Economic implications of technological and energy advancement on CO_2 emission intensity in selected countries

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Abstract: In the pursuit of economic prosperity, many countries have "sacrificed" the quality of their environment to achieve higher rates of economic growth. By focusing on established industrial practices that have destroyed the environment in the long run, they have harmed their own, as well as the global ecosystem. Within this context, the main challenge for a long-term sustainable economic policy is the intertwined focus on two goals - economic growth and environmental protection. The aim of this paper is to analyse the impact of the development of environmentally related technologies, renewable energy supplies, and the total primary energy supply on the intensity of CO_2 emissions based on the production within five countries in the period from 1990 to 2019. The observed countries are Italy, Germany, Croatia, Brazil, and Finland. To evaluate the relationship between the observed variables a panel analysis was used, more specifically random effect models (REM) and fixed effect models (FEM). Empirical results show that the development of environmental technologies and the supply of renewable energy have a negative impact on CO_2 emissions, while the total supply of primary energy has a positive impact on CO_2 emissions. The results of the research suggest that environment-related technologies and renewable energy promote the issue of environmental protection, while the overall supply of primary energy actually limits the perspective of green development.

Keywords: environment, sustainable development, green economy, CO_2 emissions, panel analysis
JEL classification: O33, O44, Q40, Q51

1 Introduction to the problem of the green economy

The unsustainable economic solutions that create a growing socio-economic gap between developed and other countries have resulted in an urgent need for new synergies between economic and environmental concepts, intending to achieve a more accurate assessment of true progress and prosperity in the future. At a time when the issue of population growth has become crucial for some countries to address their long-term growth perspective, many other countries are developing more intensively, reducing their arable land and increasing resource consumption. Consequently, the economic and ecological future of the world is becoming increasingly uncertain. With drastic changes in the environment, there are rising fears that economic growth and consumerism, as well as the related lifestyle requirements, disrupt the ecological balance, the economic stability, and even security. The warming of the atmosphere, the threats to flora and fauna, environmental pollution, and climate change are just some of the challenges that threaten global existence. For these reasons, an increased developmental and media focus is being placed on concepts such as sustainable development, circular economy, green economy, green economic growth, and even indicators such as green GDP.
With the United Nations goals directed towards sustainable development (e.g. *UN Agenda 2030*) and the *Paris Agreement*, the general idea of sustainable development has been transformed into a policy concept with clearly defined goals, as well as indicators for the measurement and the implementation process. In order to reduce the negative impact on the environment, two key concepts have been adopted - efficiency and sufficiency. Environmental efficiency (less environmental impact per unit of GDP) plays the most important role and has the potential to break the link between economic growth and environmental impact. In that way, the growth continues in the function of the so-called green growth. Nevertheless, more emphasis is being placed on the option of sufficiency (lower GDP), which means changing spending and lifestyle habits. These UN goals will have significant implications for the transformation of the economy, society, and government policies that have so far been dominated by growth policies. It is important to note that only with policy concepts that integrate the components of efficiency and sufficiency there is a chance to achieve fundamental changes in economic growth (Kurz, 2019). Green growth refers to a type of production based on the demand for green technological innovations aimed at cleaner production and supply chains, as well as to environmental technology related to energy production and transmission, making it an important determinant of green growth. Furthermore, green growth is a strategy to save energy and reduce carbon emissions and is a widely accepted solution to control the improvement of socio-economic life. Green technology is an effective method of fostering green economic growth, and many studies have confirmed that cleaner technological implementations significantly reduce carbon emissions making green growth one of the best alternative strategies for sustainable development (Danish and Ulucak, 2020). Other studies have shown that a consistent and efficient reduction of CO_2 emissions depends on the improvement of technical efficiency and the use of renewable energy sources vital for creating cleaner energy and thus less environmental pollution. Additional research has also confirmed that carbon mitigation is the key to understanding green growth. In many countries, efforts are being made to encourage the growth of

green awareness and to establish a green economic growth infrastructure focused on resources and environmental protection, especially in terms of energy transformation (Danish and Ulucak, 2020).
The aim of this paper is to investigate the role and the effect of the development of environmentally related technologies, renewable energy supply, and primary energy supply on the intensity of CO_2 emissions based on production, to answer the question of what factors limit or contribute to, within a broader context, to the development of a 'greener' economy. The analysis focuses on five countries during the period from 1990 to 2019. The evaluation of the observed variables is based on a panel analysis, more specifically random effect models (REM) and fixed effect models (FEM). Each variable was observed separately, and three different models were observed for the study. The results confirm the expected relations by showing how environmental technologies and renewable energy promote environmental protection, while the total supply of primary energy harms the environment and thus limits green growth and development.
The paper consists of five parts. After the first introductory part, which provides a theoretical explanation of green growth and the importance of the role of environmental awareness in achieving a sustainable competitive economy, the second part systematizes the relevant empirical research. The third, methodological segment describes the variables and the methodology used, while the fourth part focuses on the results and implications of the research. The fifth, final segment, offers concluding remarks on the topic.

2 Empirical background

Saidi and Hammami (2015) examined the impact of energy consumption and CO_2 emissions on economic growth using models of simultaneous equations with panel data for 58 countries in the period from 1990 to 2012. Their empirical results show that energy consumption has a positive effect on economic growth. This implies that energy consumption has played an important role in achieving economic growth in the observed economies, but with high pollution being one of the consequences. Because energy is an important component of economic growth, strong energy policies are needed to achieve it. On the other hand, CO_2 emissions have a negative impact on growth. Similar findings were made by Charfeddine (2017), who in his research on the case of Qatar found that electricity consumption and financial development are positively associated with the environmental footprint, and negatively with the footprint of carbon and CO_2 emissions. Ke and Boqiang (2015) found a link between urbanization and industrialization having a significant impact on energy consumption and CO_2 emissions, although this relationship varies at different stages of economic development. The main results were obtained by dynamic threshold regression models that divide the balanced set of panels of 73 countries for the period from 1971 to 2010 into four groups according to their annual income levels. The key results are: (1) in the low-income group, urbanization reduces energy consumption but also increases CO_2 emissions; (2) in middle/low and high-income groups, industrialization reduces energy consumption but increases CO_2 emissions, while urbanization significantly increases both energy consumption and CO_2 emissions; (3) for the middle/high-income group, urbanization does not significantly affect energy consumption, but hinders emissions growth, while industrialization has been found to have a negligible impact on energy consumption and CO_2 emissions; (4) from a population perspective, industrialization produces positive effects on energy consumption and also increases emissions, except for the high-income group. These findings suggest that different strategies for urban development and industrialization should be implemented, depending on income levels in an effort to limit excessive energy consumption and reduce CO_2 emissions.
The nexus between economic development, energy consumption, and CO_2 emissions was confirmed by a study from China for the period from 1990 to 2012. The existence of Granger's link between

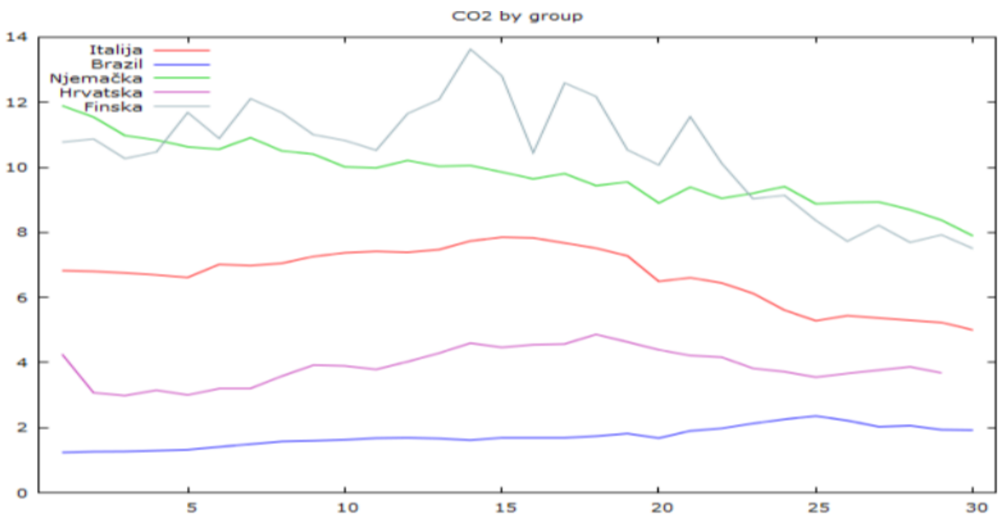
economic growth, energy consumption, and CO_2 emissions was confirmed; more specifically, a two-way causal relationship was identified between economic growth and energy consumption, as well as a one-way causal relationship between energy consumption and CO_2 emissions. The findings have significant implications for both academics and practitioners, stressing the need to develop and implement long-term energy and economic policies to effectively address China's greenhouse gas effects, placing the country on a low-carbon path (Wang et al., 2016). Dinda (2018) explores the link between carbon emissions, technological progress, and economic growth. The research focuses on technological growth, which is observed according to USPTO's utility patents. The results support the existing evidence that technological progress is a driver of economic growth, while also reducing CO_2 emissions per unit of production. The paper provides evidence of the long-term relationship between short-term dynamics of carbon intensity, technological progress, and economic growth for the period between 1963 and 2010 in the USA. The research presented by Grossman and Krueger (1995) also suggests that endogenous changes in technology will minimize the cost of meeting carbon reduction targets. Many growth theories have revealed the role of targeted technological change through patents, innovation, and taxes toward establishing a sustainable growth path (Acemoglu et al., 2012). Therefore, the level of technological innovation and the use of renewable energy sources is a crucial step in affecting CO_2 emissions (Wang and Wei, 2019), while it is assumed that other primary energy supplies will increase CO_2 levels, and thus slow down the green growth.
Škare, Tomić, and Stjepanović (2020) conducted an interesting study in which they used two models to observe the effect of energy consumption on GDP and the green GDP in 36 countries (EU countries and potential candidate countries). In one model, the relationship between total energy consumption and GDP growth, more exactly the green GDP, was observed, while in the other model the emphasis was placed on separate variables related to different energy sources, from which their individual effects on the difference between GDP and the green GDP were analysed. The results confirmed the theoretical expectations because the authors provided evidence that the increase in energy consumption affects the growth of both GDP and the green GDP. Furthermore, the second part of the analysis confirmed that solid fuels and oil have a much greater impact on the differences between green GDP and GDP than renewable sources and natural gas, which are cleaner forms of energy.

3 Methodology and data

The aim of this research is to determine the impact of the development of environmentally related technologies, renewable energy, and total primary energy supply on the intensity of CO_2 emissions based on production. Five countries were selected for the empirical study of the impact of the observed variables - Italy, Brazil, Germany, Croatia, and Finland. The heterogeneity of the sample is the result of the desire to evaluate countries that have different economic backgrounds and different approaches to solving environmental problems. This limited research focus did not create complications with the modelling and interpretation of the obtained results. The annual data was collected for the period between 1990 and 2019 from the OECD statistics. The contemporary research relating to economic growth has led us to investigate the effects of environment-protective technologies, renewable energy supplies, and the total primary energy supplies on the intensity of CO_2 emissions based on production. Therefore, the analysis will focus on the relationship between four variables, three of which are considered independent **- environmental technology, renewable energy supply, and the total primary energy supply**, while the dependent variable is **the CO_2 emission intensity**. The variables are not logarithmic because the values by countries are relatively similar and are not significantly variable, more precisely they do not fluctuate significantly. Contrary to popular belief, a logarithmic transformation can often increase rather than decrease data variability and thus the consistency of conclusions. The main disadvantage of this approach in our case is the inability to interpret the results in percentages, but due to the small values of the coefficients in the models, this does not represent a problem when addressing and explaining the results. The CO_2 emission data was measured in production per capita. The environment-related technology variable represents the development of environment-related technologies as a share of total technology. The variable of the renewable energy supply represents a percentage of the total energy supply. Based on previous research, the following hypotheses were made: (1) environmental technologies have a negative impact on CO_2 intensity, (2) the renewable energy supply has a negative impact on CO_2 emission intensity, and (3) the overall primary energy supply has a positive impact on CO_2 emission intensity.

3.1 Production-based CO_2 emission intensity

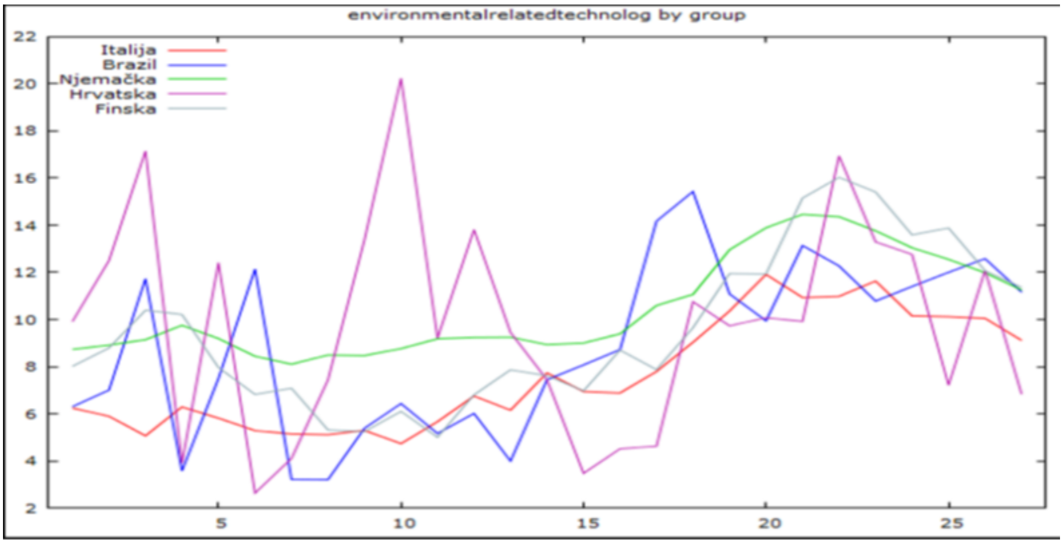
The CO_2 pollution from fossil fuel combustion is the primary cause of global warming (Davis, Caldeira, 2010). The problem of global warming and climate change rises due to the progressive increase in the concentration of carbon dioxide in the atmosphere. This causes the expansion and thickening of the atmosphere, stopping much of the infrared rays that would otherwise leave and continue to spread throughout space. Consequently, the temperature of the Earth's atmosphere, and thus the sea and oceans, is rising dangerously. This causes many natural disasters such as typhoons, hurricanes, floods, melting glaciers, imbalance of precipitation, disappearing lakes, increasing humidity, and the like. This disruption of the natural atmosphere leads to the extinction and endangerment of the lives of many plant and animal species, which biologists call the crisis of mass extinction (Gore, 2007). CO_2 emissions are usually measured on a 'production' basis. This accounting method, which is sometimes also called "territorial" emissions, is used when different countries report their emissions and set targets on a domestic and international level (Ritchie, 2019).
Graph 1 suggests that Italy, Finland, and Germany have recorded a significant decline in the emission intensity of CO_2 based on production over the observed period. Croatia recorded a slight decline, while Brazil recorded a slight increase in the intensity of CO_2 emissions during the observed period. Finland records the highest CO_2 emission intensities of all of the observed countries with the average CO_2 emission at a high 10.48. It is followed by Germany with an average CO_2 emission of 9.82. The lowest CO_2 emissions were recorded in Brazil with an average CO_2 emission value of 1.73. Croatia signed the *Kyoto Protocol* in 1999 which defined a 5 percent decrease in greenhouse gas emissions in the period from 2008 to 2012 from the levels recorded in 1990 (Franković, Blecich, and Hustić, 2015).



Graph 1. Movement of the production-based CO_2 emission intensity variable
Source: OECD Statistics (2020)

3.2 Development of environment-related technologies

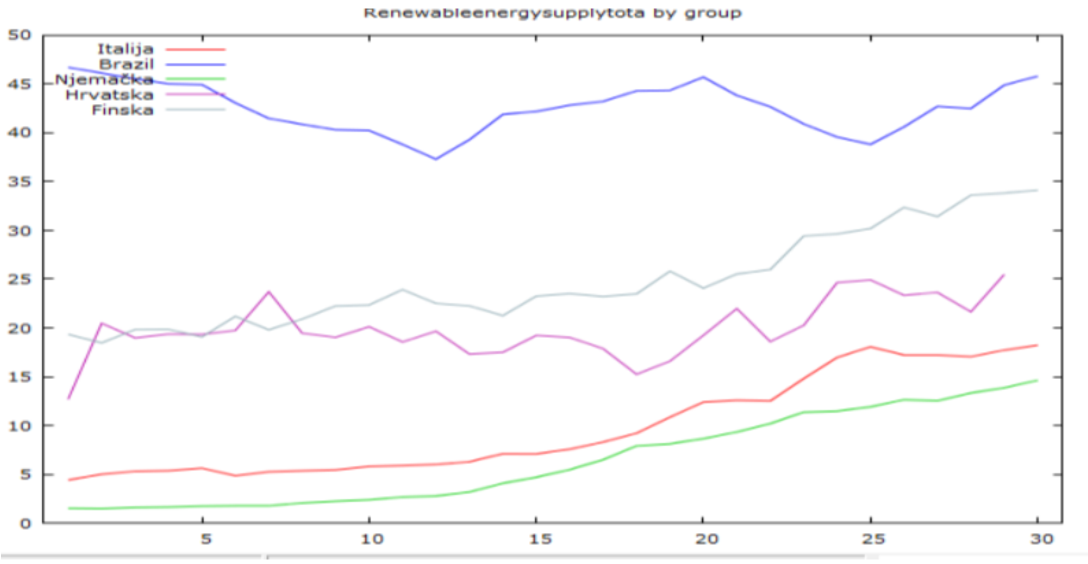
The development of environment-related technologies represents the number of environment-related inventions and is expressed as a percentage of all domestic inventions (in all technologies). The changes in 'ecological' technological innovations can then be interpreted in relation to innovations in general. The technological development indicators are constructed by measuring the inventive activity using patent data in a wide range of environmental technology areas, including environmental management, water-related adaptations, and climate change mitigation technologies. The numbers that are used here include only inventions of greater value. *Graph 2* shows how Germany, Italy, Finland, and Brazil are recording a trend of growth in environment-related technologies, while the data for Croatia fluctuates quite a bit, which does not suggest a consistent conclusion.



Graph 2. Movement of the environment-related technology variable
Source: OECD Statistics (2020)

3.3 Renewable energy supply

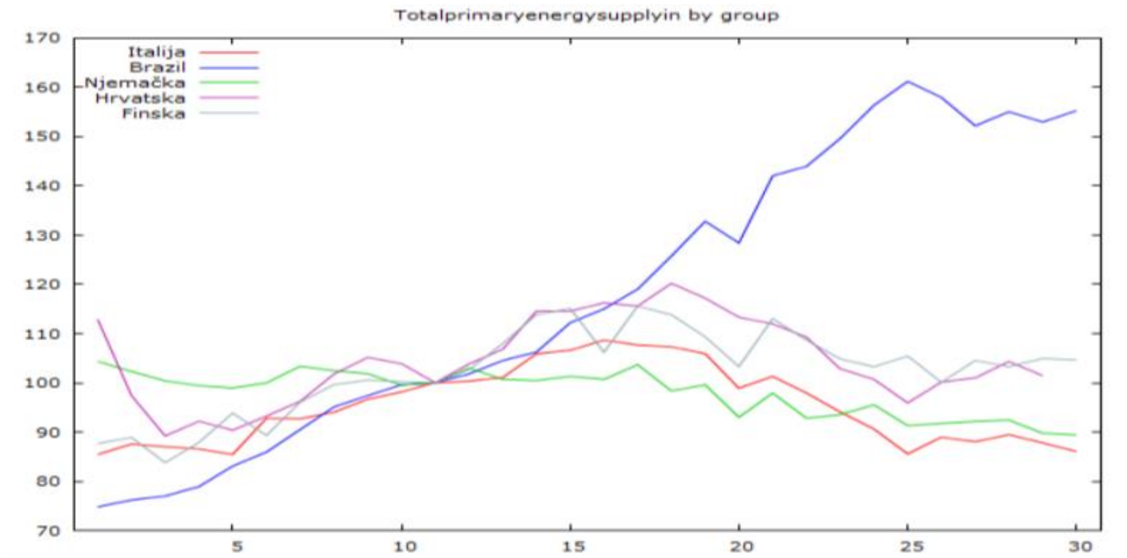
Renewable energy is defined as the contribution of renewable sources to the total primary energy supply. Renewable sources include the primary energy equivalent of hydro, geothermal, solar, wind, tidal, and wave-based power. Energy derived from solid biofuels, biogasoline, biodiesel, other liquid biofuels, biogas, and the renewable fraction of municipal waste is also included. Biofuels are defined as fuels obtained directly or indirectly from biomass. This includes wood, plant waste, ethanol, animal material/waste, and sulphate alkalis. Municipal waste includes waste generated in the residential, commercial, and public services sectors collected by local authorities for disposal at a central location for heat and/or electricity generation. This indicator is measured in thousands of tons (tons of oil equivalent), as well as in the percentage of total primary energy supply. *Graph 3* suggests that all of the observed countries within the defined time period recorded a growth trend in renewable energy supply. The highest rate of renewable energy supply was recorded in Brazil, followed by Finland and Croatia.



Graph 3. Movement of the renewable energy supply variable
Source: OECD Statistics (2020)

3.4 Total primary energy supply

The primary energy supply is defined as energy production plus energy imports, minus the energy exports, and minus international bunkers, then plus or minus changes in reserves. The energy balance methodology of the International Energy Agency (IEA) is based on the caloric content of the energy sources and a common unit of account - the equivalent tons of oil. *Graph 4* shows that the total primary energy supply for Italy, Croatia, Germany, and Finland recorded a growth trend until 2005, after which this trend began to decline slightly. This is contrasted with Brazil, which recorded a steady growth over the observed period.



Graph 4. Movement of the total primary energy supply variable
Source: OECD Statistics (2020)

In order to assess an adequate panel-based model, we will check the stationarity of the data using the KPSS test. The Kwiatkowski - Phillips - Schmidt - Shin (KPSS) test determines whether a time series is stationary around a medium or a linear trend, or is non-stationary due to a unit root. From the KPSS test, we can conclude that all variables are stationary in the first difference (results in the *Appendix*). The graphical representation also suggests that the variables in their levels are, in fact, nonstationary. Since the series are of the same order of integration (in which the time series is not too long for the non-stationarity to create problems in the interpretation of the results), there is a justification for the evaluation by a panel analysis. Certainly, there remains the possibility that due to the stated characteristic, the panel cointegration model can be observed for all variables separately. We leave this possibility for future research that could be based on a single model which analyses the relationship between the observed variables.

The relationship modelling in our research is based on the Hsiao standard panel approach (2003):

$$y_{it} = \alpha_{it} + \beta_{1,it}x_{1,it} + \beta_{2,it}x_{2,it} + ... + \beta_{k,it}x_{k,it} + \varepsilon_{it},\ i = 1,...,N,\ t = 1,\dots,T \quad (1)$$

so that y_{it} is the value of the dependent variable y, then $x_{k,it}$ being the value of the independent variable x_k, α_{it} being the value of the free member, $\beta_{k,it}$ the regression parameter of the k independent variable, ε_{it} being the random error for all observation units i and for each time period t, and N being the number of observation units while T is the number of points in time.

The data we have at our disposal to calculate the causality between the selected variables is the combined data (panel). The combined data represents a combination of time sections and time series. The panel or longitudinal data is a type of aggregated data in which the same time-averaged units appear through different time points. We have a balanced panel that has the same number of time-shifts for each time-average unit. The estimation of a regression model with panel data can be obtained using one of the two models (Mundlak, 1978) - the fixed effect approach (FEM model) or the random effect approach (REM model). FEM model is a model of fixed effects in which the parameters of the model are fixed or non-random. This is contrasted by the random effect models and mixed models in which all or some of the model parameters are random variables. REM model is a model in which the parameters are not treated as fixed coefficients but as a random error derived from a given distribution probability.
The model of fixed effects starts from the assumption that the dependent and independent variables are correlated, while in the model of random effects this connection is considered random. The Least Squares Dummy Variables (LSDV) are then applied to evaluate the fixed-effect model. In the case of random effects models, OLS residues are used to estimate the variance and parameters of the model using the generalized least squares (GLS) method.
If a correlation between variables is found, the random effect model is not a good choice and only the fixed effects model can consistently estimate the relation (Hsiao, 2003). The Hausman test (1978) was used to choose between fixed effect models and random effects to measure consistency. In this study, for the sake of simplicity of the relationship between the selected variables, a separate model was developed for each relationship that shows the bilateral cause-and-effect relationship between the dependent and one of the independent variables. Modelling a unique model that includes all variables of interest is disabled due to poor final quality indicators of the model and a poor correlation between individual variables.

4 Results and the implications of the research

The correlation matrix reveals a relatively weak correlation between the selected variables. Namely, the correlation coefficient between CO_2 variables and environment-related technologies is 0.04, which indicates the absence of correlation. The correlation coefficient between the variables CO_2 and renewable energy sources is 0.25, which in turn indicates a weak correlation between the variables. The correlation coefficient between the CO_2 variables and the total primary energy supply is 0.64, suggesting a moderately positive relationship. As no strong correlation was found between the variables, it is assumed (Hsiao, 2003) that the REM model is better for calculating the causality of variables, which we further checked with the Hausman tests for each relation, confirming in that way the relevance of REM models for cases with a weaker correlation, or the FEM model for the case with moderate correlation.

For the ratio of CO_2 and environmental technology, the value of hi-square (χ^2= 0.38) is small, p-value is greater than 0.05 (p = 0.54), which means that the GLS estimator consistency hypothesis cannot be rejected, making it better to use the REM model.

For the ratio of CO_2 and renewable energy sources, the value of hi-square (χ^2 = 0.013) is small, p-value is greater than 0.05 (p = 0.91), from which it can be derived that the hypothesis of the consistent GLS estimators cannot be rejected and that the REM model is better for the observed problem. Furthermore, for the ration of CO_2 and the total primary energy supply, the hi-square value (χ^2 = 3.97) is small, more specifically the p-value is less than 0.05 (p = 0.46), which means that it is possible to reject the GLS estimator consistency hypothesis, making the use of the FEM model more appropriate.

Table 1. Panel models

Dependent variable (*CO_2*)	**REM(1)** (*Environment-related technologies*)	**REM(2)** (*Renewable energy sources*)	**FEM(3)** (*Primary energy supply*)
Constant	**7.36** *** (st. dev. = 1.80)	**10.24** *** (st. dev. = 1.52)	**4.24** *** (st. dev. = 0.54)
Independent variable	**-0.09** *** (st. dev. = 0.03)	**-0.18** *** (st. dev. = 0.01)	**0.02** *** (st. dev. = 0.01)
Correlation $(y,ythat)_2$	corr. = 0.00	corr. = 0.41	/
Joint regressor test	χ^2 = 12.36 ***	χ^2 = 198.69 ***	F = 18.19 ***
Breuch - Pagan test	χ^2 = 1820.46 ***	χ^2 = 1907.44 ***	/
Hausman test	χ^2 = 0.63	χ^2 = 0.01	χ^2 = 3.97 **

*- the marks ***, **, * represent 1%, 5% and 10% of the significance level*

Source: Calculations were conducted by the authors (2020)

From the REM(1) model in *Table 1* (other model quality indicators are available on request) it can be concluded that when the environmental technology variable is increased by one unit the CO_2 emission intensity decreases by 0.09 units. Environmental-related technologies proved to be statistically significant, but at the same time limited in their strength in reducing the intensity of CO_2 emissions ($p < 0.05$). Furthermore, the REM (2) model suggests that when renewable energy is increased by one unit, the CO_2 emission intensity decreases by 0.18 units. Renewable energy sources have also shown limited impact in reducing CO_2 emissions. Finally, the FEM(3) model shows that when the total primary energy supply variable increases by one unit, the CO_2 emission intensity will increase by 0.02 units. This variable also proved to be statistically significant, but of limited impact in increasing the intensity of CO_2 emissions.

The research into the effects of environmental technology, the use of renewable and the total primary energy supply, is often cited within analytical discussions about the green growth process (Danish and Ulucak, 2020). Based on the random (REM) and fixed impact models (FEM) used in the paper, the expected relationships between variables that are directly or indirectly environmentally conditioned are confirmed. The advances in environmental energy technologies increase the share of clean energy and reduce the intensity of the use of other energy sources. Meanwhile, the impact of energy and technological advances on CO_2 emissions is a consequence that is gradually manifesting itself. Since the efficiency of the manufactured equipment greatly increases the efficiency of production, new energy technologies promote energy and thus economic sustainability. In the process of environmental development, technologies that use fossil fuel combustion have been somewhat replaced by new energy sources, which, as a result, reduce carbon. The results of the research also show that renewable energy sources are associated with a negative coefficient, suggesting that this kind of energy plays an interesting, but still limited, role in promoting a green economy. Renewable energy has proven to be one of the best alternatives for cleaner production and thus for reducing pollution. The development of renewable energy can ensure energy security, promote economic growth, and alleviate poverty. The use of renewable energy in production also reduces costs, which means that it pollutes less. It should certainly be emphasized that the positive effects of renewable energy within European countries have diminished, especially after the Global Crisis. The decrease in renewable energy efficiency (and thus the relatively small impact of this variable in our model) could therefore be used to explain the decrease in the implementation and growth of renewable energy sources (Abolhosseini, Heshmati, and Altmann, 2014).

Conclusively, the research shows that the total supply of primary energy increases the intensity of CO_2 emissions, which in turn limits green growth, or the economic decisions that encourage energy-intensive production are slowing down the green growth process. Danish and Ulucak (2020) state that income growth in countries, in the style of the Kuznets inverted U-curve, cannot alleviate pollution, but it can reduce it with advances in technology and increased use of renewable energy sources. The creation and improvement of technical and technological capacities in the field of energy efficiency can also be encouraged through the promotion of companies whose revenues are based on efficient energy policies, especially in the industry field. Ultimately, the macro concept of energy management is strongly related to the context of international institutions and their activities, coordinated agreements, and domestic institutional assumptions, which should reconcile the goals of various stakeholders in this political - socio - economic context of the problem. From the obtained results it can be concluded that the impact on the environment (in this context CO_2 emissions) will be determined primarily through the decisions of governments and institutions, rather than the level of socio-economic development, which signals the developing and less developed countries not to sacrifice their environment for economic progress, and *vice versa*.

5 Conclusion

With the development of societies, industrialization, urbanization, and great technological progress, the world is undergoing a variety of sudden changes that cause positive and negative consequences for humanity. The biggest negative consequences are manifested through environmental pollution and the 'immoral' and unsustainable exploitation of natural resources. Thus, topics related to renewable energy sources and aspirations toward green growth and a green GDP are becoming increasingly popular. Since there is no consistent theory behind the calculation of green growth, what can be analysed are certain aspects that affect the sustainable growth and development of the green economy. Therefore, this paper analyses the intensity of CO_2 emissions based on production, the development of environment-related technologies, the supply of renewable energy, and the total supply of primary energy. In the observed period, the following conclusions were obtained for the observed countries: the largest decrease in the intensity of CO_2 emissions based on production was recorded in Italy, Finland, and Germany; in addition to that Germany, Italy, Finland, and Brazil recorded a growth trend in environmental technologies; during the observed period, all countries recorded a growth trend in the supply of renewable energy; the total supply of primary energy for Italy, Croatia, Germany, and Finland recorded a growth trend until 2005, after which the same trend began to decline slightly, except for Brazil, which recorded a steady growth throughout the observed period. Empirical results show that the development of environmental technologies and the supply of renewable energy have a negative impact on CO_2 emissions, while the total supply of primary energy has a positive impact on CO_2 emissions. The results confirm that environmental technologies and renewable energy promote the green economy, while the overall supply of primary energy is detrimental to the green perspective. Future research of the same or similar nature should focus on a more homogeneous choice of countries to obtain a more significant international comparison, thus providing a complementary overview of CO_2 emissions - an issue that is becoming a development challenge for each country. Similarly, the application of a panel cointegration approach could provide insight into the long-term and short-term implications of the observed relationships between variables.

Every country in the world strives to introduce certain plans and goals within its national frameworks and strategies, which would achieve the desired results related to sustainable development and the introduction of social cohesion and well-being. However, it is not sufficient to think at the national level - a regional, urban and personal level is also required to introduce the desired changes and achieve the expected results. The ecological crisis is first and foremost social and moral, and not only a problem of economics or politics. The opportunities that are emerging, as well as the recent Global Crisis, present a moral, ethical and spiritual challenge to every human being. The solution to today's growing negative climate changes and environmental pollution lies in the changing human consciousness. Gore (2007) cites many positive changes that would occur in the economy if climate change were to be affected, such as the creation of new jobs, the use of renewable energy sources, and opportunities to fulfil the moral task and a common purpose. When asked why people are not doing anything despite abundant evidence of a planetary crisis, Gore stated: “The truth about the climate crisis is inconvenient because it means we will have to change our way of life” (Gore, 2007, 286).

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References

Abolhosseini, S., Heshmati, A., Altmann, J. (2014) The Effect of Renewable Energy Development on Carbon Emission Reduction: An Empirical Analysis for the EU-15 Countries, *IZA DP. No. 7989*, Forschungsinstitut zur Zukunft der Arbait, Institute for the Study of Labor.

Acemoglu, D., Aghion, P., Bursztyn, L., Hemous, D. (2012) The Environment and Directed Technical Change, *American Economic Review*, 102(1), str. 131–166.

Charfeddine, L. (2017) The impact of energy consumption and economic development on Ecological Footprint and CO_2 emissions: Evidence from a Markov Switching Equilibrium Correction Model, *Energy Economics*, [Online], 65, str. 355-374., < raspoloživo na: https://www.sciencedirect.com/science/article/pii/S0140988317301524>, [pristupljeno 21.3.2021.].

Danish, K., Ulucak, R. (2020) How do environmental technologies affect green growth? Evidence from BRICS economies, *Science of The Total Environment*, [Online], 712, str. 1-7., < raspoloživo na: https://www.sciencedirect.com/science/article/abs/pii/S0048969720300127 >, [pristupljeno 01.03.2021.].

Davis, S., Caldeira, K. (2010) Consumption-based accounting of CO_2 emissions, *Proceedings of the National Academy of Sciences*, 107(12), str. 5687-5692.

Dinda, S. (2018) Production technology and carbon emission: long-run relation with short-run dynamics, *Journal of Applied Economics*, 21(1), str. 106- 121.

Franković, B., Blecich, P., Hustić, A. (2015) Utjecaj uvođenja obnovljivih izvora energije na održivi razvoj energetskih sustava Republike Hrvatske s osvrtom na emisije stakleničkih plinova, *Energetska politika EU-a nakon 21. konferencije stranaka okvirne konvencije UN-a o klimatskim promjenama (COP21)/ B. Jelavić – Hrvatsko energetsko društvo*, [Online], < raspoloživo na: http://www.hed.hr/stari_hed/pdf/24Forum/referati/Frankovic,%20Blecich,%20Hustic.pdf >, [pristupljeno 25.3.2021.].

Gore, A. (2007) *Neugodna istina: Planetarna pojava globalnog zagrijavanja i što u vezi s njom možemo poduzeti*, Zagreb: Algoritam.

Grossman, G.M., Krueger, A.B. (1995) Economic Growth and the Environment, *The Quarterly Journal of Economics*, 110(2), str. 353–377.

Hsiao, C. (2003). *Analysis of panel data*, 2nd ed., Cambridge University Press.

Ke, L., Boqiang, L. (2015) Impacts of urbanization and industrialization on energy consumption/CO_2 emissions: Does the level of development matter?, *Renewable and Sustainable Energy Reviews*, [Online], 52, str. 1107-1122., < raspoloživo na: https://www.sciencedirect.com/science/article/abs/pii/S1364032115008321>, [pristupljeno 20.3.2021.].

Kurz, R. (2019) Post-growth perspectives: Sustainable development based on efficiency and on sufficiency, *Public Sector Economics*, 43(4), str. 401-422.

Mundlak, Y. (1978) On the pooling of time series and cross section dana , *Econometrica*, 46(1), str. 69-85.

Ritchie, H. (2019) How do CO_2 emissions compare when we adjust for trade?, < raspoloživo na: https://ourworldindata.org/consumption-based-co2>, [pristupljeno 8.3.2021.].

Saidi, K., Hammami, S. (2015) The impact of energy consumption and CO_2 emissions on economic growth: Fresh evidence from dynamic simultaneous-equations models, *Sustainable Cities and Society*, [Online], 14, str. 178- 186., < raspoloživo na: https://www.sciencedirect.com/science/article/abs/pii/S2210670714000511>, [pristupljeno 14.3.2021.].

Škare, M., Tomić, D., Stjepanović, S. (2020) Energy Consumption and Green GDP in Europe: A Panel Cointegration Analysis 2008 – 2016, *Acta Montanistica Slovaca*, 25(1), str. 46-56.

Wang, S., Li, Q., Fang, C., Zhou, C. (2016) The relationship between economic growth, energy consumption, and CO_2 emissions: Empirical evidence from China, *Science of The Total Environment*, 542(Part A), str. 360-371.

Wang, H., Wei, W. (2019) Coordinating technological progress and environmental regulation in CO_2 mitigation: The optimal levels for OECD countries & emerging economies, *Energy Economics*, 87(C).

Attachments

KPSS test for CO_2 emission variable

```
KPSS test for CO2 (without trend)
Lag truncation parameter = 0

Unit 1, T = 30
test = 1,65101, p-value < .01

Unit 2, T = 30
test = 2,57611, p-value < .01

Unit 3, T = 30
test = 2,70686, p-value < .01

Unit 4, T = 30
test = 0,843353, p-value < .01

Unit 5, T = 30
test = 1,52688, p-value < .01

H0: all groups are stationary

Choi meta-tests:
   Inverse chi-square(10) = 46,0517 [0,0000]
   Inverse normal test = -5,20187 [0,0000]
   Logit test: t(29) = -5,87097 [0,0000]
   Note: these are UPPER BOUNDS on the true p-values
   (Individual p-values < .01, and recorded as .01: 5)
```

KPSS test for the envoronment-related technology variable

```
KPSS test for environmentalrelatedtechnolog (including trend)
Lag truncation parameter = 2

Unit 1, T = 30
test = 0,13762, interpolated p-value 0,072

Unit 2, T = 30
test = 0,117065, p-value > .10

Unit 3, T = 30
test = 0,120694, p-value > .10

Unit 4, T = 30
test = 0,0676362, p-value > .10

Unit 5, T = 30
test = 0,127562, interpolated p-value 0,091

H0: all groups are stationary

Choi meta-tests:
   Inverse chi-square(10) = 23,8867 [0,0079]
   Inverse normal test = -2,97148 [0,0015]
   Logit test: t(29) = -2,92782 [0,0033]
   Note: these are LOWER BOUNDS on the true p-values
   (Individual p-values > .10, and recorded as .10: 3)
```

KPSS test for the variable total primary energy supply

```
KPSS test for Totalprimaryenergysupplyin (including trend)
Lag truncation parameter = 0

Unit 1, T = 30
test = 0,708569, p-value < .01

Unit 2, T = 30
test = 0,221204, p-value < .01

Unit 3, T = 30
test = 0,393483, p-value < .01

Unit 4, T = 29
test = 0,443293, p-value < .01

Unit 5, T = 30
test = 0,602231, p-value < .01

H0: all groups are stationary

Choi meta-tests:
   Inverse chi-square(10) = 46,0517 [0,0000]
   Inverse normal test = -5,20187 [0,0000]
   Logit test: t(29) = -5,87097 [0,0000]
   Note: these are UPPER BOUNDS on the true p-values
   (Individual p-values < .01, and recorded as .01: 5)
```

KPSS test for variable renewable energy supply

```
KPSS test for Renewableenergysupplytota (including trend)
Lag truncation parameter = 0

Unit 1, T = 30
test = 0,615027, p-value < .01

Unit 2, T = 30
test = 0,294223, p-value < .01

Unit 3, T = 30
test = 0,611108, p-value < .01

Unit 4, T = 29
test = 0,269346, p-value < .01

Unit 5, T = 30
test = 0,521436, p-value < .01

H0: all groups are stationary

Choi meta-tests:
   Inverse chi-square(10) = 46,0517 [0,0000]
   Inverse normal test = -5,20187 [0,0000]
   Logit test: t(29) = -5,87097 [0,0000]
   Note: these are UPPER BOUNDS on the true p-values
   (Individual p-values < .01, and recorded as .01: 5)
```

REM[1] model

```
Model 12: Random-effects (GLS), using 150 observations
Included 5 cross-sectional units
Time-series length = 30
Dependent variable: CO2

                      coefficient   std. error     z      p-value
  ---------------------------------------------------------------
  const                7,36245      1,79946       4,091   4,29e-05 ***
  environmentalrel~   -0,0916922    0,0260844    -3,515   0,0004   ***

Mean dependent var   6,517652   S.D. dependent var   3,505341
Sum squared resid    1854,522   S.E. of regression   3,527954
Log-likelihood      -401,4468   Akaike criterion     806,8936
Schwarz criterion    812,9149   Hannan-Quinn         809,3399
rho                  0,827210   Durbin-Watson        0,354644

'Between' variance = 15,9138
'Within' variance = 0,875719
theta used for quasi-demeaning = 0,957211
corr(y,yhat)^2 = 0,00160841

Joint test on named regressors -
  Asymptotic test statistic: Chi-square(1) = 12,3567
  with p-value = 0,00043941

Breusch-Pagan test -
  Null hypothesis: Variance of the unit-specific error = 0
  Asymptotic test statistic: Chi-square(1) = 1820,46
  with p-value = 0

Hausman test -
  Null hypothesis: GLS estimates are consistent
  Asymptotic test statistic: Chi-square(1) = 0,62638
  with p-value = 0,428686
```

REM[2] model

```
Model 37: Random-effects (GLS), using 149 observations
Included 5 cross-sectional units
Time-series length: minimum 29, maximum 30
Dependent variable: CO2

                      coefficient  std. error      z      p-value
  ---------------------------------------------------------------
  const                10,2354     1,52238       6,723  1,78e-011 ***
  Renewableenergys~    -0,179493   0,0127337   -14,10   4,03e-045 ***

Mean dependent var   6,536562   S.D. dependent var   3,509478
Sum squared resid    1073,121   S.E. of regression   2,692734
Log-likelihood      -358,5132   Akaike criterion     721,0263
Schwarz criterion    727,0342   Hannan-Quinn         723,4672
rho                  0,703263   Durbin-Watson        0,532182

'Between' variance = 11,303
'Within' variance = 0,404636
mean theta = 0,965359
corr(y,yhat)^2 = 0,413484

Joint test on named regressors -
  Asymptotic test statistic: Chi-square(1) = 198,694
  with p-value = 4,02574e-045

Breusch-Pagan test -
  Null hypothesis: Variance of the unit-specific error = 0
  Asymptotic test statistic: Chi-square(1) = 1907,44
  with p-value = 0

Hausman test -
  Null hypothesis: GLS estimates are consistent
  Asymptotic test statistic: Chi-square(1) = 0,013428
  with p-value = 0,907748
```

FEM[3] model

```
Model 46: Fixed-effects, using 149 observations
Included 5 cross-sectional units
Time-series length: minimum 29, maximum 30
Dependent variable: CO2

                      coefficient  std. error  t-ratio   p-value
  ---------------------------------------------------------------
  const                4,23996     0,543725     7,798   1,19e-012 ***
  Totalprimaryener~    0,0221805   0,00520040   4,265   3,61e-05  ***

Mean dependent var   6,536562   S.D. dependent var   3,509478
Sum squared resid    121,4707   S.E. of regression   0,921654
LSDV R-squared       0,933362   Within R-squared     0,112857
LSDV F(5, 143)       400,5817   P-value(F)           3,32e-82
Log-likelihood      -196,2035   Akaike criterion     404,4070
Schwarz criterion    422,4306   Hannan-Quinn         411,7297
rho                  0,894099   Durbin-Watson        0,239453

Joint test on named regressors -
  Test statistic: F(1, 143) = 18,1916
  with p-value = P(F(1, 143) > 18,1916) = 3,61232e-005

Test for differing group intercepts -
  Null hypothesis: The groups have a common intercept
  Test statistic: F(4, 143) = 467,002
  with p-value = P(F(4, 143) > 467,002) = 5,51048e-081
```