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TRANSITION TO A SUSTAINABLE ENERGY PRODUCTION AND CONSUMPTION MODEL – MAPPING THE PATTERNS OF SUCCESS

Maria-Floriana POPESCU [1,2*], Marius CONSTANTIN [3#], Bogdan Cristian CHIRIPUCI [4]

[1]The Research Center in International Economic Relations (CCREI), Bucharest University of Economic Studies, Bucharest, Romania
[2]International Business and Economics Department, Faculty of International Business and Economics, Bucharest University of Economic Studies, Bucharest, Romania
[3,4]Agri-food and Environmental Economics Department, Faculty of Agri-food and Environmental Economics, Bucharest University of Economic Studies, Bucharest, Romania

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Abstract. This research paper fills a literature gap by tapping into Europe's Just Transition to green energy production and consumption models and introduces empirically derived trends. The mix of analysed variables was targeted at sustainable energy transformation models according to complementary economic research areas. Based on the clustered heat maps method, double dendrograms were constructed to identify socioeconomic and environmental patterns that characterize highly economic-efficient and sustainable transition patterns from the standard energy production and consumption model to the environmental-friendly and cost-efficient model in the European area. Results show that Austria, Denmark, Norway, Ireland, and Luxembourg followed the patterns of highly economically performant European countries that turned energy and resource productivity in their favour based on multiple factors: recycling, R&D, innovation, digitization. The opposite was observed in the case of many South-Eastern European countries. Robustness checks were performed based on the linear discriminant analysis methodology and results confirmed that Northern European countries lead the change to a more sustainable future. In this context, this research brings empirical results for decision-makers and aims to facilitate a better understanding for adapting policies according to national needs, as well as to the patterns of success identified in the case of European leaders.

Keywords: sustainable energy model, sustainability, economics of clean energy, renewable energy, environmental and economic efficiency, performance assessment, clustered heat maps, double dendrograms.

JEL Classification: K32, C38, Q01.

*Corresponding author. E-mail: *maria.popescu@rei.ase.ro*
#Corresponding author. E-mail: *marius.constantin@eam.ase.ro*

Introduction

Transitioning from fossil fuels to green energy sources needs a new energy system and customer motivation to alter their consumption patterns to balance demand and a volatile energy supply and embrace new technology such as smart metres. The energy transfer is motivated by a multitude of factors. They vary by country and sometimes also by area due to the unique challenges posed by geography, the historical evolution of national energy markets, and cultural influences.

Energy markets are now experiencing significant changes to accommodate emerging (renewable) sources of energy, new (decentralized) players in the energy, and new system specifications, such as versatility and resilience (International Energy Agency, 2018). Therefore, conventional energy markets for fossil fuels are under (Oei & Mendelevitch, 2019), while renewable energy markets are not yet fully mature (Caldecott, 2018; International Renewable Energy Agency, 2017). As a result, investments in large-scale and capital-intensive energy production projects are surrounded by high uncertainty. They are difficult for private companies to hedge because they could lead to stranded assets (Löffler et al., 2019). Traditional energy-producing companies are becoming providers of energy services, and companies with various potential industry entrants are emerging, with regulatory and device management playing a growing role. Economic research, planning, modelling, and investment evaluation require new methods and approaches to overcome these growing uncertainties and complexities. In order to model multiple actor interactions and peculiar behaviour, novel research is therefore required (Hansen et al., 2019). The interventions needed can deal with the availability of electricity and provide active demand and cover structural aspects. Policy-making is challenged therefore by energy transition. Failure to organize the sector, eliminating obstacles to consolidation and mixing market signals with command-and-control policy interventions are some of the current goals of the policy (von Hirschhausen et al., 2018).

Successful local action needs a supportive and encouraging national structure, enabling local and regional governments to tackle climate change comprehensively. Research shows that citizens, enterprises, and industries look at their government to address challenges and secure their future (Istudor et al., 2019; Doppelt, 2017; Evans & Yen, 2005). These environmental issues are pertinent at the local community level, where the effects can and should be discussed. Democratic engagement in local decision-making processes and execution can be quicker, and intervention can directly affect action at other government levels. It does not, however, mean that other layers have disengaged or do not need to participate. Increasingly, local councils are taking action because they have recognised the need and benefits of their actions. Energy recycling and advanced energy-efficiency technology are prevalent action fields aimed at reducing energy usage and saving costs (Pătărlăgeanu et al., 2020). In the short-term, instant or quick financial gains can be gained; for example, using more effective technology, the amortisation period on investment can lead to savings. It can be accomplished by adding energy-efficient lighting in cities and more costly buildings like building restoration to meet new energy standards (low energy, passive house, or zero energy). Urban communities – cities and towns of all sizes – are adapting to these threats by investing in local climate and energy actions.

In order to satisfy the commitments to a low-carbon energy transition, it is critical to developing policy frameworks that allow for international trade and investments. In order to make the transition to a low-carbon energy system more affordable, policies that foster open, competitive, and demand-driven markets for such systems are necessary, as they help reduce the number of public subsidies required to speed up the deployment of low-carbon technologies. Regional solutions for low-carbon investment, such as a designated fund, comprehensive warranty schemes, incentivizing policies, and quality infrastructure, are vital to overcoming investment barriers (Anbumozhi et al., 2018).

New coal-fired power facilities must be phased out in favour of substantial expenditures in renewable energy sources. There must also be a significant investment in electric vehicles (and better batteries) and a dramatic decrease in the number of vehicles powered by fossil fuels. Low- and middle-income countries, and developing ones need to invest heavily in water and sanitation infrastructure in rapidly expanding metropolitan areas. With these issues in the spotlight, there are three significant hurdles to overcome: finding the correct projects, establishing complex plans involving public and commercial sectors (and sometimes more than one country), and organizing the funding (Sachs et al., 2019). For both investors and fund managers, this kind of behaviour would allow them to implement strategies in various volatility or economic activity contexts through a well-diversified portfolio and climate-friendly structure (Leitao et al., 2021).

Investors' confidence is also affected by the lack of experience and capacity limitations in local financial industries. In the case of renewable energy initiatives, this is especially critical because the industry is still in its early stages and has not yet been fully commercialized. Investing in developing countries might prevent investors from participating in these markets, as they might be influenced by these factors – uncertain banking laws, a lack of swap markets, and inconsistencies in financial disclosures (Sachs et al., 2019). Additionally, clean energy projects necessitate early equity in order to be bankable. Effective long-term planning and budgeting are essential to government success.

Sustainable energy production should provide sufficient energy to meet basic needs, enhance social security, and ensure economic development. Sustainable energy production should not jeopardise the quality of life of future generations and should not be harmful to vital ecological processes (Geller, 2012). A clean energy future is feasible, emphasizing green energy and more significant energy conservation than current trends afford. Improved energy production will lower energy consumption, reduce the costs of large energy projects, and boost energy services in developed and developing nations (Pătărlăgeanu et al., 2021). An economic transition from fossil fuels to renewable energies is aimed to fix all the challenges associated with current energy systems. Although energy efficiency is critical, the transition to renewable sources should not be overlooked. The balance of green energies and energy storage technologies is essential to preparing and achieving a low-carbon energy transition.

The main objective of this research was to identify socioeconomic and environmental patterns that characterize highly economic-efficient and sustainable transition patterns from the standard energy production and consumption model to the environmental-friendly and cost-efficient model in the European area, based on statistical evidence coming from prosperous European leading countries in this field. The novelty factor of this paper comes from multiple perspectives: (i) the patterns of the transition to desirable energy production and consumption model was observed through the lens of a self-designed regional country classification and validated by the results from the linear discriminant analysis, which was designed to provide robustness to the research findings; (ii) recommendations were based on the analytical hierarchical clustering approach on the research topic – at the level of the analysed regions and indicators.

This paper is structured in three main sections: the first section consists of the review elaborated on recent and valuable papers written in the field of the economics of clean energy; the second section includes details regarding the research method, as well as the conceptual reasoning concerning the design of the research; while findings are discussed in the third section, with a focus on the solutions identified that can help for a more efficient transition to the desired energy production and consumption model in the European area. Section 4 provides robustness to the research findings by resorting to the results obtained from carrying out a linear discriminant analysis.

1. Literature review

Transitioning from fossil fuels to renewable energy sources often entails constructing a sustainable energy grid, encouraging customers to adjust their consumption patterns to meet an unpredictable energy supply and new technology like smart metres. The Third Energy Package (European Commission, 2019) calls for the Member States to recognise energy-vulnerable consumers and implement policies to mitigate energy poverty. For example, in 2014, 10.3% of EU citizens could not keep their homes adequately warm, while in 2019, the estimation was 7% (Eurostat, 2021).

According to various research papers, expanding sustainable energy networks to the citizens' involvement in their energy supply chains leads to the rise of whole new businesses and worldwide transition to greener sources. The transition can be subject of financial involvement from citizens to renewable energy projects (Holstenkamp & Kahla, 2016; Yildiz, 2014) or business models that actively promote co-ownership or local energy generation, granting a cooperative property right to all producers and consumers (Gorroño-Albizu, 2020; Torabi Moghadam et al., 2020; Lowitzsch, 2020, 2019; Lowitzsch & Hanke, 2019). Examples of these business models include equitable distribution (Koirala, Chaves Ávila et al., 2016; Koirala, Koliou et al., 2016), personal capital-building (Szulecki, 2018; Fairchild & Weinrub, 2017; Becker & Naumann, 2017; Morris & Jungjohann, 2016), sustainability by the localised use of community power (Radtke et al., 2020; Radtke, 2014; Hoffman & High-Pippert, 2010) and societal decoupling (Alexander & Yacoumis, 2018; Ferrari & Chartier, 2018; Rommel et al., 2018; Kunze & Becker, 2015). Additionally, community participation in providing electricity and heating at a lower cost leads to changes in consumer behaviour that result from their local utility companies, and renewable energy support initiatives are also brought to light (Sifakis et al., 2019; Chalkiadakis et al., 2018; Šahović & Da Silva, 2016; Beggio & Kusch, 2015; Haney & Pollitt, 2013). Further study of these findings is necessary because an experiment or investigation to detect a cause and effect on the relationship between participation in energy initiatives and energy usage is not yet thoroughly researched (Höfer & Rommel, 2015).

The academic literature is not abundant on papers holistically and empirically addressing the socioeconomic and environmental patterns characterizing the smooth and sustainable transition to the environmental-friendly and cost-efficient energy consumption and production model, especially not in the context of the beginning of the new financial framework in the EU (2021–2027), under the influence of the implementation of the European Green Deal and the Recovery and Resilience Plans. This paper aims at filling the identified gap in the literature. However, since relevant papers are tackling the patterns of this transition from multi-faceted perspectives, Table 1 was elaborated to review the main findings and research methods approached in the literature.

Table 1. Examples of transition patterns (source: authors' selection)

Authors and publication year	Method	Findings
Augutis et al. (2011)	The authors designed an assessment algorithm for the security of energy supply in the context of a Nuclear Power Plant shutdown. The system of indicators included the technical block, the economic block, and the socio-political block.	The shutdown of a Nuclear Power Plant in Lithuania had multidimensional effects on the economics and security of energy. On the one hand, higher prices for electricity energy were recorded. On the other hand, the shutdown facilitated the development conditions of the free electricity market. Therefore, consumers were able to choose electricity producers according to their needs. As far as the sustainability factor is concerned, the diversity of fuel represents an essential element, and, on top of that, it also ensures higher levels of energy security.
Soava et al. (2018)	The authors applied the linear regression methodology and Granger causality test to study the impact of renewable energy consumption on the economic growth of the EU members.	The results based on panel data techniques suggest the positive impact of renewable energy consumption on economic growth and the bidirectional or unidirectional Granger causality between the selected indicators for each country (28). The authors argue that these findings justify the EU's political decisions to design its path to a more sustainable future, both economically and energetically.
Mills et al. (2020)	Toda-Yamamoto Granger causality, generalized impulse response, and variance decomposition	The economy-energy-environment nexus was explored in the USA and China, taking multiple factors into account: carbon emissions, economic growth, energy consumption, financial development, urbanization, and trade openness. Findings implied that CO_2 emissions were significantly influenced by the previously mentioned factors, directly impacting climate change.
Caruso et al. (2020)	Panel Vector Auto Regression (PVAR) focused on the cross-sectional aspect and bidirectional effects	The decrease in electricity production from oil, gas, coal, and nuclear sources does not positively impact renewable energy consumption. That is why policymakers need to make more efforts to find instruments designed to synergistically foster the sustainable economic development through the expansion of the energy market, respecting the natural capital at the same time.

End of Table 1

Authors and publication year	Method	Findings
Cepoi et al. (2020)	The environmental Kuznets curve and the STIRPAT model, smooth transition regression (PSTR)	The authors studied the negative relationship between CO_2 emissions and fuel ethanol consumption in an econometric manner. They demonstrated that countries with high levels of income inequality encounter issues in avoiding the degradation of the natural capital by empowering policies designed to foster the intensification of biofuels usage.
Voicu-Dorobanțu et al. (2021)	Cluster analysis based on the traditional k-means methodology (squared Euclidean distances)	European countries like Czechia and Poland have managed to adapt to Just Transition Mechanism successfully. In contrast, countries like Romania face vulnerabilities regarding the ongoing transition in the EU in the European Green Deal context.

Hundreds of major EU laws are directly or indirectly related to environmental preservation and the management of natural resources (Langlet & Mahmoudi, 2016). For the most part, the European Union is a signatory to the great majority of global and essential regional multilateral environmental accords. According to a vision for the year 2050, ecological restrictions on the globe have become a major driving force in environmental policy. Nevertheless, it is also clear that the EU is still working hard to break the link between Europeans' way of life and the enormous strain it places on local and global ecosystems, frequently beyond the Union's borders.

In many cases, a more fundamental goal that is gradually refined, fine-tuned, and translated into measures at the national or regional level is a logical and even required strategy when dealing with particularly complicated situations. However, there are certain negatives to it. There is a more significant possibility of uneven policies and divergent degrees of protection if the Member States are left to decide (intermediate) aims and weigh up possibly opposing interests. However, it may be challenging to attain when multiple national authorities' policy choices and degree of ambitions are more important than a common goal. According to Peeters and Uylenburg (2014), widespread criticism of EU initiatives is that increasingly ambiguous criteria make it difficult to evaluate the impact of EU actions and weaken accountability. There is a common perception that newer and more flexible types of regulation mean less regulation. However, this is not always the case and does not necessarily mean less expense or less responsibility for public authorities.

This paper complements the existing literature and expands the field of knowledge with a unique empirical approach by mapping the patterns of the Just Transition to a sustainable energy production and consumption model in Europe. In this paper, the European leaders of the smooth transition were spotlighted through cluster analysis research. Moreover, the successful patterns that contributed to success in the race for the Just Transition were pinpointed, thus aiming to make policy-makers fully aware of the vectors of change that can deliver performance.

2. Materials and methods

The raw data used in this research paper were extracted from the official Eurostat database. There are 12 indicators included in this analysis, in the case of 30 European countries – per region, as specified in Table 2.

Table 2. The regional classification of the analysed European countries

Regions	Countries
Western Europe	France, Ireland, Netherlands, Portugal, Spain, United Kingdom
Northern Europe	Denmark, Estonia, Finland, Iceland, Latvia, Lithuania, Norway, Sweden
Southern Europe	Bulgaria, Croatia, Cyprus, Greece, Italy, Malta, Serbia
Central Europe	Austria, Belgium, Czechia, Germany, Hungary, Poland, Romania, Slovakia, Slovenia

The reasons behind the classification in Table 2 are the following: (i) in order to mitigate the socioeconomic and environmental gaps between the Western and Eastern European countries (Jentleson, 1986), the study was carried out based on a design that excluded Eastern Europe as a European region and the classification was grounded on four central European regions that also include Eastern European countries (as observed in Table 2: Romania, Bulgaria, Serbia etc.); (ii) since the research was carried out in an analytical hierarchical manner, grouping more less-performant countries in terms of energy production and consumption models in one region (i.e., Central Europe) (Andrei et al., 2019) and less highly-performant countries in another different region (i.e., Northern Europe) (Fallahi & Voia, 2015) represented an advantage for highlighting the identifying patterns that Central European countries should follow for consolidating their roles in the transition to the economy of green energy efficiency, characterized by sustainable production and consumption behaviours. However, even by such a grouping, this study demonstrated that more effort is needed in order for Central European countries to catch up to the Northern European countries – and not only in the energy sector but in many more aspects that refer to the economics of wellbeing.

In this paper, the research focus was on a particular timeframe: 2014–2018. The indicators included in this analysis cover three fundamental interconnected areas relevant to mapping the transition patterns to sustainable energy production and consumption model in Europe. Table 3 contains details concerning the profile of these indicators:

The use of so many indicators in this research is considered from the following example of the mechanisms we have developed to track economic progress. The GDP measures the monetary value of all the finished goods and services produced within a country's boundaries in a certain period (Yunus & Weber, 2017). Government agencies take great care in calculating GDP, and the results are frequently published in the media. It is frequently used as a yardstick by which to judge the economic system of a country. A perceived lack of GDP development has even led to governments falling and experiencing shortages. Therefore, the economic progress of a specific country goes more than evaluating the GDP, as it should be evaluated in a broader context, not just by aggregating information about individual performance.

Table 3. Methodological description of data and variables

Variable Theme	Item no.	Abbreviation	Name of the Variable	Unit of Measurement	Short methodological description of the variable	Rationale
A. Sustainable, Innovative, and Digital Economy	1	A1	Real GDP per capita	euro per capita, chain-linked volumes, 2010	Part of the EU's SDGs, expresses the ratio of the real GDP to the average population, yearly	In the context of resource scarcity, assessing and improving resource productivity is essential for any sustainable economy. Connecting resource productivity with the nominal GDP is essential for understanding economic and environmental efficiency (Fu et al., 2015), energy consumption patterns, and governmental budgetary implications (Khajehpour et al., 2020). Moreover, Borowski (2021) analysed the linkage between consumer behaviour on the internet and the energy sector, emphasizing the importance of integrating industry 4.0 solutions by the enterprises active in the energy sector.
	2	A2	Resource productivity	euro per kg, chain-linked volumes, 2010	Part of the EU's SDGs, represents GDP divided by domestic material consumption	
	3	A3	Individuals using the internet for finding information about goods and services	percentage	Represents the ratio of the individuals aged 16–76 who use the internet for finding information about goods and services to the total individuals aged 16–76	
	4	A4	GDP expenditure on R&D	percentage	Part of EU's SDGs, expresses the ratio of the GDP on R&D to the total GDP	
	5	A5	Governmental deficit/surplus, debt	percentage of GDP	Represents the net borrowing or lending of the general government	
B. Circular and Green Economy	6	B1	Generation of municipal waste	kg per capita	Part of the Circular Economy indicator set, represents the waste collected through the waste management system	The transition to the circular economy model requires a comprehensive understanding of waste and recycling behaviours, analysed concerning resource productivity, governmental budget allocation, innovation (Banacu et al., 2019).
	7	B2	Recycling rate of municipal waste	percentage of total waste	Part of the Circular Economy indicator set, measures the share of recycled municipal waste in the total municipal waste generation	

End of Table 3

Variable Theme	Item no.	Abbreviation	Name of the Variable	Unit of Measurement	Short methodological description of the variable	Rationale
C. Economic-efficient, Clean and Sustainable Energy Models	8	C1	Share of renewable energy in gross final energy consumption	percentage	Part of the EU's SDGs, measures the share of renewable energy consumption in gross final energy consumption based on the Renewable Energy Directive	A sustainable energy supply is required for a country's economic progress. A country's social and long-term economic development may be harmed if effective, sustainable planning and methods for a consistent supply of clean energy are not implemented. As a result, a country's sustainability must remain a top focus to reduce reliance on non-renewable energy sources (Simionescu et al., 2020).
	9	C2	Final energy consumption in household per capita	kg of oil equivalent per capita	Part of the EU's SDGs, quantifies nominal energy consumption at home. The only energy considered is one of the end consumers	
	10	C3	Energy productivity	euro per kg	Part of the EU's SDGs, expresses the ratio of GDP to the gross available energy, quantifies the degree of decoupling of energy use from growth in GDP	
	11	C4	Greenhouse gas emissions from the energy sector	million tonnes of CO_2 equivalent	Part of the EU's SDGs, measures total national emissions from the energy sector	
	12	C5	Energy import dependency	percentage	Part of the EU's SDGs, represents the ratio of total energy needs of a country to the energy import from foreign countries	

The Clustered Heat Maps Method – Double Dendrograms procedure was applied to the data to hierarchically plot-clustering in two directions: one referring to the countries of analysis and one referring to the indicators mentioned in Table 3. Based on the methodology, the two most similar clusters are joined into a single new cluster, gradually and continuously, until all indicators and countries are mapped. Once fused, observations were never separated. The simple average (weighted pair-group) clustering method was applied based on the Euclidean distance type. The distance between groups is considered the average distance between each observation, equally-weighted for the two groups to influence the final result equally.

Regarding clustering validation, the cophenetic correlation coefficient was calculated. It represents the actual distances and those that result from the cluster configuration. This type of correlation is the Pearson correlation between the resulting distances and the predicted ones, based on a specific hierarchical configuration. A value of 0.75 or above is expected for the clustering to be considered meaningful (Holgersson, 1978). Another measure of goodness of fit performed in this type of quantitative research is called delta, described by Mather (1976). This test refers to the degree of distortion rather than the degree of resemblance (compared to the cophenetic correlation). Delta coefficients are given by Eq. (1):

$$\Delta_A = \left[\frac{\sum_{j<k}^{N} \left| d_{jk} - d_{jk}^{*} \right|^{1/A}}{\sum_{j<k} \left(d_{jk}^{*} \right)^{1/A}} \right]^{A}. \quad (1)$$

A can be either 0.5 or 1, and d_{jk}^{*} is the cophenetic distance obtained from the cluster configuration. Values as close to zero are desirable; configurations with the smallest delta value fit the data better.

Robustness checks were performed with the help of the discriminant analysis methodology, as this proved to be a solid test for validating results based on clustering methods. For example, Chang et al. (2018) explored energy consumption models in the case of a region of China using K-means clustering algorithms and discriminant analysis. Skordoulis et al. (2020) used the same combination of methods to assess Greece's transition to a sustainable energy consumption model. In the case of this study, from a methodological perspective, three sums of squares and cross products matrices were defined: S_T, S_W, and S_A considering K groups, N_k observations per group, with each observation consisting of the measurement of p variables. In this context, K_{ki} represents the ith observation and M – the vector of means of these variables across all groups. Lastly, the vector of means of observations in the k_{th} group was named M_k. Moreover, two degrees of freedom values were defined, df1 (K – 1) and df2 (N – K), as well as a parameter of goodness-of-fit, Wilks' Lambda (Λ), in Eq. (5).

$$S_T = \sum_{k=1}^{K} \sum_{i=1}^{N_k} \left(X_{ki} - M \right) \left(X_{ki} - M \right)'; \quad (2)$$

$$S_W = \sum_{k=1}^{K} \sum_{i=1}^{N_k} \left(X_{ki} - M_k \right) \left(X_{ki} - M_k \right)'; \quad (3)$$

$$S_A = S_T - S_W; \tag{4}$$

$$\Lambda = \prod_{j-1}^{m} \frac{1}{1+\lambda_j}. \tag{5}$$

λ_j represents the j_{th} eigenvalue corresponding to the eigenvector described above, and m is the minimum of K-1 and p. The within-group covariance matrix (W) was given by Equation (6), while the linear discriminant functions were defined according to Eq. (7).

$$W = \left(\frac{1}{N-K}\right) S_W; \tag{6}$$

$$LDF_k = W^{-1} M_k. \tag{7}$$

The discriminant analysis methodology was applied, and results were discussed in Section 4 of this paper to ensure more robustness to the findings resulting from the correlation and the clustered heat maps methods.

3. Results and discussions

The socioeconomic and environmental gaps between the European regions were initially studied according to the classification from Tables 2 and 3. Considering the aim to identify the patterns that can ensure the smooth transition to desirable energy production and consumption models, it is necessary to approach the East–West European gaps in an analytical hierarchical manner.

The evolution of the correlations between indicators analysed in Figure 1 illustrates the fact that at the level of the 30 analysed European countries, the share of renewable energy in gross final energy consumption is slowly but steadily scoring better positive Pearson correlation coefficients with the real GDP per capita and with the final energy consumption in household per capita. It signals a tendency at the European level to increase nominal sustainable energy demand and consumption, simultaneously with the increase of the overall purchasing power of the European citizens.

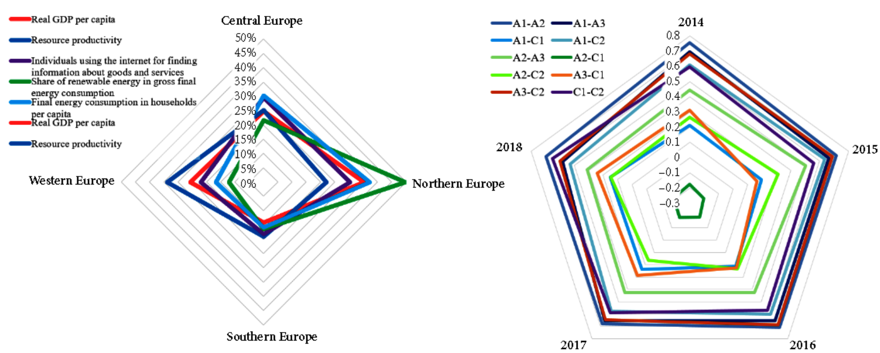

Figure 1. Regional A1, A2, A3, C1, and C2 share from the analysed European area. The evolution of the Pearson correlation coefficient (source: authors' design)

From a hierarchical perspective, the following regional leaders were identified: (a) Northern Europe: the share of renewable energy in gross final energy consumption (49.77%), final energy consumption in household per capita (37.19%), and real GDP per capita (35.37%); (b) Central Europe: almost on the same position with Northern Europe regarding the individuals using the internet for finding information about goods and services, energy providing services included (29.57%); (c) Western Europe: resource productivity (33.76%); (d) Southern Europe: always at the bottom of any ranking, except the one specific to the share of renewable energy in gross final energy consumption. Figure 1 hints that the level of understanding of responsible energy consumption of each European household is influenced by the share of people using the internet, the purchasing power of the European citizens, and energy market accomplishments.

Resource productivity and the real GDP per capita were positively correlated (71.14% on average), but the bond has constantly weakened. A negative and weak correlation was identified between resource productivity and the share of renewable energy in gross final energy consumption, hinting at the fact that the transition to the sustainable energy consumption and production model does not necessarily imply an increase in economic productivity directly but rather a paradigm shift concerning the nature of productivity, which is yet to be analysed and quantified in other studies. However, positive correlation increased trends were observed in the case of: (a) real GDP per capita and the share of renewable energy in gross final energy consumption; (b) the percentage of individuals using the internet for finding information about goods and services and the share of renewable energy in gross final energy consumption; (c) final energy consumption in households per capita and share of renewable energy in gross final energy consumption. These results are encouraging from the perspective of environmentally-friendly practices.

As displayed in Figure 2, municipal waste generation and the recycling rate of municipal waste were positively and weakly correlated in the European countries analysed (39.67% on average), with the maximum correlation in 2014 (48.23%), while the minimum correlation was identified in 2017 (28.77%).

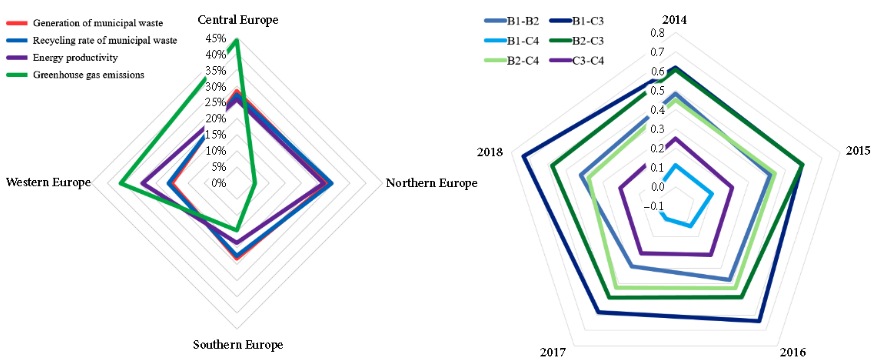

Figure 2. Regional B1, B2, C2, and C4 share from the analysed European area.
The evolution of the Pearson correlation coefficient (source: authors' design)

Judging from a regional perspective, the shares of these two indicators scored from the total are very similar in all four European regions. However, there are specific differences between Europe's Central – Northern regions and Southern–Western regions (27–29% and

20–23%). It indicates a higher level of ecological culture and performant technological equipment used in Northern and Central Europe municipal waste recycling. On the other hand, the productivity of the energy sector (25.77–44.04%) and the generated greenhouse gas emissions (26.75–35.66%) signal a discrepancy between Central and Northern Europe. As far as improvement patterns are concerned, the evolution of the municipal waste recycling rate shows a positive outcome in Hungary and Germany. Interestingly, Germany encountered some issues in 2016 but managed to overcome them in 2017, especially considering its performance in Central Europe.

As it can be noticed in Figure 3 with respect to Central and Northern Europe, the GDP expenditure on R&D scored the best performance (33.90–33.44%), while the southern part of the continent has recorded a poor performance (12.59%). This indicates that Southern Europe was less interested in research and development in this sector than Central and Northern Europe's countries. Not only that, but Northern Europe is also a leader as far as energy import dependency is concerned: mainly due to Norway, the European country that constantly scored negative ratios of the total energy the country needed to the energy import from foreign countries. In this regard, Malta is the most affected by potential energy security issues, looked upon from the perspective of the energy import dependency (scored a ratio of 97.82% in 2018).

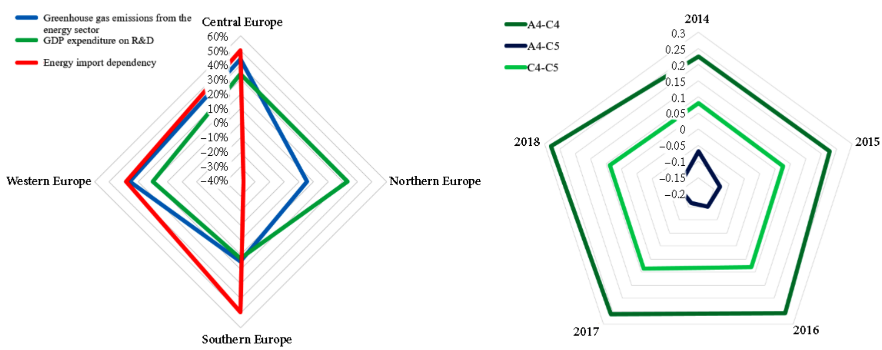

Figure 3. Regional A4, A5, C4, and C5 share from the analysed European area.
The evolution of the Pearson correlation coefficient (source: authors' design)

Regarding the greenhouse gas emissions from the energy sector, Central Europe generated 44.04% of all the greenhouse gas emissions in the 30 analysed European countries, followed by Western Europe (35.83%), Southern Europe (14.46%), and Northern Europe (5.67%). Once again, these findings position Northern European countries as the leaders in terms of the transition to a less polluted Europe, especially from the perspective of the energy sector. In this context, an emergent research question is whether the regional difference in the purchasing power of the individual, R&D financing, the cultural aspect, the energy market accomplishments are they factors that have significantly contributed to ensuring sustainability and energy security in Northern Europe, or are there other factors that helped to generate this gap between Northern Europe and the rest of the European regions? Based on the cluster analysis results, this question is partially answered. To provide a larger picture of the European context, Luxembourg was also included in the cluster analysis.

The clustering design and the heat map in Figure 4 are validated based on the resulting clustering coefficients. Considering the cophenetic correlation coefficient calculated in Table 4: 0.75 in the case of variables and 0.70 in the case of rows, the results are considered optimal for this type of quantitative analysis.

Table 4. Double dendrograms – clustering validation tests (source: authors' computation)

	Clustering variables (selected indicators)	Clustering rows (European countries)
Cophenetic Correlation	0.752164	0.700060
Delta (0.5)	0.160829	0.110637
Delta (1.0)	0.204938	0.136149

From the perspective of Mather's delta coefficients (1976), the proposed model for clustering is optimal since the delta values are 0.11 in the case of clustering rows and 0.16 in the case of clustering variables, corresponding to an A value of 0.5 in Equation 1. Therefore, data is well fit into the clustering model.

Based on results, as far as the energy productivity–real nominal GDP relation is concerned, one can notice the best performing cluster consists of Austria, Denmark, Norway, Ireland, and Luxembourg. Moreover, these countries are the European leaders in terms of resource productivity – cluster average: 2.55 EUR per kg, whereas the average at the level at all the analysed European countries is 0.33 EUR per kg, signalling a considerable gap between the resource productivity leaders and the rest of European countries. Moreover, the recycling rate of municipal waste marks a higher degree of success in transitioning to the circular economy in the analysed cluster (average rate: 49.60%), compared to all the analysed countries (average rate: 38.85%). In the same regard, there were two clusters formed based on their poor performance: first cluster – Bulgaria, Greece, Malta, Portugal, Lithuania, Slovenia; second cluster – Croatia, Latvia, and Serbia, each with different specificities: (a) the countries part of the first cluster understood the importance of R&D and have allocated more significant GDP expenditure in this regard: 1.21% of the GDP on average, compared to the average of 0.84% in the case of the second cluster; (b) recycling is better instrumented in the case of the first cluster (36.7% recycling rate of municipal waste, on average), compared to the second (16.9% on average); (c) the energy import dependency is more unfavourable in the case of the first cluster (73.9%), compared to the second (43.8%).

Regarding the percentage of individuals using the internet for finding information about goods and services, including energy providing services, there is a cluster generated around the European countries whose citizens are well-informed: Czechia, Estonia, Finland, Iceland, and Sweden (cluster average: 83.2%, compared to the 70.7% average in the case of all the analysed European countries). Moreover, respect is also paid in the direction of national education and innovation if considering the GDP expenditure on R&D activities carried out by the members of this cluster compared to the average GDP expenditure on R&D reported by all the analysed countries (2.29% compared to 1.63%). Regarding the share of renewable energy in gross final energy consumption, the European countries part of the analysed cluster registered the best performance compared to the rest of the cluster. They scored an average share of 42.6% of renewable energy in gross final energy consumption, 1.75 times greater than the average of all the analysed countries. However, the final energy nominal consumption scored better overall results (593.2 kg of oil equivalent per capita) than in the case of this cluster (915.2 kg of oil equivalent per capita).

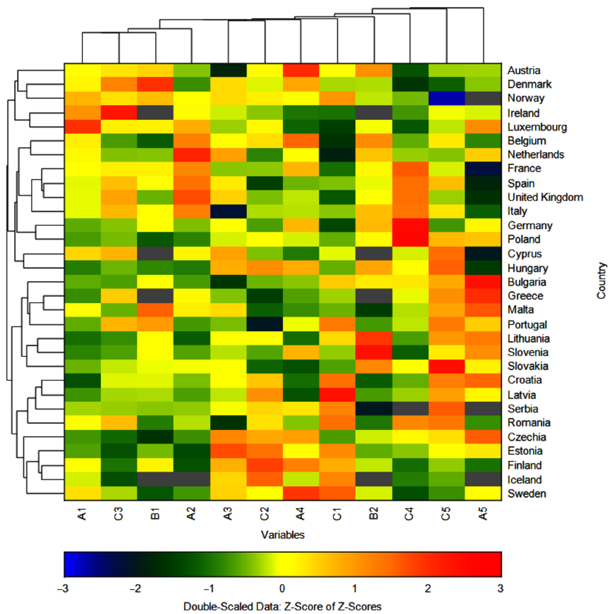

Figure 4. Clustered heat map analysis (source: authors' computation)

The heat map signals that there are certain values well-below the average of the European countries analysed in the case of some indicators: (a) final energy consumption in household per capita: Portugal; (b) the share of renewable energy in gross final energy consumption: the Netherlands; (c) recycling rate of municipal waste: Serbia; (d) energy import dependency by products: Norway (favourable national result, as it signals the lack of energy dependency); (e) government deficit/surplus and debt: Cyprus (favourable national result, as it signals the lack of government debt).

At the same time, looking at the values well-above the average of the indicators analysed in the case of all the European countries: (a) real GDP per capita was recorded the highest in Luxembourg; (b) energy productivity had Ireland as a leader; (c) source productivity: the Netherlands registered the most remarkable performance; (d) real GDP expenditure on R&D analysis had Austria in the top of the ranking; (e) the share of renewable energy in gross final energy consumption by sector was the most favourable in the case of Latvia; (f) greenhouse gas emissions from the energy sector analysis signalled that Germany is the leading European generator of such emissions; (g) energy import dependency by products analysis signalled that Slovakia is facing potential energy security issues; (h) government deficit/surplus and debt: Bulgaria is facing the most significant debt issues.

The mix of variables considered for the cluster analysis were aimed at highlighting performant transitioning models, as well as sustainable energy production and consumption models in Europe. On the one hand, it shows that the European territory has different natural, cultural and educational resources, and, on the other hand, it shows that the analysed countries are trying to converge to the sustainable and circular economic model. They strive to provide future generations with the best possible conditions regarding resource availability and management.

4. Robustness checks

To add robustness to the research findings, a discriminant analysis was carried out to explore membership in naturally occurring groups (Wears, 2002) and provide answers to questions such as: *Can variable combinations help predict membership in a group?*

The estimation method was the linear discriminant function, and, consequently, a set of linear prediction equations were defined, based on values of the indicators described in Table 3, and Table 2 – which contains the classification of the European regions. The regions represent the dependent variable, while the rest of the indicators act as independent variables. The variable influence was computed in Table 5.

Table 5. Variable influence analysis (source: authors' computation)

Variable	Removed Lambda	Removed F-Value	Removed F-Prob	Alone Lambda	Alone F-Value	Alone F-Prob	R^2 Other X's
A1	0.928018	3.03	0.032	0.809514	10.04	0.000	0.879410
A2	0.778995	11.06	0.000	0.628247	25.25	0.000	0.740028
A3	0.606491	25.30	0.000	0.695593	18.67	0.000	0.589969
A4	0.587536	27.38	0.000	0.778989	12.11	0.000	0.766793
A5	0.813538	8.94	0.000	0.861514	6.86	0.000	0.253829
B1	0.971224	1.16	0.329	0.993124	0.30	0.828	0.374845
B2	0.942557	2.38	0.073	0.996805	0.14	0.937	0.366234
C1	0.480762	42.12	0.000	0.472782	47.58	0.000	0.547753
C2	0.754670	12.68	0.000	0.607404	27.58	0.000	0.681979
C3	0.997070	0.11	0.951	0.794827	11.01	0.000	0.724095
C4	0.984218	0.63	0.600	0.843334	7.93	0.000	0.428835
C5	0.882931	5.17	0.002	0.745093	14.60	0.000	0.370601

Removed Lambda represents Wilks' lambda computed to test the impact of removing an independent variable, while the *Alone Lambda* represents Wilks' lambda obtained if one particular independent variable were the only one of this type used in the analysis. *R^2 other X's* represents the R^2 value obtained if a particular independent variable were regressed on the rest of the variables. The exceptions about the F-Prob value exceeding the threshold of 0.05 are B1 – generation of municipal waste and B2 – recycling rate, both types of lambda. In the case of removed lambda, the only exceptions were: C3 – energy productivity and C4 – greenhouse gas emissions from the energy sector. The discriminant scores based on the linear functions were graphically represented in Figure 5.

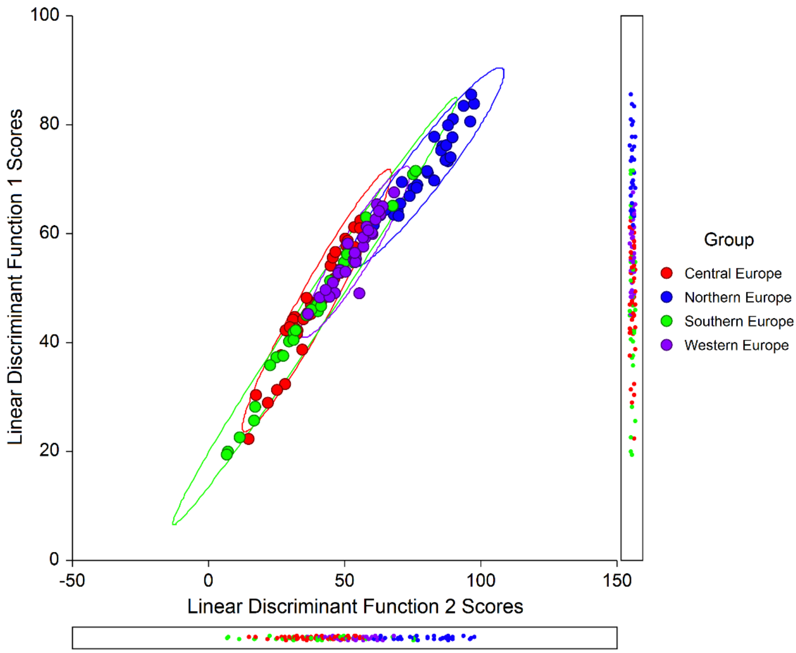

Figure 5. Linear discriminant functions – regional score analysis (source: authors' computation)

Results from the discriminant analysis confirm the overall advance of the Northern European countries in terms of the transition to a more sustainable energy production and consumption model, followed by Western European countries, Central European countries (with positive group-outliers like Germany and negative group-outliers like Poland). In the case of Southern European countries, significant gaps were observed by reporting to the rest of the analysed groups, judging from the perspective of all independent variables. Many factors contributed to the advance of Northern European countries: energy productivity and the share of renewable energy in the gross final energy consumption, the preference for recycling, the transition towards the circular economy model, the national government budget allocation, and the attention paid to the R&D sector – the percentage of the GDP dedicated to R&D activities.

In accordance with the findings of the Nobel Prize winner Muhammad Yunus, results from the discriminant analysis carried out in this study confirm that it is a misguided idea that economic expansion and environmental protection are mutually exclusive goals. A growing economy may pull entire societies out of poverty while also preserving the environment. It is now easier than ever to accomplish, thanks to the latest technological advances. Scientists and engineers have made enormous progress in producing renewable, sustainable sources of energy, less-polluting systems for manufacturing and delivering products, and strategies for agriculture, fishing, mining, and other forms of resource extraction that do not harm the environment (Yunus & Weber, 2017).

Conclusions

Despite recent progress in waste prevention and management, waste generation at the European level remains substantial, and performance to policy targets is mixed. European countries' domestic policy seems to be moving toward its target of reducing waste generated per capita – although waste management still has to change radically to phase out the recyclable or recoverable waste disposal completely and gradually.

The challenges in the field of energy include issues such as increasing import dependencies, limited diversification of energy sources, high energy prices and price volatility, increasing global energy demand, security risks affecting producer and transit countries, the growing threats caused by climate change, slow progress in energy efficiency, the challenges arising from the increasing share of renewable energy, and the need for greater transparency and better integration and interconnection in energy markets. Energy policy at the European level has at its heart a variety of measures aimed at achieving an integrated energy market and ensuring the security of energy supply and the sustainability of the energy sector, provided that investment in research and development is maintained and improved in the medium to long term. Local governments worldwide should pursue energy recycling/conservation, energy sustainability, and the use of clean energy to build energy-resilient cities that use as much renewable energy as possible.

The actions of decision-makers worldwide should follow the following stages for ensuring a smooth transition to a sustainable model of energy production and consumption: systematically provide options for consumer to reduce energy consumption, or at least use energy more efficiently; promote and foster the use renewable energy sources; gradually offer benefits and financial support for the acquisition of new performant and innovative technologies in the field of renewable energy, simultaneously with a proper budgetary allocation for R&D in the energy sector – which is able to propose new solutions for decision-makers, in accordance with the specific demand of the European energy market.

The mix of variables considered for the cluster analysis were aimed at highlighting performant transitioning models, as well as sustainable energy production and consumption models in Europe. Thus, it was found that the countries in Northern Europe offer more importance to the area of research and development in promoting the applicability of renewable energy and recycling mechanisms among the population, focusing on improving the circularity factor in the economy.

The research conducted has some minor limitations, most of which reside in the complexity of approaching the characteristics of the transition to a sustainable energy production and consumption model in a quantitative manner that would ultimately enable pinpointing the exact formula that successfully delivers the desirable economic ecosystem that has both the sustainability and the high economic performance factors at its core. Nevertheless, this research brings a valuable scientific perspective on this topic by mapping some of the patterns of success. In this regard, this research can be further extended by including more variables in the analysis to ensure a broader perspective on the impact of the most influencing factors to the transition to sustainable energy consumption and production model in Europe.

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