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ASSESSING THE IMPACT OF CLEAN ENERGY ON SUSTAINABLE ECONOMIC GROWTH IN EUROPEAN UNION MEMBER STATES

Abstract. *Based on the role played by clean energy on the Sustainable Development Goals (SDGs), this study aims to examine the relationship between sustainable growth and some of these goals. The data set comprises 8 indicators from the SDGs, 560 observations on 28 European Union countries (including the United Kingdom) over a period of 20 years (2000-2019). The focus is on Clean and Affordable Energy (SDG 7), Industry, Innovation and Infrastructure (SDG 9) and Decent Work and Growth (SDG 8) in European Union countries. We were particularly interested in studying whether SDG 7 is a determinant of sustainable growth. Results showed a significant influence of the selected variables on sustainable growth in the European Union. The importance of this study derives from the analysis of the interdependence relations.*

Keywords*: economic growth; renewable energy; research and development; sustainability; clean energy; GDP per Capita.*

JEL Classification: C02, C11, C45, C46, C63

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1. Introduction

For most of the nations of this world, without the exception of the EU countries, sustainable economic growth is an important goal to be achieved. Sustainable development is firmly entrenched in the European Treaties and is a central element of European Union policies.

Accordingly to this goal, nations understand that energy consumption, with its vital importance for economic activities and most social pursuits, plays a key role in the production process (Dogan et al., 2020).

As it can be found on every government's agenda, the concept of *economic growth* was transformed over the years from a purely quantitative aspect to one that has behind numerous qualitative objectives. The word that is most commonly linked to economic growth nowadays is *sustainability*. Hence, society no longer aims at pure growth but at a sustainable one, and this has been and continues to be a growing concern. Additionally to the concept of *growth,* there is the one of *development*, a broader term, which includes both the quantitative aspects of growth, and also the structural and qualitative features. However, hereafter, for the present paper, we will assume gross domestic product (GDP) per capita is the indicator best expressing the economic growth, whether sustainable or not.

Another conceptual clarification that has to be made is related to the use of terms such as *renewable energy* and *clean energy*, as many authors use these terms without providing clear definitions from the beginning. Hence, it could be believed they are synonyms and can be interchanged just for the sake of good topics. However, while renewable energy comes from sources that can naturally replenish themselves, clean energy is a broader term, as it encompasses all zero-carbon energy sources (Gordon & Beck, 2019).

For the purpose of this study, we utilise the terminology in accordance to its usage in the Sustainable Development Goals (SDGs), where both renewable and clean energy are used to define goals.

Currently, researchers maintain an alive debate whether the usage of clean and renewable energy contributes in the same way to economic growth as the non-renewable sources of energy, keeping in mind that the matter is heavily researched, yet the empirical evidence and the theoretical opinions remain at odds (Dogan et al., 2020).

We took into account the work performed in 2015 by the United Nations, which have issued a series of 17 goals named SDGs, established through the 2030 Agenda (United Nations, n.d.), as seen in Figure 1.

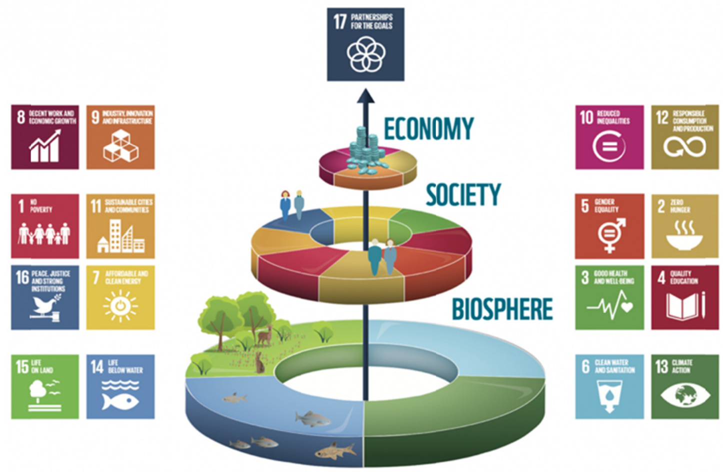

Figure 1. The 17 Sustainable Development Goals. Source: (WWF, 2018)

Briefly, the SDGs offer a necessary framework to align the need for sustainable development at the international level. For our research, we closely examined the targets associated with SDG 8 in relation with the objectives of SDG 7 and 9.

For the time being, regarding the state of research in terms of GDP-energy nexus, and considering GDP the indicator that gives information regarding economic growth, we can observe it is a relatively common research topic. Researchers have mainly tested four hypotheses regarding the relationship between GDP and energy use (Shakeel, 2021). The first one is named the "neutrality hypothesis" as it tries to show there is no causal link between energy use and GDP growth. The second hypothesis, "conservation hypothesis" attempts to prove a one-way causal linkage in the direction of GDP growth towards energy. The third hypothesis, named "feedback hypothesis" tries to prove the bi-directional causal relations between GDP growth and energy use. Finally, under the name of "growth hypothesis" a fourth hypothesis would argue a one-way causal linkage from the direction of energy use towards GDP growth. Additionally, the same author concludes that currently, almost 44% of the literature goes in the direction of the "growth hypothesis", another 50% of the researches support the "feedback hypothesis" and found evidence in this direction, and only 6% of the studies offered evidence in support of the "neutrality hypothesis". Evidence shows there is a scarcity of research in terms of the "conservation hypothesis".

The more recent scientific debate brings into discussion other aspects such as: a) the key macroeconomic determinants of economic growth in developing and developed economies, without quantifying their influence (Chirwa & Odhiambo, 2016); b) the relationship between development and financial markets in the context of a new approach to endogenous growth theory (Najeb, 2014); c) the spectacular experience of China which has managed, for the past three decades, to increase energy consumption in order to stimulate economic growth (Lin & Moubarak, 2014).

In fact, the relationship between energy consumption and economic growth has been a hot scientific topic for many years. Numerous studies have confirmed the existence of a historical correlation between these two variables with noticeable empirical results indicating that economic growth can lead to increases in energy consumption (Akinlo, 2008; Apergis & Payne, 2009; Ghali & El-Sakka, 2004; Glasure & Lee, 1998). Also, studies have demonstrated and admitted the existence of several types of causation in this relationship: unidirectional causation, bidirectional causation and non-causality (absent causality).

Unidirectional causality can manifest itself from energy consumption to economic growth or vice versa. In other words, it allows us to answer a key question and see if energy consumption leads to economic growth or economic growth leads to increased consumption. In the first case, energy-saving policies seem to have a negative impact on economic growth, while in the second case, where causality is geared from growth to energy consumption, the implementation of energy-saving policies does not affect economic growth. The existence of two-way causation means that energy consumption and economic growth are complementary and that reducing energy consumption by adopting conservation policies can lead to contraction effects. Finally, the third situation that refers to the absence of causality allows the implementation of energy policies without affecting economic growth (Bozoklu & Yilanci, 2013).

The traditional relationship between economic growth and energy consumption has generated other valuable reasoning. Thus, starting from unfavourable direct experiences, such as the oil shocks of 1973 and 1979, developed countries began to become aware of the fragility of the growth model based exclusively on natural resources. The year 1992 and the Rio Conference marked a turning point in the way humanity viewed development. The model of infinite growth is incompatible with the limited nature of the resources we use and most of the inhabitants of this planet have begun to accept the idea that it will no longer be possible, in the long run, to target development and ignore environmental issues. For this reason, many of the models and strategies used previously have been analysed, and economic policies have been increasingly linked to environmental policies (Esseghir & Haouaoui Khouni, 2014).

In essence, the current model of economic growth, based largely on non-renewable resources, is considered unfair in relation to the generations that come after us and hence the quasi-general concern to find solutions for sustainable growth. Within the sustainable development strategies, the energy issue is a priority and requires in-depth study in several directions highlighted by this research.

The first direction concerns the more profound understanding of the concept of renewable energy. The researchers' concern is not recent and covers a broad and diverse area. Celiktas et al. studied trends in renewable energy research over a long period of time (1980–2008) in Turkey and identified many relevant publications on biomass and systems conversion as well as the solar energy system (Celiktas et al., 2009). In Europe we have a valuable review of research in the field of renewable energy (Romo-Fernández et al., 2011), which shows that sustained efforts in this field have led, in the first decade of this century, to double production in many developed countries; however, the pace of transformation is much slower than in the rest of the world. This dynamic has been strongly supported by targeted investments, with the help of the Renewable Energy Country Attractiveness Index (RECAI), which ranks 40 countries on the attractiveness of their renewable energy investment and deployment opportunities. (Cîrstea et al., 2018).

The European Court of Auditors (ECA) mentions in a report on the main types of renewable energy sources, relevant technologies and specific applications and argues that the use of more renewable energy is essential if the EU is to meet its objectives of sustainable development (EEA, 2017), through various technologies – photovoltaics, turbines, dams and tidal barrages, hydro plants and dams, geothermal and heat pumps, biomass combustion, biogas plants, biofuels.

Research on renewable energy has broadly covered the concept and its relationship with other areas of activity such as carbon dioxide emissions, gross domestic product (GDP), non-renewable energy production and foreign trade, international trade or economic development, have shown that: a) economic growth has a positive effect on renewable energy consumption and economic development; b) renewable energy consumption has a drastic influence on short-run economic growth, whereas renewable energy consumption has a slightly significant impact in the long-run; c) there is a bidirectional long term causality between renewable energy consumption and economic growth; d) there is a long term balance relationship between renewable energy consumption and economic growth (Chen et al., 2019; Lin & Moubarak, 2014).

In essence, the researchers' results on the relationship between renewable energy and economic growth did not lead to a consensus, which can be explained if we consider that their authors used different data, time intervals, and different methodologies. Therefore, some studies have shown a one-way causality oriented from renewable energy consumption to economic growth or from economic growth to energy consumption. Others highlighted the lack of causality and/or a two-way causality between renewable energy consumption and economic growth (Ocal & Aslan, 2013).

Despite this evidence, researchers' concerns about the relationship between renewable energy demand and growth have been extremely useful. Their conclusions formed a basis for national policy makers who thus adopted decisions leading to harmonising the energy-environment-economy relationship (Ozcan & Ozturk, 2019).

Therefore, the changes taking place in the field of energy explain the need to investigate the contributions of energy consumption and energy R&D on economic growth. We also note that in developed countries with higher levels of gross domestic product (GDP), there is a tendency to allocate more money for R&D activities.

Increased budgets in energy R&D will not necessarily positively affect the economic growth of these countries (Wong et al., 2013). On the one hand, they will lead to improved production processes and, therefore, to higher labor productivity; on the other hand, the allocation of large sums for energy research and development to the detriment of other economic growth areas could have negative consequences. Therefore, the share allocated to energy R&D over total R&D demonstrates the prioritisation of energy in a country's research and development agenda.

2. Research Methodology

The research objective of this study is to examine the direct perspective of the link between sustainable growth and SDG 7, SDG 9 and SDG 8 in EU-28. The research methodology involves the development and testing of a series of hypotheses aimed at assessing the impact of clean energy on sustainable economic growth in EU countries. This aspect consists in testing some correlations, respectively the regressions of certain endogenous and exogenous variables.

In the analysis of the correlation between phenomena, the values of the regression equations have an important role. They can be considered as theoretical values, which express the tendency to manifest the interdependence between phenomena. If in the process of interaction between them would not intervene other essential or random factors that change the degree of connection for each unit.

Broadly speaking, the hypotheses of the linear regression model involve testing the following aspects, by taking into account a series of assumptions (Weisberg, 2014): (1) the dependent variable Y is a linear function of the explanatory variable X, plus an error term u (random variable) - Y being a linear and u function, it follows that Y is also a random variable; (2) The average value of the error is 0; (3) The error distribution has constant dispersion (homoscedasticity); (4) Observation errors are independent; (5) The explanatory variable and the error variable are not dependent; (6) The error variable has an approximately normal distribution.

The whole process involves: testing the hypothesis on β_1, which expresses the dimensional vector of the regression coefficient; testing the parameter β_0 (called the free term, the interception coefficient), which represents the ordinate at the origin and shows what level the value of the Y characteristic would have reached if all the factors - except the registered one - had a constant action on its formation; evaluating the quality of the regression model by R-squared statistics that measure the "success" with which the estimated regression equation manages to explain the value of the dependent variable in the data series and testing Pearson's correlation coefficient, r.

2.1. Structure of the Performance Assessment Framework

In this approach to assessing the impact of clean energy on sustainable economic growth in EU countries, six hypotheses have been developed for cross-sectional data series:

Hypothesis 1. GDP/capita (Real GDP per capita [SDG_08_10] is positively influenced by primary energy consumption [SDG_07_10]).

Hypothesis 2. GDP/capita [SDG_08_10] is positively influenced by energy production (Energy productivity [SDG_07_30]).

Hypothesis 3. GDP/capita [SDG_08_10] is directly related to Gross domestic expenditure on R&D [SDG_09_10].

Hypothesis 4. There is an inverse relationship between Share of renewable energy in gross final energy consumption [SDG_07_40] and Energy import dependency by products [SDG_07_50]. The SDGs aim to increase renewable energy, which leads to reducing dependence on energy imports from other third countries.

We believe that these hypotheses will show us the impact of clean energy on economic growth both statically and dynamically in the European Union.

2.2. Data Collection

Given the central objective of this article, on the analysis of the impact of clean energy on economic growth in EU countries, the testing of hypotheses will be applied to 8 variables associated with the objectives: SDG7, SDG8 and SDG 9 in the Member States of the European Union. In this regard, the data set consists of 28 countries of the European Union, including the United Kingdom, over a reasonable period of 20 years (period 2000-2019). The variables of interest are: [SDG_07_10] Primary energy consumption; [SDG_07_11] Final energy consumption; [SDG_07_20] Final energy consumption in households per capita; [SDG_07_30] Energy productivity; [SDG_07_40] Share of renewable energy in gross final energy consumption (OECD, 2012); [SDG_07_50] Energy import dependency by products; [SDG_09_10] Gross domestic expenditure on R&D (OECD, 2012); [SDG_08_10] Real GDP per capita (Eurostat, 2020).

2.3. Data Processing

Obviously, the primary / final energy consumption per capita depends first on the geographical position, respectively on the weather conditions, and secondly on the level of economic development, implicitly on the own resources / potential of energy generators.

As can be seen in Figures 2 and 3, Finland and Sweden have the highest primary and final energy consumption per capita. The absolute amplitude of the *Primary energy consumption per capita intensity in the EU-28 in 2019* [SDG_07_10] is 5.61 tonnes of oil equivalent per capita (Max. Luxembourg 7.26 and Min. Romania 1.65).

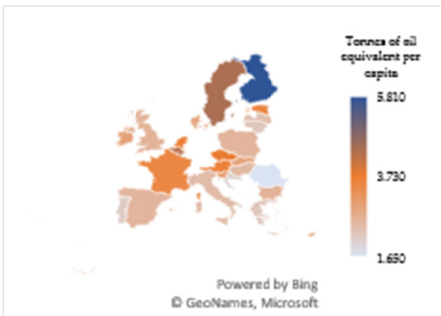

Figure 2. Primary energy consumption per capita in EU-28 in 2019 [SDG_07_10]

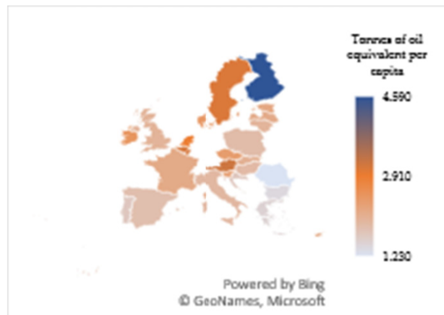

Figure 3. Final energy consumption per capita in EU-28 in 2019 [SDG_07_11]

Regarding *Final energy consumption per capita in EU-28 in 2019* [SDG_07_11], the absolute amplitude is 5.85 tonnes of oil equivalent per capita. The same maximum value is found in Luxembourg 7.8 and the minimum value in Romania, 1.23.

Finland maintains its position with an intensity of 1020 kilograms of oil equivalent per capita, while Malta is in the last place with an intensity of 201, a five times statistical discrepancy.

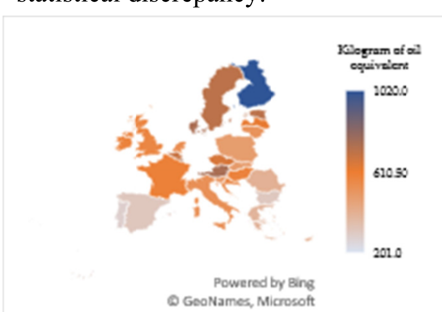

Figure 4. Final energy consumption in households per capita in EU-28 in 2019 [SDG_07_20]

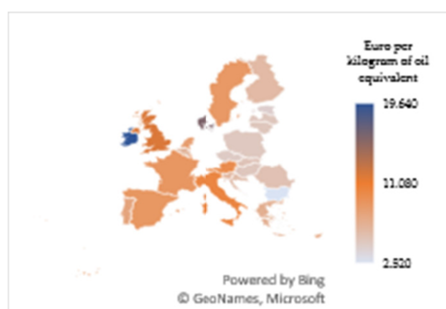

Figure 5. Energy productivity in EU-28 in 2019 [SDG_07_30]

From territorial analysis of the intensity of energy production and consumption in EU Member States, it can be seen from Figures 2-4 that they maintain somewhat the same hierarchy at the level of the three indicators: *Primary energy consumption [SDG_07_10], Final energy consumption [SDG_07_11], Final energy consumption in households per capita [SDG_07_20]*. When modeling the regression function, this aspect will involve the analysis and testing of the autocorrelation of the selected variables, in order to maintain the most relevant characteristics.

Energy productivity in the EU-28 in 2019 [SDG_07_30] slightly changes the hierarchy of the picture previously presented. As presented in Figure 5, in 2019 Ireland has the highest level of energy productivity (19.64 euro / per kilogram of oil equivalent), followed by Denmark at a distance of 16.02, and the lowest level is found in Bulgaria, 2.52 (euro / per kilogram of oil equivalent). Obviously, the size of the indicator depends on the respective countries' level of economic development (see GDP per capita SDG_08_10).

Figure 6 shows the share of renewable energy in gross final energy consumption in EU-28 in 2019. The Scandinavian countries are renowned for developing policies and implementing measures to develop renewable energy technologies. Their concern is closely related to global warming. In this sense, the level of *Share of renewable energy in gross final energy consumption in EU-28 in 2019* is the highest in the respective region, with Sweden at 56.39%, and Finland at 43.08%. At the opposite pole, we could find the Netherlands at 8.775, and Luxembourg at 7.05%.

On the other hand, energy import dependency in the EU-28 in 2019 [SDG_07_50] shows a varying degree of heterogeneity between EU Member States. As shown in Figure 7, the lowest level of dependence on energy imports is from Estonia - 4.8%, and Malta has a dependence of 97.2%.

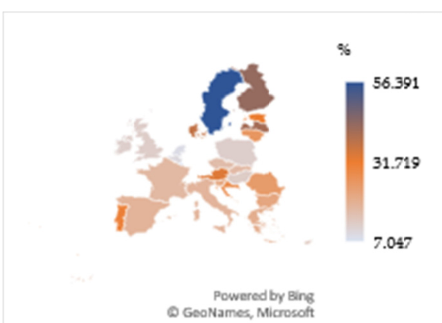

Figure 6. Share of renewable energy in gross final energy consumption in EU-28 in 2019 [SDG_07_40].

Figure 7. Energy import dependency in EU-28 in 2019 [SDG_07_50].

A more interesting and valuable picture can be observed by looking at the dynamics, as presented in Figure 8. In the last 15 years, the average level of *Share of renewable energy in gross final energy consumption in the EU-28 state* has increased by 10.3 percentage points, with the most spectacular increase in Denmark (by 22.4 percentage points, from 14.8% in 2004 to 37.2% in 2019). Denmark was followed by Sweden, with an increase of 17.7 percentage points, while Slovenia made the smallest progress, one of 3.6 percentage points.

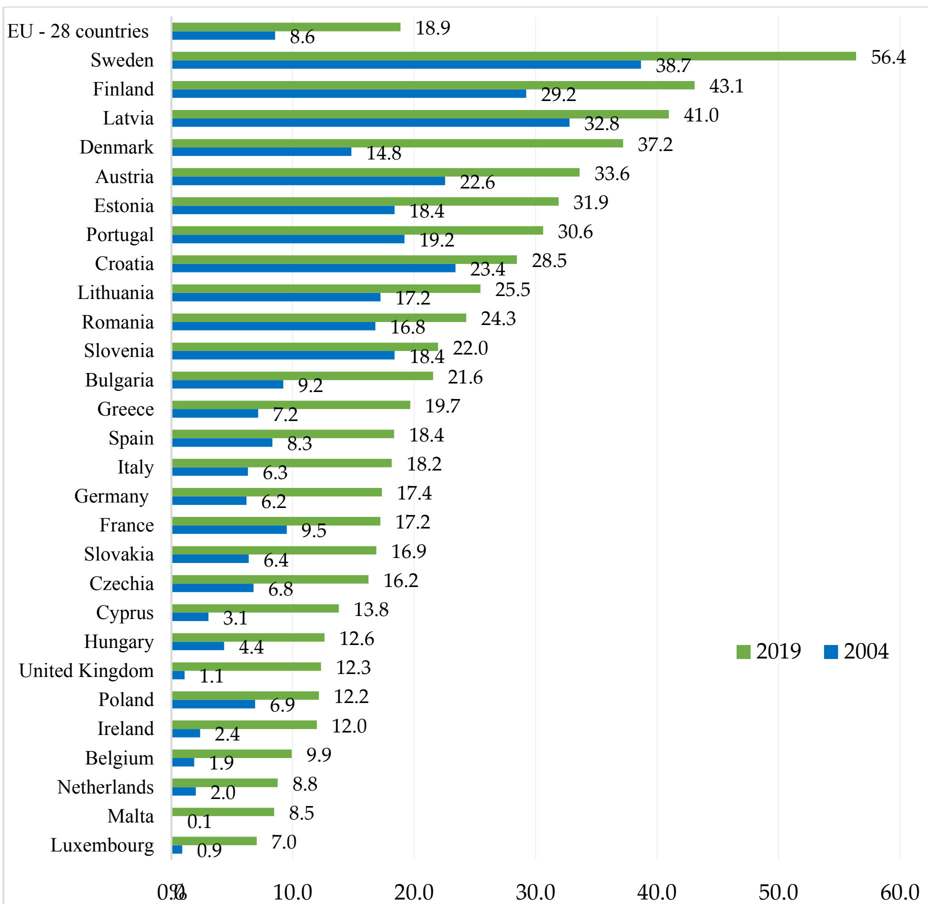

Figure 8. Share of renewable energy in gross final energy consumption in stat EU-28, in 2004 and 2019 [SDG_07_40]s (%). Source: Authors

The European Union's dependence on energy imports, especially oil and natural gas, is the basis of energy security policy concerns. This concerns primary energy production in the EU and, as a result of the output-consumption gap, the EU's growing dependence on energy imports from third countries. Indeed, in 2019, more than half (57.8%) of the available gross energy in the EU came from imports.

Figure 9 represents the visual map of the gross domestic expenditure on R&D in EU-8 in 2019 [SDG_09_10], ranging from 0.48% to 3.4%. Figure 10 shows the intensity of the level of GDP/capita in 2019 at the level of EU states, except for Luxembourg, which recorded according to Eurostat data the highest level of 83,640 euro/capita, while the level of EU average Real GDP per capita [SDG_08_10] is 28,610 euro / capita.

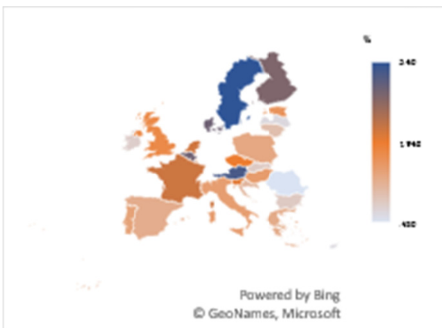

Figure 9. Gross domestic expenditure on R&D in EU-28 in 2019 [SDG_09_10]

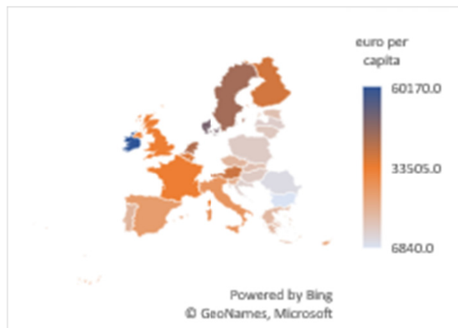

Figure 10. Real GDP per capita [SDG_08_10] in 2019

3. Results

Table 1 presents the results obtained from the processing of the cross-sectional data series (EU-28 Member States 2019) to test our previously stated hypotheses 1-4.

Table 1. Hypotheses for Transversal Series (space series EU-28, year 2019)

Hypothesis	β_1 Coefficient	*t Stat*	*P-value*	R Squared	*F*
Hypothesis 1 [SDG_08_10] with [SDG_07_10]).	10,365.443	5.9133	0.000013	0.5250	28.7392
Hypothesis 2 [SDG_08_10] with [SDG_07_30	3,454.031	5.3609	0.000003	0.5735	34.9670
Hypothesis 3 [SDG_08_10] with [SDG_09_10]	7,687.994	2.1868	0.037948	0.1554	4.7821
Hypothesis 4 [SDG_07_40] with [SDG_07_50]	-0.9675	-3.1555	0.004022	0.2769	9.9569
$F_{critical}$ = 4.2252 and $t_{critical}$= 2.05553					

According to the analysis of the parameters resulting in the table 1, all the hypotheses developed are statistically validated by the level of marginal significance of the p-value test <0.05, by the significance of the tstatistic > tcritical regression coefficient and by the significance of the Fstatistic > Fcritical in the regression model; as a result we can say that:

Hypothesis 1. From a static and territorial point of view, in 2019, GDP/capita (***Real GDP per capita [SDG_08_10***] is positively influenced by the ***primary energy consumption [SDG_07_10])*** by the fact that the regression coefficient (β) shows a positive value of 10,365, and the degree of determination of the GDP/capita change is determined by the change of primary energy consumption in the proportion of 52.50%.

Hypothesis 2. The variation of GDP/capita [SDG_08_10] is positively influenced by the variation of the energy production (energy productivity [SDG_07_30]) in proportion of 57.35%.

Hypothesis 3. GDP/capita [SDG_08_10] is directly related to gross domestic expenditure on R&D [SDG_09_10], i.e. the regression coefficient is 7,687.99, and the intensity is moderate of only 15.54 %.

Hypothesis 4. Between *Share of renewable energy in gross final energy consumption* [SDG_07_40] and *Energy import dependency by products* [SDG_07_50] there is an inverse relationship, in which the β coefficient = -0.9675, and the intensity of the connection is 27.69%. As a result of a one percent increase in the share of renewable energy in gross final energy consumption, it causes a decrease in Energy import dependence by products by 0.97%. From Figures 11 and 12, it can be seen that the intensity of the inverse relationship increased in time.

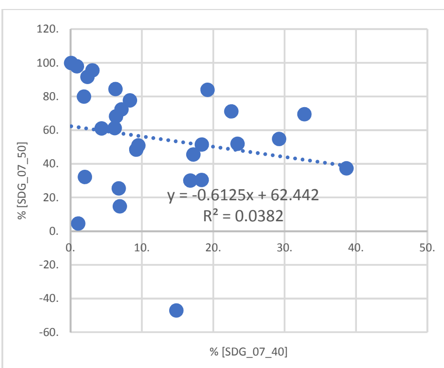

Figure 11. The relationship between Energy import dependency by products [SDG_07_50] and Share of renewable energy in gross final energy consumption [SDG_07_40] in EU-28 in 2004

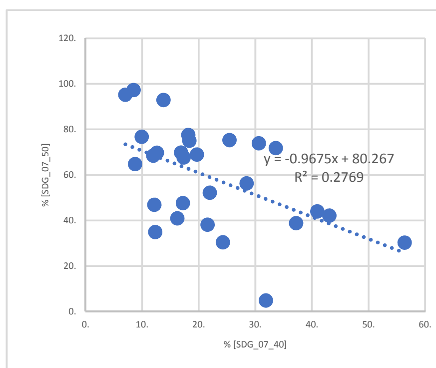

Figure 12. The relationship between Energy import dependency by products [SDG_07_50] and Share of renewable energy in gross final energy consumption [SDG_07_40] in EU-28 in 2019

4. Discussion and Conclusions

This paper has explored the relationship between clean energy and sustainable development through the perspective of renewable energy production and consumption, on the one hand, and economic growth, on the other hand. The importance of this study derives from the analysis of interdependence relations. Since most authors consider clean energy as a factor that had an impact on the SDGs, this paper developed a series of hypotheses to study whether SDG 7 is a determinant of sustainable growth.

Our results confirmed a significant relationship between SDG7 and the variables related to SDG 9 – Industry, Innovation and Infrastructure, the economic involvement of SDG 8.

The estimated models resulting from the hypothesis testing serve to establish the direction and influence of development objectives on SDG 7 – Affordable and Clean Energy as determinants of sustainable economic growth SDG 8. Most coefficients maintain the link between sustainable growth and interest variables at all stages of the analysis.

One of the main limitations of the analysis is that most of the indicators used to measure the achievement of the Sustainable Development Goals are relatively new, so for some key measurement indicators, the development of methodology and the determination of data sources are still an ongoing process.

The indicators show significant gaps between EU countries; in this sense, as a direction to deepen the research, a further analysis through panel data models or cluster analysis is recommended.

Moreover, it is important to notice that while energy consumption leads to economic growth, generally, it also still leads to global warming. This phenomenon might act in the opposite way, also on long run. Therefore, further studies that focus on both influences are needed.

Due to the COVID-19 crisis, the resulting models will most likely undergo some changes, mainly because the pandemic forced people to change their behaviour. Therefore, we expect this crisis to reshape economic activities, with further implications in all fields of activity. For example, this aspect is found in the education system because pupils, students and teachers are forced to continue their activities mostly online, which further increases the dependence on electricity.

The relationship between energy production / consumption and sustainable development is extremely important for decision makers / policy makers. In the light of recent events related to COVID-19, adaptive policies and strategies need to be created to deal with the new social situation.

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