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Decomposition analysis of industry sector CO_2 emissions from fossil fuel combustion in Kazakhstan

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Abstract
The changes in industrial structure of Kazakhstan resulted in significant transformation on its CO_2 emissions profile. Understanding the driving factors in CO_2 emissions profile is essential given the emissions reduction targets committed by Kazakhstan. The study applies Index Decomposition Analysis to identify factors affecting industrial CO_2 emissions caused by fossil fuel combustion for the period 1990-2011. The results of the analysis indicated that the main factor affecting increase in total industrial emissions was the change in the industrial activity, while improvements in energy intensity helped to reduce the emissions. Analysis of six subsectors was used to define the main reasons underlying changes in CO_2 emissions.
The study underlines policy contradictions between national plans on expansion of carbon intense commodity based industries and Kazakhstan's international commitments on CO_2 reduction. Furthermore, the changes in structure of industrial output towards overreliance on commodity based industries and decline of manufacturing could indicate that Kazakhstan is vulnerable to resource curse.

Keywords: Kazakhstan; Index decomposition analysis; Industry; Decomposition; Fossil fuel.

1. Introduction

The Republic of Kazakhstan is a landlocked country located in the center of the Eurasian continent. Kazakhstan is the ninth largest in the world and it represents around 0.2% of the world's population, 0.3% of the world's GDP and 0.7% of world total CO_2 emissions [1]. The breakup of the USSR in 1991 has resulted in a sharp contraction of the economy. That led the Government of Kazakhstan to undertake reforms to establish a market economy, improve economic freedom and extensively develop its oil sector. As a result since 2000 the economy of Kazakhstan has been steadily growing mainly due to increased prices of oil on the world market. The economy of Kazakhstan is among the most energy and carbon intense in the world.
Kazakhstan's industry is primarily based on the extraction and export of the natural resources, primarily crude oil that country possesses in enormous amounts. Share of industrial output in GDP has increased from 20.5% in 1990 till 31.6% in 2011 [2]. The industry of Kazakhstan has undergone a significant structural transformation since the Soviet period as seen in Figure 1. Kazakhstan has transformed from diverse economy with a dominant share of processing industries into mostly oil export-dependent economy. Hence, the economy of Kazakhstan could be vulnerable to oil price volatility.

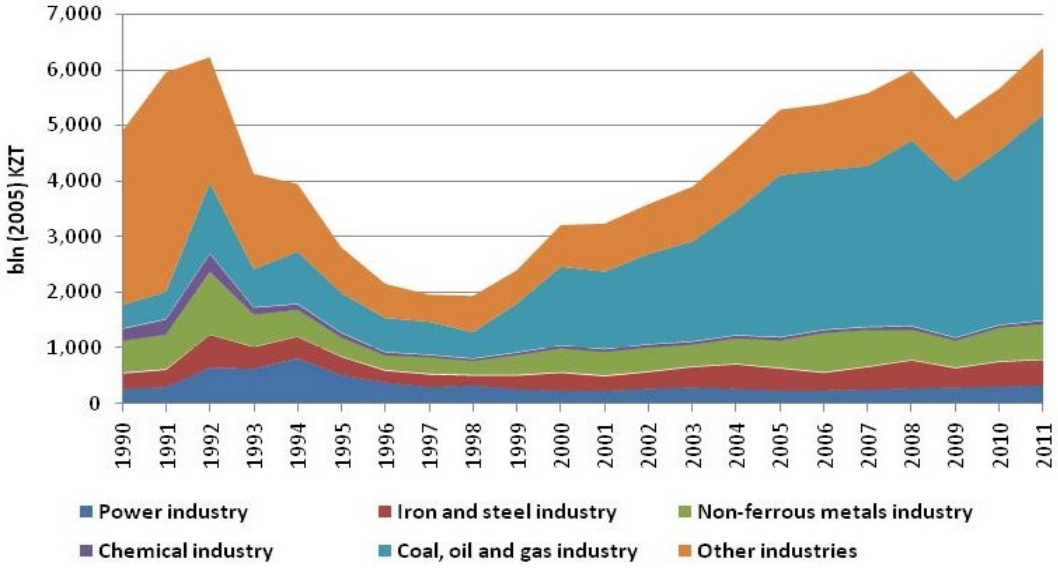

Figure 1. Structure of industrial output in Kazakhstan

1.1 Power industry

Power production in Kazakhstan mainly relies on thermal power plant. About 80% of all heat and electricity is produced by coal combustion. Traditionally, most of electricity generation comes from coal-fired power plants mainly built in the Soviet time. Due to harsh climatic conditions in winter, a significant amount of energy is utilized for district heating purposes. The heat is provided by cogeneration plants and boiler stations. Existing power plants and distribution infrastructure are often highly deteriorated and ineffective, what results in significant energy losses. The power generation sector is responsible for a majority of CO_2 emissions from industrial production and it is the most energy intense among the sectors.

1.2 Iron and steel industry

Although productions of steel and pig iron have decreased by 1.8 and 1.7 times respectively since 1990, the industry remains one of the most developed in the country. The industrial output has been on rise since 2000 following the decline caused by demand disruption after the collapse of the USSR in 1990s. The peak of industrial production was in 1992, and the output has not reached that value yet. Historically, coal has been the fuel of choice for the industry due to its abundance and cheap mining and transportation costs as the iron and steel production plants are located near the major coal mines.

1.3 Non-ferrous metals industry

Copper, lead and zinc has long been produced in the country. However, more recently production of aluminum, titanium, magnesium and other metals have become the focus. The industrial output has already surpassed 1990 level and the further growth is expected. The industry has increased its coal consumption by almost eight times since 1990. The metals are mainly exported.

1.4 Chemical industry

The chemical industry is based on the utilization of phosphate and various salt reserves and petrochemical industry. The industrial output has reduced 3.6 times since 1990 and the share of the industry in the total industrial output has shrunk from 4% till just 0.1% for the same period. However, the industry has been on the recovery path with the average annual growth of 5% since 1998, when the size of the industry has shrunk almost six times.

1.5 Coal, oil and gas industry

The industry is significantly important for the economy of Kazakhstan due to large reserves of hydrocarbons. The reserve-to-production (R/P) ratios of oil, natural gas and coal are 46, 82.5 and 293 years respectively [3]. Kazakhstan has strategic plans to increase production of coal, oil and gas. While oil and gas present a valuable export commodity, domestic consumption of coal is expected to increase

by 12% by 2020 [4]. The share of coal, oil and gas industries in total industrial output has increased from just fewer than 10% in 1990 till almost 60% in 2011, while the shares of all other industries have reduced almost twice for the same period. This may indicate that the economy of Kazakhstan maybe vulnerable to the oil curse [5]. This study includes CO_2 emissions related to production and refining activities and does not include emissions caused by flaring associated petroleum gas.

1.6 Other industries

The industries included are machinery, food processing, pulp and paper industry, light industry and other non-specified industries. In other words, mostly processing and manufacturing industries. The share of the industries in the total national industrial output has dropped from 64% in 1990 till 19% in 2011.

Due to heavy dependence on cheap domestic coal, the environmental impact of the industry is significant in Kazakhstan. The industry causes almost 60% of the total national CO_2 emissions [6]. The power industry has had the biggest contribution to CO_2 emissions due to industrial activities as seen in Figure 2. Total CO_2 emissions caused by coal, oil and gas industry, non-ferrous metals industry and other industries increased comparing to 1990 level, while CO_2 emissions from iron and steel and chemical industries have reduced. The main driving factor for CO_2 emissions increase is rise in coal consumption.

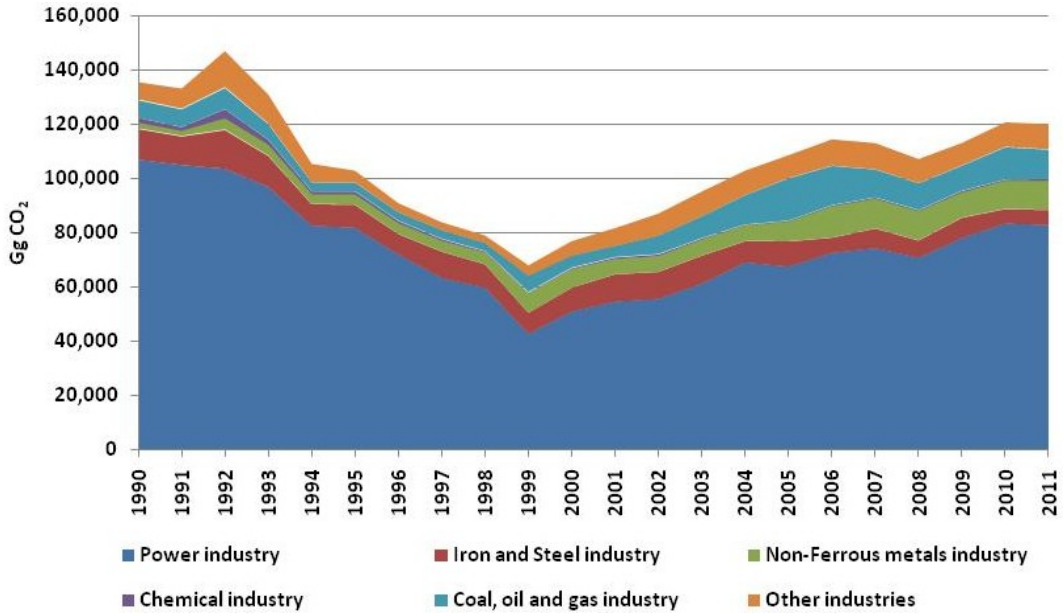

Figure 2. The total amount of CO_2 emissions related to fossil fuel combustion in six different industries

Kazakhstan is the non-Annex I party to the United Nations Framework Convention on Climate Change (UNFCCC). Quantified Emission Limitation or Reduction Objectives (QELROs) committed by Kazakhstan is 95% of 1990 base level by 2020 in Annex B of the Kyoto Protocol for the second commitment period [7]. The Government has developed the Concept of transition to green economy, where it has set the targets to reduce by 50% from the 2008 level, cut CO_2 emissions caused by electricity production by 40% and increase the share of renewable energy in electricity production by 50% by 2050 [8]. On top of that, the national Emission Trading Scheme with cap and trade approach has been launched. Hence, it is important to determine the factors affecting the growth of industry sector CO_2 emissions related to fossil fuel combustion.

In 2005, Karakaya and Ozcag [9] used decomposition analysis to define the driving forces of CO_2 emissions in Central Asia from fossil fuel combustion. The study distinguished between total primary energy supply and total final energy consumption. The factors investigated were: emission factor, energy intensity, fossil fuel intensity, conversion efficiency, economic output per capita and population for the period 1992-2001. The study revealed that the main driving force for CO2 emissions reduction in Kazakhstan due to reduction of economic activities following the collapse of the Soviet Union. Kojima and Bacon (2009) performed a multi-country decomposition analysis of CO_2 emissions from energy use for several time periods from 1994 till 2006 [10]. The methodologies used are five-factor decomposition (carbon intensity, fossil fuel share, energy intensity, GDP per capita and population effect) and six-factor

decomposition that used methodology similar to Karakaya and Ozcag (2005) study. The study indicated that primarily economic activity was the main driving force for CO_2 emissions change in Kazakhstan.

2. Methodology

Index Decomposition Analysis (IDA) has been identified as the preferred methodology in energy and environmental studies to investigate the factors influencing energy consumption and its environmental impact [11]. Among the existing IDA methodologies the Logarithmic Mean Divisia Index (LMDI) method has become popular due to its theoretical robustness, adaptability, and ability to provide perfect decomposition [12].

This study aims to conduct a year-to-year decomposition analysis of the factors affecting industrial CO_2 emissions from 1990 to 2011 in Kazakhstan. The existing studies suggest decomposition of CO_2 emissions into five explanatory effects as follows [11-13]:

$$C = \sum_{i,j} C_{ij} = \sum_{i,j} Q \frac{Q_i}{Q} \frac{E_i}{Q_i} \frac{E_{ij}}{E_i} \frac{C_{ij}}{E_{ij}} = \sum_{i,j} Q S_i I_i M_{ij} U_{ij} \quad (1)$$

where C is the total CO_2 emissions (kt), Cij are CO_2 emissions caused by consumption of fuel j by i industry, Q is total industrial output (billion Kazakhstani Tenge (bln KZT)), Q_i is the output of i industry (bln KZT), E_i is the use of fossil fuel by i industry (PJ), E_{ij} is the fossil fuel consumption of j type by i industry (PJ), S_i is the share of i industry in total industrial output, I_i is the energy intensity of i industry, M_{ij} is the energy mix of i industry, U_{ij} is the CO_2 emission factor of j fuel consumed by i industry.

Total changes in CO_2 emissions between target year T and base year (1990) could be expressed as follows:

$$\Delta C_{tot} = C^T - C^{1990} = \Delta C_{act} + \Delta C_{str} + \Delta C_{int} + \Delta C_{mix} + \Delta C_{emf} \quad (2)$$

where ΔC_{act} is the changed in CO_2 emissions caused by changes in activity, ΔC_{str} is the changes in CO2 emissions caused by industrial output structure, ΔC_{int} is the changes in CO_2 emissions caused by energy intensity, ΔC_{mix} is the changes in CO_2 emissions caused by fuel mix, ΔC_{str} is the changes in CO_2 emissions caused by emission factor. Where:

$$\Delta C_{act} = \sum_{ij} w_{ij} \ln\left(\frac{Q^T}{Q^{1990}}\right) \quad (3)$$

$$\Delta C_{str} = \sum_{ij} w_{ij} \ln\left(\frac{S_i^T}{S_i^{1990}}\right) \quad (4)$$

$$\Delta C_{int} = \sum_{ij} w_{ij} \ln\left(\frac{I_i^T}{I_i^{1990}}\right) \quad (5)$$

$$\Delta C_{mix} = \sum_{ij} w_{ij} \ln\left(\frac{M_{ij}^T}{M_{ij}^{1990}}\right) \quad (6)$$

$$\Delta C_{emf} = \sum_{ij} w_{ij} \ln\left(\frac{U_{ij}^T}{U_{ij}^{1990}}\right) \quad (7)$$

where w_{ij} is the logarithmic mean of industrial CO_2 emissions in year T and base year (1990) and expressed as follows:

$$w_{ij} = \frac{C_{ij}^T - C_{ij}^{1990}}{\ln C_{ij}^T - \ln C_{ij}^{1990}} \quad (8)$$

3. Data

The time interval under investigation ranged from 1990 till 2011 (Table 1). The industrial outputs in current prices for each sector were obtained from the Agency of the Committee on Statistics of the

Ministry of National Economy of the Republic of Kazakhstan [2], and adjusted to the constant prices of FY2005 using price deflator the United Nations Statistics Division [14].
Data on fossil fuel consumption, CO_2 emissions and implied CO_2 emission factors were acquired from Kazakhstan's national GHG inventory submitted to United Nations Framework Convention on Climate Change [6]. Biomass combustion and related CO_2 emissions are excluded from analysis as they are carbon-neutral.

Table 1. Fuel mix by industries in Petajoule (PJ)

Industry	1990					2011				
	Oil	Coal	Gas	Other	Total	Oil	Coal	Gas	Other	Total
Power	190.4	871.6	193.7	2.5	1258.3	12.8	797.7	145.8	0.0	956.3
Iron and steel	27.2	59.5	14.5	0.0	101.1	13.2	51.2	10.6	0.0	75.0
Non-ferrous metals	13.6	13.9	1.9	0.1	29.5	11.2	107.8	0.1	0.0	119.1
Chemical	2.0	1.9	23.9	2.7	30.6	0.0	0.5	11.9	0.0	12.4
Coal, oil and gas	47.4	4.3	42.1	5.9	99.7	60.7	3.0	112.8	0.0	176.6
Other	25.1	36.1	22.3	0.2	83.7	9.5	70.8	34.3	0.0	114.6
Total	305.7	987.3	298.4	11.4	1602.9	107.5	1031.0	315.6	0.0	1454.0

4. Results and discussion

Table 2 represents the results of decomposition analysis of CO_2 emissions in Gg. The results indicate that total CO_2 emissions from industrial activities in Kazakhstan have reduced by 15,455.1 Gg or 11% from 1990, while the total fossil fuel consumption have reduced by 9% for the same period. Coal and gas combustion have increased by 4% and 6% respectively, while oil consumption have dropped by 65% for the period 1990-2011. The activity effect indicates that CO_2 emissions would have grown by 24% if other effects had stayed constant. Improved energy intensity was the main factor for total CO_2 emissions reduction.

Table 2. Results of decomposition analysis 1990-2011 (Gg of CO2)

	ΔC_{tot}	ΔC_{act}	ΔC_{str}	ΔC_{int}	ΔC_{mix}	ΔC_{emf}
Power industry	-24,175.5	24,665.7	-6.485.7	-43,451.1	2,269.1	-1,173.5
Iron and steel industry	-5,720.5	2,170.1	1,949.4	-6,541.9	274.8	-3,572.9
Non-ferrous metals industry	8,419.9	1,399.7	-902.6	6,802.6	1,126.8	-6.6
Chemical industry	-1,138.4	290.2	-1,666.3	401.0	-41.7	-121.5
Coal, oil and gas industry	4,319.3	2,153.0	15,238.5	-12,795.7	-38.1	-238.3
Other industries	2,840.2	1,992.1	-9,084.9	9,426.1	342.4	164.5
Total	-15,455.1	32,670.9	-951.8	-46,159.0	3,933.3	-4,948.5

The results of the analysis are presented in the form of indexed time-series charts. The results indicate that coal, oil and gas industry, non-ferrous metals industry and other industries surpassed CO_2 emissions level of 1990, while power industry, iron and steel industry and chemical industry are still below that level.
The total CO_2 emissions from the power industry have reduced by 23% since 1990. However, the industry remains the biggest cause of CO_2 emissions in Kazakhstan. The main driving factor affecting CO_2 emissions changes caused by power industry is the industrial activity of the sector as seen in Figure 3. Energy intensity had the biggest contribution to the emissions reduction. The share of oil consumption in the fuel mix of the industry has dropped by 93% from 1990. Despite being the main cause of CO_2 emissions from total industry in Kazakhstan, the share of the power industry never exceeded 25% of the total industrial output.
CO_2 emissions related to the iron and steel industry have reduced by 51% since 1990. The decline in CO_2 emissions in 1990s was caused by output contraction, while improvements in energy intensity and emission factor due to fuel switching were the main causes of CO_2 emissions reduction in 2000s as in

Figure 4. For the whole period from 1990 to 2000, the main factors affecting emissions increase were the industrial activity and the output structure, while the energy intensity drove down the emissions by 58%.

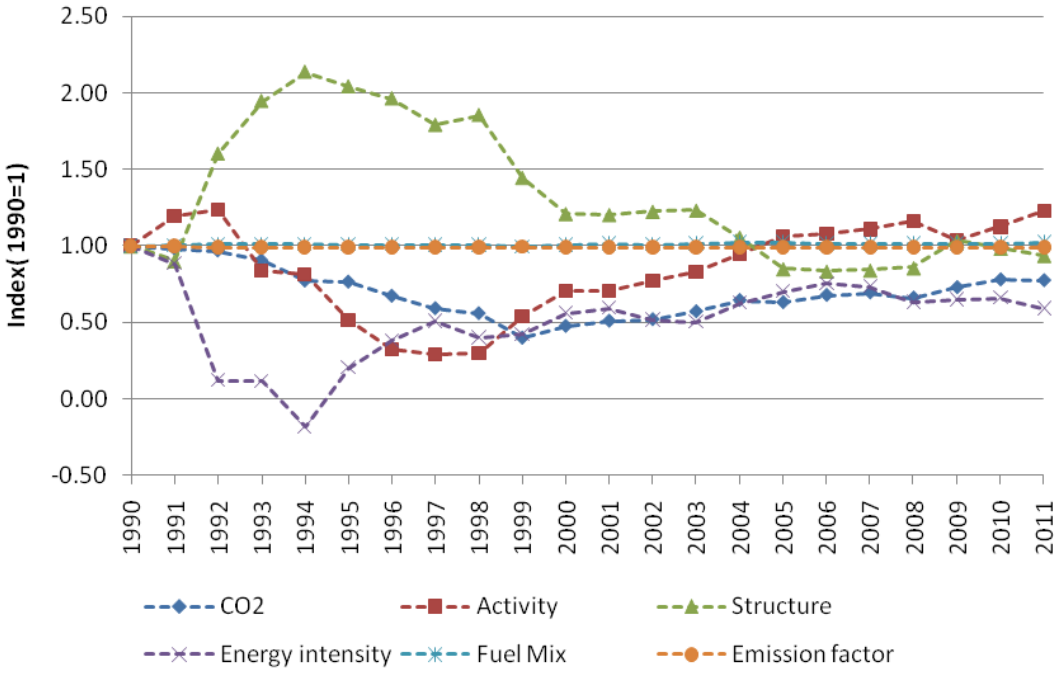

Figure 3. Results of decomposition analysis for power industry

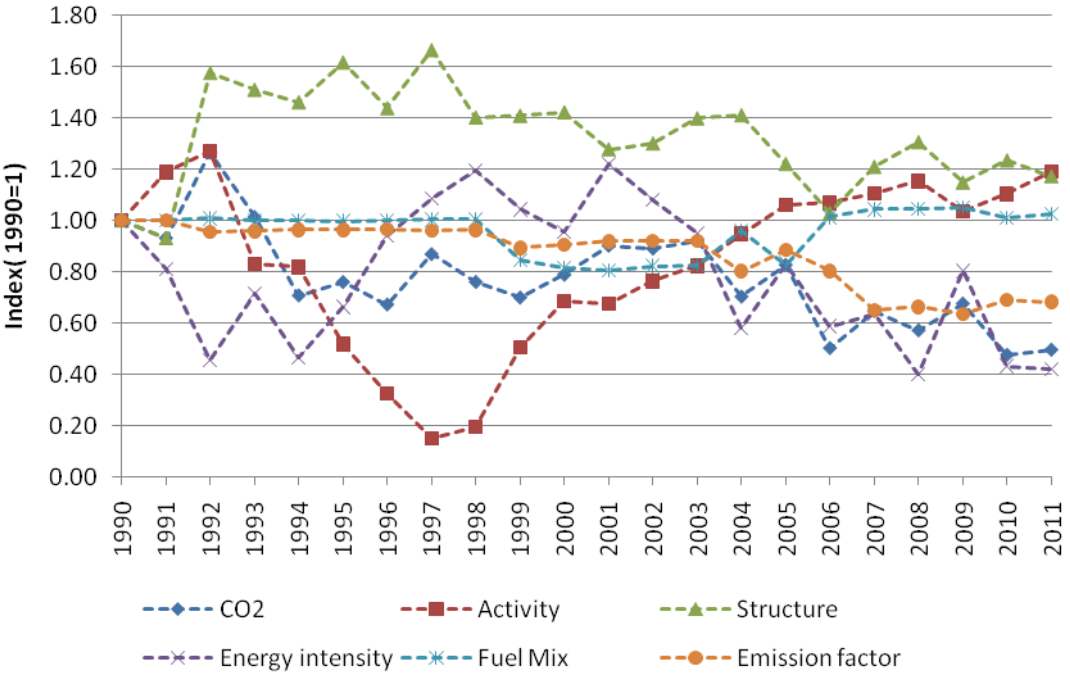

Figure 4. Results of decomposition analysis for iron and steel industry

The total CO2 emissions caused by the non-ferrous industry have increased by 347% for the whole period. The main reason behind CO_2 emissions increase is the energy intensity rise by 3.7 times since 1990 as displayed in Figure 5. Furthermore, the share of coal has reached 90% from 47% in 1990. This combination caused significant boost in CO_2 emissions caused by the industry.

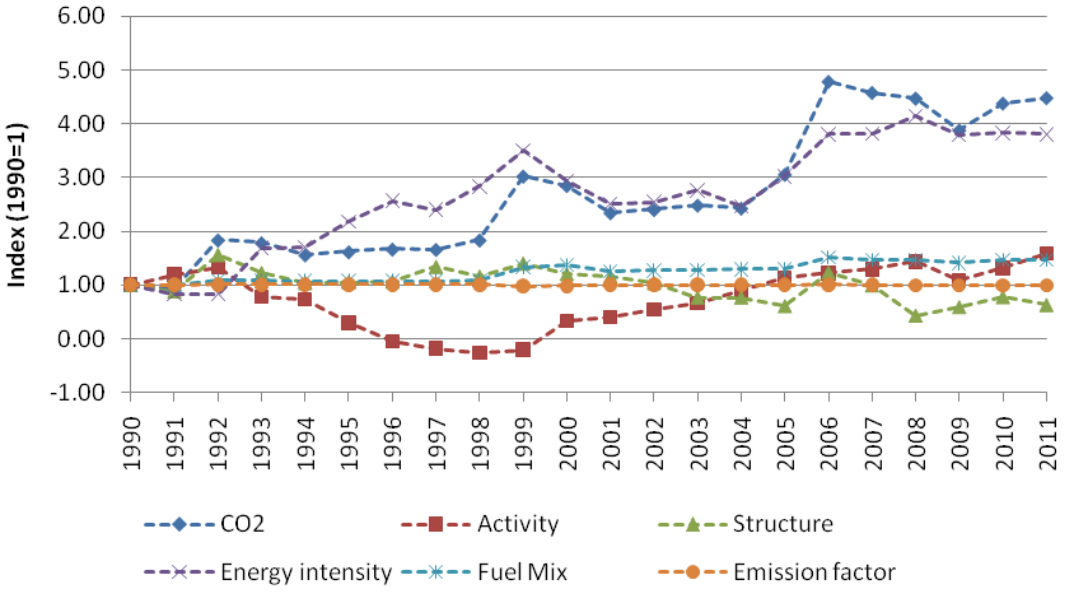

Figure 5. Results of decomposition analysis for non-ferrous metals industry

The total CO_2 emissions from chemical industry have declined by 62% since 1990. The main driving factor behind the decrease was the industrial structure effects that caused over 90% decline as seen in Figure 6. The industry is the only sector where gas is the dominant fuel in the mix and consisted 96% of the total fuel mix in 2011.

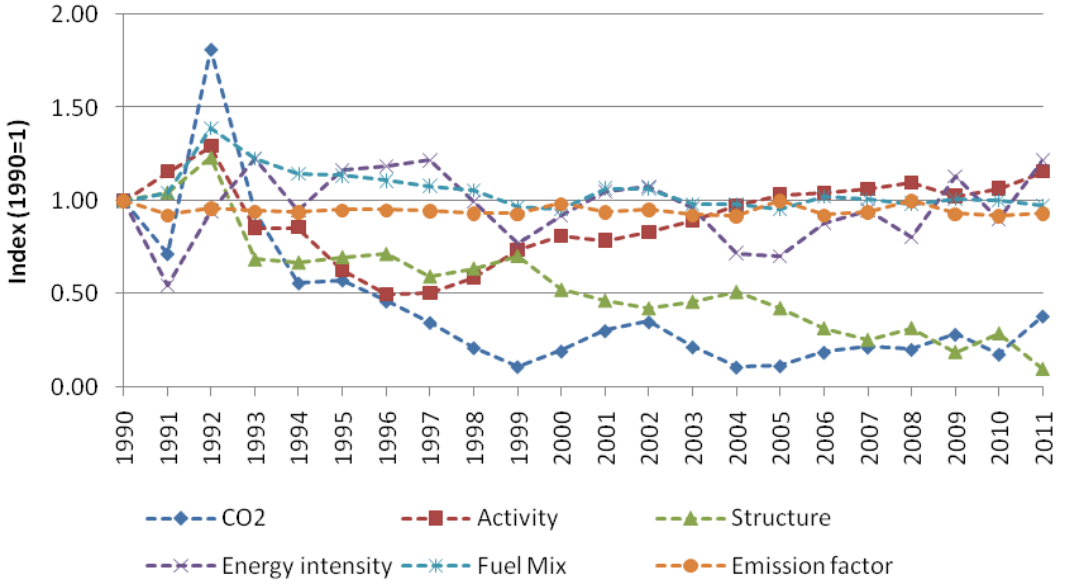

Figure 6. Results of decomposition analysis for chemical industry

The industrial output of coal, oil and gas industry has been increasing at the average rate of 14% annually since 1999 following the decline from 1992. Total CO_2 emissions caused by the industry have increased by 67% for analysis period. The main factor affecting the dynamics of CO_2 emissions from coal, oil and gas sector is the structure of industrial output in spite of improvements in energy intensity as seen in Figure 7. The industrial structure effect caused 237% increase in CO_2 emissions, while energy intensity factor pushed down emissions by almost 200% for the whole period. Furthermore, the results of the study most likely indicate that the industrial output of the coal, oil and gas sector highly depends on oil price fluctuations on the world market. This possibly explains energy intensity improvements of the sector despite increased fossil fuel consumption by 77% since 1990.

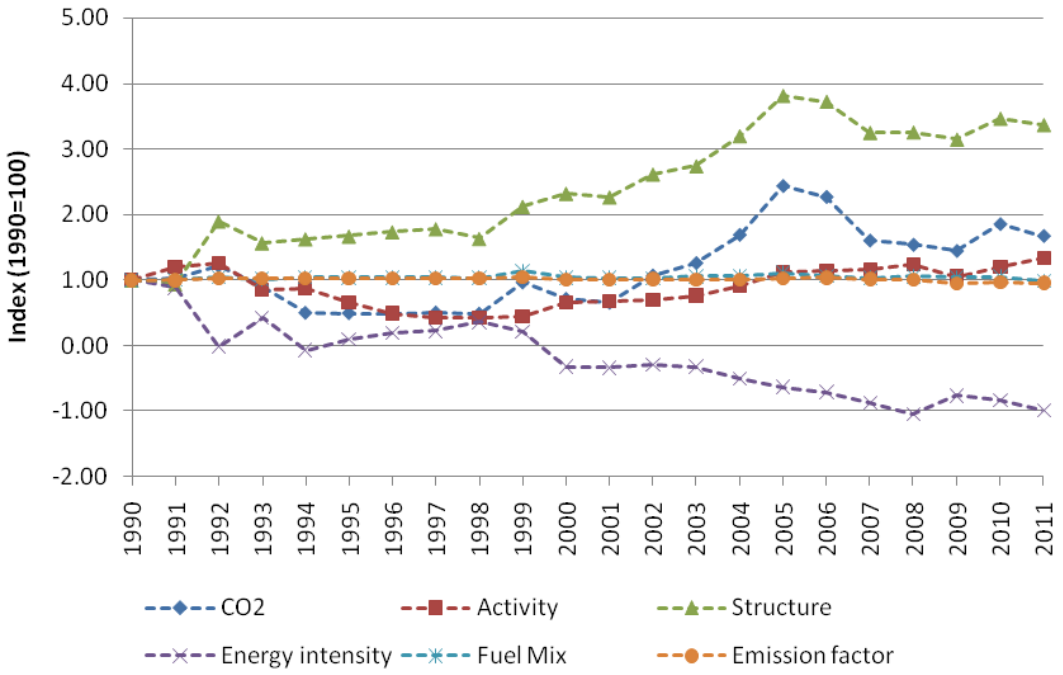

Figure 7. Results of decomposition analysis for coal, oil and gas industries

CO_2 emissions from the other sectors have increased by 45% since 1990. However, the emissions are below 1992 level when the industrial output and consequent environmental impact were at the peak as displayed in Figure 8. The biggest cause of CO2 emissions increase from the industry was energy intensity factor, while structure effect was the main driving force for reduction. The industry has increased coal consumption almost twice since 1990.

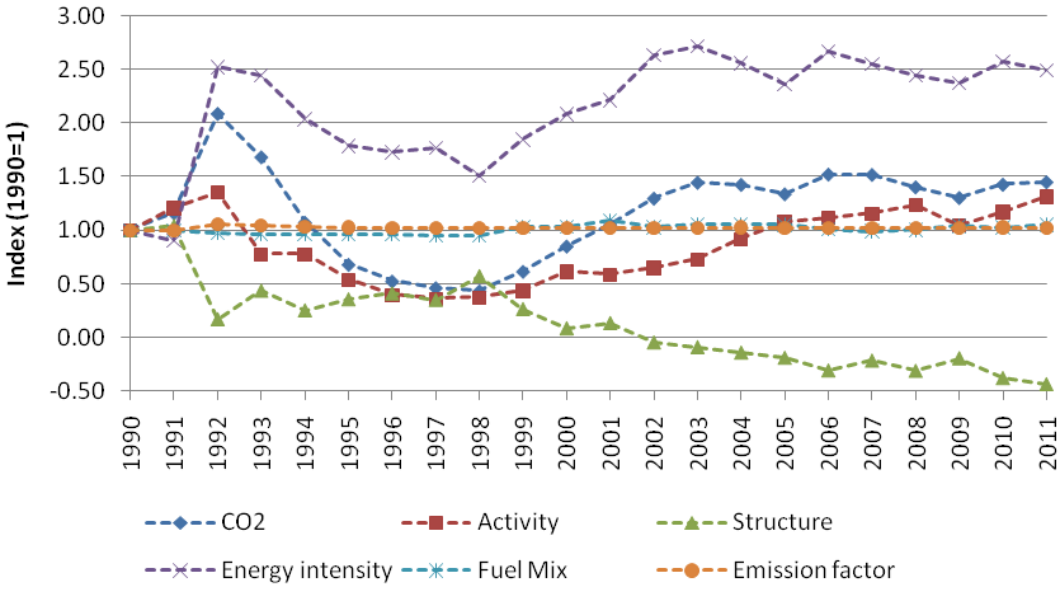

Figure 8. Results of decomposition analysis for other industries

5. Conclusion

From 1990 to 2011, CO_2 emissions related to fuel combustion by industry have increased by 11%. By applying LMDI methodology it was identified that changes in industrial activity pushed up total CO_2 emissions from industry by 24% followed by fuel mix with 3% increase, while changes in emission intensity, emission factor and structure of industrial output pushed down emissions by 34%, 4% and 1% respectively. Analysis of industries revealed that the relative CO_2 emissions reduction was achieved in chemical and iron and steel and power industries by 62%, 51% and 23% respectively since 1990.

Meanwhile, CO_2 emissions caused by non-ferrous metals, coal, oil and gas and other industries have increased by 347%, 67% and 45% respectively. Furthermore, it was identified that changes in industrial activity was the main driving force in emissions increase in power and iron and steel industries; energy intensity in non-ferrous metals, other and chemical industries; and the structure effect has significantly pushed up CO_2 emissions in coal, oil and gas industry. The energy intensity was the main factor to push down CO_2 emissions from coal, oil and gas, iron and steel and power industries, while changes in industrial output structure pushed down emissions in non-ferrous metals, chemical and other industries.

Although, Kazakhstan has achieved 31% increase in total industrial output since 1990, the growth occurred in power, iron and steel, non-ferrous metals and coal, oil and gas industries by 22%, 66%, 10% and impressive 770% respectively. On the other hand, chemical and other industries have dropped in size by 72% and 61% respectively. The transformation of industrial output towards over-reliance on natural resources export, crude oil in particular, may indicate that Kazakhstan is vulnerable to the phenomenon of the oil curse. The Government of Kazakhstan has been trying to diverse its industry from heavy dependence on export of hydrocarbons by development of non-energy intensive industries, measures for energy efficiency and energy saving improvement. However, a number of national industrial diversification programs have not succeeded. This is most likely due to greater corruption that often hits countries that undergo the oil curse [5].

Another important discovery from the analysis is the increase in coal consumption and reduction of oil presence in the fuel mix of the industry. In other words, coal, a fuel with a bigger environmental impact but cheaper cost, have become a main fuel for domestic industry, while oil and gas, major export commodities, have been sold on the world market. The fuel switch raises the questions of environmental justice and social equity in Kazakhstan.

A general policy conclusion on the basis of the study is that national strategy on increasing domestic coal consumption [4] and development of energy- and carbon-intense commodity based industries [15] contradicts Kazakhstan's international commitments on CO_2. This could create the incompatibility between national plans on transition to green economy and economic development of the country.

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