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Clustering and Multiple Regression Analysis of the Renewable Energy Sector in the OECD Countries

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Abstract

The use of energy from renewable sources has many potential benefits, including a reduction in greenhouse gas emissions, diversification of energy supply and reduction of dependence on fossil fuel markets (in particular, on the oil and gas market). The development of renewable energy sources can also influence employment by creating jobs in the new "green" technologies sector. The aim of our research was to identify the main factors influencing renewable energy consumption in OECD countries during 2017-2018. We applied data mining techniques to reduce data dimensionality and developed our research by using Clustering Analysis and Multiple Regression Analysis. We analysed the relationship between GDP per capita and primary energy supply. We considered primary energy supply as the dependent variable and the first three factor scores retained when we applied principal component analysis, as the independent variables, as well as GDP per capita. By applying the K-means algorithm we obtained 5 clusters, having USA and Canada as outliers. The compactness of the clustering, namely the similarity of the objects in the same group is of 68.5%. Applying multiple regression analysis, we obtain that 51% of the variation in primary energy supply can be explained by the three factors and GDP per capita. The results of our research show that renewable energy is an extremely valuable resource with a significant influence on GDP. States that have coherent energy policies for the use of renewable energy resources have already made major changes in their economic models to achieve sustainable development.

Keywords: renewable energy, clusters, regression.

JEL Classification: Q2, Q4, Q5

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1. Introduction

In the last decades, the interest in renewable energies has increased rapidly. One of the reasons is that environmental issues have become increasingly visible on the political agenda (Dan, 2019) and capital investment can provide the necessary impetus to reduce environmental degradation (Mesagan & Olunkwa, 2020). A significant increase in investments for the capitalization of the renewable energies can be observed. Although the conventional energy system considers renewable energy sources as alternative sources, we are actually talking about sources that, in one form or another, have been used by humanity for thousands of years - compared to fossil fuels, for which the technology of exploitation has developed only in the last 150-200 years. According to the IEA (International Energy Agency, 2019), world energy production has increased almost 4 times in the last 50 years, from about 6,000 TWh to almost 24,000 TWh. As one terawatt-hour is one billion kilowatt-hours, it means that humanity consumes in a year the amount of energy needed to operate about 70 billion refrigerators (Benda-Prokeinová et al., 2017). Considering that a western household consumes an average of 3,000 kWh/year, the total energy produced would meet the needs of 8 billion families.

At the level of large companies, investments in renewable energy are gigantic but face many administrative-bureaucratic problems. In recent years, a new concept has emerged, that of "energy citizens", who show much greater flexibility and have the ability to create a much more efficient energy distribution/storage network than in the case of large utility companies. "Energy citizens" can be both individuals and small businesses or even family communities. Experts estimate that in 2050, the network of "energy citizens" could produce over 600 TWh of solar panels, respectively over 900 TWh due to wind turbines. Interestingly, the most important contribution in the solar field would be to households (with almost three-quarters of energy production), while two-thirds of wind energy would be provided by SMEs (Tvaronavičienė et al., Kasperowicz et al., 2017). Energy security, the competitiveness of energy and economic markets, together with ecological and climate sustainability is the fundamental strategic objectives of the strategy of any responsible government.

Our research shows the renewable energy potential of the OECD countries and their impact on economic development. Five clusters were identified on these coordinates and we analysed their structure and the influences thereof on the economic development of the OECD states.

2. Problem Statement

Renewable energies mean all those types of energy sources that do not pollute or have an extremely small impact on the environment or the health of living things, being, at the same time, sources which regenerate due to natural processes or are inexhaustible (from the temporal perspective of people life). The main sources of renewable energy are wind (due to air currents and winds), solar (which captures and transforms solar energy into electricity and heat), various types of water energy (hydraulics – the energy of running water; tides − energy obtained from the flow / reflux of seas and oceans; osmotic − wave energy), geothermal (energy gained from the deep heat of the Earth) or energy obtained from biomass (fuels obtained from the processing of plants or wood mass). The transition from fossil fuel to renewable fuel units is also an economic necessity, not just a climate one. Some fossil fuel production units in Europe have costs even below 50-60 EUR/MWh. Renewables are already the second-largest source of electricity globally, but their use must be accelerated in order to meet long-term climate goals. As costs continue to fall, more and more subsidies are being given for their use of photo-voltaic panels.

In 2020 the 2019 report EY − Renewable Energy Country Attractiveness Index (RECAI) based on a study on renewable energies was published. The report (Report EY, 2020) highlights that climate change and environmental, social and governance issues are gaining increasing recognition as key factors in developing a company's potential and creating value (Çera et al., 2019). Institutional investors not only expect high-performing financial results from companies, but also demonstrate that they have a positive contribution to society. An increased number of organizations are interested by new technologies in order to reduce their emissions, improve their management system and improve the climate factors. In this context, the keys priorities of the OECD are green organizational behaviour renewable energy and so on (Ik, & Azeez, 2020; Vu & Ngo, 2019). The OECD governments increased the investments funds to develop renewable energy infrastructure as a means of hedging climate change risks. (Tishkov et al., 2020; Dudin et al., 2019; Sarma et al, 2019)

In 2020, for the first time since 2016, the U.S.A. ranks first due to a short-term expansion of the fiscal credit program for the production and long-term development of the offshore wind segment, with investments of $ 57 billion planned to install a capacity of up to 30 GW by 2030. China's growth in the renewable energy sector has slowed down, amid the authorities' intentions to phase out subsidies in order to create a more competitive market (Kuncoro, 2019). France has moved from fourth to third place, securing a strong position on energy prices and allocating 1.4 GW capacity to developers in the wind and solar energy segments, in order to eliminate gradually the dependence of its network on nuclear energy. The United Kingdom, ranked sixth, made a reference proposal to include offshore wind and solar projects in the next tender for difference contracts encouraging greater and more diverse development of the renewable energy sector. Spain rose four places to 11th, despite being severely affected by COVID-19, given that energy and climate policy remains a priority for the new government coalition. It has proposed aggressive but realistic plans to develop the wind and solar energy segment, and most investors remain optimistic about Spain's medium-term outlook.

In recent years, many multinational organizations have tried to diversify their energy sources, have begun to invest more in renewable energy sources and thus drive their development (Žižka & Pelloneová, 2019; Ślusarczyk & Ul Haque, 2019). Tax deductions, reduced fixed costs with bills, but also the opportunity to position themselves as companies trying to protect the environment have convinced many businesses to invest in sustainable energy. While at the beginning solar or wind energy worked intermittently, constant investments in such technologies have led to improved equipment and storage methods, so that these types of green energy have become as safe as traditional ones. In addition, the diversification of forms of renewable energy equalled to the emergence of new opportunities for large businesses to streamline their costs.

In the last year, US multinationals have invested record amounts in solar energy, investments that have reduced carbon dioxide emissions by 2.4 million tonnes. Companies such as Apple, IKEA, Amazon, Walmart or Target have equipped their factories with non-pressurized solar panels and classic solar panels to reduce their production costs and their footprint. But these are not the only ways in which big business benefits from the adoption of renewable energy sources.

Companies that still use traditional energy sources have costs that fluctuate from month to month, but also costs that are rising from year to year. Traditional energy sources have variable prices that rise exponentially. Instead, renewable energy sources have fixed costs: an initial investment, then minimum maintenance costs. And the investment pays off quickly. For example, in case of non-pressurized solar panels, used mainly for water heating, the installation can be done in just a few hours, and the costs are amortized in 2-3 years and in order to encourage companies to give up traditional energy in favour of renewable energy, many states offer some tax exemptions or subsidize some of the costs. This automatically means lower investment costs for businesses or a much better return on investment. Depending on the size of the company, the savings can amount to thousands or even hundreds of thousands of euro (Nevado Gil et al., 2020; Kasperowicz et al., 2017). Our research highlights the influence that renewable energy has on the OECD economic and social development (Duľová Spišáková et al., 2017). Thus, the main research variables were analysed and several correlations were found. We find out that the renewable energy will contribute significantly to the sustainable economic development of the OECD countries.

3. Aims of the research

The aim of our research was to identify the main characteristics of the renewable energy sector in OECD countries during 2017-2018 by using Cluster analyses. The K-Means cluster analysis led to 5 clusters, three of them being single-element clusters: USA, New Zealand and Lithuania. Another objective of our research was to find out and to explain the relationships between GDP per capita and specific variables and factors by using a linear regression model. We chose 13 indicators for 2017-2018 extracted from various databases: OECD, Our World in Data, International Energy Agency (IEA) and International Renewable Energy Agency (Irena). We shall enumerate as follows the 13 indicators: Primary energy supply (toe 1000USD)(V1), Electricity generation (Gigawatt-hours) (V2), Renewable energy (Ktoe) (V3), Traditional biofuels (terrawatt-hours) (V4), Hydropower (terrawatt-hours) (V5), Solar (terrawatt-hours) (V6), Wind and other renewables (terrawatt-hours)(V7), Energy production (ktoe) (V8), Energy imports (ktoe) (V9), Energy exports (ktoe) (V10), Energy capacity (MW) (V11), Energy generation (GWh) (V12) and Nominal GDP per capita (USD) (V13).

4. Research Methods

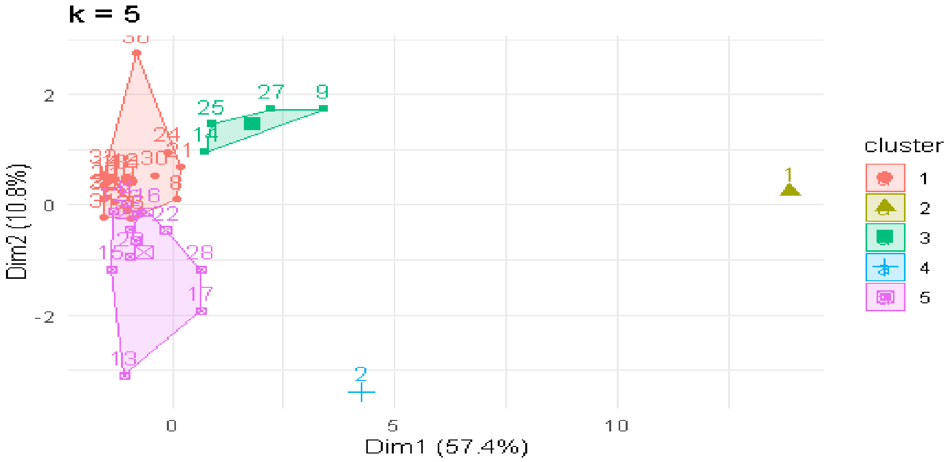
Using the R environment, we applied the k-means clustering (MacQueen, 1967) and we decided that the most appropriate number of clusters is k = 5. K-means algorithm is an iterative clustering algorithm that partitions the data into a number of predefined clusters denoted by K. The purpose of K-means algorithm is to have homogeneous objects in a cluster, such that the within cluster variation is minimized. The main steps of the K-means algorithm are:

- The number of clusters denoted by K is specified.
- The centroids are randomly initialized from the objects of the dataset.
- The objects are assigned to the closest cluster.
- The centroid of each cluster is determined by computing the average of all objects that belong to each cluster.

5. Findings

The OECD countries have been grouped in 5 clusters as in the following figure 1:

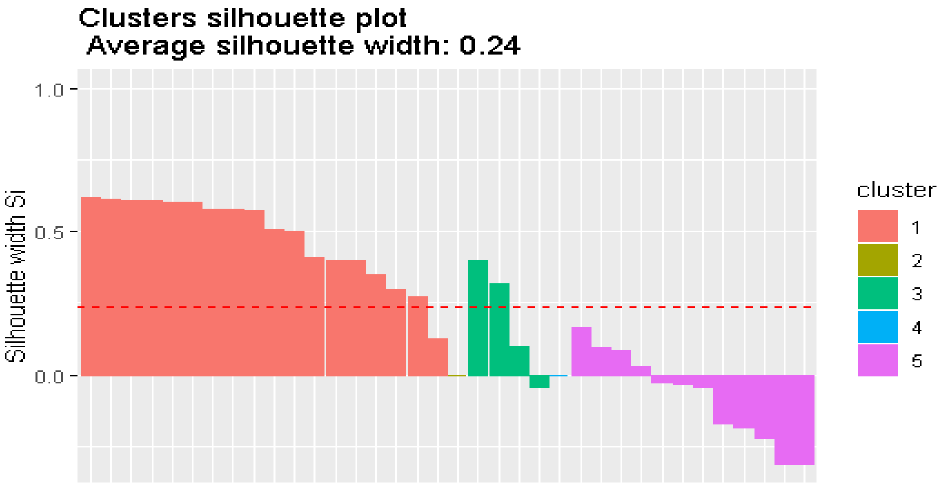
Figure 1. Cluster plot



Source: Authors

The cluster distribution is: 18, 1, 4 ,1, 12. The compactness of the clustering, i.e. the similarity of the objects in the same group is 68.5%. The quality of the clustering is measured by the average silhouette approach. It measures how well the objects are assigned to clusters and also the separation between clusters. The silhouette plot in figure 2 indicates how close an object in a cluster is or may be situated in the neighbouring clusters.

Figure 2. Silhouette plot



Source: Authors

The silhouette coefficient (Rousseeuw, 1987) takes values from -1 to 1. There are three situations: (1) If the silhouette coefficient is close to 1, then the object is located far away from the neighbouring clusters; (2) If the silhouette coefficient is close to -1, then the object could have been assigned to neighbouring clusters; (3) If the silhouette coefficient is around 0, then the object is located on the border of the neighbouring clusters. In our case the average silhouette width is 0.24, meaning that overall the cluster structure is artificial, due to single-element clusters 2 (USA) and 4 (Canada), the cluster silhouettes of which are 0.

The structure of the clusters is as follows:

Cluster 1: Belgium, Czech Republic, France, Greece, Hungary, Poland, Portugal, Slovak Republic, Spain, Turkey, South Korea, Mexico, Estonia, Latvia, Slovenia, Chile, Israel and Lithuania;

Cluster 2: USA;

Cluster 3: Germany, Italy, United Kingdom, Japan;

Cluster 4: Canada;

Cluster 5: Austria, Denmark, Finland, Ireland, Iceland, Luxembourg, Netherlands, Norway, Sweden, Switzerland, Australia, New Zealand.

17.4% of Canada's energy supply came from renewables, such as hydro power, wind power, solar power and biomass 3% of the global renewable energy production comes from Canada (Government of Canada, 2020), and 9% from USA, these statistics placing the two countries on the seventh place, and third place, respectively, in a ranking dominated by China and India.

Cluster 3 is dominated by Germany and Japan. According to Renewable Energy Sources and Figures for 2018 (Renewable Energy Sources and Figures, 2018), in the last years, in Germany, the share of renewables in energy consumption grew from

6% in 2000 to 33% in 2017 and 38% in 2018. In Germany in 2017 the most important renewables were reported as: wind power (16.3%), biomass (6.9%), photostatic and geothermal energy (6.1%), followed by hydro power (3.1%). According to the Japanese Institute for Sustainable Energy Policy (Institute for Sustainable Energy Policy. Share of Renewable Energy Power in Japan, 2018) in 2018, the share of renewable energy to demand was 16.5%; in the total power generation, the solar PV power generation was 6.5%, the share of variable renewable energy (solar PV and wind) was 7.2%, while hydro power and geothermal power remained constant in the electricity generation.

In Cluster 5, we remark Iceland, Sweden and Denmark, which, according to Click Energy (Click Energy, 2017), ranked in a top of 12 world countries generating most of energy from renewables. Iceland ranks first, producing 100% energy from geothermal and hydro power plants. Sweden ranks second, and Denmark eighth. In 2017, Denmark generated electricity enough for 10 million average EU households, only from wind power.

In Cluster 1, Latvia, Portugal, Lithuania and Slovenia occupy top positions, intercalated with some countries from cluster 5, Sweden, Finland, Denmark, Austria in Eurostat 2018 statistics regarding the share of energy from renewable sources expressed as percent of gross final energy consumption.

6. A Multiple Regression Analysis Model

In this section we used the Principal Component Analysis results from the paper (Androniceanu A-M et al., 2020) and retain the score factor matrix**.** We followed Zhang et al. methodology (Zhang et al., 2012). An analysis of energy goes in hand with GDP per capita. We intend to discover the effect of GDP per capita on primary energy supply. We consider primary energy supply (V1) as the dependent variable and the first three factor scores F1, F2, F3 as the independent variables, as well as (V13) GDP per capita.

The original variables and the factor scores F1, F2, F3 will be standardized according to the formula:

$$x' = \frac{x - m}{\sigma^2} \tag{1}$$

where x' denotes the standardized data, x denotes the original data (V13, F1, F2, F3, V1), m is the mean and σ is the standard deviation of the original data.

We apply OLS to estimate the parameters a, b, c, d and e in equation (2):

$$V_1' = aV_{13}' + bF1' + cF2' + dF3' + e \tag{2}$$

where by $V_1', V_{13}', F1', F2', F3'$ we denoted the standardized indicators.

Table 1. Multiple regression analysis

Variable	Coefficient	Std. Error	t-Statistic	Prob.
V13	-361.6254	206.1550	-1.754143	0.0893
F1	0.017795	0.018509	0.961394	0.3438
F2	-0.047545	0.009423	-5.045462	0.0000
F3	0.009307	0.007367	1.263246	0.2159
C	0.102139	0.006412	15.92959	0.0000

R-squared	0.510829	Mean dependent var	0.102139
Adjusted R-squared	0.447710	S.D. dependent var	0.051767
S.E. of regression	0.038471	Akaike info criterion	-3.549559
Sum squared resid	0.045881	Schwarz criterion	-3.329625
Log likelihood	68.89205	Hannan-Quinn criter.	-3.472796
F-statistic	8.093133	Durbin-Watson stat	2.096581
Prob(F-statistic)	0.000137		

Source: Authors

The regression line is:

$$V_1' = 0.1021 - 361.62V_{13}' + 0.01777F1' - 0.0475F2' + 0.0093F3' \quad (3)$$

Equation (3) shows that when the GDP per capita raises by one unit, the dependent variable primary energy supply decreases by 361.62 units. The adjusted R-square statistic is equal to 0.44, indicating a moderate fit. R-squared equals 0.51, which means that 51% of the variation in primary energy supply is explained by the independent variables F1, F2, F3 and GDP per capita.

7. Conclusions

The results of cluster analysis showed that Canada and USA are single elements clusters, due to their top positions in generating electricity mainly from renewables and the investments in carbon-free energy sources.

The results of our research show that massive investments will be needed in the field of renewable energy in order to modernize, expand and decentralize the networks for the production, storage, transport and distribution of renewable energy to make them more robust and resilient. Innovation plays a key role in this transition process. The newest flexible gas turbines and engines already convert natural gas into electricity at low costs and allow operators to introduce intermittent renewable energy such as solar or wind energy into the mix. Big Data and the industrial Internet will also facilitate the efficiency of energy utilities. Our research shows that renewable energy helps build and exist modern economies and is essential for everyday life on the planet.

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