Nexus between ECO-Innovation, Human Development and CO2 Emissions

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Abstract
Climate change and environmental issues have become increasingly acute in recent decades, raising global concerns about environmental sustainability. In this context, eco-innovation has become an indispensable component of the efforts to undertake these challenges and build a more sustainable future. This research focuses on analysing the relationship between the eco-innovation index, the human development index (HDI), greenhouse gas (GHG) emissions, CO2 emissions per capita in European Union member states, for the period 2013-2021. Adopting statistical analysis, particularly the Pearson correlation coefficient, the research examines the relation between these variables. The findings shed light on the complex dynamics between eco-innovation, human development, economic indicators, and environmental factors, providing valuable insights for policy makers, researchers who want to deal with sustainability challenges and promote inclusive growth.
Keywords: eco-innovation, human development, greenhouse gas emissions, CO2 emissions, sustainability

JEL Classification: O31, O15, Q56

DOI: 10.24818/REJ/2024/87/01

1. Introduction

In an era when concerns for the environment and human well-being dominate the global agenda, analysis of the link between the eco-innovation index and the human development index becomes imperative. Eco-innovation, a driving force for economic sustainability, and human development, a pillar of social progress, seem to be two distinct worlds. However, closer investigation reveals a subtle and powerful interdependence between these two seemingly separate domains. This article explores the deep connections between eco-innovation and human development, highlighting their importance in building a sustainable and equitable future for generations to come.

The aim of this article is to highlight the influence of human development, through the human development index and GDP per capita, on the degree of development of eco-innovation in the European Union, with eco-innovation aiming to reduce greenhouse gas emissions and CO2 emissions per capita. Thus, this paper is based on the following research questions:

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1. Is there a positive link between human development and the level of eco-innovation recorded by EU Member States?
2. What influence do greenhouse gas emissions have on eco-innovations?

The results of this work could be the basis for the further development of social programmes, focusing on human development through various actions in areas such as education, health, infrastructure development, all of which are carried out in a sustainable way through eco-innovations. Exploring these complex relationships could also contribute to advancing knowledge in the field of sustainable development and developing more effective solutions to achieve the goals of protecting the environment and improving the quality of life.

2. Review of the scientific literature

Climate change is currently one of the biggest challenges and threats to natural life and prosperity, primarily caused by increasing CO2 emissions (Akbar et al., 2021). Initially, developing countries did not pay significant attention to reducing CO2 emissions; however, after realizing the negative effects, their concern has grown. The most dangerous impact of greenhouse gas emissions is their adverse effect on well-being and health. An analysis of the link between greenhouse gas emissions and the human development index can determine the extent to which countries mobilize to achieve sustainable development goals (Wang et al., 2019).

The human development index comprises various indicators, including life expectancy, education, and per capita income, as well as factors related to people's freedom for well-being, such as autonomy, sustainability, cooperation, security, productivity, and equity (Akbar et al., 2021). Some studies have shown a strong correlation between economic development and human development, positively correlated with human capital (Wang et al., 2019).

Economic development is necessary to improve the standard of living and community welfare through enhancements in all areas of activity. Furthermore, to enhance well-being, there is a need for stable and evenly distributed economic growth (Zainurossalamia Za et al., 2021).

However, some researchers have found that economic growth is associated with increased energy consumption, which is positively linked to CO2 emissions, detrimental to the environment and human welfare (Akbar et al., 2021).

On the other hand, other studies show that high CO2 emissions would reduce the value of human development for some developing countries, but would benefit economic growth in developed countries (Wang et al., 2019). This is because high-income countries pay more attention to improving human welfare (Zhang et al., 2021).

Although the results of various research contradict each other, the literature states that economic growth will not be generated if it is not supported by equitable distribution of resources. (Zainurossalamia Za et al., 2021). Thus, there must always be mutual support between economic growth and human development. For this to be possible, economies must become increasingly innovative and emphasise eco-innovation.

It has been shown that eco-innovation can play a crucial role in promoting economic sustainability and environmental protection. For example, research in the field (Díaz-García et al., 2015) has shown that the adoption of eco-innovative practices within industry can not only lead to reduced carbon emissions and resource consumption, but also boost innovation and economic competitiveness.

However, it should be noted that innovation is not only an economic or technical mechanism, but above all a social phenomenon. The ability to innovate and create new things is one of the hallmarks of civilisation (Cajaiba-Santana, 2014).

Eco-innovations in almost every field will be possible given rapid developments in technology, accelerating GDP growth in some countries and the growing number of skilled human resources. Analysis of Innovation-Based Human Resources for Sustainable Development However, some studies show that in addition to technological development, eco-innovations also depend on cooperation between the public sector, academia and business (Chistov et al., 2021).

At EU level, research highlights a number of obstacles to the development and mainstreaming of environmental and social innovations. These include traditional cultures of administrations, closed systems favouring solutions to individual problems developed within groups of organisations lacking mutual awareness, communication, networks and trust. Moreover, insufficient funding at all stages of the innovation cycle is a major challenge, as they are not well adapted to support social innovation (Hubert, 2010).

Given the current focus on sustainability, it is also worth mentioning the link between eco-innovation and the achievement of the 17 Sustainable Development Goals (SDGs). Studies show that eco-innovations positively influence the implementation of the SDGs, even SDGs 7, 8 and 9, which have implications for clean and renewable energy, economic development and infrastructure and innovation. It has been shown that countries with higher eco-innovation efficiency scores tend to score higher on the SDGs, highlighting mutual reinforcement. Eco-innovation strategies reduce carbon emissions and environmental footprints, contributing to climate change mitigation and promoting sustainable practices (Fatma and Haleem, 2023).

3. Research methodology

The dataset analysed in this study comprises key indicators reflecting eco-innovation, human development, and per capita greenhouse gas (GHG) emissions across European Union countries. over several years. The data were aggregated from various recognized international sources, aiming to explore the relationships between eco-innovation efforts (represented by the Eco Innovation Index - ECO II), levels of human development (reflected by the Human Development Index - HDI), and environmental impact measured through per capita GHG emissions.

The selected indicators for this analysis are defined as follows:

- Eco Innovation Index (ECO II): „a composite index that is based on 16 indicators which are aggregated into five components: eco-innovation inputs, eco-innovation activities, eco-innovation outputs, resource efficiency outcomes and socio-economic outcomes" (Lesáková and Laco, 2020).
- Human Development Index (HDI): „a summary measure of average achievement in key dimensions of human development: a long and healthy life, being knowledgeable and having a decent standard of living. The HDI is the geometric mean of normalized indices for each of the three dimensions" (United Nations, 2023).
- GHG per capita: „greenhouse gas emissions per capita, measured in tons of CO2 equivalent. This indicator reflects the average contribution of each citizen to the country's total GHG emissions, offering a perspective on the impact of human activities on climate change" (Ritchie et al., 2023).

Data were collected for the period 2013-2021, thus allowing for the assessment of medium-term trends and correlations among these indicators for the European Union countries. All the data were available at Ourworldindata.org (Ritchie et al., 2023) and European Commission (European Commission, 2022). The analysis of correlations was performed using the Pearson correlation coefficient, aiming to identify linear relationships between eco-innovation, human development, and GHG emissions per capita. The results indicate a moderate to strong positive correlation between ECO II and HDI, suggesting that eco-innovation efforts are associated with higher levels of human development. Additionally, a positive, albeit weaker, correlation was observed between ECO II and GHG per capita, as well as between HDI and GHG per capita, indicating complex links between sustainable development, human well-being, and environmental impact.

4. Results and discussion

The analysis of Eco Innovation Index and their correlation with various factors including CO2, Greenhouse Gas emissions, Human Development Index, and

Gross Domestic Product per capita offers a complex but significant insight into the intersection of economic development, human welfare, and environmental impact.

A foundational observation from the statistical analysis presented indicates that CO2 and GHG values alone offer a meagre explanation of the changes in ECO II, accounting for only 5.6% of its variability. This low percentage suggests that while the emission of greenhouse gases and CO2 is inherently related to environmental conditions, they do not offer a comprehensive understanding of environmental outcomes. It is a reminder that ECO II's determinants are multifaceted and that a singular focus on carbon metrics may not be sufficient for nuanced environmental policy.

More significantly, the combination of HDI and GDP per capita proves to be a stronger predictor, explaining 58% of the ECO II change. This can be interpreted to suggest a robust link between human development and economic performance with environmental conditions. The regression equation (1) provided,

$$\text{ECO II} = -367.82 + 505.778*\text{HDI} + 0.000495\ \text{GDP/cap} \quad (1)$$

captures this relationship quantitatively, indicating that as HDI and GDP per capita increase, there is a corresponding improvement in ECO II. Here, HDI appears to have a substantial weight. This suggests that improvements in human development, more than economic growth alone, are conducive to better environmental outcomes.

The nuanced change when CO2 per capita is added to the regression model is also worth noting. The explanatory power of the model increases slightly to 60% with the inclusion of CO2 per capita, yet the coefficient for CO2 is minimal (shown by the exponent notation, which indicates a number very close to zero).

The updated equation (2) (according to Figure 1),

$$\text{ECO II} = -373.77 + 513.488*\text{HDI} + 0.000481\ \text{GDP/cap} - 2.60912\text{E-}07*\text{CO2/cap} \quad (2)$$

implies that while CO2 emissions per capita do contribute additional explanatory power, their impact is relatively insignificant. This could point to the effectiveness of technology and policy measures that decouple CO2 emissions from environmental degradation or suggest that current CO2 emissions are a less dominant force in the broader environmental condition than other factors.

Figure 1. Results of statistical analysis

Regression Statistics	
Multiple R	0.77526675
R Square	0.601038533
Adjusted R Square	0.593784688
Standard Error	22.69625059
Observations	225

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	-373.7709178	47.61436914	-7.849960517	1.80579E-13	-467.6095827	-279.9322528
GHG	-2.60192E-07	1.24504E-07	-2.089833165	0.037781854	-5.05565E-07	-1.48194E-08
CO2	2.15163E-07	1.12812E-07	1.907281897	0.057786619	-7.16621E-09	4.37493E-07
HDI	513.4879796	57.74349992	8.892567655	2.2083E-16	399.6867671	627.2891922
GDP	0.000480168	0.000108813	4.412789312	1.59826E-05	0.000265719	0.000694617

Source: by the author based on Ritchie et al., 2023 and European Commission, 2022

The slight increase in the model's explanatory power after adding CO2 per capita might be interpreted as evidence that carbon emissions still play a role, albeit a small one, in determining environmental quality. Given the global emphasis on reducing CO2 emissions, this finding may at first seem counterintuitive or even discouraging. However, it could also be understood as an indicator that efforts to mitigate CO2 emissions are having a positive effect, or that other factors included in ECO II, such as biodiversity loss or pollution, might be worsening due to drivers not directly related to CO2 emissions.

The relationship between Human Development Index and Eco innovation index is particularly compelling, with HDI alone explaining 54% of the evolution in ECO II. This robust correlation may reflect the fact that human development encompasses more than just economic growth; it includes education, health, and the level of living standards, which are critical components of environmental conditions. Essentially, as societies become more developed, they may have more resources and infrastructures to support better environmental management practices, leading to an improvement in ECO II.

The lack of a statistical correlation between Greenhouse Gas emissions and ECO II, despite GHG emissions productivity being a component of ECO II, raises interesting questions. It could be that the way GHG emissions are accounted for within ECO II does not capture their full impact on environmental conditions. Alternatively, it could suggest that other factors within ECO II may be offsetting

the potential negative impact of GHG emissions. For example, advancements in technology might be mitigating the effects of GHG emissions, or other environmental policy efforts could be compensating for the damages caused by these emissions.

This unexpected finding might also highlight the complexity of environmental outcomes, which are influenced by a myriad of factors beyond emissions. These could include biodiversity conservation, water quality, land use changes, and waste management, among others. Therefore, while GHG emissions are undeniably a significant aspect of environmental health, their direct correlation with broader environmental conditions may not always be straightforward.

Additionally, the lack of correlation might indicate a delay between the emission of GHGs and observable changes in environmental conditions. Environmental degradation often results from cumulative effects over time; hence, current GHG levels might not immediately reflect in the ECO II metrics. This delay poses challenges for policymakers, who must anticipate future impacts of present-day emissions and act accordingly.

It is also worth considering the implications of GHG productivity, which involves measuring the output or benefit gained per unit of emission. If GHG emissions productivity is not correlated with ECO II, it suggests that simply being efficient in terms of emissions relative to economic output is not sufficient to ensure positive environmental outcomes. This could call for a re-evaluation of how we measure productivity in relation to environmental sustainability.

5. Conclusions

In conclusion, the analysis of the relationship between Human Development Index, Greenhouse Gas emissions, and Eco innovation index reveals several significant insights.

Firstly, HDI appears to be a substantial predictor of ECO II evolution, indicating that factors contributing to human development such as education, healthcare, and living standards play a critical role in shaping environmental outcomes. This suggests that policies and initiatives that aim to enhance human development are likely to have a positive impact on the environment, reinforcing the idea that sustainable development and environmental health are interconnected.

The absence of a statistical correlation between GHG emissions and ECO II, even though GHG emissions productivity is a component of ECO II, is a particularly intriguing finding. It challenges the assumption that GHG emissions, by themselves, are a direct indicator of environmental quality. This could imply the effectiveness of modern technologies and environmental policies in mitigating the

impact of emissions or indicate that GHG emissions may not be the most immediate concern in certain environmental contexts.

The data prompts a re-evaluation of current environmental indicators and measures of productivity. It becomes evident that efficiency in GHG emissions alone is insufficient for predicting environmental health. Therefore, a more nuanced understanding of productivity that incorporates broader environmental impacts is essential.

For policymakers, these conclusions underscore the importance of a multifaceted approach to environmental policy. The findings advocate for integrating human development goals with environmental objectives, highlighting the need for investments in education, health, and technology that can lead to both improved human development indices and better environmental conditions.

Finally, the complexity and delayed nature of environmental degradation call for proactive and preventative measures in policymaking. Policies need to be forward-thinking, considering the long-term implications of GHG emissions and other environmental stressors. The intricacy of environmental outcomes necessitates a strategic approach that balances economic development with the imperative of ecological preservation, ensuring that the growth today does not come at the cost of tomorrow's environment.

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