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NEW CONCEPTUAL APPROACHES IN UNDERSTANDING THE "GREEN" STATE MODEL: CENTRAL ASIAN CASE

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Abstract. *This research analyzes the state of the 'green' economy in Uzbekistan in comparison with Kazakhstan, Kyrgyz Republic, Tajikistan and Turkmenistan, focusing on the descriptive analysis of the situation within the last 20-30 years. The core element of the research is the analysis of the Random Effects model (Panel Data analysis). There are various types of models to analyze panel data. For this research, the choice was made between Fixed Effects and Random Effects models using the Haussmann test. One area of the green economy is to minimization of the greenhouse gas (GHG) emissions. The researcher attempts to connect GHG emission (total) with various ESG (Environment, social and government) factors across Central Asian (CA) countries within the last 30 years. As the CA countries are post-soviet countries, they have about 30 years of independent economic activity, thus for comparison purposes Denmark is also added partly to the research. During the research, the Environmental Kuznets Curve (EKC) will be used to model the equation, thus will be proved by graphics and the REM model. The research used data from various sources, such as the Eurostat, the OECD (Organization of Economic Cooperation and Development), the United Nations, and the Uzbekistan National Statistics Committee.*

Keywords *– Environmental Kuznet's Curve, GHG emissions, CA countries, GDP, primary energy supply, renewable energy consumption, urbanization, green economy, transition, green growth.*

Introduction.

The world is facing unprecedented challenges in the 21st century, such as climate change, biodiversity loss, resource depletion, social inequality, and global pandemics. These challenges pose serious threats to the well-being of humanity and the planet, and require urgent and coordinated actions from all stakeholders. However, the current economic system, based on the capitalist model of production and consumption, is not capable of addressing these challenges effectively. On the contrary, capitalism is one of the main causes of these problems, as it relies on the exploitation of natural and human resources, the accumulation of wealth and power by a few, and the generation of externalities and waste that harm the environment and society. According to the United Nations Environmental Program (UNEP), today the richest 80 people own the same wealth as the 3.5 billion poorest people[1].

According to the World Bank, Uzbekistan is one of the most energy- and carbon-intensive economies in the world, with a high dependence on fossil fuels, especially natural gas[2]. This makes Uzbekistan vulnerable to external shocks, such as fluctuations in energy prices and trade policies, as well as to the impacts of climate change, such as water scarcity, desertification, and extreme weather events. Moreover, Uzbekistan faces significant challenges in terms of social development, such as poverty, unemployment, gender inequality, and low human capital[3].

Therefore, there is a need for Uzbekistan to transition to a green economy and green growth, which are defined by the United Nations as “a system that results in improved human well-being and social equity, while significantly reducing environmental risks and ecological scarcities”[4]. A green economy and green growth can offer Uzbekistan multiple benefits, such as enhancing its economic competitiveness, diversifying its energy sources, increasing its resource efficiency, improving its environmental quality, and, last but not the least, achieving its balanced and inclusive development.

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[1] UNEP (2015) Uncovering pathways towards an inclusive green economy: a summary for leaders. Available at: https://www.unep.org/resources/report/uncovering-pathways-towards-inclusive-green-economy-summary-leaders

[2] World Bank (2022) Towards a greener economy in Uzbekistan. Available at: https://openknowledge.worldbank.org/entities/publication/7046a76c-f533-5846-83e4-7dde22f2ad03

[3] UNDP. (2023). Uzbekistan | United Nations Development Programme. [online] Available at: https://www.undp.org/uzbekistan.

[4] Environment, U.N. (2017). Why does green economy matter? [online] UNEP - UN Environment Programme. Available at: https://www.unep.org/explore-topics/green-economy/why-does-green-economy-matter.

Central Asian countries and environmental issues.

Kazakhstan, since gaining independence in 1991, has faced significant environmental challenges inherited from the Soviet era's industrial practices. However, the country has progressively shifted its policies towards a green economy. While fossil fuels continue to dominate the energy mix, Kazakhstan's renewable energy share has shown modest but consistent growth, rising from 0.1% in 2000 to 1.8% in 2023 (forecast), alongside increased investment in green technologies. To address environmental legacies and promote greener development, Kazakhstan established the Ministry of Ecology, Geology and Natural Resources and enacted the Environmental Code (2007). Additionally, Kazakhstan's international commitments, such as ratifying the Kyoto Protocol, along with national programs such as Green Kazakhstan (2013) and its Emissions Trading Scheme (2016), signal a growing emphasis on reducing emissions and enhancing sustainability (Ministry Of Ecology, Geology And Natural Resources Of The Republic Of Kazakhstan, 2020)[5].

Kyrgyzstan with its significant portion of its economy reliant on agriculture, challenges such as deforestation, water scarcity, and climate change pose a considerable threat. Despite possessing abundant renewable energy potential, particularly in hydropower, solar, and wind, Kyrgyzstan's green transition faces hurdles. While the National Sustainable Development Strategy (2018-2040) acknowledges the significance of a green economy and sets an ambitious target of achieving "negative CO_2 emissions"[6], a substantial green investment gap persists. Previous economic practices caused severe consequences, for example, in an air quality. World Bank reports that particulate matter ($PM_{2.5}$) concentration in capital of Kyrgyzstan, Bishkek, significantly exceeded international air standards, exceedingly over 10 times the guideline of the World Health Organization (WHO) of 5 $\mu g/m^3$ (World Bank, 2023)[7]. Limited financial resources and vulnerability to climate change pose significant obstacles.

[5] PAGE (2020), Kazakhstan's transition to a Green Economy: A stocktaking report. Available at: https://rise.esmap.org/data/files/library/kazakhstan/Renewable%20Energy/Kazakhstan_Transition%20to%20Green%20Economy_2016.pdf

[6] Partnership for Action on Green Economy (PAGE) (n.d.) Kyrgyz Republic. Available at: https://www.un-page.org/countries/kyrgyz-republic/

[7] The World Bank (2023), Air Quality Analysis for Bishkek. PM2.5 Source Apportionment and Emission Reduction Measures. Available at:

Tajikistan, a mountainous country with abundant hydroelectric potential, faces environmental challenges such as water management, land degradation, and heightened vulnerability to climate change (UNFCCC, 2020)[8]. While Tajikistan has made notable efforts in the field of green economy and environmental economy, the government increasingly recognizes the imperative of transitioning towards a greener economy, but financial and technological limitations persist. Tajikistan has significant potential for hydropower generation, and the country has been increasingly investing in renewable energy sources. Hydroelectric power accounts for the majority of Tajikistan's electricity production, reducing reliance on fossil fuels and contributing to lower carbon emissions (Asian Development Bank, 2019)[9].

Turkmenistan, an arid nation with significant natural gas resources, faces environmental challenges including water scarcity, land degradation, and air pollution exacerbated by its hydrocarbon-dependent economy. Despite possessing abundant solar potential, renewable energy penetration remains negligible, with less than 1% of electricity generation derived from these sources[10]. Turkmenistan's high per capita carbon emissions reflect its reliance on fossil fuels and energy-intensive industries[11]. The government has initiated tentative steps towards a greener policy framework in recent years. This includes the National Strategy on Climate Change (2012) and a focus on reforestation, but concrete progress remains limited[12]. While Turkmenistan participates in international environmental agreements, robust environmental legislation and its effective enforcement are still developing.

The analysis of the GHG emissions

The increasing trend of annual CO2 emissions in Uzbekistan, as recorded by both Uzhydromet and OECD, shows slight fluctuations above 95 million

https://documents1.worldbank.org/curated/en/099110123211021470/pdf/P17087000827dd04e09d6a0d01dc0ab3c41.pdf

[8] UNFCCC. (2020). Tajikistan's NDC Partnership Plan. Available at: https://www.ndcs.undp.org/content/ndc-support-programme/en/home/ndc-pairs/tajikistan.html

[9] Asian Development Bank. (2019). Tajikistan: Sector Assessment (Summary): Energy. Available at: https://www.adb.org/sites/default/files/linked-documents/cps-taj-2016-2020-ssa-02.pdf

[10] International Energy Agency (IEA) (2023) Turkmenistan Energy Profile. Available at: https://www.iea.org/countries/turkmenistan/renewables

[11] World Bank (2023) Climate Change Knowledge Portal - Turkmenistan Country Data. Available at: https://climateknowledgeportal.worldbank.org/country/turkmenistan/vulnerability

[12] UNDP (2012), National Climate Change Strategy of Turkmenistan. Available at: https://info.undp.org/docs/pdc/Documents/TKM/110712_Strategy_en.pdf

tonnes but remains below 125 million tonnes from 1990 to 2020. This trend experienced a surge in the early 2000s, followed by a decline between 2012 and 2016, and then resumed an upward trajectory post-2016, with a notable decrease in 2020. Notably, in 2021, the CO2 emissions per capita in Uzbekistan, indicating the average citizen's contribution to total emissions, was recorded at 3.6 tonnes, significantly lower than the Central Asia average of 6.7 tonnes per person (OWD, 2023)[13]. Despite the rise in emissions, Uzbekistan's contribution to global carbon emissions remains minor. In 2020, its emissions were 20 times less than the Eastern Europe, Caucasus, and Central Asia (EECCA) average, accounting for 5% of the region's emissions. Over the last three decades, Uzbekistan's share of global emissions has consistently been 0.33% (OWD, 2023), with the energy sector being the major contributor, responsible for 79% of emissions due to natural gas combustion for electricity and heat generation.

The variation in carbon emissions in Uzbekistan correlates with economic activity changes. Post-independence economic expansion in the late 1990s led to increased emissions, which decreased with reduced fossil fuel usage. Mirkasimov et al. (2023) analyzed emission drivers using Fixed Effects model (Panel Data analysis) over 30 years (1990-2020), finding that emissions rose with increases in the economy (real GDP), energy use, exports, urbanization, and population[14]. Specifically, a 1% rise in population growth, energy use, and urbanization increased CO2 emissions by 1.1 units, 0.0003 units, and 0.071 units, respectively. Conversely, a 1% increase in renewable energy use and forest cover would decrease CO2 emissions by -0.063 and -0.516 units, respectively. The study also highlighted that while exports of goods raise CO2 emissions, imports are negatively associated. Furthermore, it was found that emissions decrease with sustained GDP growth, as further economic development lowers CO2 emissions through investments in sustainable environmental projects, including renewable energy sources.

Within the REM (Random Effects Model) used in this research, the EKC (Environmental Kuznets Curve) concept is used. The EKC hypothesis suggests an inverted U-shaped relationship between environmental degradation (here

[13] OWD (2023), "CO2 emissions", Our World in Data (database), https://ourworldindata.org/co2-emissions

[14] Mirkasimov, B. et al. (2023), "Determinants of carbon emission and the potential economic impact of 'green' economy strategies" in Central Asia: Kazakhstan and Uzbekistan, CAREC Institute, Chapter-5.pdf. Available at: https://www.carecinstitute.org/wp-content/uploads/2023/01/Chapter-5.pdf

represented by GHG emissions) and economic growth (indicated by GDP) (Lan Xu, 2011)[15]. According to this hypothesis:

- **Initial Economic Growth:** In the early stages of economic growth, environmental degradation increases as economies prioritize growth over environmental concerns.
- **Turning Point:** As an economy matures, a turning point is reached where the rate of environmental degradation starts to decrease.
- **Further Economic Growth:** With further economic development, investment in cleaner technologies and higher environmental regulations leads to a reduction in environmental degradation.

Within the framework of green economics, it is also necessary to elucidate the following categories: “Greenhouse Gases,” “1.5°C Pathway,” “COP (Conference of the Parties),” and “Net Zero”.

- **Greenhouse Gases (GHG):** These gases, primarily carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and fluorinated gases, possess the molecular capacity to absorb infrared radiation, thereby trapping heat in the Earth’s atmosphere. This phenomenon, known as the greenhouse effect, is pivotal in maintaining the Earth’s climate. However, anthropogenic (human-induced) augmentations in GHG concentrations, chiefly due to fossil fuel combustion, deforestation, and industrial processes, have perturbed this natural balance, leading to global warming and climate change
- **1.5°C Pathway**: The “1.5°C Pathway” is intrinsically linked to the concept of limiting global temperature rise. Stemming from scientific consensus, notably the Intergovernmental Panel on Climate Change (IPCC) reports[16], this pathway delineates the urgent need to limit average global temperature increase to 1.5°C above pre-industrial levels. This target is crucial, as surpassing it significantly escalates risks of severe climatic disruptions, including extreme weather events, irreversible loss of biodiversity, and critical impacts on human health and livelihoods.
- **Kyoto Protocol and Paris Agreement**: Both the Kyoto Protocol and the Paris Agreement are milestones in international climate policy, rooted in

[15] Lan Xu, (2011). Theory of Environmental Kuznets Curve. China. East China University of Science and Technology. DOI:10.4028/www.scientific.net/AMR.361-363.1697. Available at: https://www.researchgate.net/publication/272058242_Theory_of_Environmental_Kuznets_Curve

[16] IPCC, 2023: Sections. In: Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, H. Lee and J. Romero (eds.)]. IPCC, Geneva, Switzerland, pp. 35-115, doi: 10.59327/IPCC/AR6-9789291691647. Available at: https://www.ipcc.ch/report/ar6/syr/downloads/report/IPCC_AR6_SYR_LongerReport.pdf

the principles set forth by the UNFCCC. The Kyoto Protocol[17] (1997) was the first agreement to set legally binding emissions reduction targets for developed countries. However, its impact was limited due to non-participation by key emitters and its exclusive focus on developed nations. The Paris Agreement[18] (2015) expanded this scope, including all countries, and introduced Nationally Determined Contributions (NDCs), enabling each country to set its own emissions reduction targets. This shift signified a more inclusive and flexible approach, aligning global efforts with the 1.5 Degrees Celsius Pathway.

Econometric model based on panel data analysis.

Panel data, a unique blend of cross-sectional and time-series data, captures the essence of multiple observations across various entities over successive time periods. This dual dimensionality not only enriches the dataset with diversity but also imbues it with the dynamism of temporal variations, making it an invaluable asset in econometric analysis. At its core, panel data is distinguished by its multidimensional structure. Each data point within a panel dataset is defined by two distinct dimensions: the cross-sectional dimension, which refers to the different entities under observation (such as individuals, firms, or countries), and the time dimension, which spans multiple time periods, providing a temporal snapshot of each entity's evolution. This intricate structure of panel data sets it apart, enabling researchers to explore a wide array of questions that neither pure cross-sectional nor time-series data could adequately address on their own.

The modeling framework for panel data is designed to exploit its unique structure, addressing both the cross-sectional and time-series dimensions. Key models in this framework include the Fixed Effects Model and Random Effects Model approach, each catering to specific scenarios and assumptions about the data.

The Fixed Effects Model (FEM) accounts for unobserved heterogeneity by allowing each entity to have its own intercept term, effectively controlling for all time-invariant characteristics, whether observed or unobserved. This model is particularly useful when the unobserved variables are correlated with the explanatory variables, thus eliminating the omitted variable bias. The FEM is estimated using the Within-Group Estimator, which removes the entity-

[17] Kyoto Afreement: https://www.un.org/ru/documents/decl_conv/conventions/kyoto.shtml
[18] Paris Agreement: https://www.un.org/en/climatechange/paris-agreement

specific effects by demeaning the data with respect to each entity's mean[19] (Baltagi, 2005).

The Random Effects Model (REM) assumes that the unobserved individual effects are uncorrelated with the explanatory variables. Unlike FEM, REM considers the entity-specific effects as part of the error term, leading to a composite error structure. This model is more efficient than FEM if its assumption holds, as it utilizes both within and between entity variations. The estimation of REM is typically done via Generalized Least Squares (GLS), optimizing the use of available data (Baltagi, 2005).

The Random Effects Model assumes that the individual effects are uncorrelated with the explanatory variables, allowing for a more efficient use of the data by considering both within and between entity variations. The REM is represented as:

$$Y_{it} = \alpha + \beta \cdot X_{it} + u_i + \varepsilon_{it} \qquad (1)$$

where Y_{it} is the dependent variable for individual i at time t, α is the overall intercept, X_{it} is the vector of explanatory variables, β is the vector of coefficients, u_i is the random individual-specific effect. The composite error term $u_i + \varepsilon_{it}$ combines the individual effect and the idiosyncratic error, with REM typically estimated via Generalized Least Squares (GLS) to account for the structure of the composite error.

In our model, where there are 6 countries *(i)* and 32 years *(t)*, the following representation of the REM model equation will be used:

$$GHG^{it} = \alpha + \beta_1 \cdot GDP_{it} + \beta_2 \cdot GDP_{it}^2 + \beta_3 \cdot PES_{it} + \beta_4 \cdot X_{it} + u_i + \varepsilon_{it} \qquad (2)$$

Where CO_2 (numeric dependent variable) is carbon dioxide emission (mln metric tons), *GDP* (numeric variable) – Gross Domestic Product (constant at 2015, 100 mln USD rate), GDP^2 relates to the model of EKC (Environments Kuznets Curve), *PES* (numeric variable) – primary energy supply (tonne of oil equivalent, toe is defined as 107 kilocalories (41.868 gigajoules))[20], *X* – is a vector of other variables in country *i* at time *t* (there might be multiple of them). Other complementary variables include: forest area (percentage of total land area), population (total), Renewable energy consumption (percentage of total final energy consumption), Urban population (percentage of total population).

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[19] Baltagi, B.H., (2005). Econometric Analysis of Panel Data, 3rd ed. Wiley.

[20] More about Primary Energy Supply here: https://data.OECD .org/energy/primary-energy-supply.htm

Testing in Panel Data Analysis. The Haussmann test is a critical tool for deciding between fixed effects and random effects models. It tests the null hypothesis that the preferred model is random effects against the alternative of fixed effects. The test compares the estimates from the fixed and random effects models; a significant difference indicates that the random effects estimates are inconsistent due to correlation between the individual effects and the regressors, favoring the fixed effects model.

Assumptions testing. Serial correlation and heteroskedasticity tests are vital for diagnosing the error term structure in panel data models. Serial correlation, or autocorrelation, refers to the correlation of error terms across time within the same entity. Heteroskedasticity involves the variance of the error terms being unequal across observations. Tests for cross-sectional dependence examine whether the residuals are correlated across entities, which may occur due to omitted common factors or spillover effects.

Analysis of the REM model. From the correlation analysis between ALL numerical variables, we omitted several of them which were highly correlated (high correlation coefficient between independent variables might have caused problems of multicollinearity further). The final correlation analysis brings us to this graph:

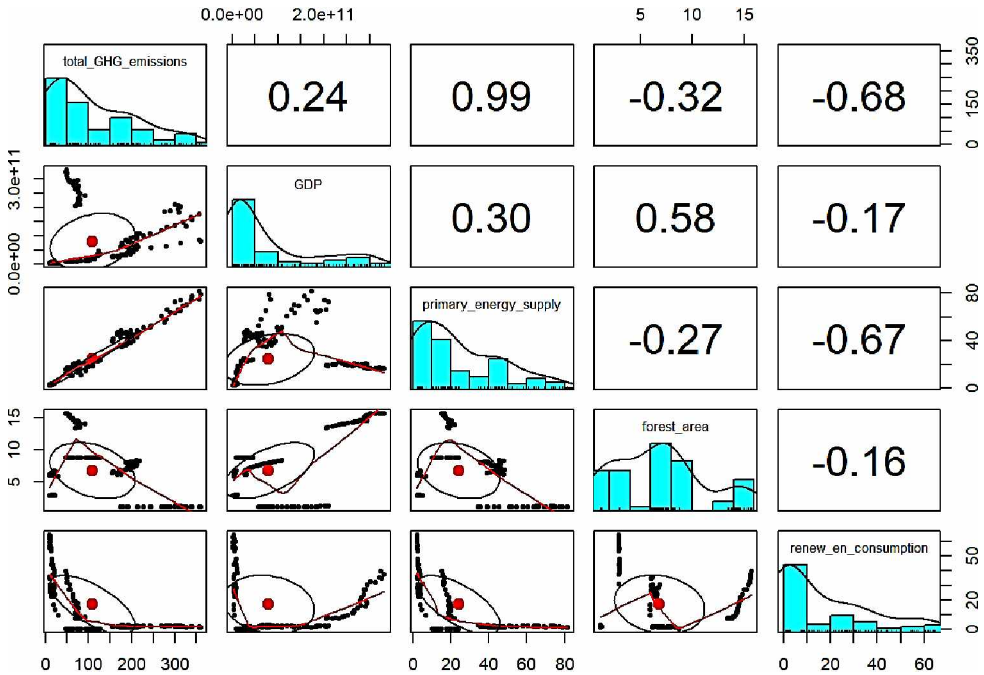


Figure 1. Correlation matrix

The correlation of GHG emissions with:

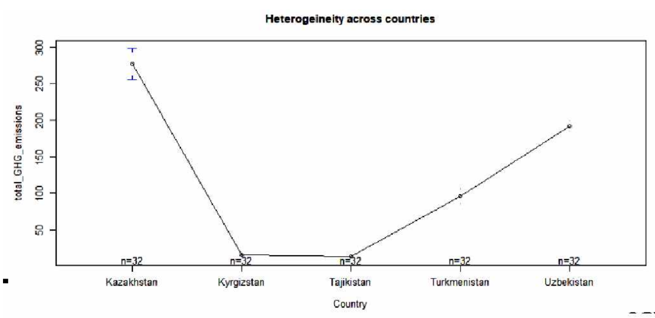
GDP: - 0.24. A correlation coefficient of 0.24 between GHG emissions and GDP suggests a weak positive relationship. This implies that, in this data set, as GDP increases, GHG emissions tend to increase slightly. Economic growth often leads to increased energy consumption and industrial activity, which can result in higher emissions. However, the weak correlation here might also suggest that the economies could be transitioning towards less emission-intensive activities or becoming more energy-efficient. A low correlation between GDP and GHG emissions might imply a decoupling of economic growth from emissions, which is a desirable outcome for sustainable development.

Primary Energy Supply: (0.99). A very strong positive correlation of 0.99 indicates an almost one-to-one relationship between primary energy supply and GHG emissions. This is expected since primary energy supply generally includes fossil fuels, which are major sources of GHG emissions. It implies that changes in the level of energy supply are almost directly mirrored by changes in emissions. This could reflect an economy heavily reliant on fossil fuels for energy production, as was stated in introduction part of this research article.

Forest area: (-0.32). The negative correlation coefficient indicates an inverse relationship between forest area and GHG emissions. A larger forest area, which serves as a carbon sink, is associated with lower emissions. The moderate strength of the correlation suggests other factors may also play a significant role in determining GHG emissions, but increased forest coverage does contribute to reducing the overall emissions.

Renewable energy consumption: (-0.68). This moderate negative correlation indicates that higher renewable energy consumption is associated with lower GHG emissions. This suggests that renewables are effectively replacing more carbon-intensive energy sources, leading to a reduction in overall emissions. It may also reflect a broader commitment to sustainable practices and technologies that both increase renewable energy consumption and decrease emissions.

Analyzing Heterogeneity Across countries and years we begin by exploring the variability in pollution levels, or heterogeneity, across different countries and over time.



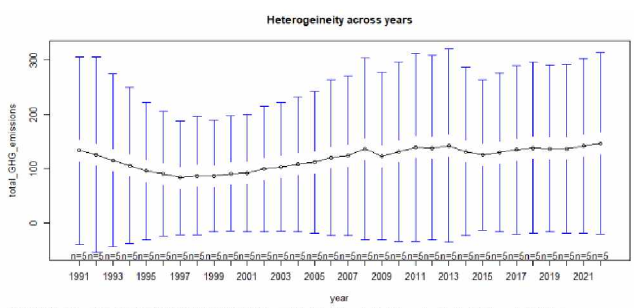


Figure 2. Analyzing Heterogeneity

The first graph in figure 2 shows GHG emissions for various countries. The stark variability in emissions across these countries is immediately apparent. The error bars, representing 95% confidence intervals, are notably long for Kazakhstan, suggesting a high variance in its GHG emissions data. Kyrgyzstan and Tajikistan shows smaller error bars, implying more consistency in their emissions data.

The second graph illustrates the fluctuation of GHG emissions over time, from 1991 to around 2022. We observe a wave-like pattern with no clear upward or downward trend, indicating that average GHG emissions have varied year by year without a consistent direction of change. The confidence intervals are quite wide for most years, which denotes substantial yearly variability in emissions across the countries. The trend line does not show a definitive long-term increase or decrease in GHG emissions but rather suggests periods of higher and lower emissions that may correlate with economic cycles and policy changes, as it is seen in the year of 2008, the period of global financial crisis, when the GHG emissions dropped, and 2016, after the Paris Agreement was initiated.

The Random Effects model with the final set of variables represents the following:

```
## Balanced Panel: n = 6, T = 30, N = 180
##
## Effects:
##                   var  std.dev share
## idiosyncratic 0.010771 0.103783 0.523
## individual    0.009833 0.099163 0.477
## theta: 0.8123
##
## Residuals:
##      Min.   1st Qu.    Median   3rd Qu.      Max.
## -0.275927 -0.078927  0.019394  0.076614  0.275385
```

```
## Coefficients:
##                          Estimate  Std. Error  z-value  Pr(>|z|)
## (Intercept)            2.4219e+00  1.4440e-01  16.7727 < 2.2e-16
***
## log(GDP)               2.9268e-01  2.4413e-02  11.9887 < 2.2e-16
***
## GDP_squared           -4.7733e-08  1.1654e-08  -4.0959 4.206e-05
***
## primary_energy_supply  1.7334e-02  1.3717e-03  12.6370 < 2.2e-16
***
## renew_en_consumption  -1.6385e-02  1.6164e-03 -10.1367 < 2.2e-16
***
```

```
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Total Sum of Squares:    18.054
## Residual Sum of Squares: 2.4469
## R-Squared:      0.86447
## Adj. R-Squared: 0.86137
## Chisq: 1116.23 on 4 DF, p-value: < 2.22e-16
```

Figure 3. The Random Effects model

Model analyzed here is within the range of 31 years. Compared to huge databases of developed countries, the newly independent countries of the Central Asia have a data time range at maximum 34-35 years. At the same time, the main question of the research (to find the main factors and drivers that influence Uzbekistan's transition to a green economy and green growth) indicates to finding only the main variables and their influence towards the green growth in Uzbekistan (and other Central Asian countries), thus the condition of heteroscedasticity and stationarity is not observed.

Table 1

Test name	Test statistics	p-value
Cross-sectional Dependence		
Breusch-Pagan LM test	82.126	$2.85 * 10^{-11}$
Pearson CD tests	-2.543	0.01099
Serial-correlation	128.03	$4.48 * 10^{-14}$
Stationarity (Augmented Dickey-Fuller test, k=1)		
GHG (Greenhouse Gases)	-2.1608	0.509
GDP	-1.877	0.6276
GDP^2	-2.607	0.3225
Primary energy supply	-2.4083	0.4056
Renewable energy consumption	-1.7516	0.68

The REM model has the following attributes (looking at the Figure 3):

High adjusted R2=0.86; each coefficient of RE model-2 is significant; only drawback - assumptions. There is a cross-sectional and serial correlation. For this reason, as a suggestion for further analysis, it is better to build models which deal with those. Even though, it is still possible to draw some conclusions on the basis of this model.

Equation of the model:

$$GHG^{it} = 2.4219 + 0.29268 \cdot GDP_{it} - 4.7733 \cdot 10^{-8} \cdot GDP_{it}^{2} + 0.0173 \cdot PES_{it} - 0.0163 \cdot REC_{it} + u_i + \varepsilon_{it}$$

Note: The GHG and GDP are in natural log forms

Where RES (new variable in the general REM equation (2)) – is the renewable energy consumption, u_i - is the unobserved country-specific random effect and ε_{it} - is the idiosyncratic error term. Unobserved country-specific random effect:

```
##      Kazakhstan  Kyrgizstan   Tajikistan  Turkmenistan   Uzbekistan
##      0.1961505   -0.4283945   -0.1158202   0.2525338     0.2828653
```

The scatter plots (Figure 4) depict the relationship between GDP (constant at 2015 USD rate) and total GHG emissions (in million metric tons). From the visualizations, one can see a non-linear relationship between the two variables, indicative of the Environmental Kuznets Curve (EKC) hypothesis.

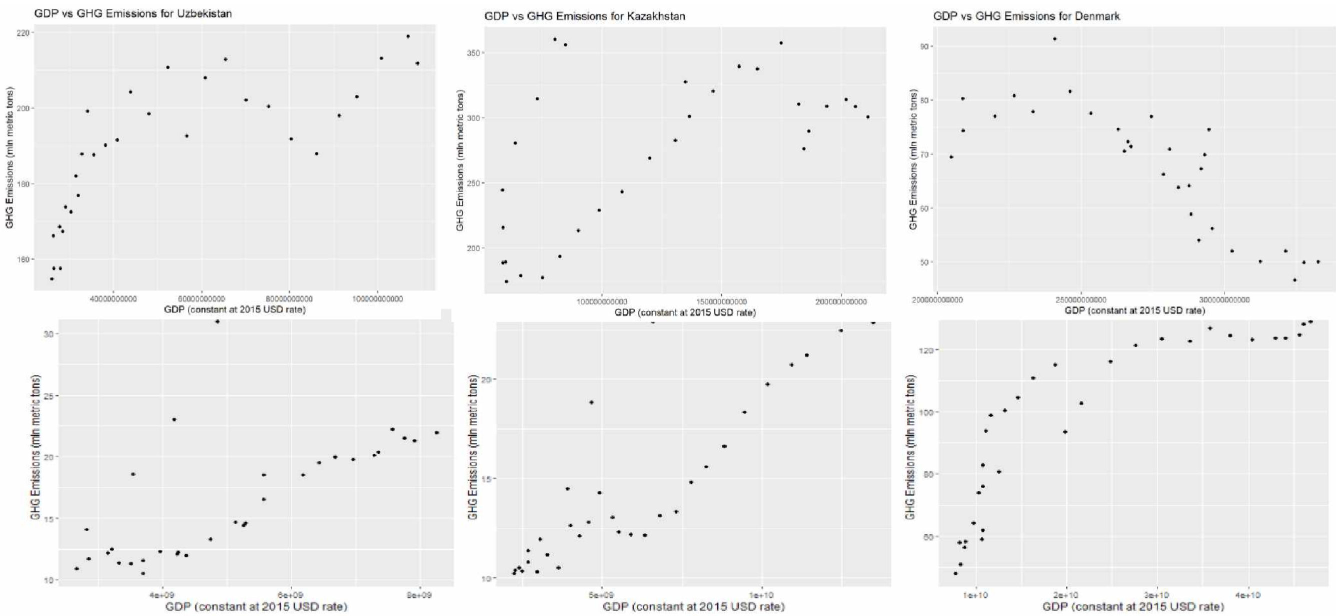


Figure 4. EKC curves

It is visible that Uzbekistan has already gone through the turning point and on the right side of the curve, which means further GDP growth might potentially decrease the GHG emissions and environmental degradation. As for the Denmark (we decided to add the country for comparison purpose), this country is the icon country in green economy in the world, thus within the last 31 years, the plot depicted basically the declining curve, which means each year the economy of Denmark increases, the GHG emissions will decrease further.

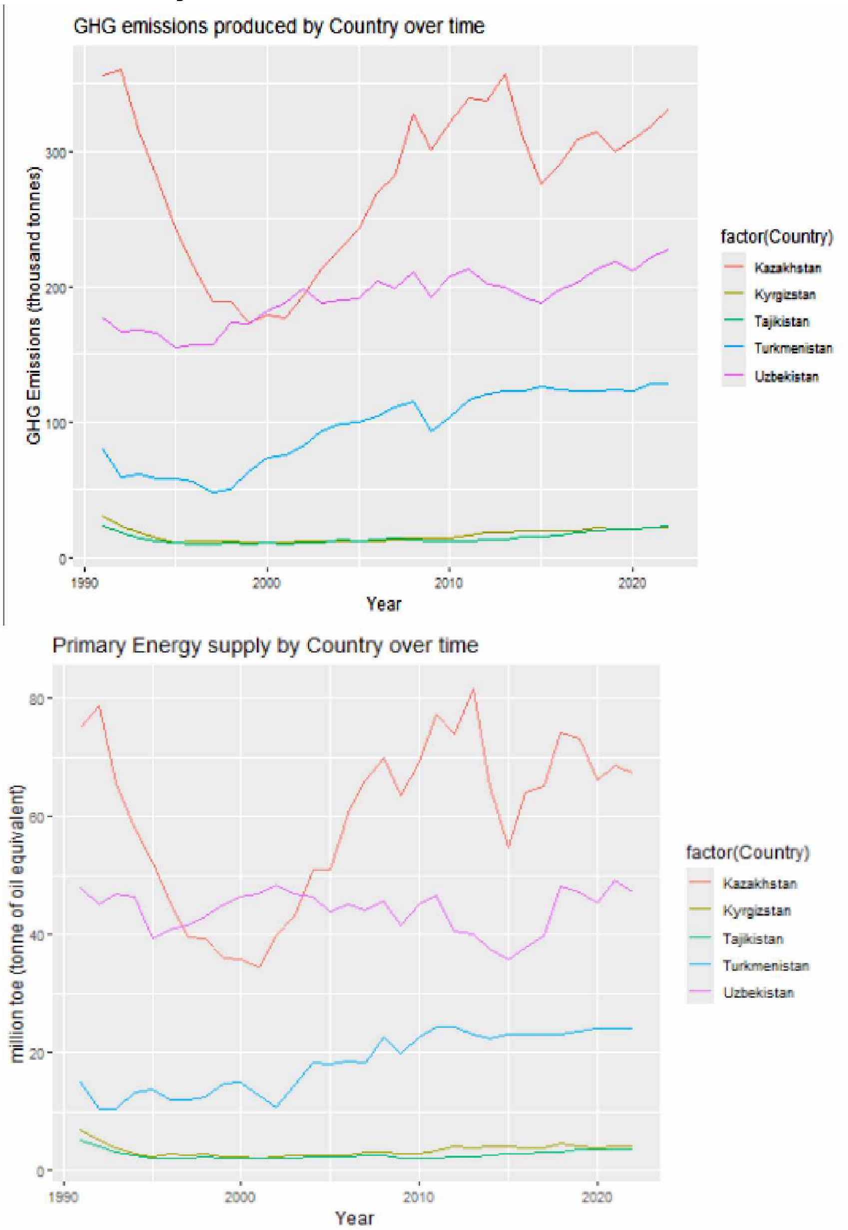


Figure 5. The greenhouse gas (GHG) emissions produced

The line charts depict the greenhouse gas (GHG (Greenhouse Gases)) emissions produced and the primary energy supplied for each of the six countries over time, measured in thousand tonnes from 1991 to approximately 2020.

- **Uzbekistan's Increase:** Uzbekistan's emissions are rising steadily over the years, which might be associated with its economic development and increased energy consumption. The Primary Energy supply in Uzbekistan fluctuates along the 45 mln toe within the last 31 years. However, this indicator started to increase since 2015.
- **Kazakhstan's Emissions:** Kazakhstan displays the highest levels of emissions among the represented countries, with notable fluctuations. There's an increasing trend until the early 2000s, a sharp decline, and then a rising trend again, which could reflect economic changes, energy policy shifts, or industrial growth patterns (might be the subject of the further research). Kazakhstan stands out with the highest primary energy supply, showing significant fluctuations that parallel its GHG emissions trends seen in the previous chart.
- **Kyrgyzstan, Tajikistan, and Turkmenistan:** These countries exhibit relatively low and stable emissions throughout the years, indicating smaller industrial sectors or lower energy consumption needs. Kyrgyzstan, Tajikistan, and Turkmenistan demonstrate relatively stable and low primary energy supplies, aligning with their low and stable GHG emissions patterns.

Conclusion

The empirical analysis of GHG emissions across countries underscores the intricate relationship between economic activity, energy consumption, and environmental impact. The positive coefficient on log(GDP) confirms the hypothesis that economic expansion, as measured by GDP, exerts upward pressure on GHG emissions, corroborating the conventional narrative linking economic growth with environmental degradation. *This coefficient indicates that a 1% increase in GDP is associated with an approximately 0.293% increase in total GHG emissions.* The positive sign signifies that GHG emissions tend to increase with rising GDP.

However, the emergence of a negative coefficient on the squared GDP term introduces a non-linear dynamic, suggestive of the Environmental Kuznets Curve (EKC) hypothesis, which posits that emissions initially increase with economic growth up to a turning point, beyond which they decline. This inflection point is critical, reflecting a threshold at which a country's development reaches a stage where increased income allows for and supports cleaner technologies and stricter environmental regulation, thereby reducing emissions despite continued economic growth.

Furthermore, the model reveals that a unit increase in primary energy supply, dominantly from non-renewable sources, significantly raises GHG emissions, reinforcing the energy-emissions nexus. This suggests that ***for each additional unit (million toe) of primary energy supply, GHG emissions increase by 1.7334%.*** This reflects the direct relationship between energy supply and emissions.

Contrastingly, renewable energy consumption emerges as a pivotal factor in mitigating emissions. The negative sign of the coefficient for renewable energy consumption indicates that transitioning to green energy plays a substantial role in curtailing emissions, aligning with sustainable development goals. ***The negative coefficient means that increasing renewable energy consumption is associated with a decrease in GHG emissions by 1.6385%.*** This highlights the beneficial impact of renewable energy on reducing emissions.

Country-specific effects, encapsulated in the random effects model, attest to the critical role of nation-specific policies, resource endowments, and technological advancements in determining the GHG emissions profile. These effects, coupled with a robust R-squared, signify that a considerable share of the variance in emissions is explained by the model's variables, cementing the relationship between the examined predictors and emissions. The statistical significance of all coefficients further reinforces the reliability of the model, thereby providing a credible framework for policymakers to scrutinize the energy-growth-emissions triad while strategizing for economic advancement in an environmentally sustainable manner.

Policy Implications. The significant coefficients for GDP, primary energy supply, and renewable energy consumption imply that policies promoting economic growth and energy supply must be balanced with environmental considerations. Specifically, investment in renewable energy sources is validated as an effective measure to combat rising GHG emissions.

In economic terms, this non-linear REM model highlights the complexity of the relationship between economic activity, energy consumption, and environmental impact. It provides evidence that while economic growth and energy supply are vital for development, there needs to be a simultaneous focus on sustainable practices, particularly the adoption of renewable energy and increasing the forest area to mitigate the environmental costs of development.

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