ISSN: 2029-4913 / eISSN: 2029-4921

TECHNOLOGICAL and ECONOMIC DEVELOPMENT of ECONOMY

2025
Volume 31
Issue 1
Pages 23–44
https://doi.org/10.3846/tede.2024.22112

FACTORS HINDERING AND BOOSTING SDG7 IMPLEMENTATION IN EU COUNTRIES

Marta KUC-CZARNECKA [1✉], Iwona MARKOWICZ [2], Agnieszka SOMPOLSKA-RZECHUŁA [3], Alina STUNDŽIENĖ [4]

[1] *Faculty of Management and Economics and EkoTech Center, Gdansk University of Technology, Gdansk, Poland*
[2] *Institute of Economics and Finance, University of Szczecin, Szczecin, Poland*
[3] *Faculty of Economics, West Pomeranian University of Technology in Szczecin, Szczecin, Poland*
[4] *School of Economics and Business, Kaunas University of Technology, Kaunas, Lithuania*

Article History:
- received 01 February 2024
- accepted 21 June 2024
- first published online 15 November 2024

Abstract. One of the sustainable development goals (SDG7) is to ensure access to clean and affordable energy, which is related to most other SDGs and plays a crucial role in economic development and human well-being. The aim of the article is to identify factors that enhance and delay one of the most crucial goals of sustainable development, SDG7. The study's originality lies in the spatiotemporal approach to analysing the impact of selected factors on the development of green energy and increasing its availability. Three groups of potential SDG7 determining factors have been identified: ecological, social and economic. The proposed approach and the use of sensitivity analysis to variables weighting and ranking constructions of EU countries is an innovative aspect of the work and fills the gap in research on SDG7. The study showed that Denmark and Sweden occupy leading positions in the rankings based on the extent of SDG7 implementation. In contrast, Bulgaria, Cyprus and Lithuania occupied one of the last positions. The results of panel-data model estimations showed that in each estimated model, the same "indispensable variables" significantly affect the implementation of SDG7. Among these variables, only the unemployment rate significantly negatively impacted the SDG7 execution.

Keywords: SDG7, clean energy boosters, clean energy obstacles, sensitivity analysis, panel-data model, EU countries.

JEL Classification: C23, C43, Q01.

✉Corresponding author. E-mail: ***marta.kuc@zie.pg.edu.pl***

1. Introduction

In 2015, the UN General Assembly introduced 17 Sustainable Development Goals (SDGs) to balance meeting current needs with ensuring a sustainable future for economic, social, and environmental development. The fundamental principle of sustainable development is to enhance human well-being while maintaining this progress over time. However, climate change and the growing demand for energy and resources make it progressively challenging. As the population increases, the need for affordable energy grows, but the reliance on fossil fuels is causing significant climate change. Achieving SDG7, access to clean and affordable energy requires investing in renewable energy and increasing energy efficiency (United Nations Development Programme [UNDP], 2020). Achieving SDG7 is a crucial task for many countries, and researchers are studying the connections between the progress on SDG7 and the progress on other SDGs (Pradhan et al., 2017; Scharlemann et al., 2020; Warchold et al., 2021). The results presented in the study by Kuc-Czarnecka et al. (2023), indicating the lack of a significant relationship between SDG7 and the other SDGs, prompted the authors to undertake further research and answers to the question: What factors boost and hinder the degree of implementation of SDG7?

SDG7 is particularly synergistic with SDG8 (economic growth) and SDG13 (climate change). Achieving energy transition is essential for fulfilling the objectives of SDG7, which will also help realise the SDG13 objectives. In particular, energy is essential for achieving almost all SDGs, from eradicating poverty through health, education, water supply and industrialisation advancements to combating climate change (Wang et al., 2023). Chishti et al. (2023) showed that green financing and technologies, supported by environmental policies positively impact energy transition, while the geopolitical risk is found to have a negative impact. The study of Awijen et al. (2022), who investigated economic, financial, and political variables, showed that the primary factors driving renewable energy deployment are governance quality, innovation, political stability, and financial development. Energy availability is essential for economic growth and human well-being (Marcillo-Delgado et al., 2019). Yu et al. (2022) state that energy poverty, a consequence of a lack of access to clean and affordable energy, should be reduced as a priority to achieve SDG7.

According to Zhao et al. (2023), a limited number of studies have created composite indices to comprehensively measure the various aspects of energy development. There is currently no widely accepted and practical framework for assessing countries' overall progress towards achieving SDG7. Progress towards developing a quantitative framework that encompasses all aspects of SDG7 has been minimal.

In the EU, the concept of sustainable development has been defined by 17 SDGs in the Agenda 2030 strategy. Although sustainable development has been recognised as a principle of EU action, work on implementing the SDGs is ongoing. It can be seen in 6 Commission priorities for 2019–2024 (6 Commission priorities for 2019–2024). The goals of the 2030 Agenda primarily emphasize the significance of initiatives like the European Green Deal. It concerns actions aimed at a modern, resource-efficient and climate-neutral EU economy. Particular attention is paid to climate, energy and transport policies (European Commission: Directorate-General for Communication & Leyen, 2020). Scientists also notice the great importance of the implementation of the SDGs. Numerous studies indicate the identification of interactions between individual SDGs. One significant result was that SDG7 did not interact with other targets (Kuc-Czarnecka et al., 2023). This was the inspiration for further research. There have been attempts in the literature to explain what factors may affect SDG7. These are usually political and country-specific factors. However, there is a lack of studies on spatial analysis covering different countries.

The research aims to fill the gap in research on SDG implementation by identifying the factors that enhance and delay one of the most crucial goals of sustainable development, SDG7. The study uses data from the Eurostat (Eurostat, 2023) database and the Human Development Report from 2013 to 2020 (UNDP, 2013, 2014, 2015, 2016, 2019, 2020) for EU countries. The originality is a spatiotemporal approach. Ecological, social and economic factors are investigated. The unique aspect of this study is the use of a sensitivity-based approach to assign variable weights and construct rankings of EU countries. The novelty is an original selection of factors potentially affecting green energy development and increasing availability. Additionally, the authors' proposal to divide the potential influencing factors into three groups is an original approach to the study of SDG7 implementation. Our contributions to the new body of knowledge are, firstly, to demonstrate changes in the performance of SDG7 by individual EU countries over time, and secondly, to determine whether economic factors are decisive in terms of changes in the ways of obtaining energy ecological and social factors are still less important.

The article has the following structure: (1) Introduction, presenting the study's main objectives and the reasons for the authors' interest in investigating the factors affecting SDG7 implementation in EU countries. (2) Literature review, highlighting the scarcity of research on the specific factors influencing SDG7 implementation instead of the abundance of research on the interactions between SDGs. (3) Research method, applying sensitivity analysis to create a linear ordering of countries between 2013 and 2020 and panel-data models to identify the determinants of SDG7 implementation. (4) Study results, discussion and conclusions from the study.

2. Literature review

In the literature on renewable energy (RE), there is a growing emphasis on the benefits of its implementation, such as reducing carbon dioxide emissions and increasing energy independence (Marques & Fuinhas, 2012). However, there needs to be more discussion on the specific factors and policies that drive the transition to green energy from traditional sources; in most cases, studies focus on wind energy. Bird et al. (2005) analyse the policy and market factors driving wind energy development in the United States. They listed Renewable Portfolio Standards, Federal and State financial incentives, consumer demand for green energy, and natural gas price volatility. They also found that the "feed-in tariffs" factor that previously facilitated the wind generator market in Denmark and Sweden, and now in Germany and Spain, no longer exists in the United States (Bird et al., 2005; Faber et al., 2001). Such financial factors as "feed-in tariffs" or investment subsidies, loans or tax credits are positively assessed in the context of the general development of wind energy and green energy). Still, they are troublesome to include in scientific research. Examples of such policies are the feed-in tariff in the UK in 2010–2013 (Abolhosseini & Heshmati, 2014), the mix of renewable energy support mechanisms within the European Union (Del Rio & Mir-Artigues, 2014), subsidy programs in Poland in 2019 (Bieszk-Stolorz, 2022). Menz and Vachon (2006) also studied the determinants of wind energy development in the United States. They showed the positive impact of the Renewable Portfolio Standards (RPS) policy on wind energy development and the negative relationship between the development of wind power and renewable energy technologies (such as enabling retail customers to select their power source). The literature highlights the presence of social opposition to the placement of renewable energy facilities as a hindrance to the growth of the renewable energy sector in the UK and many other European countries (West et al., 2010).

An important area of study in literature is the relationship between the economy and the natural environment, specifically the relationship between changes in energy production methods, energy availability, and the concept of "green growth" (Machiba, 2011; Kim et al., 2014; Hickel & Kallis, 2020; Söderholm, 2020; Cheba & Bąk, 2021; Khan et al., 2021). According to Tiba and Omri (2017), the goal of every decision-maker is economic growth. However, there is a link between economic growth and energy consumption (electricity, nuclear, renewable and non-renewable) and environmental quality. Tiba and Omri (2017), analysing 264 literature items, conclude that energy consumption can stimulate economic growth by increasing productivity and environmental damage by increasing pollutant emissions. Therefore, economic policy must be consistent with energy and environmental policy. They also point to the Environmental Kuznets Curve (EKC) hypothesis – meaning that economic growth contributes to environmental degradation, but only up to a certain level. After reaching a certain income threshold, environmental care increases (inverted U-curve between economic growth and environmental quality) (Tiba & Omri, 2017; Ozturk, 2010; Payne, 2010).

The problems of combining various policies, such as innovation, environmental, energy, and labour policy, are discussed by Crespi (2016). He points out that public policies and management systems must provide conditions conducive to economic development while protecting the environment. To improve the quality of the environment, it is necessary to decarbonise the industry and reduce gas emissions; for this, appropriate policies are needed in all countries (Wang & Chen, 2019). The subjective nature of policy and uneven economic development as factors influencing countries' actions towards climate change are indicated by Ma et al. (2023). Bardal et al. (2021) argue that according to console development, social, environmental, and economic aspects should be integrated into decision-making, ensuring a harmonious balance among them. However, there are many ways to conduct the right policy. Countries and regions differ geographically, demographically and economically, and in governance systems. This impacts the solutions used by national, regional and local authorities to implement Sustainable Development Goals (Bardal et al., 2021; Satterthwaite, 2017; Kulonen et al., 2019). Scientific publications emphasise that the actions of local authorities and communities are necessary to achieve the SDGs (Moallemi et al., 2020; Caruana & Pace, 2018). Tuchno and Kumsa (2020) write about differences in socio-economic policy and numerous barriers to access to modern energy in Sub-Saharan Africa. On the other hand, the European Committee of the Regions (2019) points out that implementing the SDGs in the EU depends on the performance of appropriate policies at the level of countries, regions, and cities.

Papież et al. (2018) emphasise that the development of RES (Renewable energy sources) is a long-term process, and the current development of RES is a consequence of decisions made several years ago. They stress that three types of RES initially dominated in the EU – hydropower, biomass and geothermal energy hydropower. In the following years, there was a noticeable increase in the share of wind and solar energy in total RE consumption. The energy situation in individual countries depends on long-term investments in infrastructure and legal regulations; as a barrier to developing clean energy, the country possesses sources of dirty energy (coal and oil). According to Tee et al. (2021), the majority of renewable energy initiatives require significant initial investment, competitive technologies, and extended periods for investment returns. Consequently, governmental support in enforcing intellectual property rights is crucial for the progression of renewable energy. By bolstering intellectual property rights, there is a boost in confidence within the renewable energy sector as it ensures protection for investors' innovative endeavours.

McCollum et al. (2017) found that not everyone experiences the benefits that modern forms of energy can provide. Energy resources are not evenly spread across the globe. In areas where these resources are abundant and easily accessible, establishing the essential infrastructure for extraction and processing requires substantial financial investment. However, limitations in financial and human capital often lead to certain populations being excluded from access to modern energy services. McCollum et al. (2017) indicate possible interactions between SDGs. They argue that science is not yet solid enough to assess some interactions between goals or establish their dependencies regarding time, place, management, and technology. However, a more comprehensive assessment should be possible as science progresses and the database grows. Marques et al. (2010) emphasise that there are more and more scientific papers on renewable energy. However, they believe research is needed on factors promoting renewable energy sources. Their study covers European countries from 1990–2006 (they used panel-data techniques). Research shows obstacles to developing renewable energy sources, such as the lobby of traditional energy sources (oil, coal, and natural gas) and CO_2 emissions.

Ways to assess the development of renewable energy sources (RE) in a given country include the share of renewable energy sources in the energy supply (percentage of total primary energy supply) (Marques et al., 2010), the total amount of RE produced (Bird et al., 2005) or the natural logarithm of the share of RE in total electricity production (Carley, 2009). Variables explaining the development of green energy are grouped into categories in the research; for example, the following types are mentioned: political, socioeconomic, and country-specific factors (Marques et al., 2010). The importance of political factors is emphasised in the literature (Wang, 2006; Johnstone et al., 2010; Marques & Fuinhas, 2012), but precise information on the policies applied in individual countries is not always available. According to Marques and Fuinhas (2012), public policy measures (incentives/subsidies) contribute to the broader renewable energy sources. Socio-economic factors include, for example, oil, natural gas and coal prices, carbon dioxide emissions, alternative energy sources (lobbying for coal, oil, natural gas and nuclear energy), as well as energy consumption and income (Domac et al., 2005; Chang et al., 2009; Marques et al., 2010). A country's energy consumption and income (GDP) are development indicators, providing better opportunities and needs to develop green energy.

It should be noted that each SDG deals with multidimensional development. Analysis of relationships between goals can yield varied outcomes – synergies (positive results) or trade-offs (negative ones) (Firoiu et al., 2021; Kuc-Czarnecka et al., 2023). Achieving Sustainable Development Goals will depend on exploiting the positive connections among the goals. On the other hand, trade-offs are hindrances to achieving Sustainable Development Goals (Pradhan et al., 2017). Firoiu et al. (2021) emphasise that achieving SDG7 is critical to human well-being, economic growth and meeting climate change goals. In general, the literature highlights that ensuring access to energy for the poor, large-scale deployment of renewable energy sources, and increasing energy efficiency will have a positive impact on the SDGs in terms of climate, poverty, water availability and quality, health, improved quality of life in cities (Nerini et al., 2018; Nilsson et al., 2018). However, it also highlights gaps in knowledge about how SDG7 will interact with other goals. Kuc-Czarnecka et al. (2023) research indicated the lack of interaction of SDG7 with other goals (EU countries in 2020). Research findings indicate that EU Member States face difficulties in accessing modern energy services (Pereira et al., 2021). Bersalli et al. (2020) emphasise that Europe pioneered policies to promote RE, which were first introduced at the end of the 1980s in emphasise. They also stressed the need to apply the RE policy and the unequal effectiveness of this policy across countries. Roussafi (2021) points out that the development of nuclear energy has allowed France to be one of the countries with the lowest greenhouse gas emissions in the world. The literature emphasises the importance of sustainable energy development in countries and the ways of measuring this development. Various indicators measuring the level of development and studies of factors influencing the intensity of action are indicated (Elavarasan et al., 2022; Herrero et al., 2020; Neelawela et al., 2019).

A literature review shows that different policies and factors influence clean energy development. However, the available analyses are country-specific or time-specific. Our goal was to identify the boosters and limiters of the implementation of SDG7 in EU countries. Our previous research showed no connection between this goal and the other SDGs. Therefore, it is interesting to reveal what affects the performance of SDG7 in individual countries. An innovative solution in the presented study is the selection of factors that can affect the development of clean and available energy and are available for the nations and years under investigation.

3. Materials and methods

Taking into account information presented in the introduction and literature review sections, the following research hypotheses were formulated:

H1: *The variation in the rankings of EU countries in terms of SDG7 implementation results from overlapping effects, i.e., countries with initially lower values of indicators develop faster than countries with high initial levels.*

H2: *Economic indicators have a mightier impact on the progress of SDG7 than ecological and social indicators.*

The research procedure intended to verify the above hypotheses is presented below.

3.1. SDG7 quantification – composite indicator

To measure the extent of the seventh sustainable development goal's implementation within the European Union in 2013–2020, a composite indicator (CI) was constructed and adjusted using methods based on sensitivity analysis. The initial set of diagnostic variables regarding the degree of implementation of SDG7 was the data contained in the Eurostat (2023) database under the section – Affordable and clean energy:

- Primary energy consumption (SDG_07_10);
- Final energy consumption (SDG_07_11);
- Final energy consumption in households per capita (SDG_07_20);
- Energy productivity (SDG_07_30);
- Share of renewable energy in gross final energy consumption by sector (SDG_07_40);

- Energy import dependency by-products (SDG_07_50);
- Population unable to keep home adequately warm by poverty status (SDG_07_60).

The variables' set mentioned above was used to construct a composite indicator following the procedure proposed by the OECD (2008) and extended by the Lindén et al. (2021) approach:

1. Calculating the first version of CI as the arithmetic mean of all diagnostic variables listed above. Eurostat studies do not indicate otherwise, so we assumed that all variables are equally important. We decided to use the arithmetic mean since, despite its disadvantages, it is the most common aggregation method used in CI's construction (Bandura, 2008, 2011; Yang, 2014).

$$y_j = \sum_{i=1}^{d} w_i x_{ji},\ j = 1,2,\ldots,d;\ \ i = 1,2,\ldots,n, \tag{1}$$

where: y_j – the value of the composite indicator for the j-th country, x_{ji} – the normalised value of the i-th variable in the j-th country, w_i – weight assigned to the i-th variable. Variables were normalized using the max-min method. Variables SDG_07_30 and SDG_07_40 are stimulants where higher values are preferable, whereas all other variables are destimulants, where lower values are desirable.

2. Verifying if the assigned weights align with the intended significance of variables using techniques derived from sensitivity analysis:

   a. Calculating first-order sensitivity index:

$$S_i \equiv \frac{V_{x_i}\left(E_{x\sim i}\left(y \mid x_i\right)\right)}{V\left(y\right)}, \tag{2}$$

where: S_i – first-order sensitivity measure, $S_i \in [0,1]$, $x_{\sim i}$ – vector containing all variables but x_i, $E_{x\sim i}\left(y \mid x_i\right)$ – expected value of y at a given value of x_i with the expectation taken over $x_{\sim i}$, $V(y)$ – unconditional variance of y.

   b. Estimating of uncorrelated contribution (Harezlak et al., 2018):

$$\widehat{z_i} = x_i - \widehat{x_i} = x_i - \left(\beta_0 + \sum_{l \neq i}^{d} \widehat{\beta_l} x_i\right), \tag{3}$$

where: $\widehat{z_i}$ – residuals of a regression of x_i on $x_{\sim i}$, β_0 – y-intercept from multivariate linear regression, β_l – coefficient from multivariate linear regression.

$$S_i^u = \frac{\sum_{j=1}^{n}\left(\hat{y}_j^{(\sim i)} - \bar{y}^{(\sim i)}\right)^2}{\sum_{j=1}^{n}\left(y_j - \bar{y}\right)^2}, \tag{4}$$

where: S_i^u – uncorrelated contribution. $\hat{y}_j^{(\sim i)}$ – non-linear regression fitted values, $\bar{y}^{(\sim i)}$ – average value of $\hat{y}_j^{(\sim i)}$, y_j – composite indicator value in the j-th object, $\bar{y}$ – average value of y_j.

   c. Estimating of correlated contribution:

$$S_i^c = S_i - S_i^u, \tag{5}$$

where: S_i^c – correlated contribution. A detailed description of the test procedure for sensitivity analysis is included in (Kuc-Czarnecka et al., 2021).

3. Weight optimisating (Becker et al., 2017) using the Nelder–Mead method (Nelder & Mead, 1965):

$$w_{opt} = \arg\min_w \sum_{i=1}^{d} \left(\tilde{S}_i^* - \tilde{S}_i(w)\right)^2, \tag{6}$$

where: $\tilde{S}_i^*$ – target normalised correlation ratio, w – set of initial weights assigned by CI creator, $w = \{w_i\}_{i=1}^{d}$, $\tilde{S}_i$ – normalised correlation ratio of x_i, computed as (Lindén et al., 2021):

$$\tilde{S}_i = \frac{S_i}{\sum_{i=1}^{n} S_i}. \tag{7}$$

4. Calculating final CI as the weighted arithmetic mean (1) using optimal weights (7). When obtaining equal S_i for initial variables was impossible, the input set was reduced by one, starting from the variable with the highest Variance Inflation Factor (VIF). The procedure was repeated until all diagnostic variables were equally important (the weights could vary).

3.2. SDG7 determinants – panel models

The degree of implementation of SDG7 was quantified using a composite indicator. Our previous research reveals that this goal (in EU countries) shows no synergies or trade-offs with other sustainable development goals. Therefore, we estimated panel models using economic, social and ecological variables to explain its development. The research procedure was as follows:

1. Estimating pool model (POOLS)

$$y_{it} = \alpha + \sum_{i=1}^{n} \beta_j x_{ijt} + u_{it}, \tag{8}$$

where: y_{it} – dependent variable in the i-th country in year t, x_{ijt} – j-th independent variable in i-th country in year t, α – intercept, β_j – structural parameters, u_{it} – error term.

2. Estimating fixed-effects model (FEM)

$$y_{it} = \alpha_i + \sum_{i=1}^{n} \beta_j x_{ijt} + u_{it}, \tag{9}$$

where: α_i – individual intercept in the i-th country, which controls individual-specific and time-invariant characteristics (Torres-Reyna, 2007).

3. Estimating random-effects model (REM)

$$y_{it} = \alpha + \sum_{i=1}^{n} \beta_j x_{ijt} + \mu_i + \varepsilon_{it}, \tag{10}$$

where: μ_i – individual-specific random component, ε_{it} – idiosyncratic disturbance.

4. Checking with panel diagnostics tests whether it is reasonable to use the fixed-effects or random-effects model (Stock & Watson, 2020) since the limitations of the POOLS estimation (Arrelano & Bond, 1991). The choice of the model is made based on Breusch–Pagan and Hausman tests.

Therefore, they were omitted from the description of the research procedure. In our model, we have included (in addition to CI approximating 7th SDG realisation) several control variables reported in the literature as essential determinants of energy usage and availability (Table 1). To compare the impact of given variables, standardised beta coefficients were calculated:

$$\tilde{\beta} = \beta \cdot \frac{S_x}{S_y}, \tag{11}$$

where: $\tilde{\beta}$ – standardised beta coefficient, β – regression coefficient, S_x – standard deviation of the explanatory variable, S_y – standard deviation of the dependent variable.

Table 1. Variables used in the investigation (source: author's investigation)

Symbol	Description
Ecological indicators	
X1	Average CO_2 emissions per km from new passenger cars
X2	Net greenhouse gas emissions (tons/person)
X3	The area under organic farming as a percentage of the total agricultural area
X4	Share of energy from renewable sources
X5	Share of renewable energy sources in transport
X6	Share of renewable energy sources in electricity
X7	Area of solar collectors (per 1000 km_2)
Social indicators	
X8	Life expectancy at birth in years
X9	Healthy life expectancy at birth in years
X10	The average number of years of education received by residents aged 25 and over
X11	The expected number of years of education for children entering education
X12	Inability to maintain adequate heat in the home
X13	Percentage of the population with higher education
Economic indicators	
X14	Final energy consumption by agriculture/forestry per ha of utilised agricultural area
X15	Real GDP per capita
X16	Unemployment rate
X17	Share of fossil fuels in gross available energy
X18	Nominal labour productivity per person employed (Percentage of EU27)
X19	Household expenditure on final consumption
X20	R&D personnel

4. Results

4.1. SDG7 quantification – composite indicator

After con sensitivity analysis, the CI values were determined based on the following indicators: SDG_07_10, SDG_07_30, SDG_07_40, SDG_07_50 and SDG_07_60. Composite indicators values are presented in Table 2, and countries' rank positions are in Table 3.

The highest values of CI in each surveyed year were recorded for Denmark, the first throughout the period. Another country where SDG7 was implemented at a high level was Sweden, ranked second in 2013–2017 and third in 2019–2020. An interesting situation was observed in the case of Finland, which in 2013–2018 implemented SDG7 at a reasonably high

Table 2. SDG7 composite indicator values (source: author's investigation)

Country	Years							
	2013	2014	2015	2016	2017	2018	2019	2020
Belgium	0.0638	0.0608	0.0558	0.0662	0.0639	0.0542	0.0903	0.0831
Bulgaria	0.0519	0.0515	0.0471	0.0465	0.0427	0.0457	0.0754	0.0721
Czechia	0.0805	0.0802	0.0772	0.0851	0.0802	0.0779	0.1021	0.0958
Denmark	0.1727	0.1766	0.1665	0.1697	0.1653	0.1541	0.1565	0.1433
Germany	0.0940	0.0935	0.0888	0.0941	0.0916	0.0879	0.1168	0.1020
Estonia	0.0944	0.0980	0.0992	0.1054	0.1040	0.1053	0.1185	0.1117
Ireland	0.1019	0.1052	0.1117	0.1221	0.1270	0.1249	0.1416	0.1392
Greece	0.0766	0.0681	0.0605	0.0600	0.0590	0.0570	0.1061	0.0985
Spain	0.0893	0.0823	0.0773	0.0845	0.0804	0.0726	0.1177	0.1073
France	0.0982	0.0986	0.0930	0.0992	0.0949	0.0917	0.1113	0.1059
Croatia	0.0950	0.0933	0.0852	0.0920	0.0864	0.0815	0.1273	0.1208
Italy	0.0944	0.0919	0.0828	0.0860	0.0816	0.0753	0.1178	0.1123
Cyprus	0.0520	0.0467	0.0403	0.0448	0.0440	0.0425	0.0865	0.0798
Latvia	0.0888	0.0955	0.0846	0.0956	0.0959	0.0918	0.1280	0.1234
Lithuania	0.0601	0.0569	0.0512	0.0544	0.0523	0.0439	0.0889	0.0825
Luxembourg	0.0823	0.0804	0.0780	0.0857	0.0816	0.0737	0.0639	0.0608
Hungary	0.0715	0.0631	0.0634	0.0689	0.0642	0.0619	0.1080	0.1017
Malta	0.0201	0.0205	0.0243	0.0350	0.0342	0.0290	0.1044	0.0982
Netherlands	0.0973	0.0960	0.0809	0.0886	0.0831	0.0769	0.1045	0.0980
Austria	0.1236	0.1163	0.1109	0.1162	0.1107	0.1044	0.1257	0.1196
Poland	0.0779	0.0782	0.0759	0.0805	0.0737	0.0716	0.1127	0.1061
Portugal	0.0852	0.0824	0.0742	0.0809	0.0743	0.0685	0.1124	0.1087
Romania	0.0966	0.0986	0.0932	0.0955	0.0916	0.0893	0.1272	0.1189
Slovenia	0.0918	0.0898	0.0838	0.0901	0.0866	0.0817	0.1170	0.1107
Slovakia	0.0635	0.0630	0.0629	0.0697	0.0649	0.0609	0.1027	0.0980
Finland	0.1106	0.1049	0.1020	0.1109	0.1103	0.1018	0.0985	0.0906
Sweden	0.1489	0.1446	0.1418	0.1449	0.1430	0.1335	0.1330	0.1272

Note: $CI \in [0,1]$ – the higher the value, the better from the point of view of achieving SDG7.

level, taking places from fourth in 2013 to sixth in 2018, while in 2019–2020, being placed 22nd. Finland's fall to one of the last positions in the ranking of EU countries in 2019–2020 is not due to the deterioration of the SDG7 indicators. Analysing the data, it can be seen that in Finland, there has been an improvement in the values of SDG7 indicators, e.g., the share of renewable energy in gross final energy consumption has been increasing year by year, on average, by 2.6%. However, in other countries, the pace of change was much higher than in Finland, hence this drop in the ranking. Perhaps there has already been a saturation in Finland, and introducing further changes is becoming increasingly difficult. Thus, the so-called overlapping effect occurred.

Table 3. SDG7 composite indicator values (source: author's investigation)

Country	Years								Direction of change
	2013	2014	2015	2016	2017	2018	2019	2020	
Belgium	22	23	23	22	22	23	23	23	↓
Bulgaria	26	25	25	25	26	24	26	26	–
Czechia	18	18	17	16	17	13	21	21	↓
Denmark	1	1	1	1	1	1	1	1	–
Germany	12	11	9	10	9	10	12	15	↓
Estonia	10	8	6	6	6	4	8	9	↑
Ireland	5	4	3	3	3	3	2	2	↑
Greece	20	20	22	23	23	22	17	17	↑
Spain	14	16	16	17	16	17	10	12	↑
France	6	7	8	7	8	8	15	14	↓
Croatia	9	12	10	11	12	12	5	5	↑
Italy	11	13	13	14	15	15	9	8	↑
Cyprus	25	26	26	26	25	26	25	25	–
Latvia	15	10	11	8	7	7	4	4	↑
Lithuania	24	24	24	24	24	25	24	24	–
Luxembourg	17	17	15	15	14	16	27	27	↓
Hungary	21	21	20	21	21	20	16	16	↑
Malta	27	27	27	27	27	27	19	18	↑
Netherlands	7	9	14	13	13	14	18	19	↓
Austria	3	3	4	4	4	5	7	6	↓
Poland	19	19	18	19	19	18	13	13	↑
Portugal	16	15	19	18	18	19	14	11	↑
Romania	8	6	7	9	10	9	6	7	↑
Slovenia	13	14	12	12	11	11	11	10	↑
Slovakia	23	22	21	20	20	21	20	20	↑
Finland	4	5	5	5	5	6	22	22	↓
Sweden	2	2	2	2	2	2	3	3	↓

In Latvia, the indicator "population unable to keep home adequately warm" improved on average by almost 17 p.p. in the analysed period, being the highest rise compared among EU countries. In the case of Latvia, the values of other indicators improved from year to year, which was reflected in the improvement of its position in the ranking of EU countries; in 2020, Latvia was ranked fourth, while in 2013, it was fifteenth. A similar situation occurred in Malta, ranked 27th in 2013 and 18th in 2020. The last places in the ranking in terms of the implementation of SDG7 are occupied by: Luxembourg, Bulgaria, Cyprus and Lithuania. Only Luxembourg has seen a significant deterioration in its position, from 17th in 2013 to 27th in 2020. One of the reasons is a substantial increase in the "population unable to keep home adequately warm" from 0.6% in 2014 to 3.6% in the last year of the study. The remaining three countries occupied similar positions in the ranking every year.

When analysing the changes in the position of EU countries, it can be seen that in 2020 compared to 2013, the improvement in the rank position was observed in 14 countries. 9 out of 14 countries joined the EU in 2004 or later. On the other hand, in many "old" EU Member States, the degree of implementation of SDG7 has deteriorated, and the position of these countries has been lowered in the ranking. In the case of four countries in 2020, the place in the linear ordering remained the same. In each year of the study, three countries (Bulgaria, Cyprus and Lithuania) study occupied one of the last positions. While in contrast, Denmark occupied the first position in the ranking throughout the period. Kendall's rank correlation coefficients were calculated to determine the relationship between the country's place in the rankings in 2013–2020 (Table 4).

All values of Kendall's rank correlation coefficients are statistically significant and indicate a strong relationship between the positions occupied by individual countries in the rank. The association was strongest for the positions of countries in 2019 and 2020. The weakest relationships were observed between countries' positions in the last year of the study and the beginning of the period under review, which may indicate the beginning of the overlapping effect.

The presented results confirm the first hypothesis. Some countries with previously low indicators have the potential for rapid development, allowing them to attain high rankings among EU countries. Therefore, the change of places in the hierarchy of the leading countries does not result from a decrease in the level of indicators achieved.

Table 4. Correlation coefficient matrix of Kendall for the rank positions (source: author's investigation)

Year	2013	2014	2015	2016	2017	2018	2019	2020
2013	1.000	0.915	0.846	0.829	0.818	0.789	0.550	0.544
2014	0.915	1.000	0.897	0.892	0.869	0.852	0.578	0.584
2015	0.846	0.897	1.000	0.949	0.926	0.920	0.590	0.573
2016	0.829	0.892	0.949	1.000	0.966	0.937	0.573	0.567
2017	0.818	0.869	0.926	0.966	1.000	0.926	0.573	0.567
2018	0.789	0.852	0.920	0.937	0.926	1.000	0.578	0.561
2019	0.550	0.578	0.590	0.573	0.573	0.578	1.000	0.949
2020	0.544	0.584	0.573	0.567	0.567	0.561	0.949	1.000

4.2. SDG7 determinants – panel models

In the subsequent part of the analysis, panel models explaining the development of the CI value approximating SDG7 were estimated. The models were estimated in many variants: for all variables simultaneously (M1) and separately for determinants from each group – social (M2), ecological (M3) and economic (M4). The models were estimated for absolute and normalised CI values with similar results. Therefore, only the estimates for the CI value presented in Table 2 are given in the text. The results of the estimation are presented in Tables 5–8. We decided to show the models after the omit variable test; hence only variables at the significance level α = 0.1 were included in the presented models. Logarithms of the explanatory variables were used in the estimated models.

In the first step of the analysis, we estimated models including all variables simultaneously. The p-value in the Breusch–Pagan test indicated that the random effects model is better than the pooled one. Moreover, the low p-value in Hausman's test counts against the null hypothesis that the random effects model is consistent in favour of the fixed effects model. Therefore, the best estimator was FEM, and the estimated model is of good quality.

Table 5. SDG7 implementation estimates 2013–2020 – all variables (M1) (source: author's investigation)

Variables	POOLS	FEM	REM
l_X1	---	0.101 (<0.0001)	0.070 (0.0001)
l_X2	−0.014 (0.002)	−0.01 (0.074)	−0.019 (0.003)
l_X3	−0.006 (0.001)	---	---
l_X4	0.036 (<0.0001)	---	0.015 (0.048)
l_X5	−0.006 (0.009)	0.004 (0.063)	---
l_X6	0.007 (0.045)	---	0.014 (0.014)
l_X8	---	−0.021 (0.047)	---
l_X13	0.009 (0.0818)	0.033 (0.040)	0.018 (0.044)
l_X14	---	0.023 (0.0003)	---
l_X15		0.058 (0.007)	---
l_X16	−0.018 (<0.0001)	−0.013 (0.033)	−0.018 (<0.0001)
l_X17	0.045 (0.0001)	---	0.046 (0.004)
l_X18	0.039 (<0.0001)	---	0.031 (0.003)
l_X19	---	0.101 (<0.0001)	0.070 (0.0001)
R2 Adjusted R2 Within-R2 LSDV-R2 LSDV F Log-likelihood	0.711 0.696 --- --- --- ---	--- --- 0.481 0.880 37.637 (<0.0001) 668.798	--- --- --- --- --- 566.320
Obs. Breusch–Pagan test Hausman test		216 58.249 (<0.0001) 36.343 (<0.0001)	

Notes: The variables' symbols used in the models are described in Table 1; *p*-values are given in parentheses.

Logarithms of the explanatory variables were used in the estimated models. Out of 20 variables (Table 2), nine had a statistically significant influence on the extent of the 7 SDGs implementation (Table 5). The variables X2 (net greenhouse gas emission), X8 (life expectancy at birth), and X16 (unemployment rate) harm the introduction of clean and renewable energy. Simultaneously, its introduction is favoured by factors such as X1 (average CO_2 emission per km from new passenger cars), X5 (share of renewable energy sources in transport), X13 (percentage of the population with higher education), X14 (final energy consumption by agriculture/forestry per hectare of utilised agricultural area), X15 (real GDP per capita), and X19 (household expenditure on final consumption). It turned out that when all the variables are put together, many social variables do not show a statistically significant impact on the degree of implementation of SDG7. This may be due to the strong connection between social and economic variables. Therefore, in the next step, models were estimated using just one group as regressors. The results are presented in the 6–8 Tables.

For a model with only ecological group variables (Table 6), the Breusch–Pagan and Hausman test showed that a random effects model (REM) should be used. In this case, 3 out of 7 selected variables turned out to be statistically significant – X1 (average CO2 emission per km from new passenger cars), X5 (share of renewable energy sources in transport), and X6 (share of renewable energy sources in electricity). All of these positively influence the CI value, indicating progress in the implementation of the SDG7.

All statistically significant variables from the social group (2 out of 6) also had a positive impact on the implementation of SDG7: X9 (healthy life expectancy at birth in years) and X13 (percentage of the population with higher education). Diagnostic tests, in this case, indicated the use of the fixed effects estimator (Table 7).

Table 6. SDG7 implementation estimates 2013–2020 – ecological variables (M2)
(source: author's investigation)

Variables	POOLS	FEM	REM
l_X1	---	0.065 (0.004)	0.033 (0.086)
l_X2	0.016 (<0.0001)	---	---
l_X3	---	0.017 (0.001)	---
l_X4	0.011 (0.016)	0.026 (0.001)	---
l_X5	0.009 (<0.0001)	0.006 (0.010)	0.007 (0.001)
l_X6	0.021 (<0.0001)	---	0.026 (<0.0001)
R2	0.493	---	---
Adjusted R2	0.484	---	---
Within-R2	---	0.254	---
LSDV-R2	---	0.827	---
LSDV F	---	29.473 (<0.001)	---
Log-likelihood	---	649.152	520.214
Obs.		216	
Breusch–Pagan test		243.116 (<0.0001)	
Hausman test		3.108 (0.540)	

Notes: The variables' symbols used in the models are described in Table 2; *p*-values are given in parentheses.

Table 7. SDG7 implementation estimates 2013–2020 – social variables (M3)
(source: author's investigation)

Variables	POOLS	FEM	REM
l_X8	0.144 (0.022)	---	---
l_X9	−0.069 (0.007)	0.074 (0.045)	---
l_X10	0.053 (0.006)	---	---
l_X11	0.107 (<0.0001)	---	---
l_X13	---	0.073 (<0.0001)	0.060 (<0.0001)
R2 Adjusted R2 Within-R2 LSDV-R2 LSDV F Log-likelihood	0.241 0.227 --- --- --- ---	--- --- 0.199 0.814 29.295 (<0.0001) 641.547	--- --- --- --- --- 450.695
Obs. Breusch–Pagan test Hausman test		216 307.309 (<0.0001) 19.017 (<0.006)	

Notes: The variables' symbols used in the models are described in Table 2; *p*-values are given in parentheses.

Table 8. SDG7 implementation estimates 2013–2020 – economic variables (M4)
(source: author's investigation)

Variables	POOLS	FEM	REM
l_X15	0.009 (0.003)	---	---
l_X16	−0.010 (0.004)	−0.028 (<0.0001)	−0.026 (<0.0001)
l_X17	−0.033 (<0.0001)	----	---
l_X19	0.043 (<0.0001)	0.106 (<0.0001)	0.088 (<0.0001)
R2 Adjusted R2 Within-R2 LSDV-R2 LSDV F Log-likelihood	0.362 0.350 --- --- --- ---	--- --- 0.327 0.844 36.160 (<0.0001) 660.409	--- --- --- --- --- 484.534
Obs. Breusch–Pagan test Hausman test		216 348.738 (<0.0001) 11.357 (0.022)	

Notes: The variables' symbols used in the models are described in Table 2; *p*-values are given in parentheses.

The FEM estimator also turned out to be the most suitable for models in which only economic variables were regressors (Table 8). Two of the seven variables: X16 (unemployment rate) and X19 (household expenditures on final consumption), had a statistically significant impact on the CI value. However, the direction of their influence was different. X16 hinders the implementation of SDG7, while X19 favours it. Table 9 contains standardised beta coefficients that compare individual diagnostic variables' impact strength.

Table 9. Standardised beta coefficients for M1–M4 models (source: author's investigation)

Variables	M1	M2	M3	M4
Ecological indicators				
X1	0.076	0.038	---	---
X2	–0.004	---	---	---
X5	0.0001	0.001	---	---
X6	---	0.007	---	---
Social indicators				
X8	–0.076	---	---	---
X9	---	---	0.095	---
X13	0.018	---	0.030	---
Economic indicators				
X14	0.005	---	---	---
X15	0.043	---	---	---
X16	–0.003	---	---	–0.003
X19	0.066	---	---	0.070

Notes: The variables' symbols used in the models are described in Table 2; Only statistically significant variables from models M1–M4 are included.

The results of modelling SDG7 determinants only partially confirmed the second hypothesis. In the M1 model, most of the variables belonged to the group of economic indicators; also, their collective impact on the implementation of SDG7 is the highest (Table 9). However, the results of estimating the M2–M4 models no longer confirm this hypothesis. When considering the models for individual groups of factors, it turns out that the largest number of statistically significant factors occurred in the ecological group. The strength of their impact on SDG7 was the highest in the social group.

5. Discussion and conclusions

In our research, the highest values of CI in each surveyed year were recorded for Denmark, which was the first throughout the whole period. Our analysis indicated a high position of France in the ranking of EU countries, especially in the initial period covered by the analysis. The development of nuclear energy has allowed France to be one of the countries with the lowest greenhouse gas emissions in the world. However, the development of atomic energy is associated with the problem of safety (radioactive waste) and social acceptance. Therefore, the energy transition must be focused mainly on RE.

Our research showed that in the model for all variables (M1), economic indicators (4/7) prevailed among the significant ones. Of course, this may be due to the existence of links between economic-ecological-social variables. After determining the models using variables from only one group (M2–M4), it turned out that some variables ceased to be significant, and some gained importance. Our research allowed us to identify those variables that significantly impact the implementation of SDG7, regardless of the version of the estimated model (M1–M4). These "indispensable variables" include X1-average CO2 emissions per km from new passenger cars; X5-share of renewable energy sources in transport; X13-percentage of the population with higher education; X16-unemployment rate; X19-household expenditure on final consumption.

Only one of these factors has a negative impact on the implementation of SDG7 (X16), and the others are conducive to achieving this goal. If there is high unemployment in the country, it is difficult to focus resources and attention on clean energy available to all. On the other hand, they are increasing the level of other "indispensable variables" to favour the development of the green energy sector. Our results confirmed that more CO_2 per capita means more incentive to make renewable energy commitments. In addition, research shows that important factors influencing the implementation of renewable energy sources in European countries are the pressure of the lobby of traditional energy sources (negative impact), energy self-sufficiency, CO_2 emissions and income (positive impact). Therefore, the awareness of too high CO_2 emissions (X1 in our study) and high income (in our research, this is indicated by X19-household consumption expenditure) encourage society to care for the environment. The high awareness of the society may also be influenced by education (X13-higher percentage of the population with higher education) and perceived benefits of using energy sources (X5-share of renewable energy sources in transport). Household consumption expenditure (variable X19) is an important determinant. We would also like to emphasise that the "significant variables" obtained in the survey represent all the aspects studied and come from three groups: ecological, social and economic indicators.

The literature emphasises the importance of sustainable energy development in countries and the ways of measuring this development. Various indicators measuring the level of development and studies of factors influencing the intensity of action are indicated. However, the research conducted so far does not exhaust the topic of factors influencing the implementation of SDG7. Our study fills this gap.

We are aware of the limitations of our research. First of all, identifying potential factors that affect the development of green energy relies on the availability of statistical data. These data must be defined in the same way in the compared countries. Another problem is the way of assessing the energy development of countries. In the literature, we find various approaches in this area and the use of various measurement tools (indicators). Our study is, therefore, a voice in the discussion on sustainable energy development. We are also aware that the methodology for weighting variables is intricate and necessitates separately recalculating weights for each year. Nonetheless, these constraints do not undermine the reliability and robustness of the findings presented.

Acknowledgements

The author thanks the anonymous reviewers for their valuable comments and suggestions for improving the quality of the paper.

Funding

Financial support of these studies from Gdańsk University of Technology by the DEC-15/2023/IDUB/IV.2/EUROPIUM grant under the EUROPIUM – "Excellence Initiative – Research University" program is gratefully acknowledged.

The research was carried out as part of the scientific internship "Assessment of the implementation of the Sustainable Development Goals and the interconnections between them in European Union countries" (2023).

The publication was partially funded by the Faculty of Economics, West Pomeranian University of Technology in Szczecin: "The International Center for Inclusive Economic Development (IDEAL)".

Author contributions

Author 1: conceptualization, data curation, investigation, writing – original draft, writing – review & editing, data curation, formal analysis, methodology, software, visualization. Author 2: conceptualization, data curation, investigation, writing – original draft, writing – review & editing, resources. Author 3: resources, conceptualization, data curation, investigation, writing – original draft, writing – review & editing. Author 4 – conceptualization, writing – original draft, writing – review & editing.

Disclosure statement

Conflict of Interest: The authors declare that they have no conflict of interest.

References

Abolhosseini, S., & Heshmati, A. (2014). *The main support mechanisms to finance renewable energy development* (IZA Discussion Paper No. 8182). Institute of Labor Economics. https://doi.org/10.2139/ssrn.2441478

Arrelano, M., & Bond, S. (1991). Some tests of specification for panel data: Monte Carlo evidence and an application to employment equations. *Review of Economic Studies*, *58*(2), 277–297. https://doi.org/10.2307/2297968

Awijen, H., Belaïd, F., Zaied, Y. B., Hussain, N., & Lahouel, B. B. (2022). Renewable energy deployment in the MENA region: Does innovation matter? *Technological Forecasting and Social Change*, *179*, Article 121633. https://doi.org/10.1016/j.techfore.2022.121633

Bandura, R. (2008). *A survey of composite indices measuring country performance and state behavior*. Office of Development Studies United Nations Development Programme, New York.

Bandura, R. (2011). *Composite indicators and rankings*: *Inventory 2011* (Technical Report). United Nations Development Programme (UNDP).

Bardal, K. G., Reinar, M. B., Lundberg, A. K., & Bjørkan, M. (2021). Factors facilitating the implementation of the sustainable development goals in regional and local planning – experiences from Norway. *Sustainability*, *13*(8), Article 4282. https://doi.org/10.3390/su13084282

Becker, W., Saisana, M., Paruolo, P., & Vandecasteele, I. (2017). Weights and importance in composite indicators: Closing the gap. *Ecological Indicators*, *80*, 12–22. https://doi.org/10.1016/j.ecolind.2017.03.056

Bersalli, G., Menanteau, P., & El-Methni, J. (2020). Renewable energy policy effectiveness: A panel data analysis across Europe and Latin America. *Renewable and Sustainable Energy Reviews*, *133*, Article 110351. https://doi.org/10.1016/j.rser.2020.110351

Bieszk-Stolorz, B. (2022). Impact of subsidy programmes on the development of the number and output of RES micro-installations in Poland. *Energies*, *15*(24), Article 9357. https://doi.org/10.3390/en15249357

Bird, L., Bolinger, M., Gagliano, T., Wiser, R., Brown, M., & Parsons, B. (2005). Policies and market factors driving wind power development in the United States. *Energy Policy*, *33*(11), 1397–1407. https://doi.org/10.1016/j.enpol.2003.12.018

Carley, S. (2009). State renewable energy electricity policies: An empirical evaluation of effectiveness. *Energy Policy*, *37*(8), 3071–3081. https://doi.org/10.1016/j.enpol.2009.03.062

Caruana, C., & Pace, P. (2018) Local agenda 21 processes and their implications for the SDGs. In W. Leal Filho, M. Mifsud, & P. Pace (Eds.), *Handbook of lifelong learning for sustainable development* (pp. 293–305). Springer. https://doi.org/10.1007/978-3-319-63534-7_20

Chang, T.-H., Huang, C.-M., & Lee, M.-C. (2009). Threshold effect of the economic growth rate on the renewable energy development from a change in energy price: Evidence from OECD countries. *Energy Policy*, *37*(12), 5796–5802. https://doi.org/10.1016/j.enpol.2009.08.049

Cheba, K., & Bąk, I. (2021). Environmental production efficiency in the European Union Countries as a tool for the implementation of goal 7 of the 2030 agenda. *Energies*, *14*(15), Article 4593. https://doi.org/10.3390/en14154593

Chishti, M. Z., Sinha, A., Zaman, U., & Shahzad, U. (2023). Exploring the dynamic connectedness among energy transition and its drivers: Understanding the moderating role of global geopolitical risk. *Energy Economics*, *119*, Article 106570. https://doi.org/10.1016/j.eneco.2023.106570

Crespi, F. (2016). Policy complexity and the green transformation of the economies as an emergent system property. *Environmental Economics and Policy Studies*, *18*, 143–157. https://doi.org/10.1007/s10018-015-0131-4

Del Rio, P., & Mir-Artigues, P. (2014). Combinations of support instruments for renewable electricity in Europe: A review. *Renewable and Sustainable Energy Reviews*, *40*, 287–295. https://doi.org/10.1016/j.rser.2014.07.039

Domac, J., Richards, K., & Risovic, S. (2005). Socio-economic drivers in implementing bioenergy projects. *Biomass and Bioenergy*, *28*(2), 97–106. https://doi.org/10.1016/j.biombioe.2004.08.002

Elavarasan, R. M., Pugazhendhi, R., Irfan, M., Mihet-Popa, L., Campana, P. E., & Khan, I. A. (2022). A novel sustainable development goal 7 composite index as the paradigm for energy sustainability assessment: A case study from Europe. *Applied Energy*, *307*, Article 118173. https://doi.org/10.1016/j.apenergy.2021.118173

European Commission: Directorate-General for Communication & Leyen, U. (2020). *Political guidelines for the next European Commission 2019–2024*: *Opening statement in the European Parliament plenary session 16 July 2019*; *Speech in the European Parliament plenary session 27 November 2019*. Publications Office of the European Union. https://data.europa.eu/doi/10.2775/101756

European Committee of the Regions. (2019). *A territorial approach for the implementation of the SDGs in the EU – The role of the European Committee of the Regions*. European Union. https://cor.europa.eu/en/engage/studies/Documents/SDGS.pdf

Eurostat. (2023). *Sustainable development goals* (Database). Retrieved March 20, 2023, from https://ec.europa.eu/eurostat/web/sdi/database

Firoiu, D., Ionescu, G. H., Pîrvu, R., Cismas, L. M., Tudor, S., & Patrichi, I. C. (2021). Dynamics of implementation of SDG 7 targets in EU member states 5 years after the adoption of the Paris Agreement. *Sustainability*, *13*(15), Article 8284. https://doi.org/10.3390/su13158284

Faber, T., Green, J., Gual, M., Haas, R., Huber, C., Resch G., Ruijgork, W., & Twidell, J. W. (2001). *Promotion strategies for electricity from renewable energy sources in EU countries* (Review Report of the Project ELGreen). Vienna University of Technology.

Harezlak, J., Ruppert, D., & Wand, M. P. (2018). Penalized splines. In *Semiparametric regression with R*. *use R*! (pp. 15–70). Springer. https://doi.org/10.1007/978-1-4939-8853-2_2

Herrero, C., Pineda, J., Villar, A., & Zambrano, E. (2020). Tracking progress towards accessible, green and efficient energy: The inclusive green energy index. *Applied Energy*, *279*, Article 115691. https://doi.org/10.1016/j.apenergy.2020.115691

Hickel, J., & Kallis, G. (2020). Is green growth possible? *New Political Economy*, *25*(4), 469–486. https://doi.org/10.1080/13563467.2019.1598964

Johnstone, N., Haščič, I., & Popp, D. (2010). Renewable energy policies and technological innovation: Evidence based on patent counts. *Environmental and Resource Economics*, *45*, 133–155. https://doi.org/10.1007/s10640-009-9309-1

Khan, A. M., Kwiatkowski, J., Osińska, M., & Błażejowski, M. (2021). Factors of renewable energy consumption in the European countries – The Bayesian averaging classical estimates approach. *Energies*, *14*(22), Article 7526. https://doi.org/10.3390/en14227526

Kim, S. E., Kim, H., & Chae, Y. (2014). A new approach to measuring green growth: Application to the OECD and Korea. *Futures*, *63*, 37–48. https://doi.org/10.1016/j.futures.2014.08.002

Kuc-Czarnecka, M., Markowicz, I., & Sompolska-Rzechuła, A. (2023). SDGs implementation, their synergies, and trade-offs in EU countries – sensitivity analysis-based approach. *Ecological Indicators*, *146*, Article 109888. https://doi.org/10.1016/j.ecolind.2023.109888

Kuc-Czarnecka, M., Olczyk, M., & Zinecker, M. (2021). Improvements and spatial dependencies in energy transition measures. *Energies*, *14*(13), Article 3802. https://doi.org/10.3390/en14133802

Kulonen, A., Adler, C., Bracher, C., & von Dach, S. W. (2019). Spatial context matters in monitoring and reporting on sustainable development goals: Reflections based on research in mountain regions. *GAIA – Ecological Perspectives for Science and Society*, *28*(2), 90–94. https://doi.org/10.14512/gaia.28.2.5

Lindén, D., Cinelli, M., Spada, M., Becker, W., & Burgherr, P. (2021). *Composite indicator analysis and optimisation* (*CIAO*) *tool*. *Vol*. *2*: *Codebook for practitioners*.

Ma, Y., Li, Y. P., & Huang, G. H. (2023). Planning China's non-deterministic energy system (2021–2060) to achieve carbon neutrality. *Applied Energy*, *334*, Article 120673. https://doi.org/10.1016/j.apenergy.2023.120673

Machiba, T. (2011). Eco-Innovation for enabling resource efficiency and green growth: Development of an analytical framework and preliminary analysis of industry and policy practices. In R. Bleischwitz, P. Welfens, & Z. Zhang (Eds.), *International economics of resource efficiency* (pp. 371–394). Physica-Verlag HD. https://doi.org/10.1007/978-3-7908-2601-2_19

Marcillo-Delgado, J. C., Ortego, M. I., & Pérez-Foguet, A. (2019). A compositional approach for modelling SDG7 indicators: Case study applied to electricity access. *Renewable and Sustainable Energy Reviews*, *107*, 388–398. https://doi.org/10.1016/j.rser.2019.03.028

Marques, A. C., & Fuinhas, J. A. (2012). Are public policies towards renewables successful? Evidence from European countries. *Renewable Energy*, *44*, 109–118. https://doi.org/10.1016/j.renene.2012.01.007

Marques, A. C., Fuinhas, J. A., & Manso, J. R. P. (2010). Motivations driving renewable energy in European countries: A panel data approach. *Energy Policy*, *38*(11), 6877–6885. https://doi.org/10.1016/j.enpol.2010.07.003

McCollum, D., Gomez Echeverri, L., Riahi, K., & Parkinson, S. (2017). SDG7: Ensure access to affordable, reliable, sustainable and modern energy for all. In D. J. Griggs, M. Nilsson, A. Stevance, & D. A. McCollum (Eds.), *Guide to SDG interactions: From science to implementation* (pp. 127–173). International Council for Science.

Menz, F. C., & Vachon, S. (2006). The effectiveness of different policy regimes for promoting wind power: Experiences from the States. *Energy Policy*, *34*(14), 1786–1796. https://doi.org/10.1016/j.enpol.2004.12.018

Moallemi, E. A., Malekpour, S., Hadjikakou, M., Raven, R., Szetey, K., Ningrum, D., Dhiaulhaq, A., & Bryan, B. A. (2020). Achieving the sustainable development goals requires transdisciplinary innovation at the local scale. *One Earth*, *3*(3), 300–313. https://doi.org/10.1016/j.oneear.2020.08.006

Neelawela, U. D., Selvanathan, E. A., & Wagner, L. D. (2019). Global measure of electricity security: A composite index approach. *Energy Economics*, *81*, 443–453. https://doi.org/10.1016/j.eneco.2019.04.009

Nelder, J. A., & Mead, R. (1965). A simplex method for function minimization. *The Computer Journal*, *7*(4), 308–313. https://doi.org/10.1093/comjnl/7.4.308

Nerini, F., Tomei, J., To, L. S., Bisaga, I., Parikh, P., Black, M., Borrion, A., Spataru, C., Broto, V., Anandarajah, G., Milligan, B., & Mulugetta, Y. (2018). Mapping synergies and trade-offs between energy and the sustainable development goals. *Nature Energy*, *3*, 10–15. https://doi.org/10.1038/s41560-017-0036-5

Nilsson, M., Chisholm, E., Griggs, D., Howden-Chapman, P., McCollum, D., Messerli, P., Neumann, B., Stevance, A-S., Visbeck, M., & Stafford-Smith, M. (2018). Mapping interactions between the sustainable development goals: Lessons learned and ways forward. *Sustainability Science*, *13*, 1489–1503. https://doi.org/10.1007/s11625-018-0604-z

OECD. (2008). *Handbook on constructing composite indicators*: *Methodology and user guide*. OECD Publishing. https://www.oecd-ilibrary.org/economics/handbook-on-constructing-composite-indicators-methodology-and-user-guide_9789264043466-en

Ozturk, I. (2010). A literature survey on energy-growth nexus. *Energy Policy*, *38*(1), 340–349. https://doi.org/10.1016/j.enpol.2009.09.024

Papież, M., Śmiech, S., & Frodyma, K. (2018). Determinants of renewable energy development in the EU countries. A 20-year perspective. *Renewable and Sustainable Energy Reviews*, *91*, 918–934. https://doi.org/10.1016/j.rser.2018.04.075

Payne, J. E. (2010). A survey of the electricity consumption-growth literature. *Applied Energy*, *87*(3), 723–731. https://doi.org/10.1016/j.apenergy.2009.06.034

Pereira, L., Pinto, M., Costa, R. L. D., Dias, Á., & Gonçalves, R. (2021). The new SWOT for a sustainable world. *Journal of Open Innovation*: *Technology*, *Market*, *and Complexity*, *7*(1), Article 18. https://doi.org/10.3390/joitmc7010018

Pradhan, P., Costa, L., Rybski, D., Lucht, W., & Kropp, J. P. (2017). A systematic study of sustainable development goal (SDG) interactions. *Earth's Future*, *5*(*11*), 1169–1179. https://doi.org/10.1002/2017EF000632

Roussafi, F. (2021). Regional development trajectories of renewable energy: Evidence from French regions. *Energy Strategy Reviews*, *35*, Article 100639. https://doi.org/10.1016/j.esr.2021.100639

Satterthwaite, D. (2017). Successful, safe and sustainable cities: Towards a new urban agenda. *Commonwealth Journal Local Governance*, *19*, 3–18. https://doi.org/10.5130/cjlg.v0i19.5446

Scharlemann, J. P. W., Brock, R. C., Balfour, N., Burgess, N. D., Guth, M. K., Ingram, D. I., Lane, R., Martin, J. G. C., Wicander, S., & Kapos, V. (2020). Towards understanding interactions between sustainable development goals: The role of environment–human linkages. *Sustainability Science*, *15*, 1573–1584. https://doi.org/10.1007/s11625-020-00799-6

Söderholm, P. (2020). The green economy transition: The challenges of technological change for sustainability. *Sustainable Earth*, *3*, Article 6. https://doi.org/10.1186/s42055-020-00029-y

Stock, J. H., & Watson, M. W. (2020). *Introduction to econometrics* (4th ed.). Pearson.

Tee, W.-S., Chin, L., & Abdul-Rahim, A. S. (2021). Determinants of renewable energy production: Do intellectual property rights matter? *Energies*, *14*(18), Article 5707. https://doi.org/10.3390/en14185707

Tiba, S., & Omri, A. (2017). Literature survey on the relationships between energy, environment and economic growth. *Renewable and Sustainable Energy Reviews*, *69*, 1129–1146. https://doi.org/10.1016/j.rser.2016.09.113

Torres-Reyna, O. (2007). *Panel data analysis fixed and random analysis using Stata*. Data and Statistical Services. Princeton University.

Tuchno, G. T., & Kumsa, D. M. (2020). Challenges of achieving sustainable development goal 7 from the perspectives of access to modern cooking energy in developing countries. *Frontiers in Energy Research*, *8*. https://doi.org/10.3389/fenrg.2020.564104

United Nations Development Programme. (2020). *Human development report 2020*: *The next frontier*: *Human development and the anthropocene*. https://hdr.undp.org/content/human-development-report-2020

United Nations Development Programme. (2019). *Human development report 2019*: *Beyond income*, *beyond averages*, *beyond today*: *Inequalities in human development in the 21st century*. https://hdr.undp.org/content/human-development-report-2019

United Nations Development Programme. (2016). *Human development report 2016*: *Human development for everyone*. https://hdr.undp.org/content/human-development-report-2016

United Nations Development Programme. (2015). *Human development report 2015*: *Work for human development*. https://hdr.undp.org/content/human-development-report-2015

United Nations Development Programme. (2014). *Human development report 2014*: *Sustaining human progress*: *Reducing vulnerabilities and building resilience*. https://hdr.undp.org/content/human-development-report-2014

United Nations Development Programme. (2013). *Human development report 2013*: *The rise of the south*: *Human progress in a diverse world*. https://hdr.undp.org/content/human-development-report-2013

Wang, Y. (2006). Renewable electricity in Sweden: An analysis of policy and regulations. *Energy Policy*, *34*(10), 1209–1220. https://doi.org/10.1016/j.enpol.2004.10.018

Wang, H., & Chen, W. (2019). Modelling deep decarbonization of industrial energy consumption under 2-degree target: Comparing China, India and Western Europe. *Applied Energy*, *238*, 1563–1572. https://doi.org/10.1016/j.apenergy.2019.01.131

Wang, S., Yin, C., Yang, X., & Richel, A. (2023). Barter mode: The institutional innovation for affordable and clean energy (SDG7) in rural China. *Biomass and Bioenergy*, *170*, Article 106725. https://doi.org/10.1016/j.biombioe.2023.106725

Warchold, A., Pradhan, P., & Kropp, J. P. (2021). Variations in sustainable development goal interactions: Population, regional, and income disaggregation. *Sustainable Development*, *29*(2), 285–299. https://doi.org/10.1002/sd.2145

West, J., Bailey, I., & Winter, M. (2010). Renewable energy policy and public perceptions of renewable energy: A cultural theory approach. *Energy Policy*, *38*(10), 5739–5748. https://doi.org/10.1016/j.enpol.2010.05.024

Yang, L. (2014). *An inventory of composite measures of human progress* (Occiasional Paper). United Nations Development Programme Human Development Report Office. https://hdr.undp.org/system/files/documents/inventoryreportworkingpaper.pdf

Yu, Z., Khan, S. A. R., Ponce, P., Lopes de Sousa Jabbour, A. B., & Jabbour, C. J. C. (2022). Factors affecting carbon emissions in emerging economies in the context of a green recovery: Implications for sustainable development goals. *Technological Forecasting and Social Change*, *176*, Article 121417. https://doi.org/10.1016/j.techfore.2021.121417

Zhao, D., Cai, J., Shen, L., Elshkaki, A., Liu, J., & Varis, O. (2023). Delivery of energy sustainability: Applications of the "STAR" protocol to the sustainable development goal 7 index and its interaction analysis. *Journal of Cleaner Production*, *389*, Article 135884. https://doi.org/10.1016/j.jclepro.2023.135884