Digital and Green Transition in the EU27 from an Econometric Perspective

GEORGE-CORNEL DUMITRESCU
Institute for World Economy
București, Calea 13 Septembrie nr. 13
ROMANIA
george.cornel@gmail.com

Abstract: The pandemic and, currently, the war in Ukraine revealed the fragility of the linear economic system that depends on external supply chains and emphasised the need to achieve strategic autonomy regarding the critical resources for the economy and people. Since energy has become a burning issue nowadays, based on data provided by Eurostat and the European Commission, the paper analyses the relationship between the real GDP per capita, the electricity production capacities for renewables and wastes (wind, solar and solid biofuels), and the Digital Economy and Society Index. It aims to identify possible connections between prosperity, digitalisation, and green energy sources in an attempt to understand how to achieve strategic autonomy. The research identified several statistically significant relationships between the GDP per capita, DESI and the components of electricity production capacities for renewables and wastes.

Key-Words: - Econometric Modelling, DESI, solar, wind, biofuels, energy

JEL Classification: - C1, O13, Q4, Q5.

1. Literature review

Parra, Pérez-Pons, and González (2020) identified that an increase in technology in different areas implies an improvement in per capita GDP. Olczyk and Kuc-Czarnecka (2022) also revealed that economic growth, measured by GDP per capita, can be well explained by DESI. Gherghina, Pașa, and Onofrei (2021) modelled the relationship between DESI, the real GDP growth rate and the real GDP per capita. They found that the correlation between DESI values and real GDP growth rate was very weak, as explained by the convergence, and highlighted a strong and statistically relevant correlation between DESI and real GDP per capita. Regarding DESI components, Stremousova and Buchinskaia (2019) argue that the most significant factors for the growth of per capita GDP are mobile and fixed broadband subscriptions. Their research confirmed that digitalisation's economic effect depends on the Internet connection's level of development.

Yang, Ran, Wu, Irfan & Ahmad (2021) prove that the development of the digital economy tends to decrease the impact of coal-based energy structures on carbon emissions. They found the trend is more evident in resourceless provinces and eastern China and not evident in resource-based cities and central and western China.

Shahbaz, Wang, Dong and Zhao (2022) found that the digitalisation of the economy positively affects the generation and consumption of renewable energy. Thus, a 1% increase in the digital economy could increase the renewable energy consumption structure by 0.021% and the renewable energy generation structure by 0.106%. The researchers identified regional heterogeneities in the effect of digitalisation on energy transition, with the rich countries benefiting the most from the digital transition.

2. Methodology

The paper does ex-post quantitative research on some of the indicators available at the statistical office of the European Union and at the European Commission, displayed below (Tables 1 to 5). It examines the DESI overall index score, the real GDP per capita and the electricity production capacities for renewables and wastes (wind, solar and solid biofuels) for Finland, Denmark, Germany, Bulgaria, Romania and the EU27, using comparative and econometrical methods.

The research uses Microsoft Excel's functions (Data, Data Analysis, Correlation and Regression) to assess the relationships between the above indicators.

The methodology consists of calculating the correlation coefficients, testing the statistical significance of the linear relationship at a 95% confidence level using null and alternate hypotheses, calculating the coefficient of determination, writing the regression equation and interpreting the results.

3. The dynamics of the analysed indicators

According to the experts of the European Commission (2022a), "the Digital Economy and Society Index (DESI) is a composite index that summarises relevant indicators on Europe's digital performance and tracks the evolution of EU Member States, across five main dimensions: Connectivity, Human Capital, Use of Internet, Integration of Digital Technology, Digital Public Services." Electricity production capacities for renewables and wastes (wind, solar and solid biofuels) refer, according to Eurostat (2022a), to the following variables: total capacity (MWe), capacity by the source of electricity production (MWe), capacity by type of generation in power plants using combustible fuels (MWe).

Between 2016 and 2022, at the EU level, the value of DESI increased by 48.08% (Table 1). Between 2019 and 2022, the progress was also significant, 21.33, respectively. From the analysed countries, Bulgaria recorded the highest increase between 2016 and 2022 (45.09%), followed by Romania (42.99% and Finland 40.53%).

Table 1. DESI overall index score per country in 2022, weighted score (0 to 100)

Country/Year	2016	2017	2018	2019	2020	2021	2022
Finland	49.52	52.06	55.04	58.13	62.8	67.15	69.60
Denmark	50.14	53.33	54.83	57.92	61.78	70.06	69.33
Germany	38.05	39.94	42.21	45.08	49.05	54.07	52.88
European Union	35.3	37.91	40.65	43.08	46.28	50.71	52.28
Bulgaria	25.97	28.11	30.89	32.72	34.43	36.83	37.68
Romania	21.39	23.21	25.68	27.08	29.98	32.87	30.58

Source: Author's own representation, based on the European Commission (2022b).

Between 2019 and 2022, Finland experienced the highest increase in the value of the DESI overall index (19.72%), followed by Denmark (19.70%) and Germany (17.31%).
The leader of the EU27 ranking in 2022 is Finland (69.60), followed by Denmark (69.33). Germany ranks 13th (52.88), Bulgaria 26th (37.68) and Romania 27th (30.58).

Between 2016 and 2021, the GDP per capita in the EU27 increased by only 5.45%, but between 2020 and 2021, it increased by 5.33% (Table 2). Romania registered the highest increase in our selection between 2016 and 2021 (24.35%), followed by Bulgaria (13.20%) and Denmark (7.04%). Romania records the highest increase in the GDP per capita between 2020 and 2021 (5.88%), followed by Bulgaria (4.86%) and Denmark (4.43%).

Table 2. Real GDP per capita, Chain linked volumes (2010), euro

Country/Year	2016	2017	2018	2019	2020	2021
Denmark	46,720	47,740	48,450	48,970	47,890	50,010
Finland	35,330	36,380	36,740	37,150	36,270	37,280
Germany	34,610	35,410	35,650	35,950	34,590	35,480
European Union	26,400	27,100	27,600	28,040	26,430	27,840
Romania	7,680	8,360	8,920	9,300	9,020	9,550
Bulgaria	5,910	6,120	6,330	6,630	6,380	6,690

Source: Author's own representation, based on Eurostat (2022b).

Regarding the GDP per capita, in 2021, the leader of the EU27 hierarchy is Luxembourg (84,490 euros per capita). With 50,010 euro per capita, Denmark ranks 3rd in the EU27, followed by Finland (37,280 euro per capita) and 6th, Germany (35,850 euro per capita) the 9th. Romania and Bulgaria close the ranking with 9,550 euros per capita and 26th and 6,690 euros per capita and 27th, respectively.

The EU27 wind electricity production capacities increased by 28.24% between 2016 and 2020 (Table 3). The growth rate in just one year between 2019 and 2020 is significant, namely 5.88%. The highest increase between 2016-2020, among the five analysed countries was recorded in Finland (65.24%), followed by Germany

(25.80%) and Denmark (19.34%). Romania experienced a decrease in wind electricity production capacities between 2016 and 2020 (-0.41%), while Bulgaria increased its capacities by just 0.54%.

Table 3. Wind - Electricity production capacities for renewables and wastes (WEP), megawatt

Country/Year	2016	2017	2018	2019	2020
European Union	138,010.88	148,920.39	157,166.76	167,162.15	176,985.20
Germany	49,435.00	55,580.00	58,721.00	60,742.00	62,188.00
Denmark	5,245.14	5,488.95	6,115.05	6,102.94	6,259.46
Romania	3,025.00	3,029.80	3,032.26	3,037.52	3,012.53
Finland	1,565.00	2,044.00	2,041.00	2,284.00	2,586.00
Bulgaria	699.00	698.39	698.92	703.12	702.80

Source: Author's own representation, based on Eurostat (2022c).

The EU27 ranking for 2020 regarding wind electricity production capacity was led by Germany (176,985 megawatts). Denmark ranked eighth (6,259 megawatts) and Finland the 15th (2,586 megawatts), while Romania 14th (3,013 megawatts) and Bulgaria 17th (703 megawatts).

The EU27 solar electricity production capacities increased by 51.31% between 2016 and 2020 (Table 4). Finland`s capacity grew by 715.38%, Denmark`s by 53.27% and Germany`s by 32.06% in the same timeframe. Bulgaria and Romania experienced lower growth rates (6.75% and 0.77%, respectively).

Table 4. Solar - Electricity production capacities for renewables and wastes (SEP), megawatt

Country/Year	2016	2017	2018	2019	2020
European Union	91,498.80	96,231.81	104,052.25	120,221.82	138,442.69
Germany	40,679.00	42,293.00	45,158.00	48,914.00	53,721.00
Romania	1,372.00	1,374.20	1,385.91	1,397.80	1,382.63
Denmark	850.95	906.35	998.00	1,080.00	1,304.29
Bulgaria	1,028.00	1,035.57	1,032.68	1,047.95	1,097.36
Finland	39.00	82.00	140.00	222.00	318.00

Source: Author's own representation, based on Eurostat (2022c).

In 2020, Germany ranked first in the EU27 hierarchy regarding solar electricity production capacities (53,721 megawatts). Romania ranked 12th (1,383 megawatts), Denmark 13th (1,304 megawatts), Bulgaria 16th (1,097 megawatts) and Finland 19th (318 megawatts).

The EU27 solid biofuel electricity production capacities grew by 8.42% between 2016 and 2020 (Table 5). Denmark registered the highest increase rate (43.91%), followed by Finland (39.78%) and Romania (26.95%). In the same period, Bulgaria experienced a contraction of 20.72% and Germany of only 0.19%.

Table 5. Solid biofuels - Electricity production capacities for renewables and wastes (SBEP), megawatt

Country/Year	2016	2017	2018	2019	2020
European Union	14,351.84	15,037.22	15,558.12	15,749.93	15,560.78
Finland	1,747.00	1,966.00	1,966.00	1,963.00	2,442.00
Germany	1,600.00	1,601.00	1,585.00	1,598.00	1,597.00
Denmark	1,031.70	1,501.26	1,484.66	1,501.26	1,484.66
Romania	107.00	118.88	119.28	118.77	135.83
Bulgaria	19.00	22.97	33.02	23.51	15.06

Source: Author's own representation, based on Eurostat (2022c).

Sweden ranked first in 2020, within the EU27 countries, regarding the solid biofuel electricity production capacities (2,942 megawatts), followed by Finland, second (2,442 megawatts), Germany third (1,597 megawatts) and Denmark fourth (1,485 megawatts). Romania ranked 17th (136 megawatts), and Bulgaria 23rd (15 megawatts).

4. Econometric analysis of the relationship between real GDP per capita and DESI in Romania (example)

The correlation coefficient of the relationship between real GDP per capita and DESI is calculated using Data Analysis and Correlation under Microsoft Excel and the data in Table 6. The results are displayed in Table 7.

Table 6. Real GDP per capita, in euro, and DESI, weighted score (0 to 100) in Romania

Year	Real GDP per capita	DESI
2016	7,680	21.39
2017	8,360	23.21
2018	8,920	25.68
2019	9,300	27.08
2020	9,020	29.98
2021	9,550	32.87

Source: Tables 1 and 2.

Table 7. Correlation coefficient

	GDP per capita	*DESI*
GDP per capita	1	
DESI	0.890143982	1

Source: Author's own representation

The value of r is 0.89. It means a robust linear relationship between the analysed indicators with a positive slope. Therefore, if one indicator increases, the other increases too (See Chart 1).

The linear relationship between the analysed indicators is tested at a 95% confidence level (0.05 level of significance) to see if it is statistically significant.

The null hypothesis (H_0) implies no statistically significant linear relationship in Romania between the real GDP per capita and DESI.

The alternate hypothesis (H_a) supports a statistically significant linear relationship between the two variables.

H_0: $\rho = 0$. H_a: $\rho \neq 0$.

The regression statistics are displayed in Table 8.

Table 8. Regression Statistics of the relationship between real GDP per capita and DESI in Romania

Correlation coefficient **r**	0.890143982			
r^2	0.792356309			
Adjusted **r^2**	0.740445386			
Standard Error	2.165808971			
Observations	6			
	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	-22.18010641	12.54275	-1.768361136	0.151729345
PIB/locuitor	0.005551526	0.001421	3.906887315	0.017439627

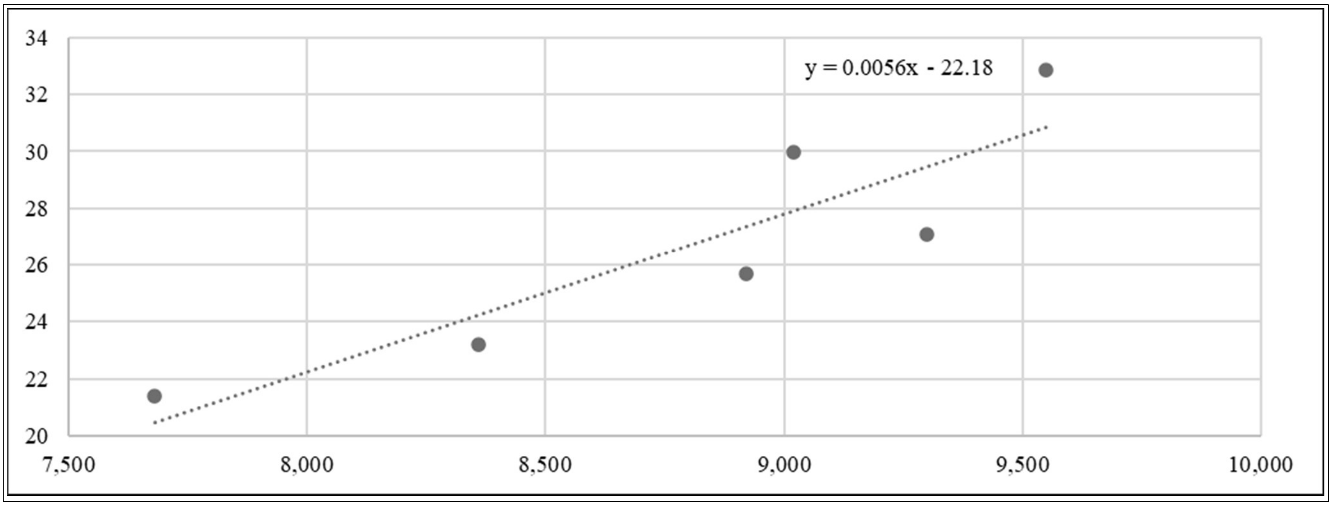
Source: Author's own representation

Since P-value is smaller than the significance level: $\alpha = 0.05$, the null hypothesis (H_0) is rejected (See Table 8).

Therefore, we are 95% confident that there is a statistically significant linear relationship in Romania between the real GDP per capita and the value of DESI.

The coefficient of determination (r^2) is 0.7924. That implies that the relationship between the analysed variables explains 79.24% of the variation in the value of DESI. It does not mean that one variable causes the other.

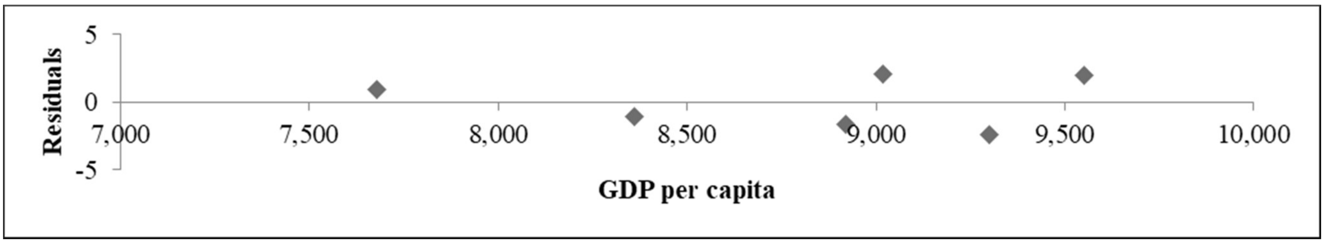
Chart 1. Relationship between real GDP per capita and DESI in Romania



Source: Author's own representation

According to the model, for one additional euro in GDP per capita, the DESI in Romania could increase by 0.005551526 points. The equation of the sample regression line is displayed on scatter Chart 1.
The residual plot shows that the prediction equation is a good fit for the data because the points are scattered randomly around the horizontal axis, and there seems to be no pattern to the points (Chart 2).

Chart 2. Residual Plot



Source: Author's own representation

The same methodology is applied for the pairs of variables in the case of EU27, Bulgaria, Finland, Denmark, and Germany, using the data in tables 1 to 5. The results are displayed below (Tables 9-15.

Table 9. Relationship between real GDP per capita and DESI

Country	r	r^2	*P-value*	Slope (b_1)
European Union	0.418877993	0.175458773	0.408430920	
Bulgaria	0.914491695	0.836295060	0.010654901	0.012387510
Romania	0.890143982	0.792356309	0.017439627	0.005551526
Finland	0.683349880	0.466967058	0.134526122	
Germany	0.121664348	0.014802214	0.818403928	
Denmark	0.835748372	0.698475342	0.038252256	0.005270536

Source: Author's own representation

In Table 9, besides Romania only in Bulgaria and Denmark, the analysed relationship was statistically significant at a level of confidence of 95%, with robust correlation coefficients and relevant coefficients of determination (P-value $< \alpha = 0.05$).

According to the identified models, and the selected samples, for one additional euro in the GDP per capita, the DESI could increase by 0.012387510 points in Bulgaria and by 0.005270536 in Denmark.

Table 10. Relationship between real GDP per capita and wind electricity production capacities (WEP)

Country	r	r^2	*P-value*	Slope (b_1)
European Union	0.216684978	0.046952380	0.726282547	N/A
Bulgaria	0.777746075	0.604888958	0.121498709	N/A

Romania	0.164713377	0.027130497	0.791232611	N/A
Finland	0.618471224	0.382506655	0.266107896	N/A
Germany	0.361255831	0.130505776	0.550245081	N/A
Denmark	0.786341348	0.618332715	0.114678388	N/A

Source: Author's own representation

Regarding the relationship between GDP per capita and wind electricity production capacities, no statistically significant relationship is identified in any of the analysed countries, even if Bulgaria and Denmark have robust correlation coefficients, and Finland recorded a moderate correlation coefficient between the analysed indicators.

Table 11. Relationship between real GDP per capita and solar electricity production capacities (SEP)

Country	r	r^2	*P-value*	Slope (b_1)
European Union	0.009436397	0.000089046	0.987985384	N/A
Bulgaria	0.437603026	0.191496408	0.461158703	N/A
Romania	0.885883271	0.784789171	0.045475826	0.014183369
Finland	0.495995929	0.246011962	0.395423211	N/A
Germany	-0.044265290	0.001959416	0.943658093	N/A
Denmark	0.441626573	0.195034030	0.456557353	N/A

Source: Author's own representation

Only Romania registers a statistically significant linear relationship between real GDP per capita and solar electricity production capacities. For one additional euro in the GDP per capita, solar energy production capacities could increase by 0.014183369 megawatts, according to the identified model, based on the given sample.

Table 12. Relationship between GDP per capita and solid biofuels electricity production capacities (SBEP)

Country	r	r^2	*P-value*	Slope (b_1)
European Union	0.638034394	0.407087888	0.246729617	N/A
Bulgaria	0.186672447	0.034846602	0.763708948	N/A
Romania	0.672355432	0.452061827	0.213721826	N/A
Finland	0.255030763	0.065040690	0.678839863	N/A
Germany	-0.339836020	0.115488520	0.575786432	N/A
Denmark	0.441626573	0.195034030	0.456557353	N/A

Source: Author's own representation

Again, no statistically significant relationship between GDP per capita and solid biofuel electricity production is identified in any of the analysed countries, even if, in the case of the EU and Romania, there is a moderate correlation coefficient.

Table 13. Relationship between DESI and wind electricity production capacities (WEP)

Country	r	r^2	*P-value*	Slope (b_1)
European Union	0.998467641	0.996937631	0.000071990	3,538.587143282
Bulgaria	0.825395623	0.681277935	0.085251470	N/A
Romania	-0.358664405	0.128640156	0.553323413	N/A
Finland	0.955600626	0.913172557	0.011155408	69.012707341
Germany	0.908183573	0.824797402	0.032933731	1059.305946605
Denmark	0.885721122	0.784501906	0.045571634	88.911655801

Source: Author's own representation

Concerning the relationship between DESI and wind electricity production capacities, there are four statistically significant linear relations in the EU, Finland, Germany, and Denmark, since P-value is smaller than the significance level: α = 0.05, and there are strong correlation coefficients.

According to the model, one unit increase in DESI could increase the capacities with 3,538.5 megawatts in the EU, 68,01 megawatts in Finland, 1,059,3 megawatts in Germany and 88.9 megawatts in Denmark. In the case of Bulgaria, there is a strong linear correlation between the indicators without statistical significance. In Romania, there is a weak correlation, with a negative slope, meaning if DESI increases, WEP decreases, but there is no statistical relevance of the relationship.

Table 14. Relationship between DESI and solar electricity production capacities (SEP)

Country	r	r^2	*P-value*	Slope (b_1)
European Union	0.973664039	0.948021660	0.005110160	4,362.332694920
Bulgaria	0.794243453	0.630822662	0.108513660	N/A
Romania	0.634743239	0.402898979	0.249961978	N/A
Finland	0.997937778	0.995879808	0.000112384	21.466765720
Germany	0.998727094	0.997455808	0.000054506	1210.485926951
Denmark	0.979468855	0.959359239	0.003520559	39.087771811

Source: Author's own representation

As to the relationship between DESI and solar energy production capacities, there are also four statistically significant linear relationships in the EU, Finland, Germany, and Denmark. Romania registers a moderate correlation coefficient without statistical significance.

Therefore, an increase of one unit in DESI would generate, according to the models, a boost of 4,362 megawatts in the EU, 21.4 megawatts in Finland, 1,210,5 megawatts in Germany and 39.1 megawatts in Denmark.

Table 15. Relationship between DESI and solid biofuels electricity production capacities (SBEP)

Country	r	r^2	*P-value*	Slope (b_1)
European Union	0.855234966	0.731426848	0.064664602	N/A
Bulgaria	-0.088299478	0.007796798	0.887719878	N/A
Romania	0.907749795	0.824009691	0.033165169	2.791371632
Finland	0.897909283	0.806241080	0.038552128	44.213719202
Germany	-0.143165542	0.020496372	0.818340593	N/A
Denmark	0.979468855	0.959359239	0.003520559	39.087771811

Source: Author's own representation

The analysis identifies three statistically significant linear relations at a level of confidence of 95% in the case of Romania, Finland, and Denmark with strong correlation coefficients. According to the analysed samples, the models reveal increases in SBEP by 2.79 megawatts in Romania, 44.2 megawatts in Finland and 39 megawatts in Denmark, following one unit increase in DESI.

5. Conclusion

In general, in the timeframe of this research, the analysed countries improved their performances regarding the selected indicators. Some exceptions occurred; Romania`s wind electricity production capacities or Bulgaria`s and Germany`s solid biofuel electricity production capacities decreased.

Regarding the relationship between GDP per capita and DESI, the analysis revealed that only three out of the five countries investigated proved to record statistically significant linear relations at a level of confidence of 95%, namely Bulgaria, Denmark, and Romania. The relationship between the analysed variables explained a high percentage of the variation in the value of DESI.

As to the relationship between real GDP per capita and the electricity production capacities for renewables and wastes (wind, solar and solid biofuels), there were no statistically significant relationships identified in all the five countries and the EU27, except Romania`s relationship between GDP per capita and solar electricity production capacities.

From all the analysed entities, Romania had the best statistics concerning the relationships between GDP per capita with DESI and GDP per capita and electricity production capacities for renewables and wastes. Romania ranked 12th in the EU27 regarding solar electricity production capacities but 26th in GDP per capita.

There was a statistically significant relationship between DESI and wind electricity production in Germany, Finland, and Denmark. The relationship between the variables explained, to a high degree, the variation in the value of WEP (there are robust coefficients of determination). Though there were strong correlation coefficients in the case of Romania and Bulgaria, the relationships were not statistically significant. Romania ranked 14th regarding the capacities for wind electricity production, while Bulgaria 17th.

Germany, Finland, and Denmark had statistically significant relationships between DESI and solar electricity production capacities, with high correlation coefficients and a high percentage of the variation in the SEP value explained by the relationship between the variables. Though Romania and Bulgaria have strong correlation coefficients, the relationship is not relevant from a statistical standpoint. It is worth mentioning that Romania ranked 12th regarding solar electricity production capacities, better than Denmark, Bulgaria, and Finland.

Denmark, Romania, and Finland recorded statistically significant relations between DESI and SBEP, with high coefficients of determination. Romania ranked 17th in the EU as to solid biofuel electricity production capacities.

Out of seven investigated relationships, in the case of Romania, three proved to be statistically significant. The higher the GDP per capita, the better the DESI score. It does not mean that one variable causes the other. The same applies to the relationships between DESI and SEP and DESI and SBEP.

The relationship between GDP per capita and SBEP proved statistically insignificant in all the analysed countries.

In conclusion, the more prosperous the country, the better the value of DESI, and the better the value of DESI, the higher the electricity production capacities for renewables and wastes (wind, solar, solid biofuels) with variations from one country to another, depending on the country specifics.

Further analyses should investigate the relationships between the components of DESI and electricity production capacities for renewable and wastes to identify which are more statistically significant.

The main limitation of the research is the limited number of observations used for the regressions.

References:

[1] European Commission. (2022a). Digital Economy and Society Index. Available at: https://digital-agenda-data.eu/datasets/desi/visualizations

[2] European Commission. (2022b). Digital Economy and Society Index. Aggregate score. Available at: https://digital-agenda-data.eu/charts/desi-components#chart={%22indicator%22:%22desi_total%22,%22breakdown-group%22:%22desi_totals%22,%22unit-measure%22:%22pc_desi%22,%22time-period%22:%222022%22}

[3] Eurostat. (2022a). Electricity production capacities by main fuel groups and operator (nrg_inf_epc). Available at: https://ec.europa.eu/eurostat/cache/metadata/en/nrg_inf_epc_esms.htm

[4] Eurostat. (2022b). Real GDP per capita, Chain linked volumes (2010), euro per capita. Available at: https://ec.europa.eu/eurostat/databrowser/view/SDG_08_10/default/table

[5] Eurostat. (2022c). Electricity production capacities for renewables and wastes. Available at: https://ec.europa.eu/eurostat/databrowser/view/nrg_inf_epcrw/default/table?lang=en

[6] Li, Y., Yang, X., Ran, Q., Wu, H., Irfan, M., & Ahmad, M. (2021). Energy structure, digital economy, and carbon emissions: evidence from China. Environmental Science and Pollution Research, 28(45), 64606-64629.

[7] Parra, J., Pérez-Pons, M. E., & González, J. (2020, June). Study Based on the Incidence of the Index of Economy and Digital Society (DESI) in the GDP of the Eurozone Economies. In International Symposium on Distributed Computing and Artificial Intelligence (pp. 164-168). Springer, Cham.

[8] Olczyk, M., & Kuc-Czarnecka, M. (2022). Digital transformation and economic growth-DESI improvement and implementation. Technological and Economic Development of Economy, 28, 775-803.

[9] GHERGHINA, E. M., PAŞA, A. T., & ONOFREI, N. (2021). The effects of digitalization on economic growth. Economic Convergence in European Union, 131.

[10] Shahbaz, M., Wang, J., Dong, K., & Zhao, J. (2022). The impact of digital economy on energy transition across the globe: The mediating role of government governance. Renewable and Sustainable Energy Reviews, 166, 112620.

[11] Stremousova, E., & Buchinskaia, O. (2019). Some approaches to evaluation macroeconomic efficiency of digitalisation. Business, Management and Economics Engineering, 17(2), 232-247.