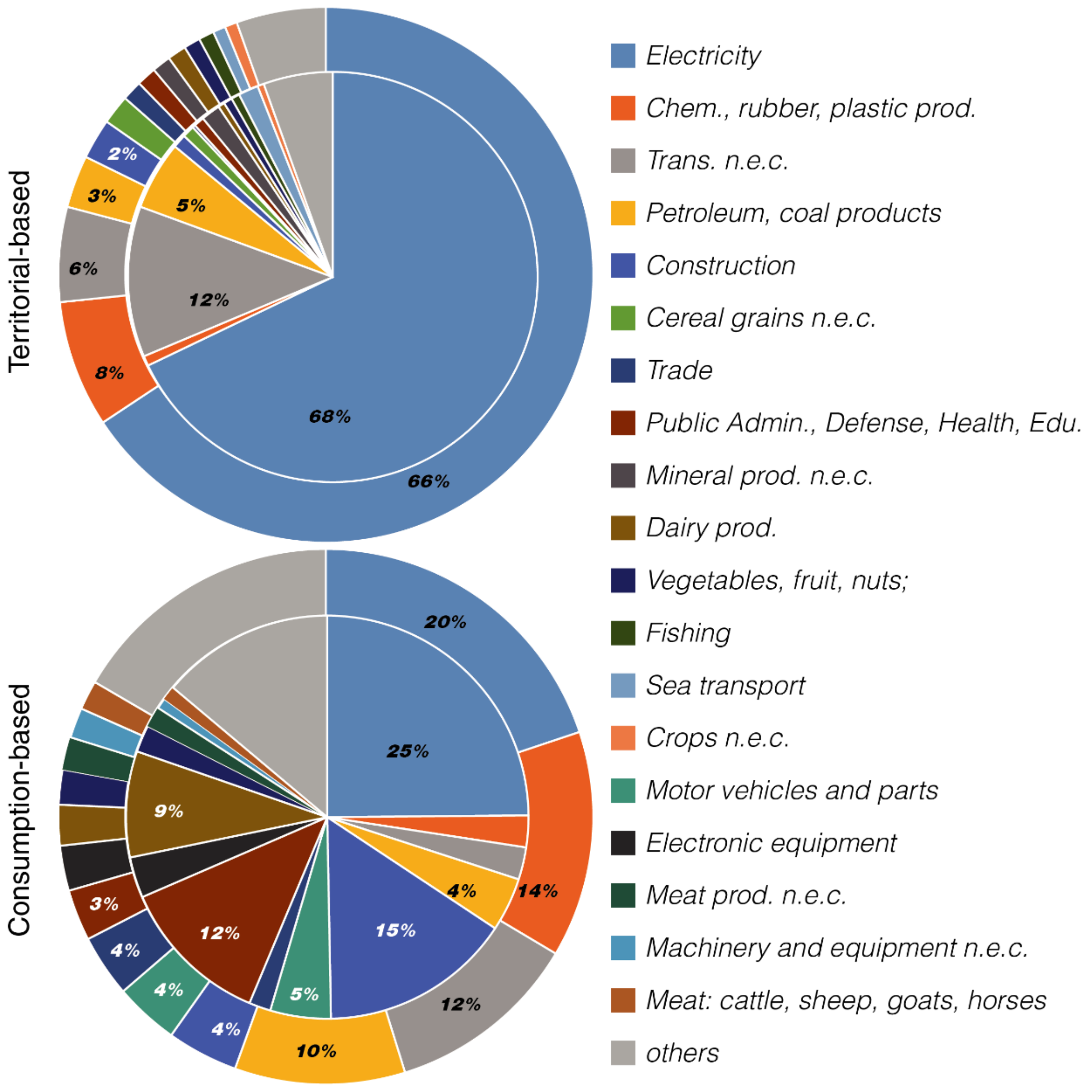

Figure 3 Top 15 emission sectors and their trends from 2011 (inner pie) to 2014 (outer pie) from production and consumption perspectives[1]

As shown in Figure 3, emissions from the territorial perspective rely greatly on the 'electricity' sector, which is over 65% in 2011 and 2014, followed by the 'chemical, rubber, plastic products' sector, the 'transportation' sector and the 'petroleum, coal products' sector. The emission patterns remain stable from 2011 to 2014 for most of the sectors in Belarus. The changes are mainly concentrated in sectors such as 'chemical, rubber, plastic products', 'transportation', 'construction', and the 'petroleum, coal products' sector. The 'chemical, rubber, plastic products' sector experienced the fastest growth from 0.79% in 2011 to 7.67% in 2014, and its impact on Belarus' carbon emissions cannot be underestimated. With the construction of the BRI, Belarus' role as not only a transfer port but also a processing factory is becoming more and more important, and its participation in the GVCs is increasing. The 'transportation' sector together with the 'sea transport' sector showed the greatest decline in CO_2 emissions, from 13.46% in 2011 to 6.49% in 2014. The railway of the 'New Eurasia Land Bridge Economic Corridor' and improvement of infrastructure is considered to be more energy-efficient and can reduce the carbon emissions from transportation.

In contrast, emission patterns from the consumption perspective are more complicated. 'Electricity' is the largest contributor to CO_2 emissions, which takes up about 20% of the total emissions, but it experienced 4.63% of decrease from 2011 to 2014. Secondly, 'construction', with a percentage of around 15%, also witnessed a 1.49% decline from 2011 to 2014. Compared with the smaller proportion at the production-based scope, CO_2 emissions caused by 'public services' rank third in the consumption perspective, reaching 12.20% (2011) and 11.89% (2014). Such scope differences also occur in 'dairy products'. Growing from 8.50% in 2011 to 10.49% in 2014, 'dairy products' plays a significant role in consumption-based emissions with the largest increase in CO_2 emissions, while 'meat products' and 'vegetables, fruits and nuts' also contribute a lot in the increase of CO_2 emissions from the perspective of consumption. Vigilance is also required over the emissions from 'chemical, rubber, plastic products' because although it accounts for a small proportion of the total consumption, its emissions growth rate is the largest. It is generally believed that the participation of GVCs will change the trade patterns. From the perspective of consumption, emissions showed an obvious increase from 'food processing products' and 'chemical, rubber, plastic products' and a significant decrease from 'electricity', 'construction' and 'petroleum and coal products' in Belarus. Although some of the changes account for a small proportion of total carbon dioxide emissions, it does reveal the emissions trend in consumption-based accounting.

3.3 The net emissions transfer status of Belarus

[1] n.e.c. is defined as "Not Elsewhere Classified".

The net emissions transfer status can be calculated through territorial-based emissions minus consumption-based emissions (42). The net emissions exporter has greater territorial-based emissions than consumption-based emissions, and the net emissions importer is the opposite. According to Peters, Minx, Weber and Edenhofer (50), developed countries collectively show higher consumption-based CO_2 emissions than territorial-based emissions. They are net importers of emissions, benefiting from the upstream location along the GVCs and energy-intensive production shifts abroad. As an export-oriented country, as well as a significant transportation hub on the Eurasian continent, Belarus is an active participant in the global value chains. The degree, location, and competitiveness of participating in global value chains directly determine the net emission transfer status of participants (51).

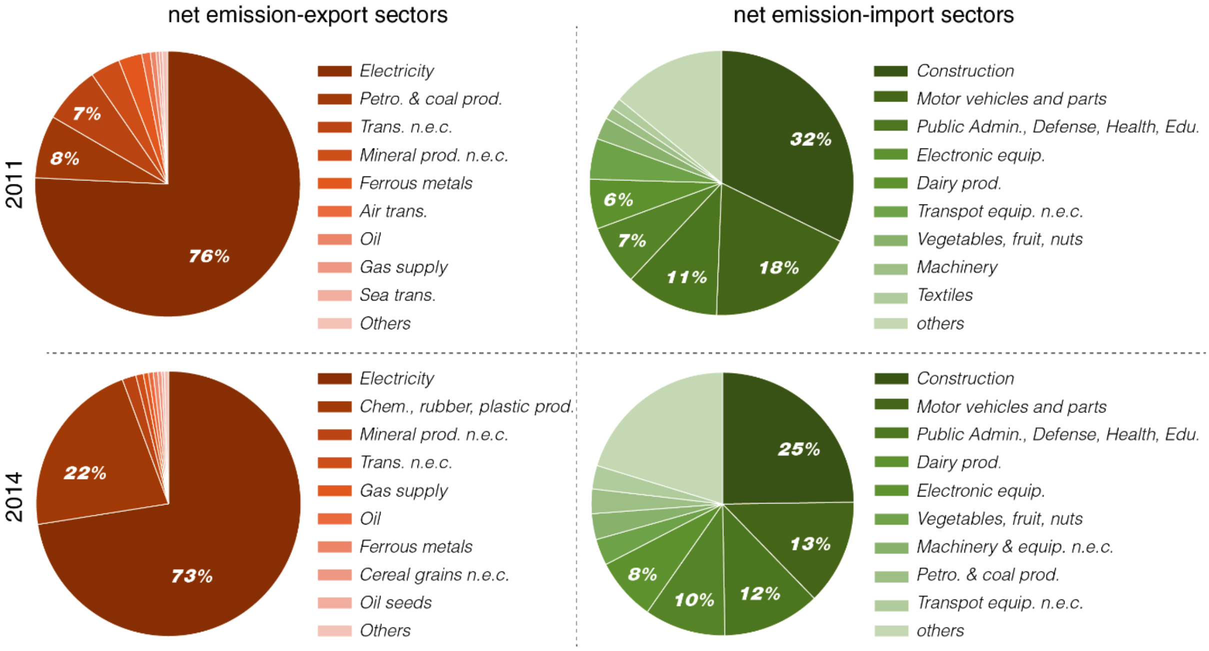

Figure 4 Net emission-export/import sectors from the consumption-based perspective

With the territorial-based CO_2 emissions of 50.59 Mt and the consumption-based CO_2 emissions of 48.26 Mt in 2011, Belarus was a net carbon emissions exporter in that year. Participating in the GVCs has brought trade opportunities to Belarus, yet has also made it absorb a number of CO_2 emissions caused by consumption demands from other trading partner countries. The situation improved in 2014 for Belarus with a net CO_2 emissions import of 3.78 Mt.

As shown in Figure 4, from the sectoral perspective within the consumption-based accounting, the major contributor that led to a net export of carbon emissions is 'electricity', which takes up over 70% in both 2011 and 2014. 'Transportation' and 'mineral product' also play important roles. Emissions come from 'petroleum, coal products', which experienced the most significant increase from 2011 to 2014. The main drivers that result in net import of CO_2 are 'construction', 'motor vehicles', 'public services', 'dairy products', and 'electronic equipment'. Viewed from the consumption perspective, Belarus is a net emission exporter for many energy-intensive and heavy manufacturing sectors, and a net emission importer for construction and different types of food processing.

3.4 Embedded emissions in Belarus' bilateral trade

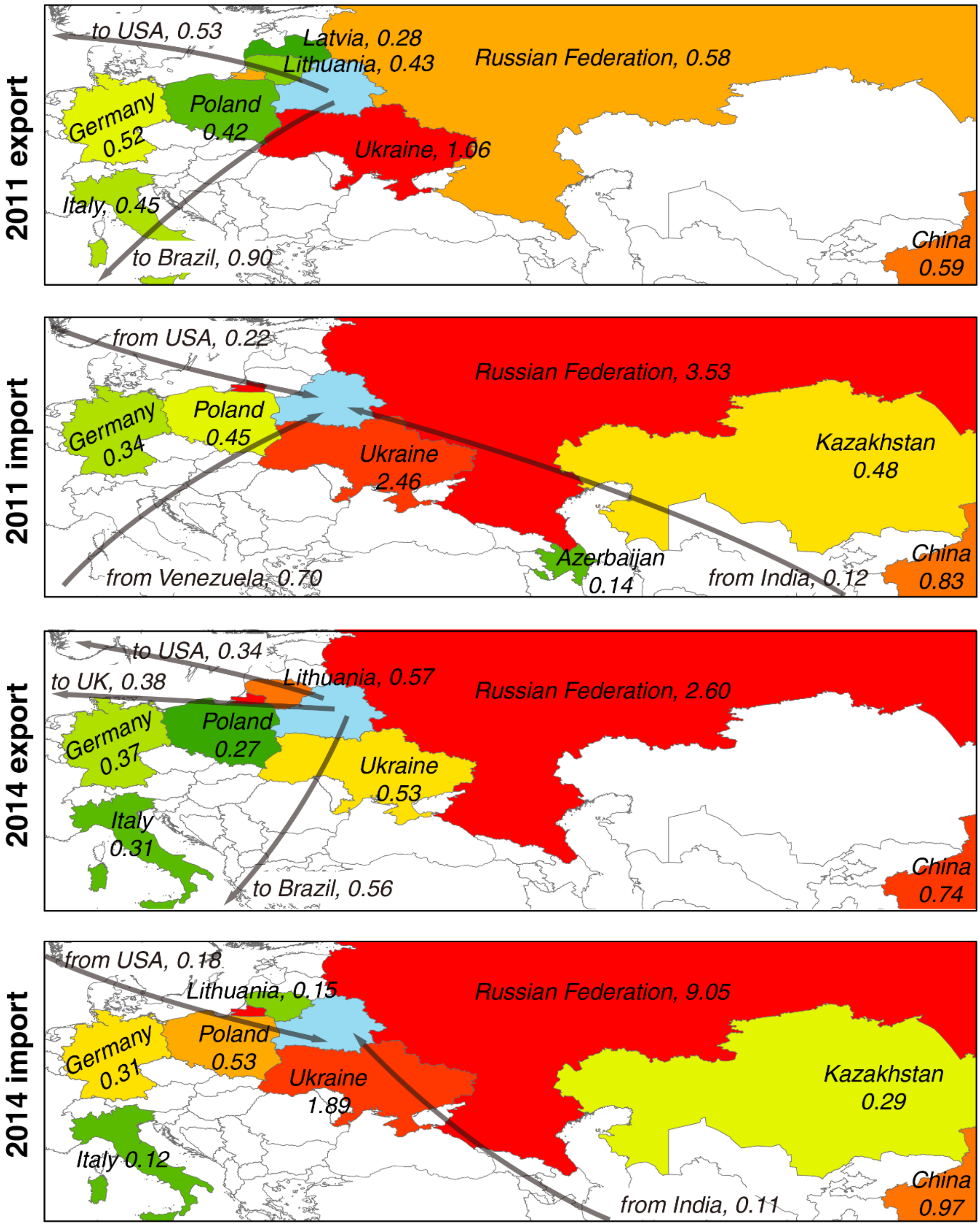

Figure 5 Major CO_2 emissions (Mt) transfer partners of Belarus in 2011 and 2014

Since the global value chains have seen the transfer of carbon emissions embodied in every step of international trade (6), we select 10 major emissions transfer partner countries of Belarus to analyse the influence of international trade on carbon emissions transfer. The major emission export and import countries of Belarus have some notable changes in 2011 and 2014 (as shown in Figure 5). In 2011, Ukraine, Brazil, China, Russia, Germany and the US are Belarus' main trading partners. Ukraine is the largest net emission-export partner of Belarus, and the exports are close to the sum of Russia and China (ranked second and third). Meanwhile, Russia and Ukraine supply more than half of the carbon imports of Belarus. Imports from China ranked third in all partner countries, and only accounts for a quarter of the emission imports from Russia. In 2014, the ranks of export-carbon partners have been slightly changed. Russia imports four times as much carbon from Belarus as it did in 2011, and becomes the first major carbon-export partner to Belarus. Carbon emissions export to China and Lithuania have tiny increases while to Brazil and the US they show slight decreases. In the meantime, the carbon imports from Russia is equivalent to three times the amount imported in 2011. Carbon imports from most other trading partners appear to show a descending tendency.

As shown in Figure 6 & Figure 7, although the top emission sectors present clustering characteristics, significant differences exist among countries. In general, Belarus undertakes part of the CO_2 emissions from 'construction', 'public services', 'chemical, rubber, plastic products', 'machinery and equipment', 'motor vehicles' and 'trade' demands of other countries. In contrast, 'electricity', 'ferrous metals', 'chemical, rubber, plastic products', 'mineral products', 'transport', 'petroleum, coal products' and 'metals products' require supply from other emissions transfer partners. When making further comparisons among these partner countries, we can clearly trace the top emission sectors for every country involved in carbon emissions transfer during the participation of global value chains.

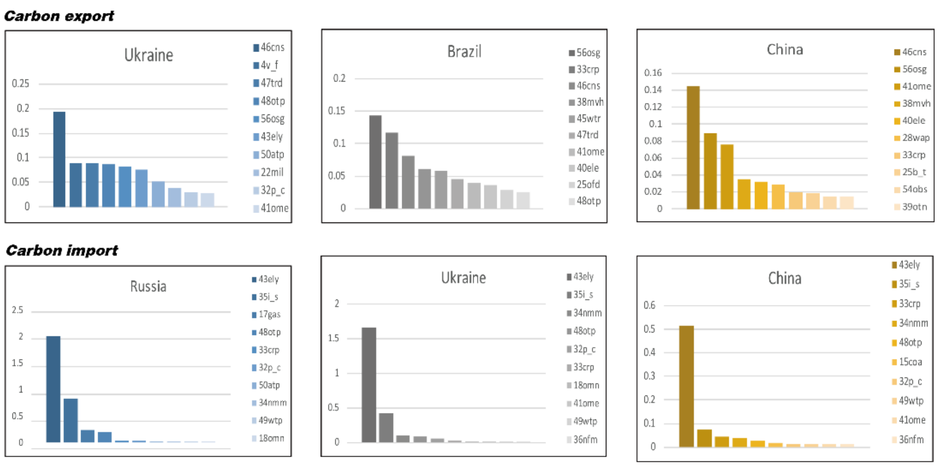

Figure 6 sectorial carbon transfer from major transfer partners in 2011

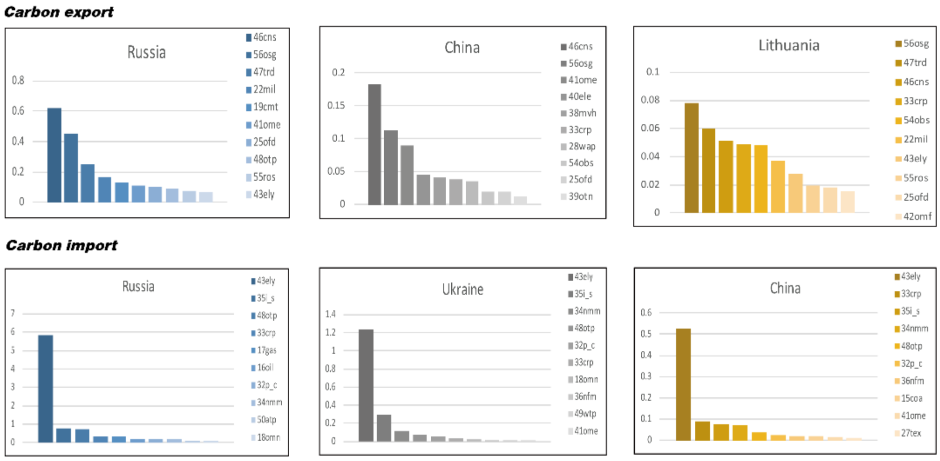

Figure 7 sectorial carbon transfer from major transfer partners in 2014

Taking China as an example, in 2011 the export to China for its 'construction', 'public services' and 'machinery and equipment' demands account for the main part of carbon-export from Belarus to China; while the consumption of 'electricity', 'ferrous' and 'mineral products' in Belarus take up a great share of carbon-import from China to Belarus. By 2014, the emission transfer status between China and Belarus remained steady as a whole, with only minor changes in the emission amounts and the rankings between sectors. However, not all countries are in the same situation. When comes to the case of Russia, the carbon import from Russia mainly concentrates on the sector of 'electricity', 'ferrous metals', 'other transport' and 'gas'. An obvious difference is that in 2014, Russia becomes the largest carbon importer of Belarus, import a large number of products and services in sectors such as 'construction', 'public services', 'trade' and 'dairy products'. Sectoral differences between countries could not be underestimated, which means that strategies should be implemented according to the carbon transfer characteristics of different countries when upgrading along the global value chains.

4 Discussion and conclusions

4.1 Discussion

Belarus is an export-oriented country with a well-developed manufacturing sector. It is also a country typically without abundant fossil fuel reserves; 85% of its fossil fuels are imported. But its location offers a significant geographical advantage, making Belarus an important transport thoroughfare from all over the world. Energy-intensive industries and some low value-added processing and manufacturing industries in Belarus are at the bottom of global value chains. Under the pressure of resources scarcity and global competition, economic growth and environmental protection have always been a dilemma. It is a matter of urgency for Belarus to upgrade along the global value chains.

Regional development in Belarus is unbalanced. As an economic center, Minsk has the highest population density, rapid industrial development, and the largest CO_2 emissions. The carbon intensity of the traditional industrial areas (such as Gomel, Vitebsk and Mogilev) and agriculture base (Grodno) are high. In contrast, the carbon intensity of Brest, which is mainly based on port trade and light industry, is relatively lower. In order to achieve the upgrade along GVCs, Belarus should actively take advantage of its geographical superiority to develop transport, service industries and increase the value-added and energy efficiency of its industries. The traditional heavy manufacturing industrial areas need to complete a process of industrial upgrading and energy structure optimization. In addition, excessive dependence on the import of fossil fuels such as natural gas and oil has hidden dangers to Belarus' economic development and energy security. Promoting the processing and utilization of peat and enhancing the energy efficiency of firewood in residential consumption would be an effective measurement for Belarus to improve its energy structure.

From the territorial-based perspective, 'electricity' is the top emission sector, which takes up over 65% of the total emissions of Belarus from 2011 to 2014. Meanwhile, the emissions from the 'chemical, rubber, plastic products' industry has expanded about tenfold from 2011 to 2014. Belarus should pay greater attention to improving its value-added capabilities in this industry and gain technological competitiveness to reduce or off-set the possibility of a disadvantaged position in GVCs. The increasing emission rate of the 'trade' sector means that the side effect of GVCs cannot be underestimated. However, the 'transportation' sector decreases the CO_2 emissions share, which may further benefit from the infrastructure improvement brought by the BRI. From the consumption-scope, the top emission sectors are more fragmented, but the changes are obvious in various sectors. Emissions from 'food processing products' and 'chemical, rubber, plastic products' showed an obvious increase from 2011 to 2014. While it is generally believed that the participation in GVCs will change the trade patterns – and although some of the changes account for a small proportion of total carbon dioxide emissions from the consumption-based accounting - the revealed the trend of the consumption pattern is very significant and worthy of attention.

Compared with the total CO_2 emissions from territorial-based accounting and consumption-based accounting, Belarus has changed from a net carbon exporter in 2011 to a net carbon importer in 2014. Viewed from the consumption perspective, the net carbon exporters come from energy-intensive and heavy manufacturing sectors. 'Petroleum and coal products' experienced the largest increase of net carbon export from 2011 to 2014. In contrast, the contributors of net carbon importer are concentrated in 'food processing' and 'construction'.

Due to differences in actual international trade conditions, sectoral emissions in different countries are diversified, which means that strategies should be implemented according to the carbon transfer characteristics of different countries, and targeted solutions should be adopted for specific industries to achieve a greening global value chain.

4.2 Conclusions

Through participating in the GVCs, Belarus absorbs part of the carbon emissions from 'construction', 'chemical, rubber, plastic products' and 'machinery and equipment' demands of other countries, and transfers emissions to trade partners via consumption of 'electricity', 'ferrous metals' and 'mineral products. Russia and Ukraine have always been important trade partners of Belarus. However, their trade relations with Belarus are greatly affected by the international political situation. In order to develop the green economy and green global value chains, countries need to establish market-oriented and equal trade cooperation relationships to ensure the implementation of green development plans. The proposal of the 'BRI' can provide a more stable trading environment for the countries participated in as it is supposed to spare effort on infrastructure construction, inter-regional energy cooperation, and international trade coordination. On the one hand, it will expand international trade and bring greater opportunities for Belarus to enhance its importance as an international trading port. On the other hand, countries along the 'BRI', such as Russia, China, Ukraine, Poland, and Kazakhstan, are the main trading partners, as well as the main carbon emission transfer partners, of Belarus. Trade with these countries will influence the carbon emissions of Belarus through different sectors. For that reason, collaborative sectoral cooperation and technological reform are needed for emissions import and export partners of Belarus. As a result, CO_2 emissions mitigation targets will be realized for both Belarus and its trading partners.

Fossil fuel combustion is the main cause of carbon dioxide emissions. Improving energy efficiency and using renewable energy are effective ways to reduce carbon dioxide emissions. Technological progress is a key point to improve energy efficiency. In the process of international trade, Belarus needs to pay attention to the introduction of technical and intellectual support from other countries. What's more, the promotion of renewable energy is related to the government enforcement and public awareness. According to Su, Ye, Zhang, Baležentis and Štreimikienė (52), the countries with developed sectors of renewables face easier adjustment of the energy-mixes. The development of renewable energy in Belarus is limited by resource endowments and natural factors, government should formulate a prudent plan for renewable energy development in appropriate regions and specific industries.

Supporting information

We publish the production- and consumption-based emission inventories as the supporting information for data re-use. The command file is published as well.

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Authors’ contribution

Y.S. and K.F. designed the study, H.W. conducted the study and drafted the manuscript, Y.H. and H.Z. calculated the consumption-based emissions, D.G., S.Q. and X.L. revised the manuscript.

Appendix Tables

Appendix table 1 Concordance GTAP sectors with production sectors

Major sectors	Specific sectors	GTAP sectors
Agriculture	Agriculture, forestry, and fisheries	1 pdr, 2 wht, 3 gro, 4 v_f, 5 osd, 6 c_b, 7 pfb, 8 ocr, 9 ctl, 10 oap, 11 rmk, 12 wol, 13 frs, 14 fsh
Industry	Mining industry	15 coa, 16 oil, 17 gas, 18 omn
	Food, beverage and tobacco manufacturing	19 cmt, 20 omt, 21 vol, 22 mil, 23 pcr, 24 sgr, 25 ofd, 26 b_t
	Manufacture of textiles, clothing, leather, and fur	27 tex, 28 wap, 29 lea, 30 lum
	Manufacture of wood and paper products; printing and reproduction of recorded media	31 ppp,
	Production of coke and refined petroleum products	32 p_c
	Chemical production	33 Crp
	Manufacture of rubber and plastic products, other non-metallic	33 Crp
	Metallurgical production; manufacture of finished metal products, except machinery and equipment	34 nmm, 35 nfm, 36 nfm, 37 fmp
	Manufacture of machinery and equipment not included in other groups	38 mvh, 39 otn, 40 ele, 41 ome, 42 omf
	Production of vehicles and equipment	38 mvh, 39 otn, 40 ele, 41 ome, 42 omf
Electricity, gas, steam, hot water and air conditioning	Electricity, gas, steam, hot water and air conditioning	43 ely, 44 gdt
	Water supply; collection, treatment, and disposal of waste, pollution control activities	45 wtr
Construction	Building	46 cns

Service	Wholesale and retail trade; car and motorcycle repair	47 trd
Transportation	Transport activities, warehousing, postal and courier activities	48 opt, 49 wtp, 50 atp
	Temporary accommodation and food services	
	Information and communication	51 cmn
	Financial and insurance activities	52 ofi, 53 isr
	Real estate transactions	57 dwe
	Professional, scientific and technical activities	56 osg
Service	Administrative and support services	56 osg
	Public administration	56 osg
	Education	56 osg
	Health and social services	56 osg
	Creativity, sport, entertainment, and recreation	55 ros
	Provision of other types of services	54 obs

Appendix table 2 Top 15 emission sectors and their changes from 2011 to 2014

	Territorial-based emissions (%)			Consumption-based emissions (%)		
	2011	2014	differences	2011	2014	differences
Electricity	67.9	65.70	-2.2	24.87	20.23	-4.63
Chemical, rubber, plastic products	0.79	7.67	6.88	2.54	3.95	1.42
Transport nec	11.88	5.72	-6.16	2.59	2.00	-0.59
Petroleum, coal products	5.42	3.17	-2.25	4.31	3.82	-0.48
Construction	1.08	2.44	1.36	15.40	13.91	-1.49

Cereal grains nec	0.95	1.77	0.82	4.87	4.37	-0.49
Trade	0.23	1.22	0.99	1.75	2.14	0.40
Public Administration, Defense, Health, Education	0.82	1.19	0.37	12.20	11.89	-0.32
Mineral products nec	1.51	1.14	-0.38	3.27	3.15	-0.13
Dairy products	0.51	1.14	0.62	8.50	10.49	1.99
Vegetables, fruit, nuts	0.68	1.00	0.32	2.17	2.78	0.60
Fishing	0.66	0.93	0.27	1.65	2.49	0.85
Sea transport	1.58	0.77	-0.81	0.87	1.86	0.99
Crops nec	0.50	0.74	0.24	1.13	1.81	0.68
Others	5.47	5.41	-0.06	13.89	16.91	3.02

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