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Kazakhstan's CO_2 emissions in the post-Kyoto Protocol era: production- and consumption-based analysis

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Highlights

- CO_2 emission inventories are estimated in Kazakhstan from 2012 to 2016.
- Consumption-based emissions patterns are different from production-based ones.
- Construction drives most emissions embodied in trade.
- Kazakhstan should develop renewable energy to achieve the "Green Economy".

Abstract

The first commitment period of the Kyoto Protocol came to an end in 2012 and more developing countries began to participate in the new phase of world carbon emission reduction. Kazakhstan is an important energy export country and a pivot of the "Belt and Road Initiative" (BRI). Despite its emissions are relatively small compared with huge emitters such as China and the US, Kazakhstan also faces great pressure in terms of CO_2 emission reduction and green development. Accurately accounting CO_2 emissions in Kazakhstan from both production and consumption perspectives is the first step for further emissions control actions. This paper constructs production-based CO_2 emission inventories for Kazakhstan from 2012 to 2016, and then further analyses the demand-driven emissions within the domestic market and international trade (exports and imports) using environmentally extended input-output analysis. The production-based inventory includes 43 energy products and 30 sectors to provide detailed data for CO_2 emissions in Kazakhstan. The consumption-based accounting results showed that certain sectors like construction drive more emissions and that the fuel consumption in different sectors varies. Furthermore, Russia and China are major consumers of Kazakhstan's energy and associated emissions, with the construction sector playing the most important role in it. The results suggested that both technology and policy actions should

be taken into account to reduce CO_2 emissions and that the BRI is also a good chance for Kazakhstan to develop a "Green Economy".

Keywords: CO_2 emissions   Kazakhstan   Emission inventory   Production-based   Consumption-based   Multi-regional input-output analysis

1. Introduction

The threat of global climate change is one of the greatest challenges worldwide [1-3]. From the Kyoto Protocol, the world began to realize the importance of controlling greenhouse gas emissions. After the first commitment period of the Kyoto Protocol (1997-2012), the world began to seek a more effective way to promote carbon mitigation. The Paris Agreement emphasizes the emission reduction obligations of developed and developing country groups, as being different but equally important [4]. This responsibility-sharing system indicates that emerging economies are getting involved in the global emission reduction process. Kazakhstan is the largest landlocked country in the world with plentiful natural resources and is also one of the largest oil and gas exporters in the world, especially for the "Belt and Road Initiative" (BRI) [5]. The exploration of emission reduction in Kazakhstan is of great significance and the approval of the Paris Agreement is a milestone for this fossil energy-intensive country [6]. According to the Paris Agreement, Kazakhstan is committed to fulfilling its unconditional target of a 15% reduction in greenhouse gas (GHG) emissions by 31 December 2030 (compared to 1990) and a conditional target of a 25% reduction in greenhouse gas emissions by 31 December 2030 (compared with 1990) [7, 8]. At the same time, Kazakhstan faces serious environmental problems [9]. To help to limit a global temperature rise well below 2 degrees with reference of pre-industrial levels by the end of this century, Kazakhstan has made great efforts toward low carbon energy structure through the use of policy and technology [10], such as the "Green Economy in Kazakhstan" project, aiming at cutting carbon emissions by 40% in 2050 from 2012 levels [11, 12].

One of the serious challenges to the "Green Economy" idea comes from the energy-oriented exports in Kazakhstan. Domestic use and foreign demand together constitute about 80% of energy distribution in nearly the same share [13]. In December 2015, Kazakhstan became a full member of the World Trade Organization and in the following year, it exported energy and mineral products worth 22.58 billion dollars (68.7% of total exports) to more than 190 trade partners in the world [14]. Within that large amount of annual energy exports to the world, Kazakhstan exports three types of energy resources (coal, oil and gas) for more than 100 billion tonnes of oil equivalent every year. More than 43% of fuel exports is consumed by the Asia-Pacific region every year, and the BRI stimulates the passion to cooperate with Kazakhstan on natural resource extraction and transportation, especially for China [15, 16]. Now, China is committed to proposing a "Green Belt and Road" and achieve the goal of the Paris Agreement with partners along the New Silk Road [17]. To offer a scientific foundation for designing efficient mitigation measures in developing "Green Belt and Road", it is necessary to further study Kazakhstan's potential for the green transition.

Accurate cognition of emission and energy accounts in Kazakhstan is the first step towards further implementing emission reduction actions. It is also the most important contribution of this study. The sketch of Kazakhstan's national emissions starts from production-based accounting. Production-based accounting is based on emissions emitted from a sector or a country. United Nations Framework Convention on Climate Change (UNFCCC) and the Kyoto Protocol utilized this framework to determine the emission reduction responsibility of each country [2, 18]. The most widely-used methods to compile production-based CO_2 emissions were proposed by the Intergovernmental Panel on Climate Change (IPCC), based on fossil fuels' combustion and default factors [19]. Since the

1970s, many researchers began to construct GHG emission inventories for main countries in the world, including CO_2, CH_4 and N_2O etc., and CO_2 accounted for 60% of the total GHG emissions worldwide [20-22]. Besides some international academic institutes, such as the Emission Database for Global Atmospheric Research (EDGAR), International Energy Agency (IEA) and the Carbon Dioxide Information Analysis Centre (CDIAC), many scholars also published their own inventories every year [21, 23-25] and improved accounting methods based on country-specific emission factors [26, 27]. Those individual datasets usually focused on a specific country so that can be an effective supplement for generalized data from international agencies. However, targeted studies for CO_2 accounting in developing countries were very limited. Research about carbon emission accounting in China was diversified and active, even province-level and city-level inventories were relatively complete [23-25]. In contrast, Kazakhstan's national carbon emission accounting is virtually a blank space. The first goal of this study is to construct Kazakhstan's national CO_2 emission inventories, including detailed data on fuel products and socioeconomic sectors.

Furthermore, we will keep another eye on emissions from a consumption perspective. Consumption-based accounting focuses on demand-driven emissions in supply chains. Due to Kazakhstan's important status in energy exports, we will further analyse the driving forces of CO_2 emissions from domestic and foreign markets using the environmentally extended input-output model. Sun et al. (2017) [28]used MRIO analysis to prove that several booming regional economies outsourced huge energy demands to foreign regions via trade. Oven et al. (2017) [29] compared energy-extracted and energy-used vectors in the consumption-based calculation and encouraged MRIO model databases for both of them. Due to the disadvantaged status of developing countries in international emission reduction from the production perspective [30], many scholars tried to construct a fairer shared emission responsibility system. Numerous studies estimated the CO_2 emissions embedded in domestic and international trade at both national and local levels [30-32]. Other related studies also demonstrated the advantages of consumption-based accounting and provide a better understanding of different driving forces for carbon or other pollution emissions [33-38].

Energy and environment issues in Kazakhstan entered the academic field from the early years of this century [39, 40], but most of the researches focused on case studies and empirical studies of the production-based emissions. Research about the driving forces of CO_2 in Kazakhstan covers the first commitment period of the Kyoto Protocol. Karakaya et al. (2005) [41] applied a decomposition analysis to study the driving forces of fossil fuel combustion emissions in Central Asia from the collapse of Soviet Union to the beginning of 21st century (1992-2001), emphasizing that Kazakhstan improved its energy intensities to save energy and reduce carbon emissions, but emissions might increase due to the economic recovery since 2000. Regarding Kazakhstan as a part of the former Soviet Union, Brizga et al. (2013) [42] adopted the IPAT model to study the decoupling and driving forces of the former Soviet Union in different stages of economic development, when decoupling between CO_2 emissions and economic growth was obvious while driving forces were various. For Kazakhstan, the economic recession led to fewer emissions and the industrialization led to more emissions. Akhmetov (2015) [43] further studied the key factors of industrial CO_2 emissions in Kazakhstan for the period 1990-2011 using Index Decomposition Analysis, concluding that Kazakhstan still strongly depended on carbon-intense industries which would lead to worse environmental condition. Karatayev and Clarke (2014) [44] reviewed the energy utilization in Kazakhstan and pointed out that coal-based power generation was the main cause of the greenhouse gas emissions, so it was necessary to adopt renewable energy resources. Based on previous research, this paper tries to explore Kazakhstan's CO_2 emissions in the post-Kyoto Protocol era, which refers to both production- and consumption-based analysis. Assembayeva et al. (2018)

[45] focused on Kazakhstan's electricity system and used a techno-economic model to account for related particularities; Tokbolat et al. (2018) [46] evaluated the efficiency of energy consumption of residential buildings in Astana and Kerimray, as well as the decarbonisation of the residential sector [47, 48]; Onyusheva et al. (2017) [49] researched a similar topic in the transport and energy sectors. For empirical studies, Li et al. (2018) [50] adopted the Logarithmic Mean Divisia Index (LMDI) decomposition and the Stochastic Impacts by Regression on Population, Affluence, and Technology (STIRPAT) model to study major driving factors of CO_2 emissions in Kazakhstan from 1992 to 2013 and Kerimray et al. (2018) [51] used LMDI to analyse energy intensity; Xiong et al. (2015) [52]explored the development of Kazakhstan's low-carbon economy by decoupling relationship analysis, reflecting the relationship between energy consumption and economic growth. Besides, Kazakhstan also established the domestic national Emissions Trading Schemes [53], where an extended GTAP-E model was applied to estimate emissions permits allocation [54]; carbon sequestration as a reduction tool was also discussed to help toward building low-carbon society [55]. Therefore, a gap remains in the connection between production- and consumption-based emissions.

This study presents the production-based CO_2 emission inventories of Kazakhstan from 2012 to 2016, which are calculated using the national emission factors and sectorial level energy consumption data. This period is essential to a developing country like Kazakhstan to adapt to the post-Kyoto Protocol area. Based on the production-based emission inventories, we further estimate the carbon emissions in 2012 and 2014 from the consumption perspective. Moreover, emissions embodied in international trade are also traced, including emission flows between sectors and trade partners using the GTAP multi-regional input-output model. This framework provides a complete system to properly understand how different fuels, sectors and trade partners are implicated, with the final aim of further emission controls.

2. Methods and data

2.1 Production-based accounting

The production-based accounting in this study presents as an annual CO_2 emission inventory from 2012 to 2016. The accounting scope is limited to energy consumption related CO_2 by socioeconomic activities in Kazakhstan.

According to the 2006 IPCC guidelines [19], the production of CO_2 emissions from fossil fuel combustion can be calculated by the following equation:

$$CE = \sum_j \sum_i CE_{ij} = \sum_j \sum_i AD_{ij} \times NCV_i \times CC_i \times O_i \qquad (1)$$

In Equation (1), CE_{ij} refers to the accounting results of carbon emissions, which are from the combustion of fuel *i* in sector *j*, and CE is the total result of all sectors and fuel products; AD_{ij} stands for the amounts of fuels combusted by fuel *i* in sector *j*, and also defines as activity data; NCV_i is net calorific value of fuel *i*, representing the amount of heat released during the combustion; CC_i means the carbon content of fossil fuel *i*, referring to carbon emissions per unit of fuel consumed; O_i is the oxygenation efficiency during combustion [23-26]. In this study, we adopt $i \in [1, 43]$ and $j \in [1, 30]$ from official statistical data (see details in Section 2.3), suggesting the amounts of related energy products and socioeconomic sectors.

Considering the data diversity and sample size, we calculate the emissions based on physical fuel consumption. The analysis adopts NCV_i provided by *Fuel and energy balance of the Republic of Kazakhstan* (FEB of Kazakhstan) and default*ed* CC_i and O_{ij} value in IPCC guidelines, the factors are listed in Table 1.

As a result, the final emission inventory includes CO_2 emissions by fossil fuel combustion of 43 energy products and 30 socioeconomic sectors.

2.2 Consumption-based accounting: IO and MRIO analysis

In contrast to production-based emissions, consumption-based accounting allocates the emissions along the production supply chain to meet the final demands, which specifically accounts the emissions driven by the final consumer. Consumption-based emissions in Kazakhstan include demand-driven emissions in 57 socioeconomic sectors embodied in local commodities that are consumed locally and emissions embodied in international imports that are produced in other countries. Environmentally Extended Input-output Analysis (EEIO) is widely used in trailing economic drivers of regional and global CO_2 emissions accounting [30-32]. EEIO is generated based on the classic IO model and is built upon intersectional flows in intermediate demand and final demand. The general structure of classic IO model is

$$X = Z + Y = AX + Y \qquad (1)$$

where X is the total output of each sector; Z, the direct requirement matrix, indicates the direct input for production processes; Y is the final demand matrix; and A is defined as $A = Z/X$, referring to direct technique coefficient and the contribution of each element in the direct requirement matrix makes towards total output. To further rewrite the equation (1) that X is a function of Y, we have:

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

where I is the identity matrix and $L = (I - A)^{-1}$ is the Leontief inverse matrix. Then the environmental account should be incorporated into the model:

$$e = fX^{-1} \qquad (3)$$

$$X = e^{\wedge}LY^{\wedge} \qquad (4)$$

where f is production-based emissions in Kazakhstan for each sector, and e refers to the emission intensity, which is the emissions per unit of output; $e^{\wedge}$ and $Y^{\wedge}$ represent the diagonal matrix with elements of e and Y on its main diagonal, so we finally get E, which is the matrix of emission associated with n sectors. This model can be extended to analysis emission embodied in international trade as well, in which the meaning of each symbol is extended to the corresponding range in a multi-regional case.

2.3 Data source

2.3.1 Energy activity data

Accounting for Kazakhstan's carbon emission inventories is based FEB of Kazakhstan *2012-2016*, compiled by Ministry of National Economy of the Republic of Kazakhstan Committee on statistics [13]. These official statistical yearbook series contain 43 fuel products and 14-17 socioeconomic sectors in energy balance tables at the national level. Besides the indicators above, each FEB of Kazakhstan includes other energy indicators, such as the number of heat sources and price index of enterprises manufacturing industrial products for energy resources, which can be used in further exploration about energy consumption in Kazakhstan.

2.3.2 IO tables

Input-output tables are collected from the GTAP database and provides the multi-regional input-output tables, which includes 141 countries or regions and 57 sectors in 2011 and 2014 separately [56]. As we were unable to access to Kazakhstan's national input-output tables, we use Kazakhstan's part in GTAP 2011 and 2014 instead. Also, due to the lack of input-output table in 2012, when calculating consumption-based emission in 2012 we take the input-output table from 2011 to approximate production relations in 2012.

2.3.3 Data matching process

Fuel or energy products and socioeconomic sectors vary across different indicators in FEB of Kazakhstan, 2006 IPCC guidelines and the GTAP database, so it is necessary to match data to uniform standards before accounting.

According to the method described in 2.1, a series of CO_2 emission factors from IPCC guidelines are adopted for accounting sectoral approach emissions, meaning all energy products are supposed to be the same as definitions of fuel types in 2006 IPCC guidelines. We match 43 energy products to IPCC classification according to definitions in guidelines. Some different energy products correspond to the same energy type in IPCC, and our detailed matching process is contained in Table S1 in Supporting Information.

We further adjust and standardize socioeconomic sectors according to the *National Accounts of the Republic of Kazakhstan* [57], so we have 30 socioeconomic sectors to make Kazakhstan's emission inventories. Moreover, to match the emission inventories with the GTAP database, the 30 sectors are further divided into 57 sectors based on each sector's output share for inventories in 2012 and 2014 (Table S2 in Supporting Information). As output share is not the same as emission share, we adjust some sectors' data according to the GTAP environmental account (eg. water supply). It is also why we do not divide every year's inventory into 57 sectors in the annual emission inventory.

3. Results and discussion

3.1 Basic energy and socio-economic status in Kazakhstan

Kazakhstan has plentiful natural resources, especially fossil fuel resources. Its national coal reservations are more than 176.7 billion tons and account for 4% of the world's total reservations, ranking it eighth in the world. For oil reservations, 4.8-5.9 billion tons of proven reserves on land and 8 billion tons in the Caspian Sea area (regions belonging to Kazakhstan) rank Kazakhstan seventh in the world and second in the Commonwealth of Independent States (CIS). Accompanied by such rich oil deposits, the coverable amounts of natural gas in Kazakhstan are beyond 3 trillion cubic meters.

The energy reservations directly decide the energy supply and demand structure, and further affect emissions. Fossil fuel combustion is the major source of CO_2 emissions in Kazakhstan [19], and the structure of fuel production and consumption reflects the activity level data for emissions. According to Kazakhstan's official statistics, from 2012 to 2016, domestic energy supply maintains a stable level (286.645-301.112 10^6 tons conventional fuel) and meets most of the demand for domestic and exports (75.95%-87.67%), while imports and other intakes only account for a small share of the total (3.24%-5.37%). In total primary energy supply, the percentage of coal is 40% while oil and gas separately accounts for nearly 30%, but in total final consumption, coal surpasses the other two primary energy items by more than 20%[13]. From this perspective, the energy consumption structure of Kazakhstan is coal-dominated, and countries with similar energy structure usually face serious emission reduction tasks.

Referring to the time trend of Kazakhstan's energy consumption, economic development in the same period needs to be considered. As Fig. 1 shows, the last five-year-period (2012-2016) is full of ups and downs for Kazakhstan. During 2012-2013, the global economy grows slowly and the external conditions are unfavourable for economic development in Kazakhstan. However, the domestic demand growth, together with high investment incentives, rapid service growth, and the relatively high growth rate of agriculture, machinery manufacturing and construction, leads to substantial development of Kazakhstan economy. Since 2014, the global economy has been unstable which has meant that the economic growth of Kazakhstan’s main trading partners - such as China and Russia - has slowed down, which meant the external market demand decreased more than for 2012 and 2013. The decreasing trend in total exports and energy exports continued after 2014. Moreover, Kazakhstan’s economy has also been strongly affected by Western sanctions against Russia and the sharp drop in oil prices. In this circumstance, Kazakhstan cannot avoid seeing its economy fading. Compared to GDP [58], energy consumption displays a similar time trend, as Fig. 1 displays. The consumption reaches to a peak in 2015 from 2012, and quickly drops to an even lower level than in 2014. Energy intensity, referring to the energy consumption rate related to GDP, clearly reflects the relationship between energy consumption and economic status. From 2012-2014, both energy consumption and GDP experience initial growing and followed by decline, but GDP falls much more and energy consumption intensity shows an increasing trend in the years of the economic slowdown. From the decoupling analysis perspective, there is also a weak decoupling and weak negative decoupling relationship between energy consumption and GDP.

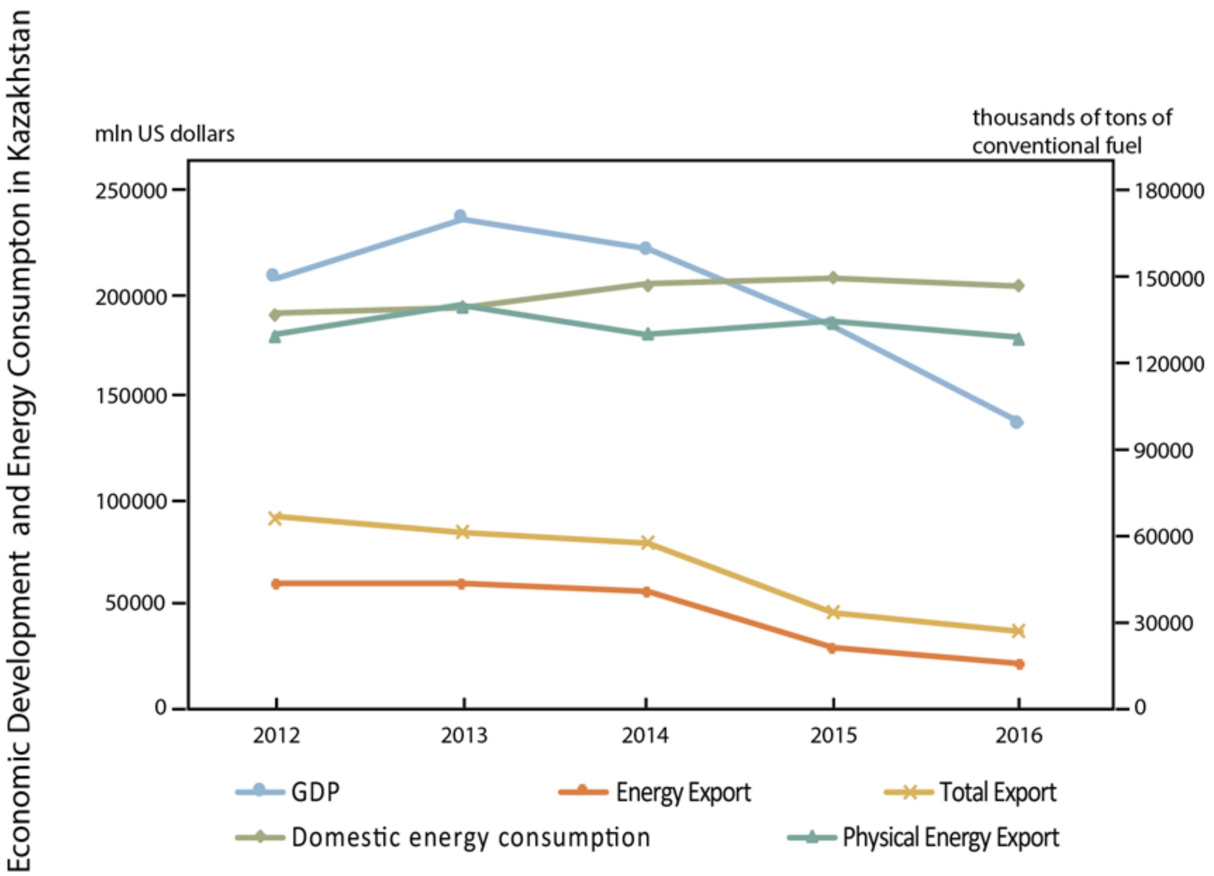

Fig. 1. Main economic and consumption indicators of Kazakhstan. The data were obtained from *Fuel and energy balance of the Republic of Kazakhstan 2012-2016* and World Development Indicators. GDP, Energy Exports and Total Exports are measured by million US dollars and Domestic energy consumption and Physical Energy Exports are measured by thousands of tons of conventional fuel.

3.2 Kazakhstan CO_2 emission accounts 2012-2016

Fig. 2 shows the main energy and sector structure in CO_2 emissions during 2012-2016. According to the trend displayed in Fig.2, we adopted the Mann-Kendall test to explore the possible decreasing trend in CO_2 emissions[59, 60]. However, the test result is p-value = 0.242, which means it fails to conclude any significant trend in the research period ($\alpha = 0.05$). This indicates the fluctuated feature of Kazakhstan's emissions at the beginning of the post-Kyoto Protocol period. With more data to collect, we will conduct the test again in future research.

Listed energy products are responsible for more than 90% of the total emissions. Among these major fossil fuel sources, a series of coal-related energy contributes to CO_2 emissions far more than others, and Stone coal for energy is responsible for nearly 70% of coal emissions on average. However, according to official Kazakhstan statistics, the share of coal consumption in total natural resources is only about 35%-45% in recent years; gas-related fuel is preceded only to coal; Associated petroleum gas and Natural gas induce nearly 6000 Kt CO_2 during the 2012-2014 period; at the same time, Gasoil is the main source of oil-induced emission, accounting for about 90% of oil-related products.

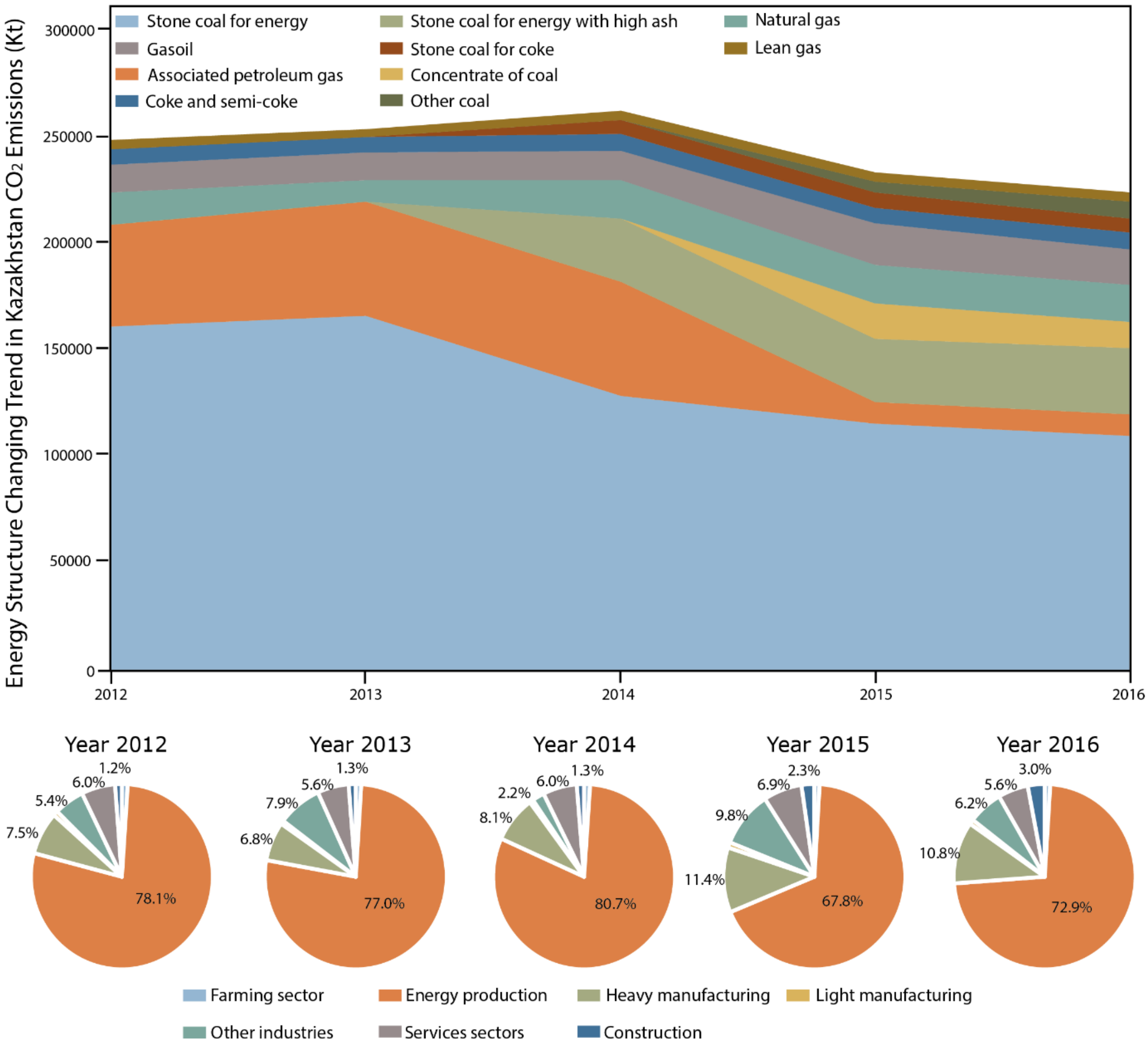

Fig. 2. Energy and sector structure of CO_2 emissions in Kazakhstan from 2012 to 2016.

A counterintuitive fact in this is that in 2014, GDP goes down while CO_2 emissions still keep increasing. Based on this fact, we assume that some important economic drivers recede so that related emissions fall as well, but other sectors emit more in 2014. According to the CO_2 emission inventory and sectoral category standards from Shan, et al. (2018) [23], we further analysed the sector structure of emission. In all, 30 socioeconomic sectors in emission inventory are aggregated to four kinds of sectors based on their socioeconomic features in Table S3 in Supporting Information: farming sector, industry sectors, construction and service sectors. Industry sectors are further divided into energy production, heavy manufacturing, light manufacturing and other industries. As Fig. 2 shows, energy production accounts for more than 70% of total emissions, and top emitters from other industries or sectors are presented as well.

Energy production industries and main heavy industries emit more while emission of non-specified industry drops sharply in 2014. Non-specified industry always plays a significant role in industrial emissions, except in 2014, the inflexion point of Kazakhstan's economy. In 2015-2016, energy production industries emit 24% less than the peak value in 2014, when heavy industry and non-specified industry become more emission-intensive. This result explains the five-year trend of CO_2 emission and economic status.

As an energy-driven emerging economy, energy production and consumption are and will be the main motivation of economic development. High-carbon developing mode usually promotes the emerging economy's development immediately at the beginning phases, but the low-carbon economic transformation will be a compulsory topic in the long run.

To better identify the CO_2 emission status of Kazakhstan, we further compare the emission intensities (ton/1000 USD GDP) of 10 similar developing countries with Kazakhstan's. Among them, Ukraine has the most similar economic structure and volume with Kazakhstan, besides they are both former Soviet Union countries; Tajikistan, Turkmenistan, Uzbekistan and Kyrgyzstan are central Asian countries as Kazakhstan, which are close in economic structures but far behind Kazakhstan in economic volumes; Algeria, Iraq, Peru, Qatar and Romania are in a nearby ranking in GDP with Kazakhstan but their economic structures vary. The results are shown in Fig.3.

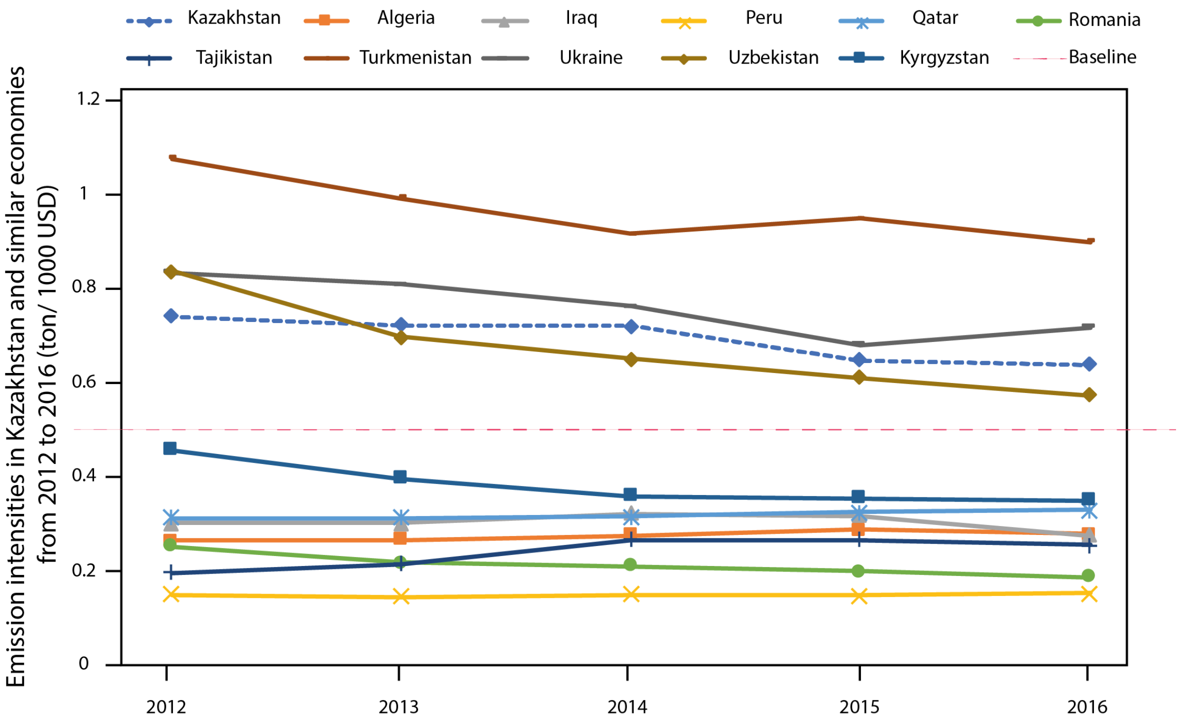

Fig. 3. Emission intensities in Kazakhstan and similar economies from 2012 to 2016 (ton/1000 USD). The data of Kazakhstan are based on this research and others are from EDGARv4.3.2 database[61].

Fig.3 indicates that compared to economic volumes, the economic structures affect emission intensities more. If we take 0.5 as the baseline to distinguish the emission intensity level, the 11 countries above can be divided into two groups: Turkmenistan, Ukraine, Kazakhstan and Uzbekistan are in the high-intensity group, and others are in the low-intensity group. The high-intensity group has a downward trend but still keeps in the high-intensity level (above the baseline). Countries in the high-intensity group all have very similar industrial structures, which are dominated by the energy industry. In that group, Kazakhstan's emission intensity ranks 3rd or 4th place from 2012 to 2016, which means the economy is relatively green and clean in energy-oriented countries. But compared to other similar economies, especially emerging economies which are not dependent on energy production, Kazakhstan seems to be much more carbon intense. In the future development even international competition, the feature of the high carbon intensity of Kazakhstan's economy may cause deeper problems in the long run.

3.3 Comparison of the consumption-based emissions in Kazakhstan of 2012 and 2014.

Fig. 4 compares sector contribution changes from the consumption perspective in total and different fuel products in 2012 and 2014. To make results clearer, 14 agriculture base sectors in the GTAP are aggregated to the "Agriculture" sector. Consumption-based emissions reflect emissions included in all sectors in the economy, which are induced by the demand of a certain sector. The result may differ from production-based emissions for complicated economic activities, and this difference also tells us the "actual" emitters in the national economy.

For total emissions, three top production-based emitters are turning to decrease in consumption-based emissions. Electricity supply (ELY), gas production (GAS) and land transport (OTP) emit more than 151.47Mt CO_2, accounting for 42, 19, and 6% of total fuel combustion emissions in the production process respectively, which mainly come from coal, oil and gas combustion. This distribution corresponds to Kazakhstan's energy-leading economic structure. However, from the perspective of consumption, those three sectors contribute only 39.49Mt CO_2, accounting for 11, 5 and 1% of total emissions. The sharp decline of electricity supply and gas production may be attributed to other sectors' strong reliability of energy and convenient land transportation, especially in some light manufacturing and service sectors.

On the contrary, due to the longer supply chain involving high-carbon industries(oil, gas, electricity supply and land transport), some sectors which are not main emitters in production contribute multiple times the level of emissions in consumption. Oil production (OIL), public administration (OSG) and construction (CNS) together emit 11.71Mt CO_2, accounting for 5% of emissions from the perspective of production, but separately emit 36.43Mt, 20.65Mt and 17.11Mt CO_2 from the perspective of consumption, accounting for more than 33% of the total emissions. Besides, many industry sectors and service sectors contribute more emissions from the perspective of consumption, such as other metals (NMF), trade (TRD), petroleum and coal products (P_C), and chemical, rubber and plastic products (CRP). For agriculture, energy and heavy industry input lead to more consumption-based emission; and for ferrous metals (I_S) and other manufactures (OMF), the main demands go to electricity and themselves, so this sector plays an important role in both the production and consumption scenario.

For emissions from different fuels, coal displays a similar pattern as total emissions for it is the main fuel resource of economic activities, while demands from the food industry (CMT, OMT and MIL) also induce considerable consumption-based emissions. Nearly 70% of oil production-based emissions go to land transport, oil production and other manufactures and oil production together with construction become the main drivers of consumption-based emissions. Gas emission distribution seems to be much simpler in that gas production and electricity supply account for more than 90% of production-based emissions, while in consumption-based emissions, demands for oil and gas result in 50% of emission and demands for heavy manufacturing and many service sectors share the other 50%.

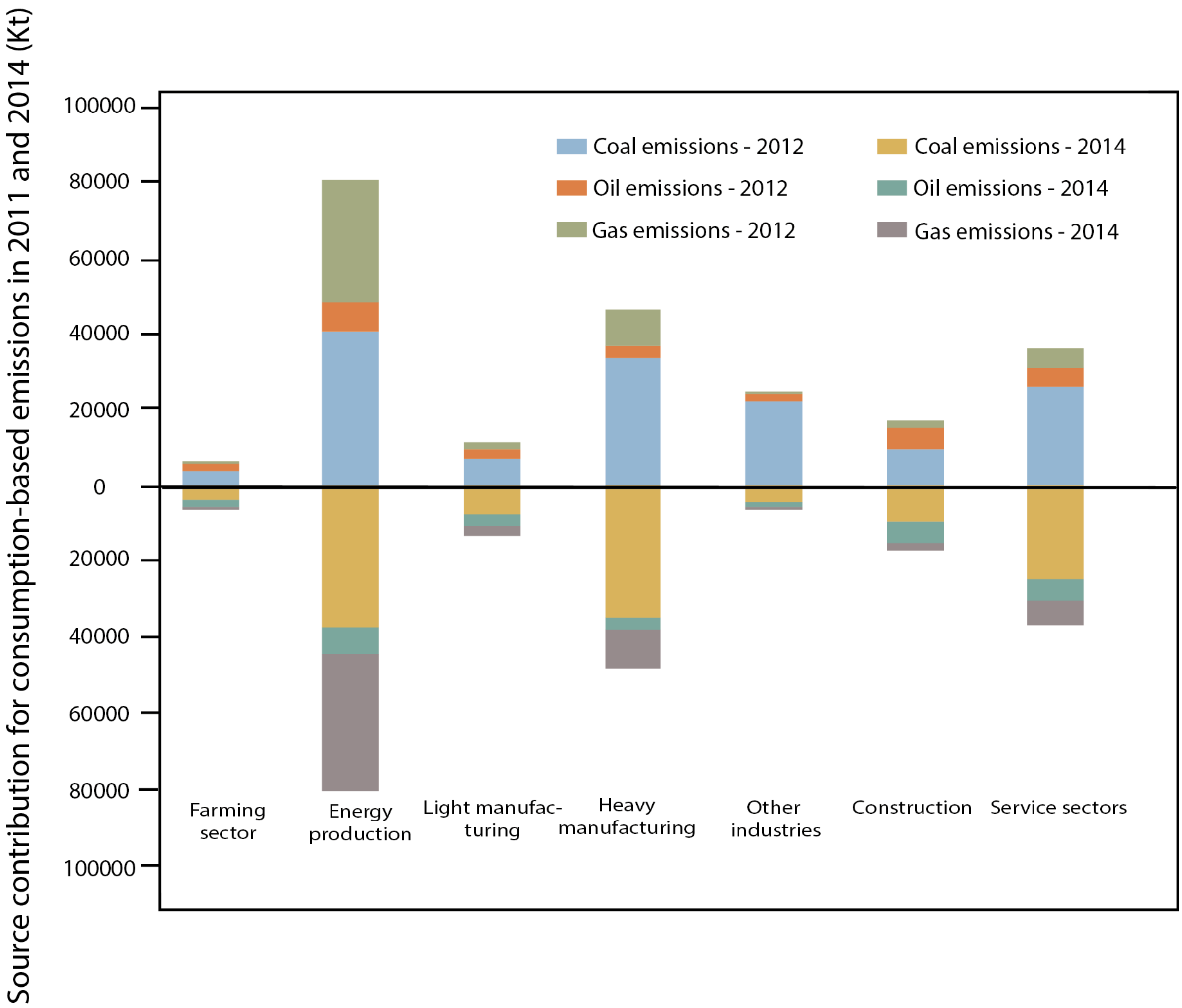

Fig. 4. Comparison of the consumption-based emissions in Kazakhstan of 2012 and 2014. The emissions of 2012 were displayed above the horizontal axis and 2014 below.

This total emissions trend is similar to emissions in 2012 when energy production and manufacturing dominated the emissions, but some changes have happened since. Taking the main emission contributors in 2011 as the baseline and comparing with emissions from the same sectors in 2014, it is obvious that the main distribution remains the same while some sectors change their rankings in emission contribution. Other manufacturing (OMF), other business services (OBS) and coal (COA) tend to emit less from consumption-based perspective. On the contrary, consumption-based emissions concerning other minerals (OMN), machinery and other equipment (OME) and other food products (OFD) prompt more emissions than before. If those sectors are clustered to a more aggregated level, results based on detailed fuel categories extend our analysis.

As analysed in section 3.2, compared to 2012, the energy production industry contributes more emissions from the perspective of production. From the perspective of consumption, only demands for gas induce more emissions than 2012, while emissions caused by both coal and oil demands in the energy production sector decline, which is opposite to the total trend. Another important emission reduction happens in other manufacturing (OMF), which has already been discussed in section 3.1. From the following figure (Fig. 5), we can see that the consumption-based emissions in other manufacturing have fallen by a fair amount, while the main source refers to coal emissions. As to demand-driven view, the huge reduction of demand from other manufacturing itself leads to this result. Other sectors keep a pretty stable demand for other manufacturing and even some heavy industry sectors induce more emissions.

Besides energy production and other industries, different fuels perform differently in emissions of various sectors. From the perspective of consumption, coal-induced emissions distribution in 2014 is consistent with 2012 except in other manufacturing; oil-induced emissions caused more by demand for service sectors, light manufacturing and farming sectors in 2014, and demand for construction is always the main driver of emissions; gas emissions are mainly led by demands for energy production, heavy manufacturing and service. The time trend is quite clear as is its distribution.

3.4 Exported and imported emission flows embodied in trade

Emissions embodied in exports and imports are driven by different sectors and countries as Fig. 5 shows. For exports, Kazakhstan produces more CO_2 emissions to meet foreign markets' needs in construction, various kinds of industrial sectors and service sectors concerning public service, transport and trade. Among those drivers, construction (CNS) is the dominant sector that drives approximately 16% of total emissions embodied in exports. From 2011 to 2014, Kazakhstan produces less CO_2 emissions (7.62%) to export. Besides construction, this fall mainly comes from industrial sectors, such as other manufacturing (OMF) and other machinery and equipment (OME), while most of the service sector drivers contribute more, except public service (OSG) and air transport (ATP). For imports, the embodied emissions are generally associated with construction (CNS), wearing apparel (WAP), chemical, rubber and plastic products (CRP), motor vehicles and parts (MVH), other machinery and equipment (OME) and public service (OSG). Compared to 2011, total emissions embodied in imports increase significantly (47.17%), and this can be attributed mainly to emerging demands for CRP in domestic markets. Demands for MVH, services and food products also contribute to the growth. Construction is the most important sector in both export and imports. In the recession of emissions embodied in exports from 2011 to 2014, the amount of emissions related to construction also falls but the proportion rises, which means the driving force from construction is relatively stable; at the same time, during the extending process of emissions embodied in imports, emissions related to construction also experiences a considerable increase in both amount (2724.03Kt to 3771.49Kt) and proportion (14.10% to 19.52%). On the one hand, construction itself is a sector which includes long value chains and has support from high carbon industries; on the other hand, construction is an essential force to promote economic development, especially for an emerging economy.

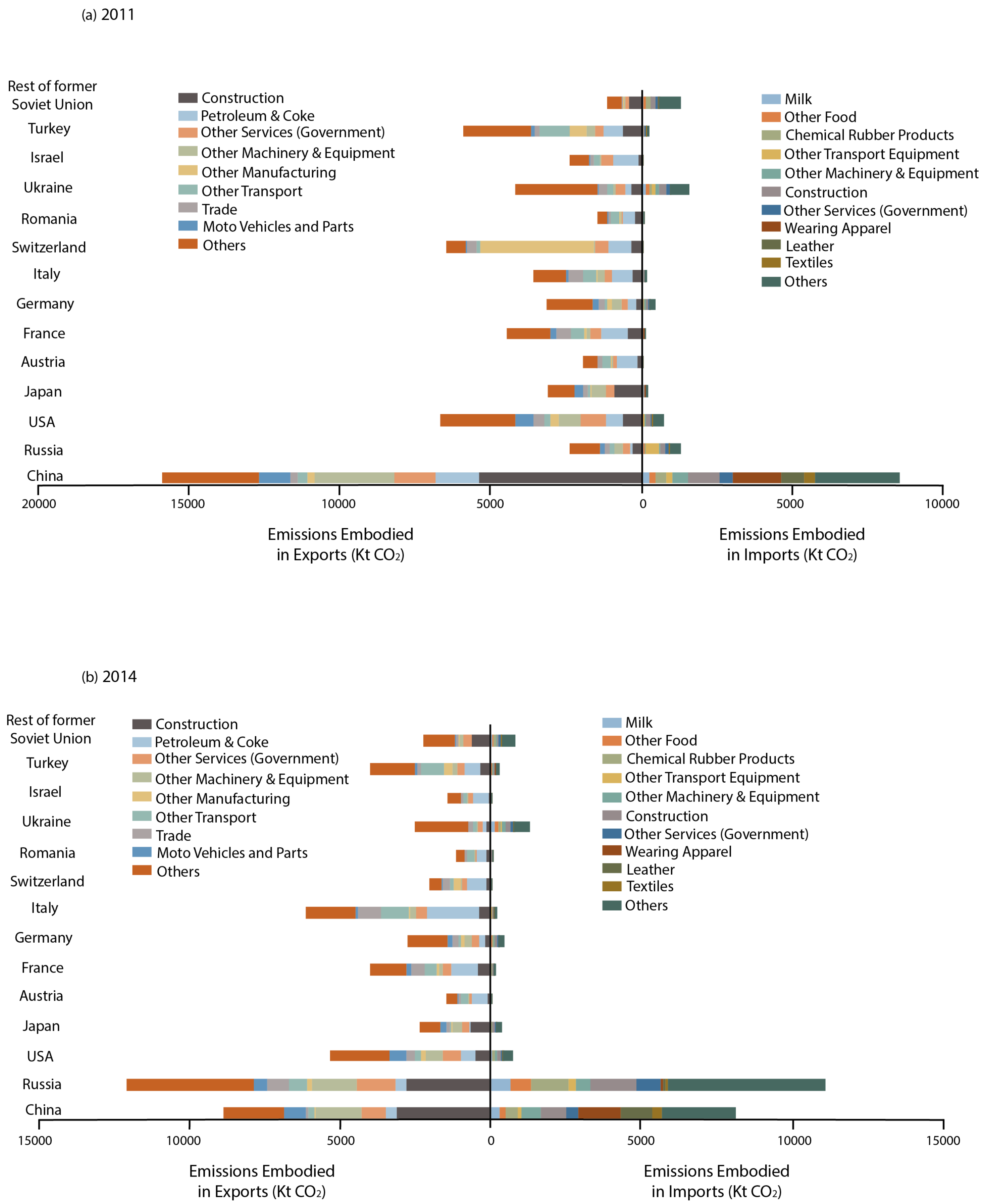

Fig. 5. Emissions embodied in trade for Kazakhstan for 2011 and 2014.

Contributions from different trade partners vary sharply from 2011 to 2014. Fig. 5 (a) and (b) display the change in both exports and imports. In 2011, main overseas consumers of Kazakhstan's CO_2 emissions were China (10%), USA (7%), EU (28%) and CIS countries (except Russia) (6%). For EU countries, Austria, France, Germany Italy and Romania were the main consumers, and emissions embodied in exports to Switzerland are even more than any single country in the EU. For CIS countries, emissions are mostly produced in exports to Ukraine and the rest of the former Soviet Union (XSU). Japan, Israel and Turkey also take significant account in emissions related to exports.

Russia, for the similar industry structure and trade structure, accounts for only 1% of Kazakhstan's emissions embodied in exports. After Russian military intervention in Ukraine in March 2014, western countries took strict economic sanctions against Russia [62, 63], which saw Kazakhstan become a key transition point between Russia and the western world [64, 65]. More energy and industrial products were re-exported via Kazakhstan and the rapid increase of emissions embodied in exports to Russia (14%) and the EU (31%) reflects that. Sanctions to Russia also stimulated re-imports for Kazakhstan for the same reason, thus we can see a larger increase for emissions embodied in imports from Russia (7% to 39%), which exceed other major trade partners (China, Ukraine and the rest of the former Soviet Union) by a significant margin.

Astana, the capital Kazakhstan, is the birthplace of China's "One Belt One Road" initiative, and China also regards Kazakhstan as its most essential trade partner in Central Asia. As to the perspective of exports, emissions induced by China are mainly constituted by investment demand, and this trend continues from 2011 to 2014 (from 61% to 65%). This is different from the constitution of final demands in total emissions embodied in exports, where household demand accounts for 58%. This trend in economic sectors reflects that emissions are driven by construction (CNS) and other machinery and equipment (OME) and is far more than other sectors, even in 2014 when related total emissions dropped a lot. For imports, the composition of final demands is consistent with the overall trend that household demand is the dominant one. Related reflection in sectors is that domestic demand of the light industry, such as wearing apparel (WAP) and leather products (LEA), lead the driving force of emissions embodied in imports. During 2011 to 2014, China's emissions induced by Kazakhstan's demands of trade (TRD) keep stable; demands of leather products (LEA), chemical, rubber and plastic products (CRP) and dairy products (MIL) significantly increase; while other sectors decrease, especially petroleum and coal products (P_C). Compared to the concentrated trend of industries in exports, sector distribution in imports is dispersed. For example, in 2014, the top three sectors in emissions embodied in exports account for 57.04% of total emissions, but the top three sectors in emissions embodied in imports account for only 33.77% of total emissions. This means that in the bilateral trade between China and Kazakhstan, the variety and complexity of each country's trade dependency is different. If Kazakhstan wants to reduce CO_2 emissions embodied in exports to China, it is more efficient to focus on the supply of certain industries.

4. Main findings and policy recommendations

4.1 Main findings

In this paper, we characterize a full picture of Kazakhstan's CO_2 emissions from both production- and consumption-based perspectives in the post-Kyoto Protocol era. First, we make Kazakhstan's CO_2 emission inventories from 2012 to 2016, which refers to 43 energy products and 30 socioeconomic sectors. Then we measure the demand-driven emissions of each economic sector using Environmentally Extended Input-output Analysis based on data in 2012 and 2014 and compare the results with production-based results. Furthermore, we trace the final demand drivers and original emitters of the exported and imported emissions through international supply chains in the same period.

The results indicate that from the production perspective, even the supply of coals depends on imports more than before, coal-related fuels are the main contributors to emissions. Correspondingly, energy production and heavy manufacturing are major emitters. Due to the western sanctions towards Russia, the emission intensities in related industries vary in 2014, as same as Kazakhstan's economy. From the consumption perspective, oil production, public administration and construction are top contributors, and other metals, trade and petroleum and coal products drive more emissions than in the production perspective. Meanwhile, different fuels play different roles: more emissions produced by energy sectors flow to industry and service sectors in coal and gas, while more emissions produced by service sectors flow to energy sectors in oil.

In the further analysis of emissions embodied in trade, construction drives most emissions in exports and consumes most emissions in imports at the same time. Besides, major drivers for emissions embodied in exports are petroleum and coal products, public service and machinery. And the main consumers of emissions embodied in the imports are wearing apparel, chemicals, and motor vehicles. For trade partners, Russia and China are important consumers and producers. Kazakhstan acts as a transition point for Russia and the western world after the sanctions and a considerable amount of emissions take place in the re-export process. Chinese active demands for investment in few sectors drive more than half of the emissions embodied in exports, while the import side is dominated by household and distribute to more sectors.

4.2 Policy recommendations

Based on the detailed analysis of Kazakhstan's emission features, the main causes of CO_2 emissions in Kazakhstan are high-coal energy production and industries, including domestic consumption and international trade. Thus, the most essential policy is developing a mature system of renewable energy to replace coal gradually. Kazakhstan began to develop renewable energy from the beginning of this century, but the coal oriented energy production has not changed yet. To achieve a low carbon transition, Kazakhstan needs a comprehensive strategy to encourage renewable energy development:

First of all, the government should increase the financial supports for the promotion of renewable energy. The potential and existed renewable energy in Kazakhstan is abundant, but the promotion is blocked by higher economic costs. Kazakhstan is still an emerging economy, so if cleaner means more expensive, the public will tend to choose cheaper energy even it leads to more carbon emissions. It is necessary for the government to take fiscal measures to guide the public adopting cleaner energy, such as tax incentives, financial subsidies, and government procurements.

Moreover, creating new economic growth chances for low carbon transition and renewable energy. As the most essential and biggest emerging economy in Central Asia, high-carbon industries are often the key drivers of the economy. The balance between emission reduction and economy development should be considered seriously. Besides the attempt to balance in the residential sector [66]. It will be more efficient if Kazakhstan can explore new economic growth chances from renewable energy applications, including more job opportunities, new industries and new supply chains. The promotion of renewable energy should not only be a burden but one of the important economic engines for this country in the long term.

Finally, more international cooperation in the green economy and renewable energy. The "Belt and Road Initiative" is an ideal opportunity for Kazakhstan to cooperate with China and other economies to solve the common development problems. Take China as an example, the northwest regions of China have a similar geographical environment with Kazakhstan, thus the experience of carbon mitigation and renewable energy development may enlighten Kazakhstan. Besides, Kazakhstan has been the energy supplier for Asia and Europe for a long time, which increases local carbon emissions. Corresponding to Kazakhstan's "Bright Road Initiative", China's "Belt and Road Initiative" also aims to strengthen Kazakhstan as a logistics pivot connecting Europe and Asia, instead of a simple energy producer.

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