Driving Forces of C02 Emissions In Central Asia: A Decomposition Analysis of Air Pollution From Fossil Fuel Combustion

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Abstract

Global warming poses serious threats on environment, ecology and socio-economic systems. In the arid ecosystem of Central Asia, for instance, the Aral Sea has been subjected to an unprecedented degree of negative anthropogenic impacts. The atmospheric concentration of CO2 emissions is rising as the result of a variety of human activities, of which the burning of fossil fuels is the most important. Since early 1990s, taking action in order to control global warming has been on the world's agenda. The design of effective and comprehensive policies to control climate change requires an understanding of the rules played by the different factors affecting CO2 production. This study tries to analyze the sources of changes in energy-related CO2 emissions for five Central Asian countries for 1992-2001 periods. For this purpose, we use a decomposition technique, which separates out the effects of changes in population, energy intensity of output, economic growth, primary energy use in final energy consumption and the carbon intensity of fossil fuel combustion. Data shows that CO2 emissions were reduced quite substantially in Tajikistan, Kazakhstan and Kyrgyzstan since 1992. Our results suggest that main decrease in CO2 emissions in these countries is due to a serious economic contraction after the collapse of Soviet Union. Other factors contributing to this result are improvements in energy intensities and decline in energy related activities in general. Even though, other two Central Asian countries, Turkmenistan and Uzbekistan, also experienced similar economic contraction for the same period, their CO2 emissions have increased. This could be explained by their energy use patterns and energy market structures. Energy intensities have increased significantly for these countries. It is suggested that liberalization of energy sectors improves energy intensities. It can be argued that, with the liberalization, Turkmenistan and Uzbekistan can find possibilities to improve energy intensity effects and in return to reduce CO2 emission levels. Finally, the study stresses that the Central Asian countries have been experiencing a recovery since the beginning of 2000. Therefore, it is possible that CO2 emissions will begin to increase in the future unless energy intensities and carbon content of energy can be decreased via policy changes and/or behavioral adaptation.

Keywords: Climate change, Central Asia, sustainable development, economics, decomposition method, CO2 emissions, energy intensity.

1. Introduction

Global warming poses serious threats on environment, ecology and socio-economic systems. In the arid ecosystem of Central Asia, for instance, the Aral Sea has been subjected to an unprecedented degree of negative anthropogenic impacts. In this region, agricultural production has already decreased in some commodity groups and quantities and qualities of water resources are at particular risk of severe effects of climate change. There is widespread scientific agreement that increases in greenhouse gases (GHG) contribute to the problem of global warming. This serious global climate change problem has resulted in proposals to set specific targets for reducing greenhouse gas emissions. The Framework Convention on Climate Change was signed at the World Summit held on June 1992 in Rio-de-Janeiro by more than 150 countries to promote international cooperation for achieving such reductions. The Kyoto Protocol, signed in 1997 at the third meeting of the Conference of Parties (COP-3), goes further and commits developed countries (Annex I) to reducing their greenhouse gas emissions according to individual quantified emission limitation or reduction commitment percentages, and outlines various mechanisms for achieving this goal. Even though, no specific targets were prescribed for developing countries, the Kyoto Protocol demanded that all developing countries should be included in GHG emission reduction efforts (Dessai and Schipper, 2003) . The reductions concern six groups of greenhouse gases: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and three categories of fluorinated gases (HFCs, PFCs and SF_6). The emission of CO_2 is the most important issue, because it has the largest share among the greenhouse gases and while the emission of the other greenhouse gases is decreasing the emission of CO_2 is increasing. The major source of anthropogenic CO_2 emissions is the combustion of fossil fuels (i.e. coal, oil and natural gas). Therefore, in this study, the main attention is given to CO_2 emissions that are resulted from fossil fuel combustions.

Central Asian countries are non-Annex countries and their commitments are to carry out a GHG emissions inventory periodically, as well as vulnerability and mitigation studies. However, any CO_2 reductions by a developing country would contribute to the ease of the global warming issue especially when we consider that mitigation of climate change issue should be a joint international effort. Morover, the Kyoto Protocol has opened new opportunities for participating in GHG mitigation projects through the flexible mechanisms like Clean Development Mechanism (CDM), Joint Implementation (JI) and Emission Trading (ET).

The design of effective and comprehensive policies to control climate change requires an understanding of the rules played by the different factors affecting CO2 production. By using a decomposition technique, we will try to analyze the sources of changes in energy-related CO2 emissions for five Central Asian countries for 1992-2001 periods. Decomposition analyses uses historical data to explain which factors contributed how much to the total change in CO2 emissions (Hamilton and Turton, 2002). Adequate information regarding the sources of these emissions will contribute to the effectiveness of policies to reduce them.

The structure of this paper is as follows. Section 2 analyses main drivers of CO2 emission changes. Section 3 describes the decomposition method used to compute the effects of several factors on the emission of CO2 for five Central Asian countries, namely Tajikistan, Kazakhstan, Kyrgyzstan, Turkmenistan and Uzbekistan. The results of the analyses are discussed in Section 4. Section 5 concludes by commenting on how these historical trends and drivers can be used in the development of greenhouse gas emissions scenarios.

2. Drivers of C02 Emission Changes

There are few aspects of environmental change that are universally agreed upon. This is due in part to the complexity of the factors that drive environmental change. Evidence continues to accumulate suggesting that much of the change in atmospheric gas concentrations is human-induced. Because human societies enjoy and utilize the environment for the fulfillment of their basic needs (food, clothing, shelter, etc.) and wants (luxury items, social prestige based e.g. on economic status etc.), humans have a vested interest in a healthy and productive environment (Shi, 2003).

Human induced contributions to CO2 emissions stem mainly from fossil fuel use through energy consumption and industrial production and these emissions have been increasing dramatically since the beginning of the Industrial Revolution. Land-use / Land-cover changes, such as deforestation, also affect the exchange of carbon dioxide between the Earth and the atmosphere (IPCC, 2001).

Human induced emissions are the result of a large set of interrelated driving variables in the domains of demographics, economics, resources and technology as well as environmental policies. In order to analyze human induced driving forces of environmental change, studies take the approaches of either Ehrlich's IPAT framework or its extended version of so-called Kaya Identity (1990).

The theoretical framework proposed by Ehrlich and Holdren (1974) formulates the drivers of the environmental changes as;

$$I = P \, x \, A \, x \, T \qquad (2.1)$$

Which hypothesizes that environmental impact (I) is determined by the interacting effects of population size (P), per capita consumption levels (A, for affluence), and finally the per capita pollution generated by the technology (T) used to satisfy the consumption levels.

Studies of energy-related carbon emissions are structured by using the Kaya identity outlined by;

$$CO_2 Emissions \quad = \quad Population \times \frac{GDP}{Person} \times \frac{Energy}{GDP} \times \frac{CO_2}{Energy} \qquad (2.2)$$

Where CO2 emissions are a function of population, income (GDP per capita), energy intensity (units of energy/GDP), and carbon intensity (CO2 emissions per unit of energy).

Both formulas suggest that population size, economic growth and technology (in other words, energy and CO2 intensities) are important in the emission of greenhouse gases. Therefore, in order to understand their influence on CO2 emissions, it requires a closer look at each of these main driving factors.

2.1. The Contribution of Population Growth to Environmental Change

Population size and its growth has been one of the main factors in causing CO2 emissions because the two seem to go hand-in-hand. If we hold affluence and technology constant, the economic activity required to support an additional person means more resources must be extracted and more emissions are generated. The contribution of population growth on environmental problems is specified through two mechanisms; First, a larger population could result in increased demand for energy for power, industry, and transportation, hence the increasing fossil fuel emissions. Second, population growth could contribute to greenhouse gas emissions through its effect on deforestation. An increase in population causes greater deforestation, land use changes and more consumption of wood for fuel; thus, larger population raises CO2 emissions and contributes to the greenhouse effect (Birdsall, 1992). Shi (2003) argued that one percent of population growth is associated with a 1.28 percentage increase in emissions on average. The impact of population pressure on emissions has been more pronounced in developing countries than developed countries. However, it should be noted that as population growth slows down on average, its contribution to increases in CO2 emissions declines, meaning that rising CO2 emissions will increasingly stem from other factors.

2.2. The Contribution of Affluence to Environmental Change

Affluence denotes the per-capita level of goods and services produced in a country in a given time period, measured by gross national product (GNP) or gross domestic product (GDP) per capita. Affluence is a critical determinant of environmental degradation because high rates of economic activity are associated with rapid rates of resource use and waste production. In general, increasing affluence tends to exacerbate environmental impacts. Many analyses show that economic growth is responsible for most of the changes in CO2 emission (see, *e.g.*, Albrecht J. et al, 2002, Luukkanen J. and Kaivo-oja, J. 2002., Ansuategi and Escapa, 2002). Regarding decreasing affluence, the main issue is that there would be no single country that accepts reducing their economic growth.

2.3. The Contribution of Technology to Environmental Change

Population and affluence determine the level of economic activity, i.e. the quantity of goods and services produced. Technology is the recipe that defines the combination of capital, labor, energy, materials, and information that are used to produce a good or service. For most goods and services, different combinations are possible. The technology term actually incorporates not only technology as it is usually conceived but also social organization, institutions, culture, and all other factors affecting human impact on the environment other than population and affluence (Nanduri, 1998). There are two ways in which technological change can lower environmental impact. First, it can reduce the materials and energy used per unit of output, which is termed as energy intensity, and, second, it can substitute less harmful technology, which is termed as energy (fuel) switch (Roca and Alcántara, 2001). In the latter case, the fuel switch can take place either from high polluting fossil fuel (eg. Coal) to less polluting fossil fuel (eg. Natural gas) or from fossil fuel to non-fossil fuel.

All three of the factors influencing environmental impact and change are interrelated and future emissions will depend on the complex interactions among population growth, economic growth, and technological innovation.

3. Decomposition Method

From a policy design perspective, it is important to find out the magnitudes, interrelationships, and significance of the primary human drivers of change in CO2 emissions. Such information is helpful for the development of energy use and carbon emissions scenarios because it provides modelers with a historical basis from which to extrapolate trends as well as information on how various factors such as population, affluence, energy intensity, and structural trends affect energy use and associated greenhouse gas emissions. In most cases, when we look at environmental changes it is not immediately obvious which force or interplay of forces caused the changes. The questions asked above can be answered by a decomposition analysis, which shows how much changes in certain factors contributed to changes in a specific variable. Decomposition analyses are widely used in energy studies. As a response to climate change policy needs, decomposition analysis has been extended in order to identify the factors influencing changes in greenhouse gases emissions and in particular in carbon dioxide emissions. Ang and Zhang (2000) provides an extensive literature review.

In this study, we present historical energy use and carbon emission trends and try to find out the main driving factors affecting CO2 emissions changes for the five Central Asian Countries, namely Kazakhstan, Kyrgyzstan, Tajikistan,Turkmenistan and Uzbekistan. Our discussion of the drivers is guided by the terms of the so-called Kaya identity (Kaya, 1990) as outlined by equation 2.2. We have redefined the terms slightly to closely match the available data and the characteristics of the countries concerned that we focus on in this paper. Thus, following Hamilton and Turton (2002), energy related emissions of CO2 for a given year can be decomposed as;

$$CO_2 = \frac{CO_2}{FOSS} \frac{FOSS}{TPES} \frac{TPES}{TFC} \frac{TFC}{GDP} \frac{GDP}{POP} \text{POP} \qquad (3.1)$$

The formula links energy-related carbon emissions (CO2) to fossil fuel consumption (FOSS), total primary energy supply (TPES), total final energy consumption (TFC), level of economic activity, that is gross domestic production (GDP), and population (POP).

Accordingly, the first factor on the right of the formula 3.1, CO2/FOSS, measures the *carbon intensity effect*, which is the CO2 intensity of fossil fuel combustion and mainly reflects the fuel mix. The second factor, FOSS/TPES is the *fossil fuel intensity effect*, which indicates the proportion of total energy obtained from fossil sources. The third term in equation 3.1, TPES/TFC is the *conversion efficiency effect* and it represents the amount of primary energy required to deliver energy for final consumption and reflects both conversion efficiency and fuel mix. The fourth term TFC/GDP is the *energy intensity effect* of economic activity, reflecting both efficiency of energy use and economic structure. These four factors can be considered to represent technological impacts of so called IPAT model. GDP/POP repsents *growth effect* and is a measure of economic output per capita. Finally, POP is the *population effect* and it measures the influence of population growth alone. The latter two factors correspond to the affluence and population in the IPAT model.

At any moment in time, for a country or group of countries, the level of CO2 emissions due to fossil fuel combustions can be seen as the product of the six Kaya Identity components as outlined above. For small to moderate changes in the Kaya components between any two years, the sum of the percent changes in each of the variables closely approximates the percent change in carbon emissions between those two years (Hamilton and Turton, 2002). Therefore, in order to analyse the historical trends, our decomposition index formula should take the form as follows;

$$\frac{CO_2(_{t=1})}{CO_2(_{t=0})} = \frac{\frac{CO_2}{FOSS}(_{t=1})}{\frac{CO_2}{FOSS}(_{t=0})} \quad \frac{\frac{FOSS}{TPES}(_{t=1})}{\frac{FOSS}{TPES}(_{t=0})} \quad \frac{\frac{TPES}{TFC}(_{t=1})}{\frac{TPES}{TFC}(_{t=0})} \quad \frac{\frac{TFC}{GDP}(_{t=1})}{\frac{TFC}{GDP}(_{t=0})} \quad \frac{\frac{GDP}{POP}(_{t=1})}{\frac{GDP}{POP}(_{t=0})} \quad \frac{POP(_{t=1})}{POP(_{t=0})} \qquad (3.2)$$

Accordingly, we can calculate percentage changes of both on the left- hand side (CO2 emissions) and right-hand side (determinants of CO2 emission changes) parameters of equation 3.2, and the effects of these factors on CO2 emissions can be analysed.

4. Data And Results

This section presents results of our case study of five Central Asian Countries to better understand the relationships between some specific driving factors and total CO_2 emission changes, based on the data and analytical method developed in the previous section. First, we provide a detailed descriptive analysis of the data, then present results of the decomposition analysis of CO_2 changes.

A historical analysis for the period 1992-2001 is complemented. To obtain the data related to the variables analyzed, we have mainly used the databases of the International Energy Agency. CO2 emissions data that are resulted from fossil fuel combustions for five Central Asian countries are obtained from "CO_2 Emissions From Fuel Combustion for Non-OECD Countries" (IEA, 2003a). Total primary energy supply data for the same countries are obtained from "Energy Balances of Non-OECD Countries" (IEA, 2003b). The data includes all fossil fuels as well non-fossil fuels. Since IEA (2003b) data gives coal, petroleum and natural gas values as seperately, for our fossil fuel (FOSS) paramater, we have aggregated these values by adding them together. For the 1992-2001 periods, data for GDP, Total Final Energy Consumption (TFC) and population (POP) were easily obtained from IEA (2003c).

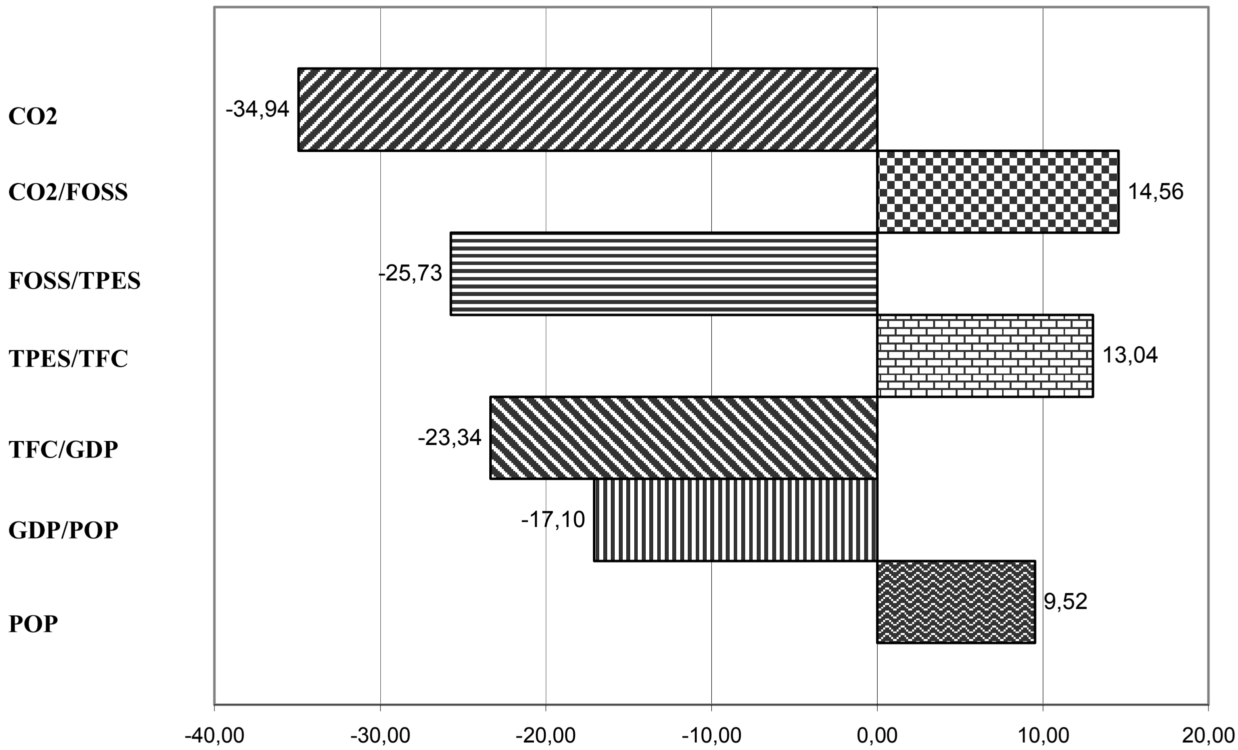
Table 1: CO_2 Changes and Driving Factors of CO_2 Changes for the Central Asia and five individual countries (*% changes*)

COUNTRIES	CO2/CO2	CO2/FOSS	FOSS/TPES	TPES/TFC	TFC/GDP	GDP/POP	POP/POP
Central Asia	-34,94	14,56	-25,73	13,04	-23,34	-17,10	9,52
Kazakhstan	-53,06	14,91	-19,27	20,22	-54,71	0,79	-8,02
Kyrgyzstan	-71,49	62,50	-60,08	26,45	-11,74	-64,07	10,22
Tajikistan	-77,60	9,19	-38,66	6,97	-65,39	-19,05	11,61
Turkmenistan	21,81	2,83	-12,43	13,40	-9,77	-2,49	36,00
Uzbekistan	2,81	-15,06	7,52	-3,43	61,54	-38,44	17,15

Table 1 presents percentege changes in CO_2 emissions and its main driving factors for Central Asia as a region and for five individual Central Asian countries for the 1992-2001 period. As can be seen from Table 1, overall carbondioxide emissions in Central Aisa have declined 34.94% from 1992 to 2001. While World CO_2 emissions showed an increase in average during the same period, such decline in emissions in Central Asia is quite important for the climate change issue. As we look in detail for the individual countries, one can see that while Tajikistan, Kyrgyzstan and Kazakhstan reduced their CO_2 emissions quite substantially, emissions in Turkmenistan and Uzbekistan increased during the same period. In order to better understand what the main driving factors of these CO_2 changes are during this period, it is essential to take a closer look at each effect in detail. In this section, after analysing the results for the whole region, a detailed analysis will be carried out for the effects of the main factors that caused CO_2 changes for individual countries.

Even though Central Asian countries as a whole have made significant contribution to reducing CO_2 emissions, it is important to note that none of these reductions have resulted from conscious domestic climate mitigation policies. When analysing the 34.94% decline in CO_2 changes in Central Asia, it is evident that this decline was achieved mainly due to a substantial economic contraction that was experienced during the 1992-2001 period. After gaining their independence, such economic decline was a common characteristics of the majority of former Soviet Union countries (Pomfret, 2003).

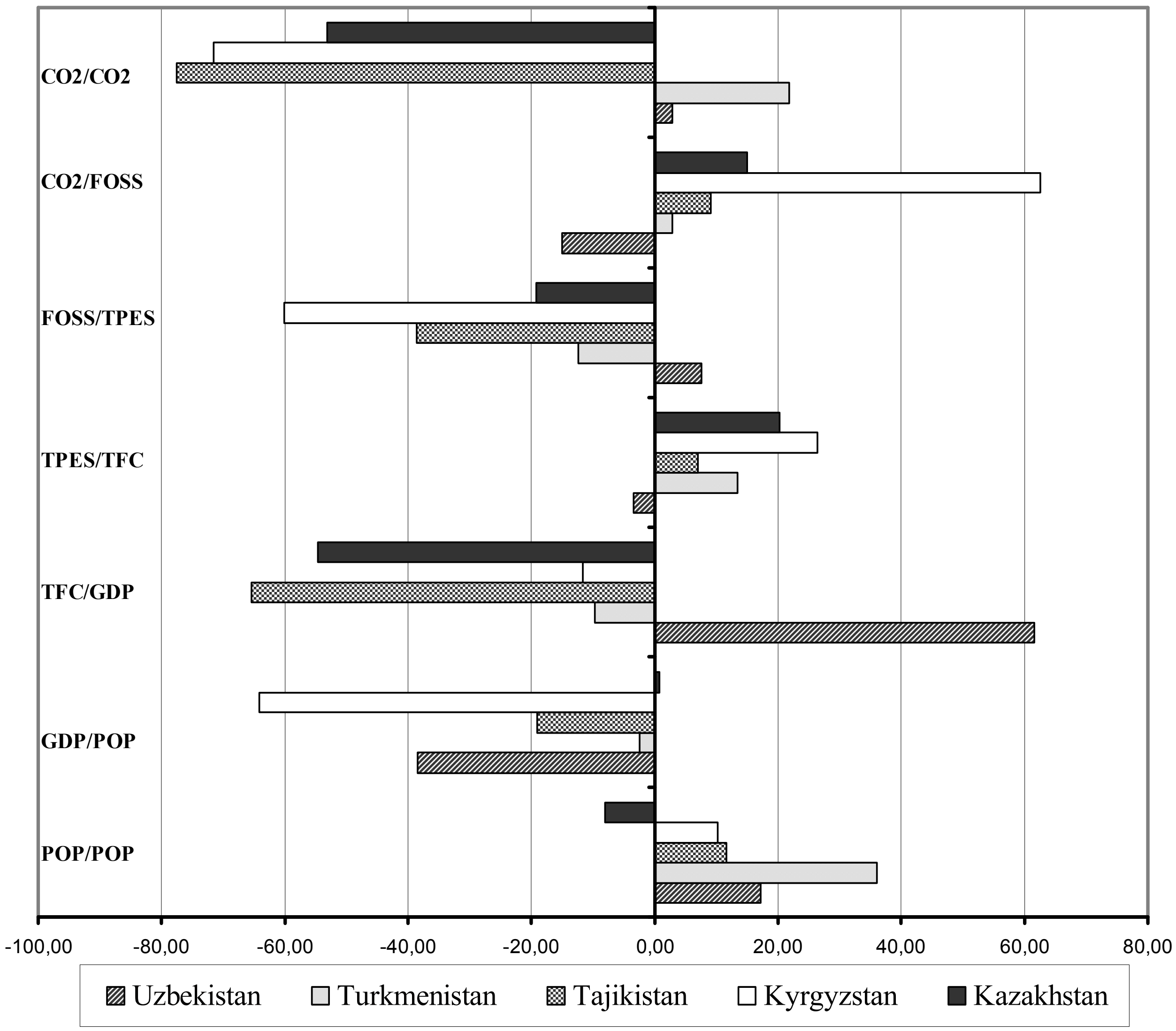
Figure 1 : 1992-2001 Average of Central Asia



Equally important, a decrease in overall energy intensites have contributed to such decline in CO2 emissions for the region. Fossil fuel intensity effect, which implies fuel switch towards less carbon emissions, also contributed to reductions in CO2 emissions. On the other hand, carbon intensity effect, Conversion Efficiency Effect and population effect were positive during this period and offset such reduction to some extend.

As mentioned earlier, CO2 emissions were reduced quite substantially in Tajikistan, Kyrgyzstan and Kazakhstan since 1992. Our results suggest that main decreases in CO2 emissions in these countries are mainly due to a serious economic contraction after the collapse of Soviet Union. Negative growth effects in Tajikistan and Kyrgyzstan are %65 and %64 respectively. The growth effect in Kazakhstan barely reached positive values, which is %0.79, in 2001, yet during the previous years the GDP growth has always been negative. Even though, the other two Central Asian countries, Turkmenistan and Uzbekistan, also experienced similar economic contraction for the same period, their CO2 emissions have increased.

Figure 2 : CO2 Emissions and CO2 Determinants of Central Asia in 1992-2001



This could be explained by their energy use patterns and energy market structures. Energy intensities, which is measured by the amount of total energy per unit of GDP, have increased significantly for these countries. Energy intensities are extremely important not only for CO2 mitigation policies but also for sustained economic growth. If one manages to improve its energy intensities, it means that less energy is used in order to produce the same amount of output, which in turn leads to lower costs and emissions. This argument is supported by our findings. Even though Kazakhstan did not experience big economic decline compared to Uzbekistan (growth effects in

Kazakhstan and Uzbekistan are +0.79% and -36.44% respectively), CO_2 emissions in Kazakhstan declined over 53% while Uzbekistan's CO_2 emissons increased over 2% during the 1992-2001 period (See Table 1). This contradictory outcome indicates the importance of energy intensities. As can be seen from Table 1, changes in energy intensities for Kazakhstan and Uzbekistan show different patterns. While Kazakhstan improved its energy intensity by reducing it upto 54.75%, energy requirement per unit of output in Uzbekistan increased by 61.54% in 2001 compared to 1992. Therefore,ceteris paribus, it can be argued that the reason behind Uzbekistan's CO_2 emission increase is due to inefficient energy use during this period. In our earlier study, which analysed the determinants of CO_2 changes in Central Asia for the 1992-1999 period, a substantial deteriotion in energy intensities were estimated in the case of Turkmenistan, which showed a 47% increase in energy intensity effect (Karakaya and Özçağ, 2004). In this updated study, however, it is estimated that energy intensity effect in Turkmenisten has improved significantly between 1992-2001 period. This dramatic change in energy intensities within two years could be explained by extra-ordinary economic growth that was experienced by Turkmenistan, which was reported as 17% in 2000 and 20.5 percent in 2001 Rapid economic growth was due to massive increase in natural gas production,where its amount was more than tripled between 1998 and 2001, and mainly this production was exported(Pomfret, 2003).. On the other hand, total final energy consumption, TFC, remained almost the same during the same period. Therefore, an increase in real GDP and stable TFC made energy intensity effect, defined as the ratio of TFC to GDP, look improved within two years.

Regarding CO_2 intensity effect, it can be seen that all countries have experienced increases in CO_2 intensities with the exception of Uzbekistan. The positive CO_2 intensity values should be interpreted cautiously. We believe that such results indicate that there was no major energy switch among the fossil fuels (e.g. from coal to natural gas). Since energy production declined quite substantially during this period, it might be considered that such fuel switch was not needed. As our findings suggest, major fuel switch from coal to natural gas was observed only in Uzbekistan. With regard to fossil fuel intensity effect, we see that, except Uzbekistan, all countries improved their situation, which suggests that some degree of fuel switch took place between fossil fuel to non-fossil fuels. Fossil fuel intensity effects were especially stronger in the case of Kyrgyzstan and Tajikistan, where fuel switch were towards hydro-electric energy sources as abundant water resources give them significant hydroelectric potential (MEEKR, 2003; MNP, 2002).

Finally, we can see that population effect has contributed to increase in CO_2 emissions in the Central Asian Countries with the exception of Kazakhstan. Negative population effect in Kazakhstan is due to emigration of some non-Kazak citizens to Russia and Europe after the collapse of Soviet Union (UNDP, 2002). Population effect is especially stronger for Turkmensitan and can be considered as one of the main contributor to increase CO_2 emissions as the population increase reached over %36 during the 1992-2001 period.

Conclusion

The analysis of the trend of CO_2 emission changes is a useful reference point for designing energy and enviromental policies in a nation. The decomposition analysis presented in this study leads to some interesting conclusions about the factors that have influenced changes in CO_2 emissions from the Central Asian countries for the 1992-2001 period. Our main findings can be listed as follows;

- Population effect is mainly stable in Central Asian countries.
- The above results make clear that the observed reduction of overall CO_2 emissions in Central Asia is practically owed to the crisis that has experienced by these countries after gaining their independence from the Soviet Union.
- Fuel switch among fossil fuels took place mainly in Uzbekistan. Fuel switch from fossil fuels to non-fossil fuels took place in all countries except Uzbekistan.
- Energy intensities are key elements of energy-saving and carbon-reduction plans. While Tajikistan, Kazakhstan, Kyrgyzstan and Turkmenistan (only recently) improved their energy intensities, Uzbekistan has problems in reducing their energy efficiencies.

The study stresses that most of the Central Asian countries have been experiencing a recovery since the beginning of 2000. Therefore, it is possible that CO_2 emissions will begin to increase in the future unless energy intensities and carbon content of energy are improved via policy changes and/or behavioral adaptation. Some Central Asian countries improved their energy intensities, yet there is still great potential to improve their energy saving positions. It is suggested that liberalization of energy sectors improves energy intensities (Cornillie and Fankhauser, 2002). Therefore, it can be argued that, with liberalization, especially Uzbekistan and Turkmenistan can find possibilities to improve energy intensity effects and in return reduce CO_2 emission levels.

Another important mitigation policy in the case of Central Asian countries could be switching energy from coal and petroleoum fuels to renevables or at least to natural gas as they have aboundant resources in the latter case.

Finally, flexible mechanisms (Clean Development Mechanism, Joint Implementation and Emission Trading) introduced by the Kyoto Protocol can offer great opportunities for the Central Asian countries in order to find financial support for their climate change mitigation policies. While CDM and JI projects can be applied to all Central Asian countries, Emission trading could be a main financial resource especially for Kazakhistan as tradeble amount of emission reductions that has been gained since 1992 in Kazakhstan totals to a substantial amount.

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