

Original Research

(De)coupling Analysis with Focus on Energy Consumption in EU Countries and Its Spatial Evaluation

Jana Chovancová¹, Roman Vavrek^{2*}

¹Faculty of Management, University of Prešov in Prešov, Prešov, Slovak Republic

²Faculty of Economics, Technical University of Liberec, Liberec, Czech Republic

Received: 26 April 2019

Accepted: 10 July 2019

Abstract

Energy is a sector that has a direct impact on quality of life and economic growth. The production and use of energy satisfies human needs, but also gives rise to a host of adverse environmental pressures, such as greenhouse gas emissions, air and water pollution, waste generation and many other negative consequences. Our paper presents a cross-country comparison of decoupling trends in order to assess the impact of economic growth on energy consumption and production of greenhouse gas emissions. The issue of using renewable energy sources in EU countries is also taken into consideration. Decoupling analysis is performed for the time period 2008 and 2016. The results of analysis suggest that resource decoupling (energy consumption) and impact decoupling (GHG emissions) of economic growth (measured in GDP) occur in most observed partial variables, which can be considered as a positive trend. On the other hand, an increased share of renewables in energy production couples in most countries with economic growth, which indicates the positive effect referring to the third-stage of Environmental Kuznets Curve, where the demand for environmental protection tends to increase, leading to a development path characterized by both economic growth and environmental quality improvements. The results of the analysis point to spatial randomness both within the EU and at the country level.

Keywords: decoupling index, spatial evaluation, Moran index, EU countries

Introduction

Energy has been a major issue in the European Union since its beginnings [1]. The evidence is shown by [2], which states that by 2010 the EU had adopted a cumulative total of over 350 energy policy legal instruments and measures. Since the publication of the

White Paper on renewable energy in 1997, the EU has produced policies and legislative measures to promote the market share of renewable, low-carbon and energy-efficient technologies and to foster the better integration of energy-efficient measures into national legislation. However, it has not developed into a fully-fledged, coherent and common energy policy [3]. An important EU goal has been to promote better market conditions for the introduction of new and emerging technologies, and to provide financial incentives for their demonstration.

*e-mail: vavrek.roman@gmail.com

Among the most recent initiatives of the European Union in the field of energy policy is the creation of the Energy Union [4], with ambition on issues such as energy efficiency, renewables, climate change action, clean energy innovation and fair pricing for energy consumers. The idea of an Energy Union can be seen as the most significant policy attempt that seeks to reform European energy governance, policy and regional cooperation, streamlining these with long-term climate protection goals. It creates a platform for integrating sustainability measures into energy policy and assuring that decarbonization of European economies is conducted in a coherent, efficient and timely manner. In the wider perspective, we can see energy policy as one of the priorities of Europe 2020 strategy, where the European Commission sets the following targets: reduce greenhouse gas (GHG) emissions to not less than 20% compared to 1990 levels; increase the share of renewable energy sources (RES) in final energy consumption to 20%; and increase energy efficiency by 20%. The long-term perspective of EU energy policy can be declared, for example, by the Roadmap to a Resource Efficient Europe, which includes a vision for 2050, wherein “the EU’s economy has grown in a way that respects resource constraints and planetary boundaries, thus contributing to global economic transformation” [5]. The Energy Roadmap indicates that by 2050, the EU should reduce GHG emissions by up to 80% compared to 1990 levels; partial steps to achieve this are 40% reduction by 2030 and 60% reduction by 2040 [6].

The EU’s 2020 targets on greenhouse gas emissions, energy consumption and share of renewables in energy production are prominent examples [7]. These and other policies share similar goals and in different ways seek to balance social, economic and environmental considerations. Implementing and strengthening them can help to push science and technological frontiers, create jobs, improve the quality of the environment and enhance competitiveness [8].

Energy policy is still very much dominated by national policies and under the control of member states [3], and this fact determines the approach of each country to the general goals, as it shall formulate its own plans and actions. The paper examines the causal relationship between energy consumption, GHG emissions and the share of renewable sources on economic growth of the EU member states in the period 2008-2016. The quantitative evaluation is based on decoupling model theory.

Findings of the paper are relevant for government, state and public institutions as well as stakeholders in general, who play an important role in the preparation of programs, projects and initiatives to make energy generation and consumption more efficient, and introduce stringent new energy efficiency standards and financing mechanisms to support a more energy-efficient society.

Material and Methods

There is a long-standing debate on the relationship between economic growth and the state of the environment. It has been widely discussed since the second half of the last century. Many authors argue that continued economic expansion in a finite world is not possible, therefore the use of material resources to produce economic growth cannot go on forever, and there has been a growing concern that such growth will cause irreparable damage to our planet [9-11].

Different indicators have been used for measuring both economic and environmental variables [12-14]. The economic variable is usually GDP, either in absolute or per capita form, though many authors have noted that GDP has some shortcomings, as it clusters diverse resources by weight, obscuring huge differences in scarcity, value and associated environmental impacts. It also provides a distorted picture of resource demands from overseas, because it includes only net imports of resources rather than encompassing the raw materials consumed in producing imports [9, 15].

The aim of this paper is to quantitatively assess the relationship between economic growth and related environmental impacts of energy production and consumption in the EU countries in the period 2008-2016 using the decoupling method.

We will particularly focus on the nexus between economic growth (measured in GDP) and final energy consumption, production of GHG emissions and the use of renewable energy sources (RES) for energy production.

The data for analysis were obtained from the databases of the Eurostat: gross domestic product at market prices (million units of national currency), final energy consumption (million tonnes of oil equivalent - TOE), greenhouse gases (CO₂, N₂O in CO₂ equivalent, CH₄ in CO₂ equivalent, HFC in CO₂ equivalent, PFC in CO₂ equivalent, SF₆ in CO₂ equivalent, NF₃ in CO₂ equivalent) (thousand tonnes) and gross inland consumption of RES (thousand TOE).

Energy and Environment Nexus

Historical data see a strong correlation between energy production and consumption and economic and social development. Energy is a basic input in the generation of wealth [16], so the power sector has a crucial role. Any measures adopted in that area should be compatible with the basic principles of sustainable development. The European Union as one of the mayor international actors seeks energy sustainability. One of the five goals set by the EU in 2011, to be achieved by 2020, is fulfilment of several objectives concerning energy and climate change. One of the pillars of the European growth strategy is meeting those green objectives [17]. The interactions between environmental, social and economic phenomena are clearly stated. Therefore, development of proper indicators capable of

collecting those interactions becomes of great interest in order to design energy and environmental policies. Among indicators related to the energy sector can be included energy productivity, CO₂ productivity, energy intensity in different sectors of the economy, and share of energy from renewable sources in gross final energy consumption etc.

In this regard, we will focus our attention on decoupling analysis as a set of methods that enable quantitative assessment of determinant factors influencing changes over time in main energy and environmental aggregates.

The dilemma of expanding economic activities while attempting to stabilize the rate of resource use and reduce environmental impacts poses an unprecedented opportunity and challenge to society. Since most of the world's economies are striving for economic growth, ways to achieve it with less environmental harm are being sought. Several concepts proposed for this include increased eco-efficiency, de-materialisation, immaterialisation, de-linking, decomposition and decoupling. The drawback in these approaches is to get more from less, which means using resources more efficiently in order to produce the same value with less material. The environmental impact remains the same, but the economy grows faster [18].

Within environmental research these approaches have been applied to several areas. "Decarbonization" refers to a decreasing energy intensity of economic activities, determined by CO₂ emissions per GDP unit [19]. Decoupling concepts vary also in the sectoral base and were applied, e.g., for decoupling of GDP from traffic volume and CO₂ emissions from transport [19], decoupling of carbon dioxide emissions per capita from income per capita in developed countries, decoupling of GHG emissions and economic growth [8, 20, 21], etc.

Decoupling as a Tool for Environmental Assessment

The decoupling of economic growth and environmental impacts caused by this growth has rich tradition within the sustainable development literature. Basically, the literature records four paradigms that may be used in order to decompose the change of a particular indicator. These are (a) econometric analysis, (b) analysis based on aggregate data, (c) index decomposition analysis and (d) structural decomposition analysis. Out of this group, the simplest technique is aggregate data analysis, since it considers aggregate variables and does not require specific information. By contrast, structural decomposition analysis (SDA) and index decomposition analysis (IDA) enable use of data from sectoral disaggregation. For assessing the energy sector of EU countries, the IDA method was selected, as it allows both additive and multiplicative decompositions, enables decomposition for any kind of aggregates (absolute variation, ratio, elasticity) and requires less initial information [17], so it is an

appropriate technique in multi-country studies. IDA has wide application in environmental studies, especially in assessing environmental pressures of the energy sector [8, 22].

The concept of decoupling environmental pressure from economic development is the crucial form of putting the concept of sustainable development into operation. This conception refers to breaking the links between two variables, often referred to as the driving force, particularly economic growth usually expressed in terms of GDP, and the environmental pressures, such as the use of natural resources (resource decoupling) and the generation of waste/pollutants (impact decoupling). The decoupling index (DI) refers to the ratio of (1) change in the rate of consumption of a given resource (e.g., water), or in the rate of production of a given pollutant emission (e.g., SO₂); to (2) change in the rate of economic growth (GDP) within a certain time period (typically one year).

For example, if we define change in the rate of resources consumption (e.g., total energy consumption) between year t and year $t-1$ as:

$$\Delta P_t = \frac{(P_t - P_{t-1})}{P_{t-1}}$$

...change in the rate of economic growth as

$$\Delta Y_t = \frac{(Y_t - Y_{t-1})}{Y_{t-1}}$$

...then the Decoupling Index in year t

$$DI_t = \frac{\Delta P_t}{\Delta Y_t}$$

In the case of continued economic growth, namely $\Delta Y_t > 0$, the DI may imply one of three following scenarios. When $DI > 1$, it means the increasing rate of resource consumption or pollutant emissions keeps pace with or is higher than economic growth (see Case B in Fig. 1). In this case, no decoupling is taking place. In other words, as the economy grows, resource consumption and environmental degradation increase rapidly. This is the first half of the Kuznets Curve, or 'climbing stage' (Area A in Fig. 2). When DI equals 1, it is the turning point between absolute coupling and relative decoupling. In the stage of absolute coupling, a higher DI value means higher dependence on resources by economic growth, lower resource efficiency and heavier environmental pollution.

When $0 < DI < 1$, it means the rate of growth in resource consumption or pollutant emissions falls short of that of economic growth. In this case, relative decoupling is taking place (Case B in Fig. 1 and area B in Fig. 2). When DI ranges from 0 to 1, lower DI means higher resource efficiency and lower dependence on resources.

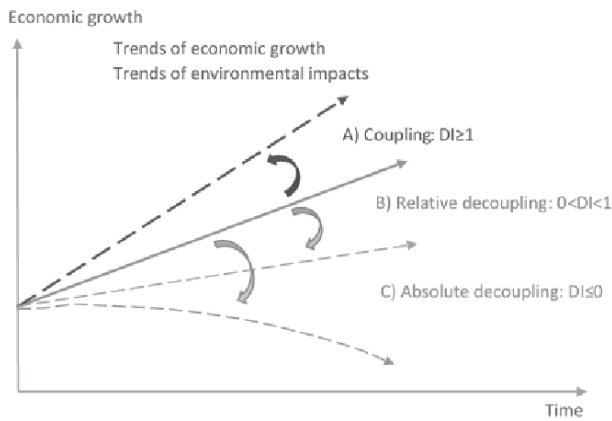


Fig. 1. Scenarios for economic growth and environmental pressure nexus (modified from UNEP, 2011).

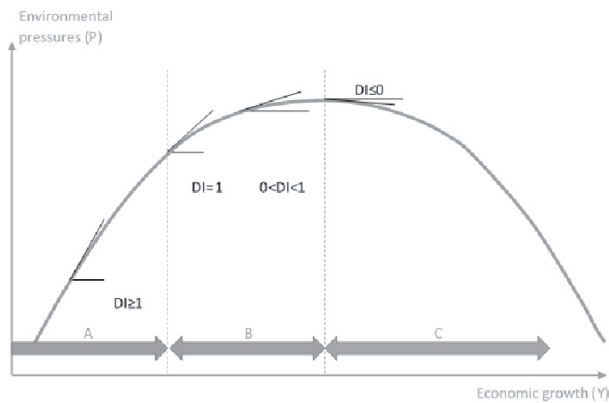


Fig. 2. Three stages of environmental pressure and economic growth based on the environmental Kuznets curve.

When $DI = 0$, it means the economy is growing while resource consumption remains constant. In other words, when the economy grows continuously, the amount of pollutants does not increase. When resource consumption or pollutant emissions/discharge decreases while the economy keeps growing, then $DI < 0$ (Case III in Fig. 2). Here the relationship between the environment and the economy can be described as the 'declining stage' of the Kuznets Curve (Area C in Figs 1 and 2), namely absolutely decoupling.

For the needs of our research, the above procedure is used to calculate the following decoupling indices:

$$DI_{Resource} = \frac{\Delta FEC}{\Delta GDP}$$

...where:

GDP – Gross Domestic Product in year i and country j

FEC – Final Energy Consumption in year i and country j

$$DI_{Impact} = \frac{\Delta GHG}{\Delta GDP}$$

...where:

GDP – Gross Domestic Product in year i and country j

GHG – Greenhouses Gases in year i and country j

$$DI_{RES} = \frac{\Delta RES}{\Delta GDP}$$

...where:

GDP – Gross Domestic Product in year i and country j

GHG – Renewable energies in year i and country j

Subsequently, individual EU countries are evaluated, and according to results of DI are divided into three areas (see Figs 1 and 2).

Moran Index for Spatial Evaluation of DI

Spatial relationships are described by their spatial scales calculated from vector data (point or polygon – the calculation method is different). The first step in analysing data is to generate a neighbourhood matrix. Spatial scale is a basic element of spatial statistics that measures spatial relationships. According to [23], spatial weight matrices represent the strength of potential interaction between individual places/spatial units. This uses Rook scales and only the areas adjacent to the research area are taken into account, which is reflected also in the neighbourhood matrix. After identifying the spatial weights, the third assumption is tested using Moran's I local coefficient (Moran I), which determines whether spatial autocorrelations exist in the given set of regions/territory.

$$I_i(d) = \frac{x_i - \bar{x}}{\frac{\sum_{j=1: i \neq 1}^n w_{ij}(d)}{n-1} - \bar{x}^2} \sum_{j=1: i \neq 1}^n w_{ij}(d)(x_j - \bar{x})$$

...where:

d - critical distance

n - number of spatial unit

x_i - value of phenomenon examined in i -th spatial unit

\bar{x} - average value of phenomenon examined

$w_{ij}(d)$ - weight of i -th value and d -th distance

The more Moran's local coefficient (I) approaches zero value, the more this coefficient indicates randomness, spatial non-correlation or statistical insignificance of the given variable in the space. The more the coefficient value approaches value 1, the more positive space autocorrelation is indicated. The closer the coefficient value approaches -1, the more negative the spatial autocorrelation is indicated.

In order to analyze the spatial autocorrelation at the local level, according to [24], the value of spatial autocorrelation must be derived for each spatial observation unit, i.e., in our case, the unit is the EU member state [25]. Because measurements are made for each polygon, it shows us how spatial autocorrelation changes within the studied territory.

According to [26], we can meet four different types within LISA:

- Locations where units with high or low values of the variable are grouped within the spatial autocorrelation and tested in accordance with the statistical tests, the hypothesis of positive spatial autocorrelation, referred as high-high (HH) or low-low (LL).
- Locations where units with high and low variables are grouped together within the spatial autocorrelation, or vice versa and tested in accordance with statistical tests, a negative spatial autocorrelation hypothesis (high-low (HL), or low-high (LH) respectively).

For the graphical representation of the obtained results, a Moran diagram of variance is used, which is, according to [27], a graphical representation of the spatial autocorrelation and its individual components (it shows the values of the monitored variable and “spatially shifted” values of the given variable – in this case the values of neighbouring micro-regions).

Results and Discussion

In this study, the nexus between gross domestic production (GDP) and final energy consumption, production of GHG emissions and the use of renewable energy sources (RES) for energy production of 28 EU countries is assessed. The analysed period is 2008-2016. Δ GDP, Δ FEC, Δ GHG and Δ RES values were calculated using data from available databases of the Eurostat using Equations (1) and (2). Subsequently the value of decoupling index DI was calculated using Equation (3).

Based on the partial calculations, we performed the decoupling analysis. Results of the analysis are summarised in Fig. 3 and Table 1. According to decoupling analysis of the EU countries in the period 2008-2016, we can distinguish the following sub-categories.

Absolute decoupling: in this sub-category the GDP increases and environmental impacts decrease. Thus the decoupling index is below 0. This is the best case for both the economy and the environment. This sub-category is in our survey the most frequent – it occurs in a total of 45 out of 56 observed cases (80%), which can be considered as a positive fact. In the case of the resource decoupling index, in our survey represented by Final energy consumption, absolute decoupling occurs in 20 cases (71%). In the case of impact decoupling index measured as production of GHG emissions, the absolute decoupling is present in 25 cases (89%).

Relative decoupling: is the case when the rate of growth in energy consumption falls short of that of economic growth. In this case DI ranges from 0 to 1, lower DI means higher energy efficiency and lower energy dependence. Decoupling occurs to some extent because final energy consumption grows more slowly than the GDP, but it is weak since the absolute amount of consumed energy nevertheless continues to grow. This situation occurs totally in 6 analysed cases (11%), and all of them are present in the case of the resource decoupling index.

Absolute coupling means that the increasing rate of energy use keeps pace with or is higher than economic growth. In this case, no decoupling is taking place. In other words, as the economy grows, energy consumption

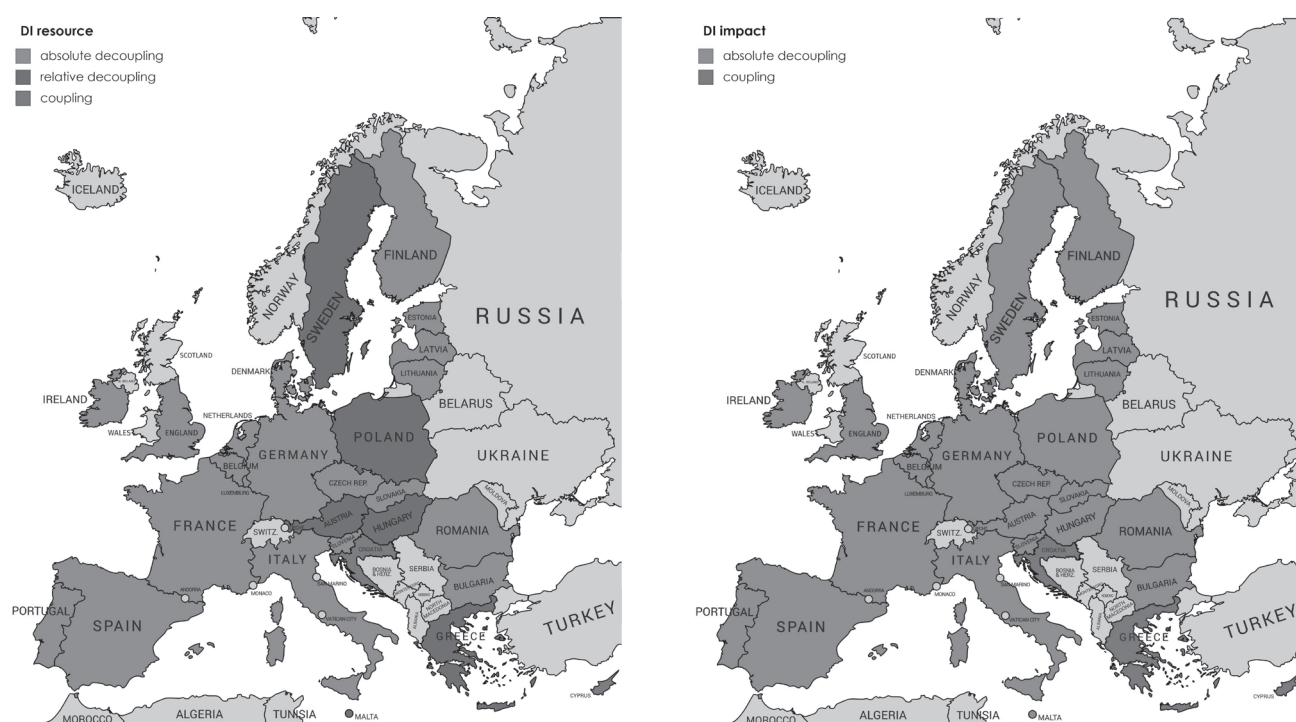


Fig. 3. Decoupling analysis – decoupling index resource and impact.

Table 1. Decoupling index – overall results.

	Δ GDP	Δ FEC	Δ RES	Δ GHG	DI resource	DI impact	DI RES
Belgium	0.17	-0.02	0.51	-0.17	-0.10	-1.05	3.08
Bulgaria	0.23	-0.03	0.45	-0.13	-0.14	-0.58	2.00
Czechia	0.09	-0.05	0.42	-0.12	-0.61	-1.45	4.87
Denmark	0.14	-0.08	0.35	-0.28	-0.53	-1.97	2.45
Germany	0.19	-0.01	0.40	-0.07	-0.03	-0.37	2.11
Estonia	0.24	-0.11	0.33	-0.02	-0.45	-0.08	1.39
Ireland	0.31	-0.16	0.48	-0.09	-0.50	-0.30	1.54
Greece	-0.37	-0.28	0.35	-0.42	0.76	1.14	-0.95
Spain	0.00	-0.15	0.39	-0.24	-65.16	-107.27	175.34
France	0.11	-0.06	0.23	-0.14	-0.56	-1.34	2.18
Croatia	-0.03	-0.12	0.19	-0.25	3.77	7.72	-5.77
Italy	0.03	-0.16	0.24	-0.27	-4.63	-7.98	7.11
Cyprus	-0.03	-0.11	0.38	-0.12	3.98	4.36	-13.64
Latvia	0.03	-0.11	0.15	-0.05	-3.86	-1.74	5.54
Lithuania	0.16	0.00	0.30	-0.20	0.00	-1.29	1.90
Luxembourg	0.28	-0.10	0.40	-0.16	-0.35	-0.58	1.40
Hungary	0.05	0.03	0.34	-0.16	0.55	-3.11	6.64
Malta	0.41	0.17	0.96	-0.50	0.41	-1.23	2.36
Netherlands	0.09	-0.09	0.19	-0.06	-1.01	-0.64	2.15
Austria	0.18	0.02	0.18	-0.09	0.14	-0.50	1.04
Poland	0.14	0.06	0.37	-0.02	0.46	-0.16	2.59
Portugal	0.04	-0.14	0.23	-0.12	-3.50	-3.03	5.63
Romania	0.14	-0.11	0.14	-0.31	-0.80	-2.21	0.98
Slovenia	0.06	-0.08	0.25	-0.22	-1.37	-3.71	4.28
Slovakia	0.19	-0.11	0.41	-0.21	-0.56	-1.12	2.16
Finland	0.10	-0.02	0.14	-0.20	-0.19	-1.97	1.34
Sweden	0.24	0.01	0.15	-0.18	0.03	-0.74	0.61
United Kingdom	0.17	-0.11	0.62	-0.33	-0.62	-1.90	3.55

Δ - change of selected indicator, GDP – gross domestic product, FEC – final energy consumption, GHG – greenhouses gases, DI – decoupling index, RES - renewable energy sources

increase rapidly. In the stage of absolute coupling, a higher DI value means higher dependence on energy resources by economic growth, lower energy efficiency and heavier environmental pollution. In this sub-category we have only five cases. In terms of resources, absolute coupling occurs in the case of Croatia and Cyprus, and in terms of environmental impacts, absolute coupling is present in Croatia, Cyprus and Greece.

We also calculated the decoupling index of renewable energy sources (RES). As their use for energy production brings positive effects in terms of

resource management (energy consumption) as well as reduction of environmental impacts (GHG emissions), the positive values signal absolute coupling as a positive phenomenon related to the willingness of countries to pay for better environmental conditions, graphically represented as area C in EKC. Positive results are visible in 25 countries (89%). Negative values occur in three cases: Greece, Croatia and Cyprus (see Fig. 4).

The last part of the research is the analysis of the above results in terms of their spatial distribution. Using the Moran index, we found the spatial randomness of



Fig. 4. Decoupling analysis – decoupling index RES.

all three variables ($I_{\text{Resource}} = -0,0018$; $I_{\text{Impact}} = -0,0017$; $I_{\text{RES}} = -0,0014$). The LISA indicator analyzes these results more closely, with which spatial changes are monitored at the local level. Results of the analysis are graphically captured in Fig. 5. On the basis of the above-mentioned graphical processing and results of our own analysis it is not possible to identify H-H areas (hot spots) as well as L-L areas (“cold spots”), i.e., areas with positive

spatial autocorrelation. Affiliation of countries to the H-L, respectively. L-H signals spatial “outliers,” i.e., areas where significantly higher or lower localization quotients (LISA) have been measured in comparison to neighboring regions. However, this spatial dependence at the local level may not be statistically significant in all cases (as evidenced by the results of the Moran index).

Our study as well as many others [28, 29] confirm the fact that all EU member states strive to reduce CO₂ emissions, increase energy efficiency and the share of RES on energy production, but they differ in their opinions on how to reach this goal. The ways to more sustainable energy in Europe can be assessed according to their compliance with scenarios of the future development of GHG emissions. Typically, such scenarios are based on the current situation and, taking into account developments so far, suggest different paths and ways to achieve the desired emission reductions by combining different measures and technologies. Scenarios are being developed on a global scale [30], at the EU17 [31] level, as well as in individual countries, and their variations differ mainly in depending on the extent to which individual measures and technologies contribute to the required emission reductions. Of course, this also has an impact on the financial or technological complexity of the individual options.

At the EU level, the so-called Strategic Energy Technology Plan [30] is the basic pillar of the transition to a low-carbon energy future. Among other things, it defines 19 strategic technologies to ensure the necessary level of greenhouse gas emission reductions in the energy sector. Not all of these technologies are equally developed and not all of them are appropriate for all member states. The issue of “national specifics”

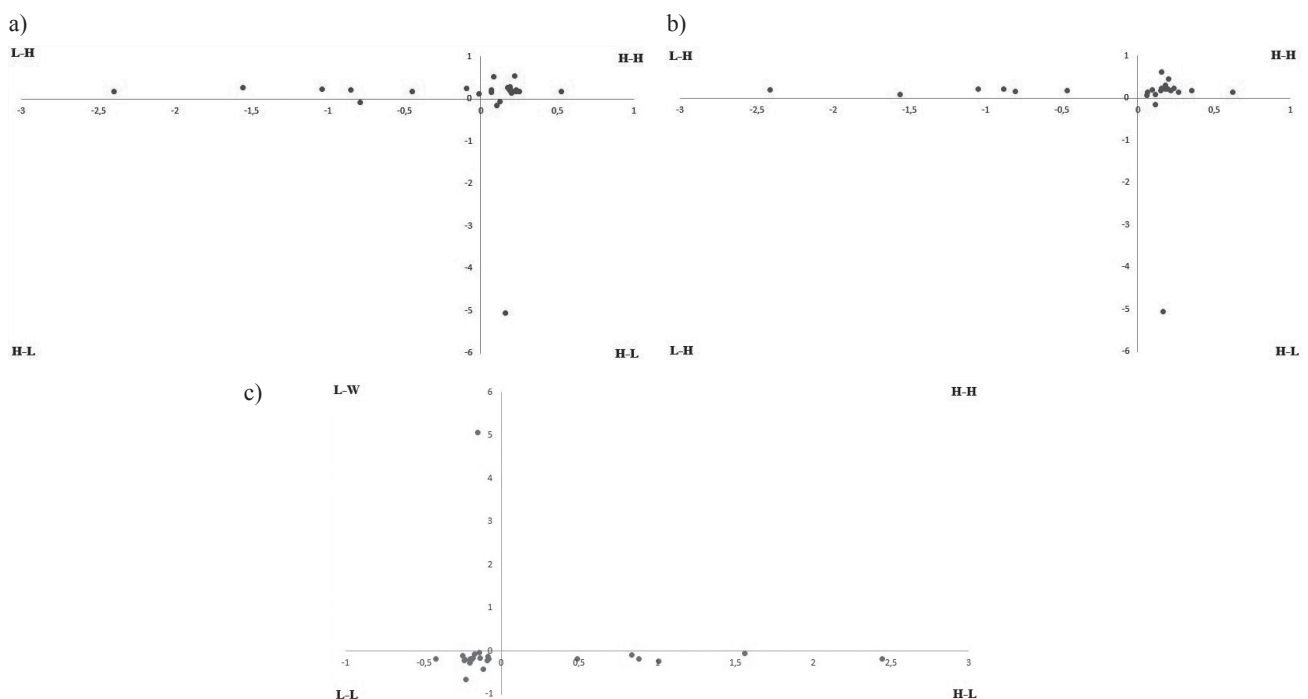


Fig. 5. Moran variance chart – DI resource a), DI impact b) and RES c).

in relation to individual low-carbon technologies is a hot topic of ongoing debate, including in EU countries, for example on the appropriateness of climate conditions for some technologies, prevailing public attitudes or different starting situations.

An important topic related to technology is science, research and technological development. These can accelerate the development of new technologies [32]. New resource management methods are rapidly gaining in importance. From this perspective, it is important at the national and European levels to set the right objectives and priorities in this area and to create favourable conditions for science, research and innovation, including prerequisites for commercial use.

Throughout the examined period, the EU countries spread out into different forms of environmental impact and resource decoupling. The largest group falls under the subcategory of absolute decoupling, which can be seen as very positive. But as with all studies, this study has limitations. First, the decoupling indices do not reveal the environment's capacity to sustain, absorb or resist pressures of various kinds. Index values cannot convey the message of whether economic growth is sufficiently decoupled from negative environmental impacts, such as GHG emissions production. Constant environmental impacts or decreased environmental impacts over time do not guarantee that human economic activity is within the physical limits of the biosphere. Even if absolute decoupling could be achieved, this would not necessarily ameliorate the environmental impacts of economic growth.

Decoupling may also experience a "rebound effect" that requires addressing the concern that efficiency gains in resource use may paradoxically lead to greater resource use. Research on micro level rebound effects has, in general, concluded that across time and across products, the rebound effect is not a major problem and does not undermine the case for investing in energy and resource efficiency or productivity [33]. In most cases, direct rebounds range from 0% to 40% [34].

We also have to state that even absolute decoupling at the individual country level, may not indicate that energy use is actually decreasing with increasing GDP. It may just indicate that more energy-intensive operations have been off-shored [35]. Developed nations experience an increase in imports of semi-finished and finished products and a change in economic structure toward service economies, which add high value to the GDP. These trends make developed countries look more resource-efficient, but they actually remain deeply anchored to a material foundation underneath.

Using this method can bring a lot of advantages. The quantification of the extent of decoupling makes it possible to assess if decoupling strategies are sufficient to reach the goal of environmental sustainability. We can track the trends, compare the extent of decoupling among countries and set future decoupling targets. Results of decoupling analysis can facilitate environmental policy-making processes.

Conclusions

The issue of mitigating the negative environmental impacts of energy production directly affects all European Union member states. Meeting ambitious goals such as cutting greenhouse gas emissions or increasing the share of renewables in energy production will require systematic and ongoing efforts of all stakeholders. Monitoring of such processes plays a crucial role as it is necessary for informed and responsible decision-making and setting appropriate policies and actions. In this regard, the decoupling method presents a useful tool for calibrating the shifts required over time to manage the transition to a more sustainable society.

From the perspective of our own research results we can state the following:

- In the evaluation of DI Resource and DI Impact, the majority of the EU member states can be considered homogeneous, i.e., the economic growth of these countries is decoupled from both energy consumption and production of GHG emissions.
- On the other hand, evaluation of DI RES shows the coupling of economic growth and the use of RES for energy production.
- For all three indicators, however, it is possible to identify Croatia and Cyprus (also Greece with the first indicator) as countries in which we see the growth of the economy accompanied by the growth of FEC and GHG, which we attribute to the dependence of the economies of these countries on sectors highly burdensome for the environment.
- From the spatial angle of assessment, these results cannot be considered spatially positive or negatively autocorrelated, i.e., analysis results can be considered spatially random.

The results obtained are limited by the construction of decoupling indices, which favour countries whose growth was close to zero in the period under review. This fact was reflected in the results of Spain in all the monitored DI, which could be evaluated as highly positive, though we believe it does not reflect the state in this country. In our opinion, the period that is the subject of the analysis and which directly determines its result also has an unreasonably high impact on the result itself. Because of the above, it is necessary to perceive the decoupling index method as a partial result of the assessment of the energy performance of the subjects of the analysis. At the same time, it is recommended to use it multiple times with the application of different evaluation periods in order to obtain more objective results and thus resulting in a greater reflection of the real state of the monitored area (which will be the subject of further research).

Acknowledgements

This work was supported by CZ.02.2.69/0.0/0.0/16_027/0008493, KEGA 038PU-4/2018, VEGA 1/0578/18.

References

- KANELAKIS M., MARTINOPOULOS G., ZACHARIADIS T. European energy policy – A review. *Energy Policy*, **62**, 1020, **2013**.
- BENSON D., RUSSEL, D. Patterns of EU energy policy outputs: Incrementalism or punctuated equilibrium?. *West European Politics*, **38**, **2015**.
- SZULECKI K., FISCHER S., GULLBERG A. T., SARTOR O. Shaping the Energy Union?: between national positions and governance innovation in EU energy and climate policy. *Climate Policy*, **16** (5), 548, **2016**.
- A framework strategy for a resilient energy union with a forward-looking climate change policy. Available online: <https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2010:0639:FIN:En:PDF> (accessed on 20th March 2019).
- Analysis associated with the Roadmap to a Resource Efficient Europe. Available online: http://ec.europa.eu/environment/resource_efficiency/pdf/working_paper_part1.pdf (accessed on 20th March 2019).
- A policy framework for climate and energy in the period from 2020 to 2030. A strategy for competitive, sustainable and secure energy. Available online: <http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?Uri=CELEX:52014DC0015&from=EN>. (accessed on 20th March 2019).
- A strategy for smart, sustainable and inclusive growth. Available online: <http://ec.europa.eu/eu2020/pdf/COMPLET%20EN%20BARROSO%20%20%20007%20-%20Europe%202020%20-%20EN%20version.pdf> (accessed on 20th March 2019).
- CHOVANCOVÁ J., VAVREK R. Decoupling Analysis of Energy Consumption and Economic Growth of V4 Countries. *Problémy ekorozvoju – Problems of Sustainable Development*, **14** (1), 159, **2019**.
- ANDERSON D. A. *Environmental economics and natural resource management*; Routledge: Abingdon, United Kingdom, **2010**.
- HUTTMANOVÁ, E., ADAMIŠIN P., CHOVANCOVÁ J. Assessment of the current state of environment in the Slovak republic with the use of green growth indicators. In *Ecology, economics, education and legislation*, STEF92 Technology: Sofia, Bulgaria, 133, **2013**.
- NAMINSE E. Y., ZHUANG J. Economic Growth, Energy Intensity, and Carbon Dioxide Emissions in China. *Polish Journal of Environmental Studies*, **27** (5), 2193, **2018**.
- ADAMIŠIN P., VAVREK R. Analysis of the links between selected socio-economic indicators and waste management at the regional level in the Slovak republic. In *5th Central European conference in regional science*, Technical University of Košice: Košice, Slovakia, 1, **2015**.
- HUTTMANOVÁ E. Evaluation of sustainability in the EU countries using selected indicators of sustainable development. In *Environmental economics, education and accreditation in geosciences: ecology, economics, education and legislation*, STEF92 Technology, Sofia, Bulgaria, 281, **2015**.
- VAVREK R., CHOVANCOVÁ J. Assessment of economic and environmental energy performance of EU countries using CV-TOPSIS technique. In *Ecological Indicators*, 106, 105519, **2019**.
- KOTULIČ R., ADAMIŠIN P. Economic Effects of the Foreign Direct Investments Management on the Development of Slovak Regions. In *15th International Colloquium on Regional Sciences*, Masaryk University: Brno, Czech Republic, 288, **2012**.
- NATHWANI J.S., SIDDALL E., LIND N.C. *Energy for 300 years*; University of Waterloo: Ontario, USA, **1992**.
- FERNÁNDEZ GONZÁLES P., LANDAJO M., PRESNO M.J. *The Driving Forces of Change in Environmental Indicators. An Analysis Based on Divisia Index Decomposition Techniques*; Springer: Berlin, Germany, **2014**.
- AYRES R.U., VAN DEN BERGH J. A Theory of Economic Growth Material/ Energy Resources and Dematerialization: Interaction with Three Growth Mechanisms. *Ecological Economics*, **55** (1), 96, **2005**.
- TAPIO P. Towards a theory of decoupling: degrees of decoupling in the EU and the case of road traffic in Finland between 1970 and 2001. *Transport Policy*, **12** (2), 137, **2005**.
- LI CH., LI X., ZHU X. Examining Economic Development and Carbon Emissions in China's Low-Carbon Pilot Provinces. *Polish Journal of Environmental Studies*, **26** (6), 2619, **2017**.
- ZHOU J., GUANG F., DU S. Decomposing the Decoupling of Carbon Emissions and Economic Growth in China's Power Industry. *Polish Journal of Environmental Studies*, **26** (5), 2407, **2017**.
- XU X.Y., ANG B. W. 2013. Index Decomposition Analysis Applied to CO2 Emission Studies. *Ecological Economics*, **93**, 313, **2013**.
- SLAVÍK V., GRÁC R., KLOBUČNÍK M. Spatial Autocorrelation – Method for Defining and Classifying Regions in the Context of Socio-Economic Regionalization in the Slovak Republic. *Sociology*, **43** (2), 183, **2011** [In Slovak].
- KLOBUČNÍK M., SLAVÍK V. Identifikácia historicky osídlených regiónov Slovenska s využitím konceptu priestorovej autokorelácie. *Geographical Journal*, **65** (4), 341, **2013** [In Slovak].
- VAVREK R., BENKOVÁ E. Performance of EU Countries over Time and Its Spatial Autocorrelation. In *Proceedings of the 4th International Conference on European Integration 2018*, VŠB – Technical University of Ostrava: Ostrava, Czech Republic, 1563, **2018**.
- ANSELIN L. Local indicators of spatial association–LISA. *Geographical Analysis*, **27** (2), 93, **1995**.
- Spatial perspective of creative industries in Slovakia. *Kultúrne a kreatívne odvetvia na lokálnej, regionálnej a národnej úrovni*. Available online: <http://www.slpk.sk/eldo/2015/zborniky/9788055212821/fazikova.pdf> (accessed on 25th March 2019) [In Slovak].
- MICIULA I., STEPIEŇ P. The Impact of Current EU Climate and Energy Policies on the Economy of Poland. *Polish Journal of Environmental Studies*, **28** (4), 2273, **2019**.
- WEN L., LI Y. The Causality Relationships between Energy-related CO2 Emissions and its Influencing Factors with Linear and Nonlinear Granger Causality Tests. *Polish Journal of Environmental Studies*, **26** (3), 1313, **2017**.
- Energy Technology Perspectives 2017, Catalysing Energy Technology Transformations. Available online: <https://webstore.iea.org/download/summary/237?fileName=English-ETP-2017-ES.pdf> (accessed on 20th April 2019).
- Impact assessment. Accompanying document to „A Roadmap for moving to a competitive low carbon economy in 2050. Available online: <http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52011SC0288&from=EN> (accessed on 20th April 2019).

32. ZHANG K., SHEN J., ZHANG J., HAN H. Recent Advances on Renewable Energies and Carbon Capture. *Polish Journal of Environmental Studies*, **28** (4), 2541, **2019**.
33. HERRING H. Rebound effect of energy conservation; Elsevier: Amsterdam, Netherlands, **2004**.
34. SORREL S. The Rebound Effect: an assessment of the evidence for economy-wide energy savings from improved energy efficiency; UK Energy Research Centre: Sussex, England, **2007**.
35. WIEDMANN T.O., SCHANDL H., LENZEN M., MORAN D., SUH S., WEST J., KANEMOTO L. The material footprint of nations. In *Proceedings of the National Academy of Sciences*, PNAS, Washington, USA, 6271, **2013**.