

Article

# How Is Mortality Affected by Fossil Fuel Consumption, CO<sub>2</sub> Emissions and Economic Factors in CIS Region?

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**Abstract:** It is widely discussed that GDP growth has a vague impact on environmental pollution due to carbon dioxide emissions from fossil fuels consumed in production, transportation, and power generation. The main purpose of this study is to investigate the relationships between economic growth, fossil fuel consumption, mortality (from cardiovascular disease (CVD), diabetes mellitus (DM), cancer, and chronic respiratory disease (CRD)), and environmental pollution since environmental pollution can be a reason for societal mortality rate increases. This study uses the generalized method of moments (GMM) estimation technique for the Commonwealth of Independent States (CIS) members for the period from 1993–2018. The major results revealed that the highest variability of mortality could be explained by CO<sub>2</sub> variability. Regarding fossil fuel consumption, the estimation proved that this variable positively affects mortality from CVD, DM, cancer, and CRD. Additionally, any improvements in the human development index (HDI) have a negative effect on mortality increases from CVD, DM, cancer, and CRD in the CIS region. It is recommended that the CIS members implement different policies to improve energy transitions, indicating movement from fossil fuel energy sources to renewable sources. Moreover, we recommend the CIS members enhance various policies for easy access to electricity from green sources and increase the renewable supply through improved technologies, sustainable economic growth, and increase the use of green sources in daily social life.

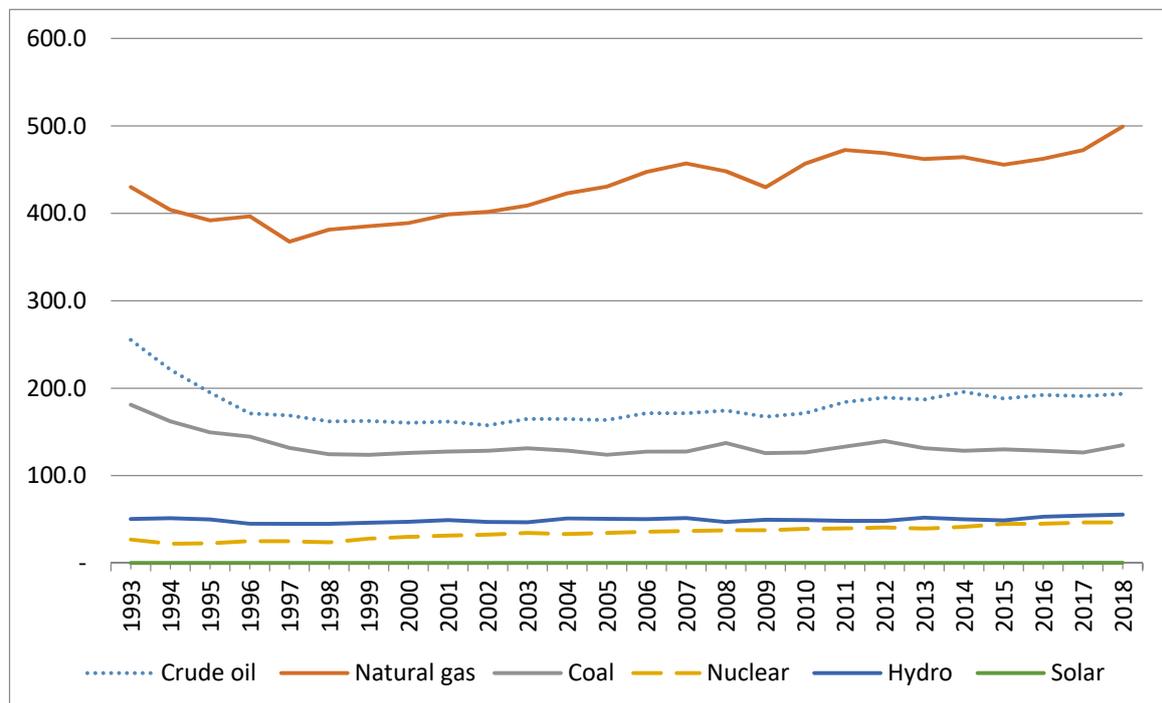
**Keywords:** economic growth; CO<sub>2</sub> emissions; mortality rate; econometrics

## 1. Introduction

It has been discussed by a number of scholars, like ref. [1], that human health has been linked to economic growth and air pollution. It is widely discussed that the population of the developing countries can be exposed to the various noxious gases coming from the combustion of consumed fossil fuels from production, transportation, and power generation due to the unavailability of the clean energy. Furthermore, energy consumption can directly or indirectly affect human health by inducing air pollution, safe water shortages, and poor medical care infrastructures. For instance, ref. [1] argue that fossil fuel energy that is consumed in industries raises human health threats, future costs from climate changes, and other environmental damages, which are considered as national health securities. However, countries especially in resource-abundant regions like in the CIS region, need to consume fossil fuel to ensure the production of goods, power generation, and access to a proper transportation system ([2,3]) as fossil fuels are cheaper compared to renewable energy technologies especially in the current low oil price era.

The problem with linking mortality from cardiovascular disease (CVD), diabetes mellitus (DM), cancer, and chronic respiratory disease (CRD) to economic growth and environmental pollution is that it is crucial for developing nations, particularly for the CIS member states (these nations are members of the Commonwealth of Independent States (CIS), which includes Armenia, Azerbaijan, Belarus, Georgia, Kazakhstan, Kyrgyzstan, Moldova, Russia, Tajikistan, Turkmenistan, Ukraine, and Uzbekistan) that have inappropriate health infrastructures and fewer contributions of renewable energy resources in economic sectors.

Figure 1 illustrates the share of fossil fuels and various renewable energy consumptions in the total energy consumption basket in the CIS region. According to the data, the contributions of fossil fuels, particularly natural gas and crude oil to total energy consumption in the CIS region, are considerably higher than the contributions of renewable sources.



**Figure 1.** Energy consumption diversification (CIS region), 1993–2018, million tons of oil equivalent [4].

Gathering and analyzing data from BP’s 2019 statistical energy review, as shown in Figure 2, reveals that the amount of CO<sub>2</sub> emissions in the CIS has increased from 1794 million tons in 2000 to nearly 2100 million tons in 2018. Comparatively, the amount of CO<sub>2</sub> that is emitted by the CIS is greater than the total emitted by African countries, South and Central America, and the Middle East [4]. However, the pollution levels in the CIS region are not the same. When considering the data from British Petroleum [4], the Russian Federation has one of largest economies in the world and has the highest contribution level (due to its giant energy industries, like electricity generation) of air pollution relative to the other CIS members. Conversely, we can express that the CIS members do not have a particular difference in their development and industrial production due to the same economic structure of the CIS members during the Soviet Union.

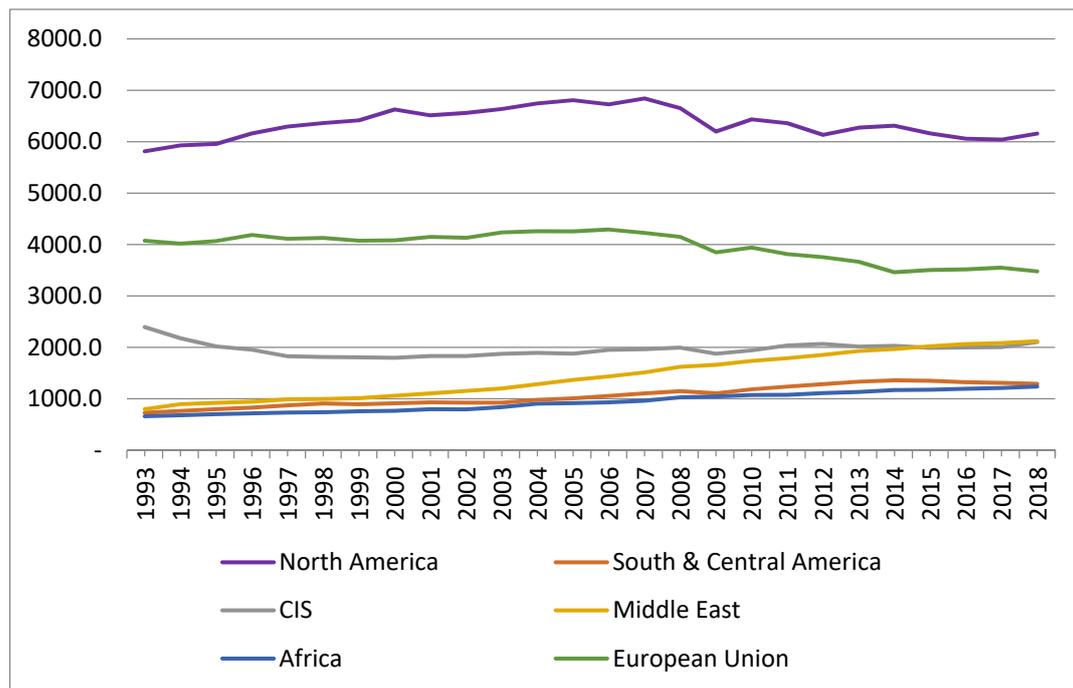


Figure 2. CO<sub>2</sub> emissions in different regions, 1993–2018, million tons of carbon dioxide [4].

Because the region's economy depends on fossil fuel consumption due to access to the available cheap fossil fuels, which leads to higher economic growth and more environmental pollution, an important question is whether there is any relationship between fossil fuel consumption, air pollution, and mortality rates?

The remainder of this paper is structured, as follows. Section 2 expresses the literature review. Section 3.1 represents the data description, and the model specification is discussed in Section 3.2. Section 4 argues the results from the empirical estimations, and Section 5 highlights the concluding remarks.

## 2. Literature Review

The related literature can be divided into five different strands.

The first strand includes important studies that focus on the impact of non-renewable energy sources on human health. Refs. [1,5] found that country consumption of non-renewable energy sources generates adverse human health impacts that are based on the future climate change cost and different strategies of environmental pollution management in countries. Ref. [6] and other scholars, such as refs. [7–10] discussed that fossil fuels are the main economic engines of many countries, which can have an impact on human health. Ref. [11] found a positive relationship between air pollution and fossil fuel consumption and their findings revealed that fossil fuel energy consumption has a dominating role in CO<sub>2</sub> emissions and air pollution, over other variables.

The second strand of the literature concentrates on earlier studies regarding the effect of carbon dioxide emissions on human health. The link between CO<sub>2</sub> emissions (according to ref. [12], CO<sub>2</sub> is the major gas responsible for climate change), and health issues have drawn attention from numerous scholars. Ref. [13] showed that the relationship between CO<sub>2</sub> emissions and human health was seen in the top ten emitting countries during 1991–2014. The study of the impacts of energy use on infant mortality in Africa carried out by ref. [14] revealed that any increase in carbon emissions has a considerable effect on infant mortality. Refs. [15–18] revealed this point.

The third strand pertains to epidemiological studies that have demonstrated the effect of air pollution combustion on the four human disease categories, including CVD, DM, cancer, and CRD. A meta-analysis that was conducted by ref. [19] revealed the effect of ozone (o<sub>3</sub>) exposure on cardiovascular deaths. In 2018, ref. [20] showed that ambient PM<sub>2.5</sub> contributed to approximately

3.2 million new cases of DM, about 8.2 million DALYs caused by DM, and 206,105 deaths from DM attributable to PM<sub>2.5</sub> exposure. In 2017, ref. [21] demonstrated the high burden of air pollution-induced lung cancer mortality in the US. In 2015, ref. [22] demonstrated that low levels of o<sub>3</sub> and particulate matters (PMs) can induce significant chronic obstructive pulmonary disease (COPD), as the major disorder of the respiratory system.

The fourth strand regards the laboratory-based studies that have revealed the pathophysiological effects of fossil fuel constituents on CVD, DM, cancer, and CRD. In 2017, ref. [23] demonstrated that fossil fuel constituents impair the cardiovascular system in several ways. They may cause vasoconstriction (means the constriction of blood vessels), arterial hypertension, arrhythmia (a condition in which the heart beats with an irregular or abnormal rhythm), and myocardial ischemia (means the nutrient deprivation of muscular layer of the heart). It has been proposed that the o<sub>3</sub> and PMs, which are emitted from fossil fuels, cause these CVDs through the release of reactive oxygen species (ROS). In 2012, ref. [24] demonstrated that atmospheric CO<sub>2</sub> is a risk factor for obesity and DM. They showed that it can increase body weight through a decrease in energy expenditure and an increase in appetite. CO<sub>2</sub> mediates these effects through the dysregulation of the hypothalamus, as the main regulator of energy expenditure and appetite. Furthermore, air pollution can directly induce DM through oxidative stress [25]. In 2019, ref. [26] proposed a mechanism regarding how fossil fuel emission can induce cancer. They showed that ROS-induced mitochondrial damage (as the main power generators of human cells) can induce cancer through a decrease in cellular adenosine triphosphate, which, in turn, results in genetic instability. In 2018, ref. [27] showed that fossil fuel emission can induce COPD through an amplified inflammatory response. The adverse effect of fossil fuel consumption on human health is well-established, according to the epidemiological and laboratory-based studies.

The fifth strand comprises of studies related to the relationship between economic growth and human health. Simply, national production cannot be improved without energy consumption as a major production input. Therefore, economic growth may have a vague impact on human health due to the fossil fuel consumption need for growth and a likely positive effect of economic growth on health infrastructure. Ref. [28] found a bi-directional link between economic growth and health expenditures. They expressed that economic growth leads to an increase in CO<sub>2</sub> emissions, which consequently increases the health expenditures of households. Ref. [29] proved a similar result for seven European countries from 1950–1999. In contrast, ref. [30] argued that economic growth might be an important instrument for improving countries' health infrastructures, which reduces mortality. However, ref. [31] discussed that this depends on the characteristics of the health care system. They proved that higher contributions, from the private sector, in developing health care systems may lead to faster adoption of health structures with economic growth changes. Additionally, ref. [32] viewed this vague effect from the aspect of countries' income levels. They realized that, in poorer nations, a socio-economic change is a more influential source of health development than a technical source, which is more important for richer countries and it has a stronger tie to economic growth. Hence, economic growth-mortality reduction is realistic for richer nations.

When considering the above, studies show that relationship issues between fossil fuel energy consumption, economic growth, air pollution, and mortality from CVD, DM, cancer, and CRD, particularly in the CIS region, have not been efficiently analyzed. Hence, our study will attempt to complete this literature gap.

### 3. Materials and Methods

#### 3.1. Data Description

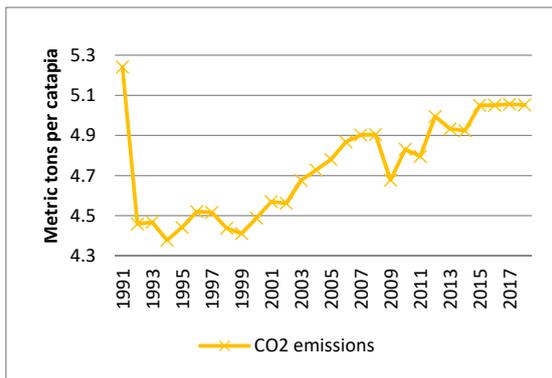
The empirical specification for capturing the possible relationship between mortality and the explanatory variables for the 12 CIS region members from 1993–2018 (the beginning year is due to data that were collected after the collapse of the Soviet Union in 1991) is based on the following function:

$$\text{Mortality} = F(\text{influential factors on the society's health})$$

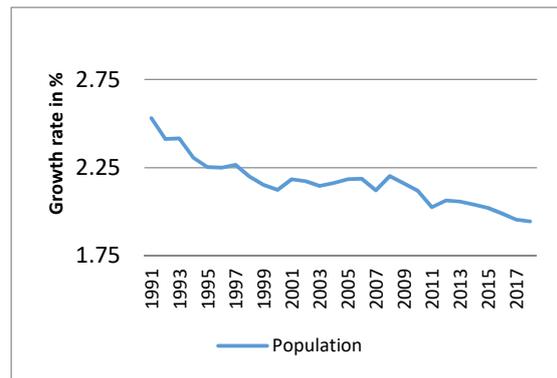
Influential macroeconomic factors on a society's health based on earlier studies (e.g., [17,18,29,31,33,34]) are fossil fuel energy consumption, CO<sub>2</sub> emissions, and economic growth as the main explanatory variables, along with population growth, inflation rate, and the human development index (HDI). Please note that there are numerous variables in earlier studies, such as income equality, urbanization, growth, and so on, which did not have complete data for the CIS members in global databases and were excluded due to their missing data. All of the variables are gathered from the World Bank, BP statistical review, and UNDP databases. Furthermore, outside of our model, there are many other biological, physiological, and environmental factors affecting the mortality variable through direct and indirect means. Considering all of them in an econometric model is not possible, but our study was a forward step towards starting vast research for studying and comparing the effects of other variables.

Figure 3 shows the trends of the variables included in our empirical model. In regards to CO<sub>2</sub> emissions for the CIS members, it was nearly 5.2 and 5 metric tons per capita in 1991 and 2018, respectively. The sudden drop of CO<sub>2</sub> emissions per capita in 1991–1992 occurred due to the consequences of the USSR (the Union of Soviet Socialist Republics) collapse in 1991 [35], which caused the permanent and temporary closing of factories (as one of the main CO<sub>2</sub> emitters) in this region. The population growth rate in the CIS region has decreased over 1991–2017. Despite the increase in population number in this region over the last decades, the rate of growth has decreased—due to the fertility reduction—from approximately 2.5% in 1991 to nearly 1.80% in 2018. Furthermore, the data for mortality from CVD, cancer, diabetes and CRD in the CIS region show that it has a share of nearly 34% and 38% to total mortality in this region in 1991 and 2018, respectively. Therefore, it can be expressed that CVD, cancer, diabetes, and CRD contribute largely to mortality in the region of CIS. In regards to the economic growth of the region, it experienced negative growth rates after the collapse of USSR in 1991. Besides, the jump in 1999–2007 occurred because of the economic reforms of Vladimir Putin in the Russian Federation (as the biggest and strongest economy in the region) since 2000. However, oil price decline and the global financial crisis stopped the economic growth of the region, particularly the Russian Federation in 2008. Our next variable is the share of fossil fuel consumption to total energy consumption in the CIS region. It can be seen that the share over 1991–2018 has been fluctuated from nearly 93% in 1991 to about 82% in 2018. The decreased trend of this variable in the CIS region was mainly due to the lowering fossil fuel consumption level of the Kyrgyz Republic and Tajikistan in the last decades. When considering the trend of Human Development Index (HDI) in the CIS region, it can be mentioned that political-economic reforms of Vladimir Putin after the Russian financial crisis of 1997–1998 helped the region to improve their HDI (due to the strong economic ties between Russian Federation and the other CIS member states) until the economic crisis of the region due to global financial crisis and Russia-Georgia war in 2008. The decreased movement of HDI in the region has continued with various political tensions (e.g., Russia-Ukraine political tension in 2014) and economic crisis (oil price drop in 2014). Finally, the inflation rate in the CIS region has moved steadily since 2000. The collapse of USSR in 1991 and unsuccessful privatization reforms in the region made hyperinflation in the CIS member states that gradually lowered since the late 1990s.

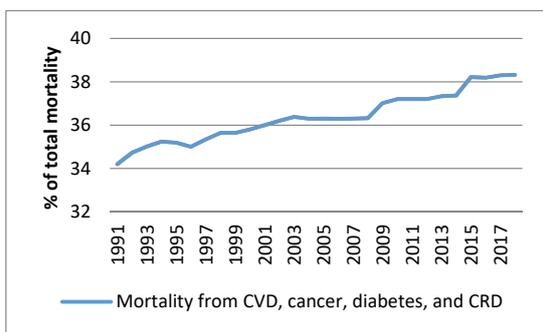
The analyses of the Pearson correlation (Table 1), between the economic growth, fossil fuel consumption, CO<sub>2</sub> emissions, and mortality from CVD, DM, cancer, and CRD, prove to be the primary link among these variables in the CIS region. This static correlation does not prove that the variables are truly linked and affect each other. Hence, the results, listed in Table 1, can help us to predict the relationships between the variables. However, earlier studies, such as ref. [37] (analyze the relationship between CO<sub>2</sub> emissions and mortality rate), ref. [38] (explore the relationship between CO<sub>2</sub> emissions and diabetes), ref. [39] (discuss the relationship between air pollution and cancer), ref. [34] (examine the relationship between HDI and mortality rate), ref. [32] (consider the relationship between economic growth and mortality rate), and ref. [40] (study the relationship between fossil fuel consumption and mortality rate) helped to prove our simple linkages that are based on the Pearson correlation technique.



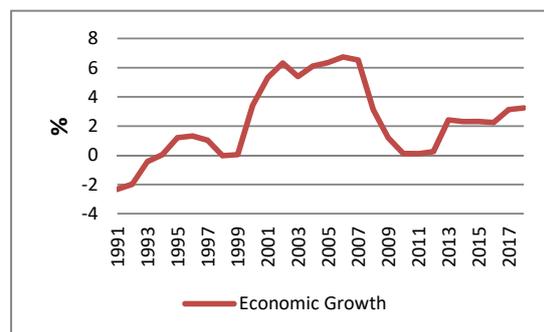
(a) CO<sub>2</sub> emissions of the CIS region



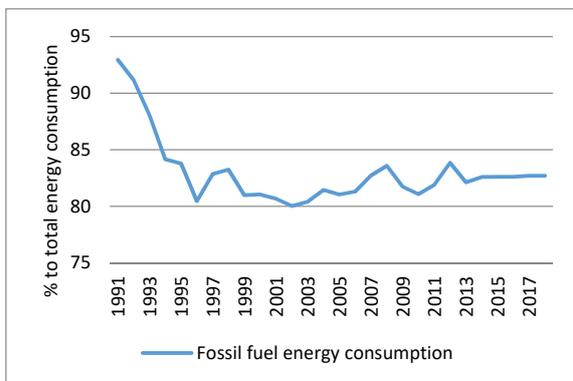
(b) Population of the CIS region



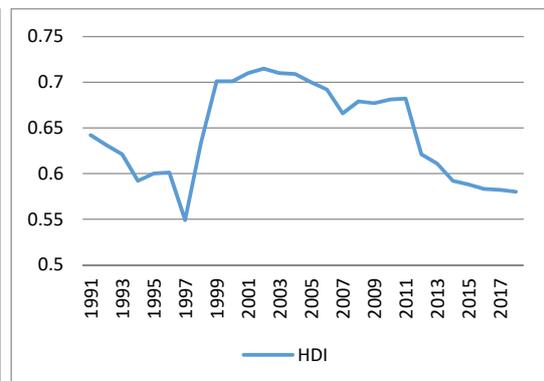
(c) Mortality in the CIS region



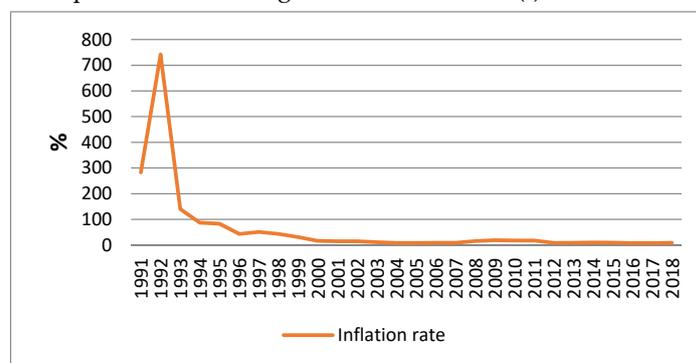
(d) Economic growth of the CIS region



(e) Fossil fuel consumption in the CIS region



(f) HDI of the CIS region



(g) Inflation rate in the CIS region

Figure 3. Trends of variables, 1993–2018 [4,36].

**Table 1.** Pearson correlation among the variables.

	CO <sub>2</sub> Emissions	Economic Growth	Fossil Fuel Consumption	HDI	Mortality from CVD, DM, Cancer, and CRD
CO <sub>2</sub> emissions	1	0.140 (0.01)	0.095 (0.00)	0.001 (0.01)	0.025 (0.03)
Economic growth	0.140 (0.01)	1	0.146 (0.02)	0.023 (0.00)	0.533 (0.00)
Fossil fuel consumption	0.095 (0.00)	0.146 (0.02)	1	0.005 (0.04)	0.171 (0.04)
HDI	0.001 (0.01)	0.023 (0.00)	0.005 (0.04)	1	−0.041 (0.00)
Mortality from CVD, cancer, DM, cancer, and CRD	0.025 (0.03)	0.533 (0.00)	0.171 (0.04)	−0.041 (0.00)	1

Source: Authors' compilation from the Statistical Package for Social Sciences (SPSS) software. Note 1: Numbers in () indicate *p*-value

### 3.2. Description of the Method

We empirically investigate the following model that is based on the six mentioned explanatory variables:

$$\begin{aligned} \ln MOR_{it} = & \alpha_1 \ln ECO_{it} + \alpha_2 \ln CO2_{it} + \alpha_3 \ln FOS_{it} + \alpha_4 \ln POP_{it} \\ & + \alpha_5 \ln INF_{it} + \alpha_6 \ln HDI_{it} + \varepsilon_{it}. \end{aligned} \quad (1)$$

The coefficients  $\alpha_1, \alpha_2, \alpha_3, \alpha_4, \alpha_5,$  and  $\alpha_6$  indicate the long-run elasticity estimates economic growth, CO<sub>2</sub> emissions per capita, fossil fuel energy consumption, population growth, inflation rate, and the HDI. Based on related literature, we expect that any increase in CO<sub>2</sub> emissions, fossil fuel consumption, and population growth leads to an increase in mortality (from CVD, DM, cancer, and CRD), while the impacts from the HDI on mortality (from CVD, DM, cancer, and CRD) are negative. Moreover, the effects of economic growth and inflation are expected to be vague.

The generalized method of moments (GMM) is applied in a panel-gravity framework among the 12 countries in the CIS region to initiate the estimation of our econometric Equation (1). Ref. [41] believed that the GMM estimator, including the lagged endogenous variable as an explanatory variable, is more convenient for panel data because it generates more consistent and robust results in the presence of arbitrary heteroscedasticity. Generally, the GMM regression for *N* observations (12 CIS members) and *T* periods (1993–2018) can be written as:

$$Y_{it} = \alpha + \beta X_{it} + \eta_{it} + \varepsilon_{it}. \text{ for } t = 1, \dots, T \text{ and } i = 1, \dots, N \quad (2)$$

where *Y* indicates the dependent variable (mortality from CVD, DM, cancer, and CRD), and *X* represents all of the explanatory variables (CO<sub>2</sub> emissions per capita, fossil fuel consumption, economic growth, population growth, inflation rate, and HDI).  $\eta_{it}$  represents the country-specific effects and  $\varepsilon_{it}$  is the error term.

Ref. [41] suggested a dynamic panel model for the GMM by adding lags for the dependent variables as independent variables.

$$Y_{it} = \alpha + \beta Y_{it-1} + \gamma X_{it} + \eta_{it} + \varepsilon_{it}. \text{ for } t = 1, \dots, T \text{ and } i = 1, \dots, N \quad (3)$$

where  $Y_{it-1}$  shows the first-order lag for the dependent variable.

To eliminate the fixed effects, Equation (3) can be re-written with the first difference, as:

$$\Delta Y_{it} = Y_{it} - Y_{it-1} = \beta \Delta Y_{it-1} + \gamma \Delta X_{it} + \Delta \varepsilon_{it}. \text{ for } t = 1, \dots, T \text{ and } i = 1, \dots, N \quad (4)$$

If we assume Equation (4) as  $\Delta Y = \Delta R + \varepsilon$ , then the following efficient GMM estimator is:

$$\pi_{EGMM} = [\Delta R'Z(Z'\Omega Z)^{-1}Z'\Delta R]^{-1} \Delta R'Z(Z'\Omega Z)^{-1}Z'\Delta Y. \quad (5)$$

In Equation (5),  $Z$  indicates the instrument matrix for  $\Delta R$  and  $\Omega$  is the  $n \times n$  asymptotic covariance matrix of the error terms.

Some tests will be conducted by checking the multicollinearity and heterogeneity using the variance inflation factor (VIF) and the Hausman test, respectively, to ensure the reliability of the GMM estimation results.

The next pre-estimation test will check the cross-section dependency among the series since the economies of the selected sample experienced various exogenous and endogenous shocks. The second-generation unit root test will be the last preliminary test to uncover whether the series are  $I(1)$  stationary or  $I(0)$  non-stationary. Additionally, the Arellano–Bond test and Sargan test will employ a verification of zero autocorrelation and the overidentifying restrictions.

Conducting the GMM estimation needs additional approval from other estimator results that use FMOLS (fully modified ordinary least squares), which was introduced by ref. [42]. FMOLS estimator does not have a problem with serial correlation or the endogeneity of independent variables. Assuming the following panel regression with a fixed effect:

$$Y_{it} = \alpha_i + \beta X_{it} + \varepsilon_{it}. \text{ for } t = 1, \dots, T \text{ and } i = 1, \dots, N \quad (6)$$

where  $Y_{it}$  represents a matrix (1,1), while  $\beta$  shows a vector of slopes,  $\alpha_i$  is the individual fixed effect, and  $\varepsilon_{it}$  denotes the stationary disturbance terms.

#### 4. Results

The VIF (checking multicollinearity among series) and Hausman (checking the nature of the panel data series) tests were utilized to identify the consistency of the GMM approach. Based on the results, it can be concluded that there is low multicollinearity between the cross-sections. Moreover, the findings from the Hausman test depict the panel data with random effects. Next, the existence of cross-section dependence in the series should be verified. Table 2 represents the results of the cross-section dependence (CSD) test for our variables:

**Table 2.** Cross-section dependence test results.

Samples	Variables	CSD Test	Corr.	Abs. (corr.)	Significant at 1% Level
12 CIS member states	LECO	9.52	0.388	0.387	Yes
	LCO2	10.28	0.429	0.429	Yes
	LFOS	9.88	0.369	0.369	Yes
	LINF	9.33	0.410	0.410	Yes
	LPOP	8.28	0.319	0.319	Yes
	LHDI	10.32	0.501	0.501	Yes

Note 1: ECO = Economic growth, FOS = Fossil fuel energy consumption, CO<sub>2</sub> = CO<sub>2</sub> emissions, MOR = Mortality from CVD, DM, cancer, and CRD, INF = Inflation rate, POP = Population growth, and HDI = the Human Development Index. Note 2: (L) indicates variables in the natural logarithms.

The results of the CSD test, as represented in Table 2, confirm that cross-sections are present in all of the series, meaning that our samples share the same characteristics. Generally, in situations where there are low multicollinearity and cross-section dependence in a series, the stationarity of the variables should be verified. Here, the second-generation panel unit root test (Pesaran's 2007 CIPS test) with the null hypothesis for all the series, where  $I(1)$ , is conducted. The findings of this test approve that all series are  $I(0)$ .

By considering the results from the preliminary tests, the Arellano–Bond dynamic for the GMM estimations for our model are completed. The results of the GMM estimations for the 12 CIS members are reported in Table 3, as follows:

**Table 3.** Generalized method of moments (GMM) estimation result.

Explanatory Variables	Coefficients	Significant at 1% Levels
Constant	0.28	No
LECO	0.29	Yes
LCO2	1.39	Yes
LFOS	0.11	Yes
LINF	0.04	Yes
LPOP	0.19	Yes
LHDI	−0.18	Yes
No. of observations		312
Range		1993–2018
Cross-sections included		12
Wald Chi2 (5)	632.18	Yes

Note 1: ECO = Economic growth, FOS = Fossil fuel energy consumption, CO<sub>2</sub> = CO<sub>2</sub> emissions, MOR = Mortality from CVD, DM, cancer, and CRD, INF = Inflation rate, POP = Population growth, and HDI = the Human Development Index. Additionally, (L) indicates variables in the natural logarithms.

Economic growth for the CIS members has a positive effect on the increase in mortality, according to Table 3 (from CVD, DM, cancer, and CRD). A 1% increase in economic growth shows a positive relationship to mortality by approximately 0.29%. This finding is comparable with ref. [28], who found a negative relationship between economic growth and health improvement. However, this contrasts with ref. [29,30], who proved that there is a positive impact from economic growth on health issues. In fact, in developing economies, like the CIS members, economic growth roughly leads to an increase in economic development due to its nature (energy-oriented economy), high bureaucracy, and corruption. Hence, just a higher economic growth rate cannot be a reliable element for improving health care in these nations. Besides, the contributions of fossil fuels, particularly natural gas and crude oil to total energy consumption in the CIS region are considerably higher than the contributions of renewable ones, as shown in Figure 1. Hence, it is unavoidable to catch significant economic growth without increasing fossil fuels extraction, consumption, and exportation.

Regarding CO<sub>2</sub> emissions per capita, the estimation proves that this variable positively affects mortality (from CVD, DM, cancer, and CRD). This finding is in line with refs. [11,13,28,43], who discovered the negative effect of CO<sub>2</sub> emissions on human health). CO<sub>2</sub> emissions per capita have a positive relationship with mortality from CVD, DM, cancer, and CRD in this region by nearly 1.39%. Unfortunately, the amount of CO<sub>2</sub> emissions in the CIS has increased from 1794 million tons in 2000 to nearly 2100 million tons in 2018, indicating that over the two last decades the problem of CO<sub>2</sub> emissions in the CIS region considerably rose, as shown in Figure 2. Fossil fuel energy consumption and the inflation rate positively affect mortality from CVD, DM, cancer, and CRD. This finding is in line with refs. [1,6–10] who proved a negative link between fossil fuel energy consumption and health issues. However, the HDI has a negative sign, meaning that a 1% increase in the HDI affects mortality from CVD, DM, cancer, and CRD in this region, which might decrease by nearly 0.18% (it should be mention that HDI is an index calculated from life education, income per capita, and life expectancy. Therefore, mortality links directly to life expectancy and, thus, HDI cannot be used to explain mortality). This result is comparable with ref. [34] who uncovered a negative relationship between the HDI and cancer incidences in Africa. Additionally, population growth has a positive relationship with mortality

from CVD, DM, cancer, and CRD. These findings correspond with refs. [33,44], who argued that a negative impact on population growth affects human health.

To verify the reliability of our estimation results, reported in Table 3, an alternative panel data technique named the Fully Modified OLS (FMOLS) was employed. The estimation findings do not significantly differ, suggesting the robustness of our results.

## 5. Conclusions

This empirical study attempted to identify what is the relationship between mortality from CVD, DM, cancer, and CRD, and economic growth, fossil fuel energy consumption, and CO<sub>2</sub> emissions for the 12 CIS members based on annual data from 1993–2018.

Regarding the methodology, the GMM was conducted to estimate the coefficients of the independent variables (CO<sub>2</sub> emissions, fossil fuel consumption, economic growth, population growth, inflation rate, and HDI).

Based on the results, it is discovered that CO<sub>2</sub> emissions in the CIS region had a positive relationship with mortality from CVD, DM, cancer, and CRD. Regarding fossil fuel consumption, the estimation proved that this variable positively affects mortality from CVD, DM, cancer, and CRD. Additionally, effects of economic growth, population growth, and inflation rate are positive, while any improvement in the HDI has a negative sign, meaning its negative effect on the increase of mortality from CVD, DM, cancer, and CRD in the CIS region. Our finding on the effects of CO<sub>2</sub> emissions on accelerating the cancer prevalence and mortality in countries is comparable with refs. [28,45–49]. Furthermore, ref. [21] confirmed a positive link between population growth and the spread of disease (mortality increase). However, this result contrasts with findings from ref. [50], who confirmed the role of population growth, especially urban population for women's health, in a South African city. Regarding the positive link between economic growth and health satisfaction, our results are similar to refs. [51,52], while they contrast with ref. [53], who discussed the effects of income inequality, rather than economic growth and income. Please note that, outside of our model, there are many other biological, physiological, and environmental factors affecting the mortality variable through direct and indirect means. Considering all of them in an econometric model is not possible, but our study was a forward step towards starting vast research for studying and comparing the effects of other variables.

Overall, it is recommended that the CIS member states enhance various policies for easy access to electricity from green resources and increase their renewable supply through improved green technologies, in daily social life. This is crucial to minimize the negative impacts of pollutions of fossil fuels combustion on health and ultimately on mortality rate in this region. Renewable projects are considered to be risky projects for many investors and financiers [54], especially in those economies that the financial system is dominated by banks and capital market and venture capital markets are underdeveloped, like CIS countries. Hence, governments in CIS countries need to provide policy supports for unlocking the private investment in the green energy sector (see [55–59] for suggestions on how to unlock the private investments in green energy projects).

Notwithstanding its limitations, this paper contributes to the existing literature in related health-energy-economic growth linkages in the CIS region. It is recommended for future research to employ different control variables, such as trade openness and monetary variables in econometric models while considering direct and indirect effects and conducting causality tests to distinguish short-run and long-run links between dependent and independent variables. Additionally, because Russia plays a larger role in the economic trends in this region, it is recommended to check the results with and without this country. Another recommendation is to consider and compare other control variables (e.g., smoking, obesity, sedentary lifestyle) directly and indirectly influencing the mortality (even lagged mortality) in these countries. Additionally, consideration of CO, NO<sub>x</sub> and PM<sub>2.5</sub> instead of CO<sub>2</sub> would bring further fruitful findings.

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