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Disparities in Energy Productivity across the EU Countries

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ABSTRACT

Energy plays a crucial role in everyday life and thus is one of the most essential inputs in all economic activities. Nowadays, the EU energy market has changed mainly due to the Russian invasion of Ukraine. The EU countries had to suddenly adapt to the new situation and secure energy supply for their citizens. But even before that, energy issues had been raised on a global scale through the United Nations' 2030 Agenda for Sustainable Development. One of the seventeen Sustainable Development Goals (SDGs) is SDG 7: Affordable and clean energy. Therefore, this paper aims to examine energy productivity in EU countries as it should be at the heart of the ongoing debate on energy security across the EU. This study uses two sources of data: the Eurostat and Organisation for Economic Co-operation and Development. The first one provides users with a composite indicator of energy productivity, which results from the division of the gross domestic product (GDP) by the gross available energy (primary production + recovered and recycled products + imports – exports + stock changes) for a given calendar year. The latter delivers an indicator of energy productivity measured in GDP per unit of total energy supply. This paper applies the β-convergence model to investigate the disparities between the EU countries in energy productivity and to see if they are widening or narrowing over time. The results show that although there are significant initial disparities, the EU countries have been converging over time; however, the speed of that process is not satisfyingly fast.

Keywords: Energy productivity, The EU countries, β-convergence
JEL Classifications: P18, P28, P48, Q43

1. INTRODUCTION

Since the beginning of the industrial era, the demand for energy in the world has been constantly increasing. Greater energy consumption has been related to economic development, industrialization and rising living standards. The particular energy sources such as coal, oil and gas are not unlimited. Their uncontrolled exploitation is perceived to be unsustainable in the long run. Hence, societies around the world, over time, started to realize that it was necessary to change the approach to energy and, in particular, its consumption. During oil crises, the issue of wise use of energy became especially crucial so it contributed to a debate on energy security. Hence, the issue of energy efficiency, the idea of reducing the amount of energy needed to perform the same task or produce the same result, has intensively gained its momentum. Energy-efficient things use less energy to operate. Thus, energy efficiency is one of the best solutions for combating climate change, especially in achieving net-zero CO_2 emissions. Energy efficiency seems to be a key to achieve stable economic development, respecting the environment and rational use of natural resources. There are many initiatives undertaken worldwide to improve energy efficiency, i.e., the European Union wants to achieve climate neutrality by 2050 (Peeters and Misonne, 2022; Wolf et al., 2021). Thus, in the current situation of energy crisis caused by energy supply security issues (raised, among others, by Russian aggression on Ukraine), environmental concerns, energy (in) justice aspects, the energy efficiency has become one of the key challenges.

Energy productivity is the wider concept than energy efficiency because it captures macro level. Hence, it indicates how efficiently a particular territory is able to harness primary energy while energy efficiency focuses more on a micro level - individuals behaviour. The link between these two terms is obvious, increasing energy efficiency improves energy productivity. The common goal of countries worldwide should be to achieve a higher level of energy productivity. They may apply different policies to enhance that process, e.g. by investing in modern energy infrastructure or introducing regulations (promoting energy savings activities or tools). Thus, the aim of this paper is to examine the level of energy productivity across the EU economies over the years.

2. LITERATURE REVIEW

Since energy productivity concerns literally everyone, this topic has been examined numerous times in the literature. It is worth to mention that energy productivity was analysed along with different factors and in different contexts, such as economic growth (Liu et al., 2023; Malanima, 2021; Nomura, 2022), trade (Jin et al., 2021; Wan et al., 2015), innovation (Li et al., 2020; Yu et al., 2022), carbon emissions (Kirikkaleli and Sowah, 2023; Shah et al., 2023; Xie and Jamaani, 2022), labour productivity (Kalantzis and Niczyporuk, 2022; Renshaw, 1981) and more. Increasing energy productivity is, in general, a positive thing as it leads to decrease CO_2 emissions (Amin et al., 2022; Oyebanji and Kirikkaleli, 2022; Wahab et al., 2021) and hence reduce environmental pollution (Aydin and Erdem, 2024). Yet, there are numerous papers devoted to enhancing renewable energy development and increasing its usage to aim for better energy productivity (Gökgöz and Güvercin, 2018; Kolosok et al., 2021; Włodarczyk et al., 2021). Another topical study analysed the development of differences in energy and labour productivities across 14 Organisation for Economic Co-operation and Development (OECD) countries in the period 1970–1997 (Mulder and De Groot, 2007). The results indicated that in most sectors lagging economies had a tendency to catch up with technological leaders, and mostly regarding to energy productivity.

For the EU countries, energy consumption related issues are of great importance since the EU imported almost 56% of their energy requirements in 2021. Although the energy productivity of the EU countries has increased over time, they are still largely dependent on imported energy so it imposes high production costs. Since the EU countries rely, to a great extent, on natural gas, oil and solid fuels, they need to diversify their energy supply sources to ensure energy security (Uğurlu, 2019; Yıldırım and Baycan, 2023).

An interesting study done by Alataş et al. (2021) confirmed that convergence in energy productivity occurred in the EU countries from 2000 to 2018, however the pace of convergence was low. Ağazade (2021) investigated Eastern European Countries in terms of energy productivity in the period of 1995-2018. He noted that convergence across these countries occurred at the pace of nearly 1.41% annually.

3. METHODS AND DATA

This research applies two different indicators of energy productivity. One of them is purchasing power standard (PPS) per kilogram of oil equivalent and the data are extracted from the Eurostat (https://ec.europa.eu/eurostat/databrowser/product/page/NRG_IND_EP). The second is gross domestic product (GDP) per unit of total energy supply (TES) expressed in USD per tonne of oil equivalent and the data come from the OECD database.

Since this paper aims to assess the energy productivity in the EU economies and compare differences in its level, the proposed methodology is based on the neoclassical Solow model of economic growth (Solow, 1956). Hence, this paper instead of measuring potential differences in economic growth (measured in GDP), it focuses on energy productivity. It applies β-convergence approach, which is useful in answering the question whether countries which initially had a low level of energy productivity managed grow its level at the faster pace than those that were initially "rich" in terms of energy productivity. Hence, the model hypothesis is closely related to the so-called the catch-up effect. In case the convergence occurs it means that initially poor countries in energy productivity managed to catch-up with the rich ones, eventually. This research applies the absolute β-convergence panel data model and its general form is as follows:

$$ln\left(\frac{EP_{i,t}}{EP_{i,t-1}}\right) = \alpha + \beta\, ln\,(EP_{i,t-1}) + \varepsilon_{i,t} \tag{1}$$

where $EP_{i,t}$ and $EP_{i,t-1}$ and are the Energy Productivity level in time t and $t-1$ respectively, α and β are the structural parameters of the model, and $\varepsilon_{i,t}$ denotes the random component. The parameter β states if the convergence process occurs (it occurs when the value of this parameter is negative and statistically significant). Alternatively, model (1) can be also described by the following equation:

$$ln\,(EP_{i,t}) = \alpha+(1+\beta)\,ln\,(EP_{i,t-}1) + \varepsilon_{i,t} \tag{2}$$

Here, the convergence is when the estimate of the $(1+\beta)$ is statistically significant and its range is within 0-1. There are two crucial characteristics associated with this model: speed of convergence (b) and half-life (t_{h1}). The first (b) concerns the level of inequalities between units reduced in one period of time. The latter (t_{h1}) describes how much time is needed to reduce differences by half. They are assessed using the following formulas (Arbia, 2006):

$$b = -ln\,(1+\beta) \tag{3}$$

$$t_{hl} = \frac{ln\,2}{b} \tag{4}$$

Since the model (2) is the first-order autoregressive model, it requires to check the presence of the unit root in the processes. One of the tests to check it is Levin, Lin, Chou test (Levin et al., 2002). The test hypothesis says that that the unit root is present in the processes while the alternative hypothesis claims that it is absent in the processes. Moreover, to test if the model contains the residuals' serial autocorrelation, this paper applies Arellano and Bond (1991) test. The desired outcome should be that the model lacks the residuals' serial autocorrelation, what would certify the quality of the model.

4. RESULTS

Energy productivity, in this paper is assessed by two measures: PPS per kilogram of oil equivalent (hereinafter refer as the EUR – as it is the Eurostat methodology) and the GDP per unit of TES expressed in USD per tonne of oil equivalent (hereinafter refer as the OECD – as it is the OECD methodology). Table 1 presents the OECD energy productivity results across the EU countries. When analysing rankings of countries, there can be several interesting characteristics noted:

- Countries from the first three places in 1995 were not leading in the 2020 rank, since they were ranked in the 7th, 6th, and 12th positions, respectively; and the first three places in 2020 went for Ireland, Malta and Denmark who were in the top 8th in 1995,
- Except Bulgaria, countries from the last three positions changed their places – Lithuania noted a significant increase from 25th in 1995 to 13th position in 2020, and Estonia from the last position in 1995 managed to get to the 24th place in 2020,
- The most significant and positive changes in energy productivity ranking were noted in: Romania and Lithuania, which advanced by 14 and 12 positions from 1995 to 2020, respectively,
- In the group of countries that noted the biggest declines were: Austria and Belgium, which declined by 9 and 8 places, respectively.

Table 1: Gross Domestic Product (GDP) per unit of Total Energy Supply (USD/tonne of oil equivalent)

Country	1995	2020	Rank 1995	Rank 2020	Rank changes 1995-2020
Italy	12754	15484	1	7	−6
Portugal	12080	15597	2	6	−4
Austria	11300	13872	3	12	−9
Malta	11274	28588	4	2	2
Greece	10990	13945	5	11	−6
Denmark	10759	19699	6	3	3
Spain	10690	14590	7	9	−2
Ireland	10675	33221	8	1	7
Cyprus	10104	15058	9	8	1
Luxembourg	9941	19603	10	4	6
Germany	8892	14413	11	10	1
Croatia	8377	12456	12	16	−4
France	8333	12321	13	17	−4
Netherlands	7923	12961	14	14	0
Belgium	6708	10492	15	23	−8
Slovenia	6592	11346	16	20	−4
Hungary	6462	11292	17	21	−4
Sweden	5789	11428	18	19	−1
Romania	5337	15676	19	5	14
Czech Rep.	5276	9642	20	25	−5
Finland	5246	7795	21	27	−6
Latvia	4867	12735	22	15	7
Poland	4662	11752	23	18	5
Slovak Rep.	4171	10653	24	22	2
Lithuania	4156	13057	25	13	12
Bulgaria	3809	8177	26	26	0
Estonia	3051	10033	27	24	3

Source: OECD : https://stats.oecd.org/viewhtml.aspx?datasetcode=GREEN_GROWTH&lang=en

Table 2 describes the EUR energy productivity results in the EU countries, in which:

- Italy, Austria, and Portugal were leading in 1995, while in 2020 they noted 5th, 8th, and 7th places, respectively; while Malta, Denmark, and Romania scored the first three places in 2020,
- Slovakia, Lithuania, and Estonia occupied the last three positions in the ranking in 1995, while in 2020 they managed to advance to the 3rd, 23rd, and 13th positions, respectively; hence in 2020, the last three places were taken by Bulgaria, Finland, and surprisingly Malta.
- In the group of countries that noted the biggest increase were: Romania and Lithuania, which advanced by 21 and 13 places from 1995 to 2020, respectively.
- The most significant and negative changes in the ranking were noticed in: Malta and Belgium, which dropped by 23 and 7 positions from 1995 to 2020, respectively.

These two indicators have similar tendencies when it comes to changes in the ranking, however, there was one significant outlier observation – Malta, which scored very well in the OECD ranking – 4th place in 1995 and 2nd place in 2020, while in the EUR ranking Malta was 4th in 1995 and the last in 2020. The next interesting question concerns the changes that occurred – if they were characterised by the convergence, the so-called catch-up effect. It would mean that these disparities in energy productivity reduce over time, eventually. Therefore, the Figures 1 and 2 shows energy productivity growth rate from OECD and EUR data, respectively. They reflect on the pace of growth in these indicators. In both figures, the results are quite similar,

Table 2: Purchasing power standard (PPS) per kilogram of oil equivalent

Country	1995	2020	Rank 1995	Rank 2020	Rank changes 1995-2020
Italy	6.52	11.66	1	5	−4
Austria	5.78	10.34	2	8	−6
Portugal	5.70	10.68	3	7	−4
Malta	5.29	5.15	4	27	−23
Ireland	5.23	22.06	5	1	4
Spain	5.12	9.97	6	9	−3
Greece	5.04	9.02	7	14	−7
Germany	4.70	10.75	8	6	2
Denmark	4.59	14.00	9	2	7
Cyprus	4.57	9.46	10	11	−1
France	4.28	9.49	11	10	1
Croatia	4.06	9.46	12	12	0
Luxembourg	3.95	12.49	13	4	9
Slovenia	3.73	8.72	14	16	−2
Netherlands	3.50	8.15	15	19	−4
Sweden	3.32	8.04	16	20	−4
Belgium	3.28	7.13	17	24	−7
Hungary	3.05	8.35	18	18	0
Czech Rep.	2.86	7.44	19	21	−2
Finland	2.84	5.84	20	26	−6
Poland	2.49	8.49	21	17	4
Latvia	2.40	9.00	22	15	7
Bulgaria	2.31	6.41	23	25	−2
Romania	2.21	13.04	24	3	21
Slovak Rep.	2.20	7.16	25	23	2
Lithuania	2.01	9.41	26	13	13
Estonia	1.36	7.17	27	22	5

Source: Eurostat: https://ec.europa.eu/eurostat/databrowser/product/page/t2020_rd310

Figure 1: Energy productivity growth rate 1995-2020 based on OECD definition and data

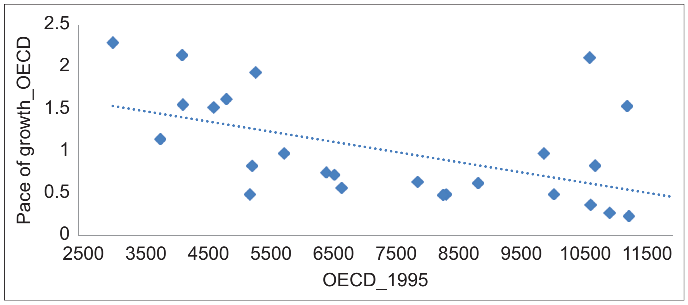


Figure 2: Energy productivity growth rate 1995-2020 based on Eurostat definition and data

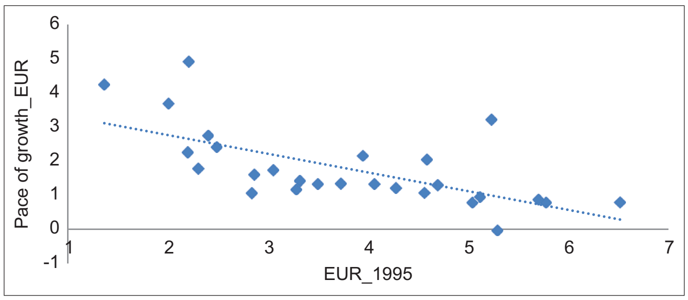
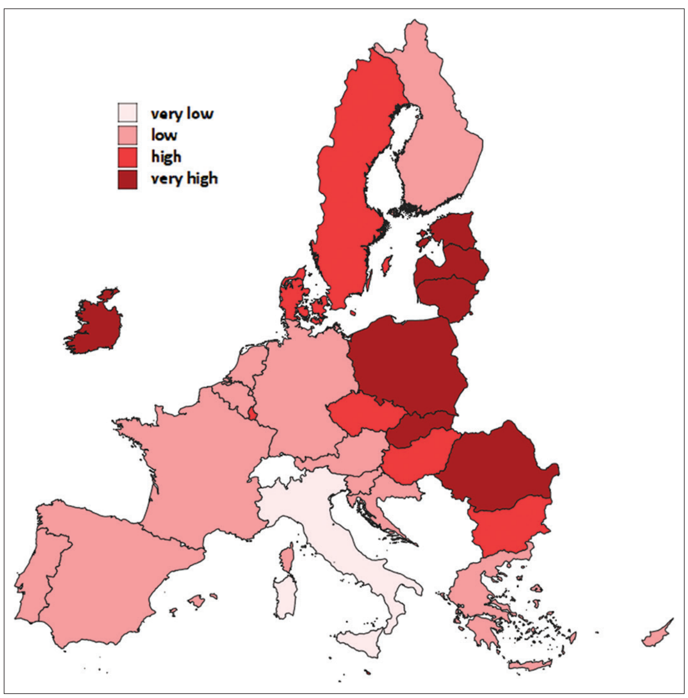


Figure 3: Pace of growth GDP per unit of Total Energy Productivity 1995-2020 (USD/tonne of oil equivalent).

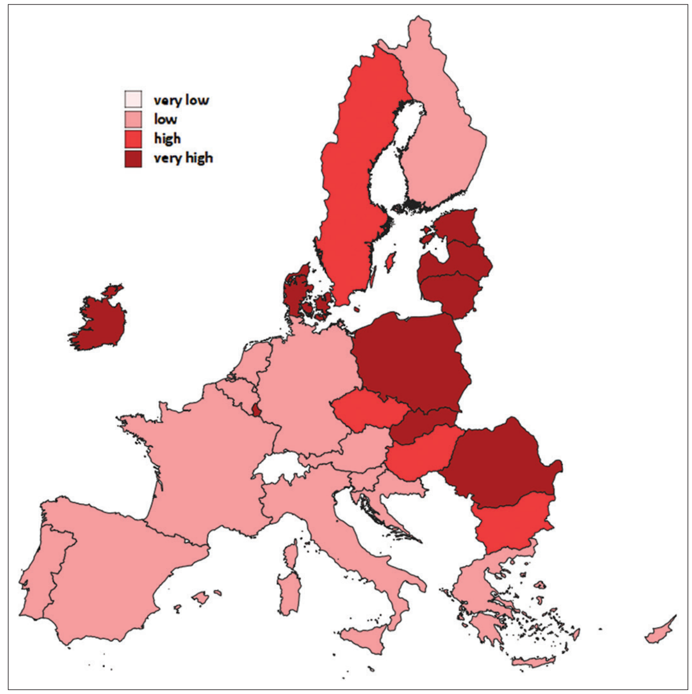


Source: own elaboration based on OECD data and QGIS software

since they show that initially 'poorer' countries in energy productivity had a higher growth rate in this indicator than initially more energy productive economies. Thus, analysing the trend of growth in both figures, it can be presumed that the convergence process occurred.

Figures 3 and 4 describes the pace of energy productivity growth from 1995 to 2020 in OECD and EUR methodology, respectively.

Figure 4: Pace of growth of PPS per kilogram of oil equivalent 1995-2020.



Source: own elaboration based on Eurostat data and QGIS software

Table 3: The results of estimation and verification of the absolute β-convergence panel data model based on OECD data

Parameter	Estimate	Std. Error	z	P-value
α	0.1627	0.1496	1.088	0.2766
$1+\beta$	0.985	0.0163	60.46	0***
Speed		1.51%		
Half-life		45.9		

***Parameter statistically significant at the 1%. Source: own elaboration

Table 4: The results of estimation and verification of the absolute β-convergence panel data model based on Eurostat data

Parameter	Estimate	Std. Error	z	P-value
α	0.057	0.0255	2.23	0.0258**
$1+\beta$	0.9889	0.0141	69.79	0***
Speed		1.11%		
Half-life		62.3		

**Parameter is statistically significant at the 5%, while ***Parameter is statistically significant at the 1%. Source: own elaboration

In general, the overview from Figures 3 and 4 is very clear - the countries that had a low energy productivity level in 1995, had, on average, a higher growth rate in this indicator in 2020. In Figure 3, the group of countries with a very high growth rate in energy productivity includes (descending order of energy productivity): Estonia, Lithuania, Ireland, Romania, Latvia, Slovakia, Malta, Poland while in EUR approach this group consists of (descending order of energy productivity): Romania, Estonia, Lithuania, Ireland, Latvia, Poland, Slovakia, Luxembourg, Denmark.

Since there are significant presumptions of convergence occurrence, it is indeed vital to check the model's results (Tables 3 and 4). Before analysing the model specific results, the

LLC test was conducted, which outcomes allowed to reject the null hypothesis on unit roots presence in the formation of energy productivity. In both models, the parameter estimate $1+\beta$ is statistically significant and lower than one. Thus, the convergence process in energy productivity occurred in the EU countries in 1995-2020. The speed of convergence is higher in OECD (1.51%) approach than the EUR (1.11%), so is the time to reduce differences by half (half-life), which in OECD data framework accounts for nearly 46 years, while in EUR data is more than 62 years.

5. DISCUSSION AND CONCLUSION

Energy productivity is a crucial aspect in the everyday life of people worldwide. It is deeply connected to ensuring climate neutrality targets. Having modern energy infrastructure, which produce energy from different sources (energy mix), not only provides the society with higher level of energy productivity but also energy security. Especially in the EU countries, this topic has gained a momentum since the Russian aggression on Ukraine in February 2022. One may note that increasing energy productivity is closely related to providing energy security in the EU countries, which had to drastically decrease its energy dependence from Russian sources, and ideally in the future become independent from Russian energy supply.

This paper clearly indicates that the EU countries are quite diverse in terms energy productivity, which might be caused by numerous factors like: infrastructure, access to natural resources, energy policy mix, etc. Hence, considered countries demonstrate convergence patter over time. Countries with low energy productivity in 1995 were slowly on the way of catching-up with initially high-energy productive countries over time. However, the convergence process in both analysed indicators proposed by the OECD and the Eurostat had a very low level of 1.51% and 1.11% annually. This all imposes a vital question on inclusive growth on energy productivity among the EU economies: (1) Do the EU policies foster the cohesion in terms of energy productivity allowing levelling up of energy productivity across the EU? (2) What are the tools (that already work/or planned to be introduced) of enhancing inclusive growth of energy productivity in the EU? (3) Are the EU policies tailored to individual countries, taking into account different specificities (like natural resources, existing infrastructure, etc.) or they treat every country in the same manner? These are just sampling questions that arise from this research paper and they are vital to be addressed to the policymakers.

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