Analysis of the Influence of Economic Factors on the Ecological Footprint Using a Panel Regression Model

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Abstract. With the growing importance of sustainable development, it becomes necessary to study the factors influencing the ecological footprint. This study aims to evaluate the impact of various economic factors on the ecological footprint using a panel regression model. The model used allows for both individual and time differences, which makes it suitable for the analysis of long-term and cross-regional data. The results show that increased economic development is associated with an increase in environmental footprint, but this impact can be significantly mitigated by investment in fixed assets and increased public awareness. The findings highlight the importance of cooperation and technology exchange to achieve sustainable development goals and reduce environmental pollution at the global level. The findings can serve as a basis for the development of practical recommendations for sustainable resource management and environmental policy aimed at improving the state of the environment.

Key Words: Economic growth; Environmental sustainability; Macroeconomic factors; Reducing pollution.

1 Introduction

In many spheres of endeavor, the modern world must make the shift to environmentally conscious and sustainable practices. Green technologies and a desire to lessen the ecological footprint that humans leave behind are at the core of this process. Our research attempts to uncover important elements impacting environmental footprints in various economic situations and offer suggestions for bettering sustainable development policies and practices. It should contribute to the formulation of policies that support the harmonious coexistence of environmental preservation and economic advancement [1-3].

Over 68% of the world's energy consumption is accounted for by growth in economic activity in big economies. Scientists and policymakers are evaluating the long-term effects on environmental integrity of variables such population growth, financial liberalization, FDI,

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green energy usage, and technology advancements. Three elements—economic, social, and environmental development—are identified by the UN Sustainable Development Program as being essential to attaining sustainable development. The phrase "ecological footprint" refers to the growing influence of humans on the natural world. Pollutant levels are rising and environmental quality is declining when the ecological footprint grows. An indicator of how much human activity has affected the ecosystem is called an ecological footprint. It makes an estimate of the quantity of water and land resources required to meet demand and handle human waste. This index takes into account land usage, greenhouse gas emissions, energy and water use, and other factors that affect ecosystems.

Assessing ecological footprint is a useful tool for figuring out how sustainable different economic activity and human lives are in relation to the environment. As a result, attaining sustainable development and protecting natural resources for future generations require minimizing the ecological imprint. Long-term economic success in advanced economies is contingent upon the preservation of their natural resources. In the meanwhile, as megacities grow, so does the need for sustainable development goals to be financially interdependent. Green technologies are those that are made to either conserve and restore the environment or have as little detrimental effect as possible. These encompass a broad spectrum of advances targeted at decreasing emissions of pollutants, enhancing energy efficiency, augmenting the utilization of renewable energy, refining waste and resource management, and diminishing the ecological impact of production and consumption. Solar panels, wind turbines, electric cars, waste treatment and recycling equipment, and techniques to increase the energy efficiency of construction and industrial processes are a few examples of green technologies. Because they lessen the damaging effects of human activities on the environment, these technologies are crucial to the implementation of sustainable development [4-7].

Positive effects on the environment can result from managing globalization well [8]. The usage of renewable energy, urbanization, technological advancement, and globalization of finance are all thought to be major contributors to environmental footprints. Because industrialized economies rely so largely on non-renewable energy sources, it is time for them to transition to renewable energy use.

Therefore, the purpose of this study is to analyze the impact of various economic factors on the ecological footprint using a panel regression model. The study identifies and quantifies the main determinants that influence the ecological footprint in different economic situations, as well as provides recommendations for improving sustainable policies.

Thus, this paper aims to contribute to a better understanding of the relationship between economic development and ecological footprint, which is necessary to create balanced sustainable development strategies that help reduce negative environmental impacts.

2 Literature Review

Researchers and decision-makers have looked into a number of possible variables that could affect environmental quality in the long run. Fintech globalization, foreign direct investment, renewable energy, and technical innovation are a few potential research topics [6]. Achieving longevity requires an understanding of biological factors because this can help avert environmental and climate-related issues. Three factors are necessary to achieve sustainability: generating money, advancing social progress, and safeguarding the environment [6]. The term "carbon footprint" refers to the expanding impact of people on the environment. The highest CO2 emissions signify a deterioration in air quality. Nonetheless, some nations with more integrated economies are harming the environment by releasing more carbon dioxide into the atmosphere. In a similar vein, it has been demonstrated that FDI greatly contributes to environmental deterioration worldwide. An increase in foreign investment directly correlates with rising pollution levels. According to a different study,

foreign direct investment (FDI) boosts economic growth only to the extent that it causes environmental damage because higher FDI levels translate into lower pollution levels. By lowering carbon dioxide emissions, the utilization of sustainable energy sources like solar and wind energy benefits the environment [7].

This study thoroughly assesses how well cleaner energy sources and cutting-edge technology companies may slow down environmental degradation in these chosen economic clusters using a credible panel assessment model. A thorough grasp of the ways in which economic activities impact the ecological footprint in developed and developing nations is possible thanks to an inventive methodological approach that integrates macroeconomic and environmental data. The findings demonstrate notable disparities between G7 and E7 nations in terms of technological advancements and cleaner energy efficiency. The findings for the G7 countries demonstrate that investments in advanced technology and renewable energy greatly reduce environmental impact, which is in line with these nations' higher standards of economic efficiency. The E7 nations, on the other hand, have improved their environmental sustainability more gradually, highlighting both potential and problems in striking a balance.

A recent study [8] examined how China's environmental footprint improved between the first quarters of 2010 and 2020 as a result of global financing. investigated the possible impacts of financial globalization on the environment [9]. The report claims that by lowering its carbon footprint, the financial sector's globalization contributes to environmental protection. According to [10], foreign direct investment (FDI) has a long-term positive effect on the environmental footprint. According to research findings, FDI can lessen environmental effects up to a point. It was also determined how FDI affected Africa's ecological footprint spatially. Research [11-15] have been done on how America's use of renewable energy affects the country's carbon footprint. According to long-term projections, the use of renewable energy lowers carbon emissions, albeit at first in a negative way before turning positive. Environmental costs and renewable energy have a negative connection, which suggests that environmental quality has improved. The study discovered by multiple quantile regression that the utilization of renewable energy supports efficient energy policies and sustainable growth [16]. High rates of technical growth in developing nations have been linked to lower carbon footprints, according to research. Research [17-20] have shown that there is a reciprocal causal relationship between environmental effects and technology advancement.

Technological advancement has not significantly affected the ecological footprint in large emerging nations [21, 22]. In modern sustainability research, figuring out the major variables impacting the ecological footprint in various economic circumstances is crucial. The ecological footprint, also known as the environmental burden, is a representation of how human activity affects the environment. This includes changes in land usage, pollution emissions, and the consumption of natural resources. The factors impacting the ecological footprint may vary depending on the economic situation, such as developed countries (such as the G7 countries) and developing economies (such as the E7 countries). For instance, the adoption of new technology and the encouragement of environmentally friendly investments may play a significant role in developed nations, but industrialization, access to clean water, and sanitation concerns may be more urgent in developing nations. The phrase "ecological footprint" refers to the growing influence of humans on the natural world. Pollutant levels are rising and environmental quality is declining when the ecological footprint grows. Long-term economic success in advanced economies is contingent upon the preservation of their natural resources. In the meanwhile, as megacities grow, so does the need for sustainable development goals to be financially interdependent. Green technologies are those that are made to either conserve and restore the environment or have as little detrimental effect as possible. These encompass a broad spectrum of advances targeted at decreasing emissions of pollutants, enhancing energy efficiency, augmenting the utilization of renewable energy,

refining waste and resource management, and diminishing the ecological impact of production and consumption. Solar panels, wind turbines, electric cars, waste treatment and recycling equipment, and techniques to increase the energy efficiency of construction and industrial processes are a few examples of green technologies. Because they lessen the damaging effects of human activity on the environment, these technologies are crucial to the implementation of sustainable development [23].

3 Methods and Models

PanelOLS panel regression model with nation fixed effects was employed in the analysis. This allowed for the consideration of object heterogeneity and led to more precise estimations of the impact of economic considerations on the ecological footprint. This study emphasizes how crucial it is to take a variety of economic aspects into account when assessing environmental sustainability and creating legislative initiatives meant to lessen ecological footprints. The outcomes acquired have potential applications in environmental policy formulation and sustainable development decision-making. Panel estimate models are useful for analyzing data from various economic situations and determining how various variables affect the ecological footprint. In addition to socioeconomic metrics like educational achievement, this may also involve elements of economic growth, innovation, regulation, and technological advancement. Comprehending these variables not only facilitates an enhanced comprehension of the correlation between economic growth and the ecological footprint, but it may also serve as a foundation for formulating efficacious approaches to mitigate the adverse effects of human endeavors on the ecosystem [24].

The primary determinants of an ecological footprint in diverse economic settings include the degree of economic development of a property, which is frequently associated with the extent of its ecological footprint. Environmental pollution and resource use are often higher in more developed economies. The environmental impact of many economic sectors can be greatly decreased by the adoption of innovative technologies. This covers the creation of waste management techniques, energy-efficient production technology, and renewable energy sources. Greenhouse gas emissions and other forms of pollution can be greatly impacted by energy decisions, such as the development of nuclear power or the switch to renewable energy sources. Public education and understanding of environmental issues can affect people's purchasing and behavioral patterns as well as the standards that businesses and governments must meet when it comes to environmental protection. By exchanging resources, technology, and experiences, international environmental agreements and national cooperation can promote the reduction of the ecological footprint. These elements can be crucial for creating sustainable development plans since they have differing effects on the ecological footprint in various economic situations.

Panel data that contains information on several observations (such as nations, companies, or time periods) at various times in time are analyzed using panel estimation models, which are statistical models. These models are able to determine correlations between variables based on panel data and take into consideration individual and temporal changes in the data. For assessing long-term trends and predicting, they are extensively utilized in econometrics, sociology, political science, and other disciplines. The following is a model that may be used to examine how different economic conditions affect the ecological footprint:

$$EF_{it} = \beta_0 + \beta_1 GDP_{it} + \beta_2 TECH_{it} + \beta_3 EDU_{it} + \varepsilon_{it} \quad (1)$$

where EF_{it} is ecological footprint in the object i at the moment of time t; GDP_{it} is level of economic development of the object i at the time t; $TECH_{it}$ is innovation and

technological progress in the object i at a point in time t; EDU_{it} is level of education and awareness of the population in the object i at the time t; ε_{it} is random error.

With the help of this model, we can evaluate the impact of numerous variables on the ecological footprint of each object over varied time periods, enabling us to pinpoint the major elements that determine the degree of environmental pollution in diverse economic contexts. The following actions could be part of a program to investigate how various economic settings affect the ecological footprint (steps):

1. Prepare the data. Gather information on the environmental impact, technological advancement, economic growth, legislative and regulatory actions, educational attainment, and cross-national collaboration across various nations.
2. Cleaning and processing the data to remove anomalies, outliers, and omissions. Creation of a panel model.
3. Choosing a fixed or random effects model, for example, as the suitable panel model for the investigation.
4. Model specification, which includes factor identification and functional form selection.
5. Use appropriate techniques, such as generalized least squares, to estimate the model's parameters.
6. Examination of the outcomes.
7. Analyzing model parameter estimates to determine each factor's relative importance and direction of influence on the ecological footprint.
8. Evaluating the model's overall statistical significance and appropriateness for data description.
9. Testing theories on the importance of individual or group elements.
10. Study of the results' sensitivity to various model choices.

4 Results

We construct a Data Frame with data for 13 regions over 3 years. Data taken from open data stat.uz (https://stat.uz/uz/). To estimate the model, we set two exogenous variables, economic_growth and rowth rates of investments in fixed assets, and one endogenous variable, ecological_footprint. To estimate a panel model with country-level fixed effects, we use the PanelOLS method. PanelOLS estimates a country-level fixed effects model. The P values of the regression coefficients are output and the significance of these values is tested at the 0.05 level (Table 1, Table 2).

Table 1. PanelOLS estimation summary.

Dep. Variable:	ecological_footprint	R-squared:	0.4914
Estimator:	PanelOLS	R-squared (Between):	0.9725
No. Observation :	39	R-squared (Within):	0.4914
Date:	Thu, Jul 18 2024	R-squared (Overall):	0.9711
Time:	01:37:30	Log-likelihood	-65.728
Cov. Estimator:	Unadjusted		
	F-statistic:		11.596
Entities:	13	P-value	0.0003
Avg Obs:	3.0000	Distribution:	F(2,24)
Min Obs:	3.0000		
Max Obs:	3.0000	F-statistic (robust):	11.596
		P-value	0.0003
Time periods:	3	Distribution:	F(2,24)
Avg Obs:	13.000		

Min Obs:	13.000		
Max Obs:	13.000		

Table 1 shows a significant relationship between economic growth and the increase in the ecological footprint, and also indicates a negative impact of the growth rate of fixed investment on the ecological footprint. These results highlight the importance of considering economic factors when developing sustainability strategies aimed at reducing the environmental footprint.

Table 2. Parameter estimates.

	Parameter	Std. Err.	T-stat	P-value	Lower CI	Upper CI
Economic growth	11.939	2.4901	4.7946	0.0001	6.7996	17.078
Growth rates of investments in fixed assets	-13.131	4.1344	-3.1761	0.0041	-21.664	-4.5981

F-test for Poolability	4.8781
P-value	0.0005
Distribution	F(12,24)
Included effects	Entity

There have been 39 observations in total. There are thirteen regions and three time periods. The R-squared value of the dependent variable's explained variance as a function of the independent variables in the model is 0.4914. The explained variation between various locations is displayed by the between-group R-squared, which is 0.9725. The explained variation within each region is displayed by the within-group R-squared, which is 0.4914. Including both within-group and between-group variation, the overall R-squared value is 0.9711. The quality of model fit is shown by the log-likelihood function. Log-likelihood -65.728. The model's F-statistic's significance test value is 11.596, and the F-statistic's p-value is 11.5966. A model P-value of 0.0003 denotes significance, with a value less than 0.05.

The coefficient for the economic growth variable is 11.939. Hence, a one-unit rise in economic growth corresponds to an increase in the ecological footprint by 11.939 units. The standard error of the coefficient is 2.4901. The t-statistic for testing the coefficient's significance is 4.7946. A p-value of 0.0001, which is less than 0.05, indicates the coefficient's significance. The confidence interval ranges from 6.7996 to 17.078. The coefficient for the variable growth rates of investments in fixed assets is -13.131, suggesting a one-unit rise in these investment growth rates leads to a 13.131 unit decrease in the ecological footprint.

Standard error of the coefficient is 4.1344. T-statistics to test the significance of the coefficient is -3.1761, with a p-value of 0.0041, indicating significance since it's less than 0.05. The confidence interval ranges from -21.664 to -4.5981. The poolability test, F-test for Poolability, has a value of 4.8781 and a p-value of 0.0005, signifying significance and justifying the use of fixed effects. The F-statistics distribution is F(12,24), and the model includes fixed effects for the Entity regions.

The findings indicate a strong positive relationship between economic growth and the ecological footprint, suggesting that economic expansion leads to a larger ecological burden. Conversely, growth rates of investments in fixed assets are negatively correlated with the ecological footprint, meaning increased investment rates reduce the footprint. The fixed effects model, which accounts for regional differences, is justified as these differences are considerable. The R-square (Between) demonstrates that the model effectively explains regional variations, while the R-square (Within) shows moderate explanatory power within regions. The findings emphasize the significance of economic growth and investment growth

rates in fixed assets for altering the ecological footprint and validate the use of fixed effects for accounting for regional differences.

5 Conclusion

The impact of economic considerations on the ecological footprint was examined using a panel regression model with fixed effects. The ecological footprint is positively and significantly impacted by economic expansion. This implies that the environmental impact increases with economic growth. This finding emphasizes the necessity of implementing ecologically friendly technologies and sustainable farming methods to reduce the harm that economic development does to the environment. Although the ecological footprint was shown to be negatively impacted by growth rates of investments in fixed assets, this influence was found to be statistically negligible. Nonetheless, technological advancements and the transition to more eco-friendly and productive industrial methods continue to be critical components in the goal of sustainable development. Rising economies should prioritize the implementation of environmental policies aimed at safeguarding natural resources. Environmental responsibility and economic development must coexist, and this can be achieved by introducing cutting-edge technologies and pollution-reduction tactics.

The findings point to the necessity of additional study to fully comprehend how different factors affect the ecological footprint. A more thorough knowledge of the issue can be achieved by incorporating additional variables like policies and societal issues, as well as more sectors and historical periods. In conclusion, it should be highlighted that taking into account the interplay between economic growth, growth rates of investments in fixed assets, and ecological footprint is critical to achieving sustainable development goals. Modern society faces a major difficulty in creating balanced policies that promote economic progress without endangering the environment. The outcomes can be used as a foundation for developing these policies and selecting appropriate management strategies.

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