

INNOVATIVE DEVELOPMENT OF RENEWABLE ENERGY DURING THE CRISIS PERIOD AND ITS IMPACT ON THE ENVIRONMENT

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Abstract. The article examines the innovative trends in the renewable power generation, taking into account the impact of crises, as well as the impact of renewable energy on air pollution in the world (environmental change). Hierarchical agglomerative and iterative methods of cluster analysis, as well as econometric models were used to test the hypotheses. Carbon dioxide emissions and renewable power generation for 78 countries during 2000-2020 are taken into account as the database of the study. The results showed that there are groups of countries with sharp, high, moderate and low growth rates of renewable power generation. In addition, the results of econometric analysis indicate that the growth of renewable power generation does not always cause a decrease in carbon dioxide emissions. For a number of countries (Australia, Canada, Mexico, Poland) such connection is not essential at all. The results of the study can be useful in shaping and adapting environmental strategies around the world.

Keywords: Carbon dioxide emissions, renewable power generation, innovative development, crises period

JEL Classification: F64, O13, O44

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1. Introduction

The growth of the Earth's population aggravates the problem of limited non-renewable natural resources. Experts are counting down the time when humanity will no longer have access to depleted resources. As on July 29, 2021, the world's oil reserves remained for 42 years, gas reserves – for 157 years, coal reserves – for 406.6 years (World Health Organization, 2021). In addition, 67% of greenhouse gas emissions are caused by energy and burning of fossil fuels, which leads to an increase in the global average temperature (Ministry of Environmental Protection, 2021). Therefore, the international community is joining forces to research, develop and commercialize "green" energy, decarbonise and determine energy efficiency areas and also to reach international agreements and develop common strategies to address global climate and environmental challenges. The Kyoto Protocol, signed in 1992, has been ratified by 191 countries. However, the tools provided to reduce CO₂ emissions have not been effective enough and the problem of global warming in the 21st century has become even more acute. Therefore, the European Union has made great efforts to formulate a climate policy based on the decarbonisation of economy. 195 countries of the world have joined the Paris Agreement, which has independently determined the percentage of reduction of CO₂ emissions in their countries.

Due to the COVID-19 crisis, energy consumption has decreased in most countries. The exception is China, which has a significant impact on global energy consumption, as it consumes 24% of the world's energy. In 2020, this indicator increased by 2.2%, which is much less than in previous years (Enerdata, 2021).

Global energy demand in 2020 fell by 4%. It has been the largest decline since World War II and the largest ever absolute decline. At the peak of restrictions in April, global oil demand was more than 20% below pre-crisis levels. Overall, oil demand was down by almost 9% across the year. The largest declines in coal use for electricity generation were in advanced economies, down 15%, which accounts for more than half of coal's global decline (Global Energy Review, 2021). Those existing coal and other fossil fuel-fired power plants cause billions of tons of CO₂ discharge into the atmosphere each year and account for about 26 % of global greenhouse gas emissions.

The economic downturn in 2020 led to a 5.2% reduction in CO₂ emissions, however, it is expected that this figure will not be contained and in 2021 it will increase again by 4.4% (Enerdata, 2021). At a regional level, the different responses to the pandemic impacted emissions in different ways. On average, advanced economies saw the steepest declines in annual emissions in 2020, averaging drops of almost 10%, while emissions from emerging market and developing economies fell by 4% in comparison with 2019 (Global Energy Review, 2020).

In the power sector, CO₂ emissions declined by 3.3% in 2020. The share of renewables in global electricity generation rose from 27% in 2019 to 29% in 2020, the biggest annual increase on record. Renewables accelerated their expansion in 2020, with a 50% increase in their

contribution to lowering power sector emissions relative to 2019 (Global Energy Review, 2020). In 2021, 17.6% of electricity in the world was used from renewable resources (World Health Organization, 2021). Increasing of renewable capacity of oil-exporting countries is also actively involved. Thus, the goal of the UAE Energy Strategy by 2050 is to achieve at least 44% of "clean" energy in the energy balance.

Economic growth achievement in China's economy was primarily fuelled by fossil fuels – particularly coal, the main source for the emission of a variety of air pollutants and carbon dioxide (CO₂). In 2020, China was responsible for 31.8% of electricity generation and 32.4% of global CO₂ emission (Our world in data, 2021). Nowadays China is searching for the new industrial and environmental policy direction to reach social sustainability, economic development and environmental prevention (Song et al., 2020).

Air quality is closely related to the economic levels of countries. It was used the bivariate local indicator of spatial association (LISA) statistic to reveal the spatial heterogeneous relationship between local GDP per capita and nearby air quality, especially fine particulate matter (PM_{2.5}) among 256 cities in China in 2015. It was found that there is a group of cities with a significant number of coal-fired power plants, iron and steel plants. It has higher technology level and lower emission intensities (Lu et al., 2020).

As the pandemic leads to a decline around the world, greenhouse gas emission is expected to decline. But the annual increases in GDP per capita and in emissions were not well-correlated (Sueyoshi & Yuan, 2015).

2. Literature Review

The results of the study (Andrée et al., 2019) suggest that pollution level peak in middle income countries, and while pollution levels can generally be expected to decline in these countries as their income level grows, pollution level will still remain dangerously high in this group.

The estimation results (Kukla-Gryz, 2009) suggest that the impact of economic growth on air pollution intensity varies between the developing and developed countries. In the developing countries, this impact occurs through the change of the structure of economic activity, while in the developed countries this impact is mainly direct and occurs through the sum of the scale and income effect. The positive sign of this impact suggests the dominance of the scale effect over the income one.

Renewable energy has a negative and statistically significant impact on CO₂ emissions in the short run. However, the depletion rate of non-renewable energy and GDP revealed a positive and statistically substantial effect on CO₂ emissions in both the short and the long run that is showed by the studies conducted in Thailand and based on the time series data collected from 1980 to 2018 (Abbasi et al., 2021).

The contribution of different sectors to carbon emissions is not equal. The environmental impact of technological progress might vary across sectors. Our findings reveal that environmental technologies in transport sector have a statistically insignificant positive effect on CO₂ emissions from the transport sector. Moreover, while economic growth and energy consumption lead to more pollution, the effect of urbanization on emissions is not statistically significant. Research is focused on the EU15 countries over the period between 1977 and 2015. This is expected to the transport sector for becoming a carbon-neutral economy by 2050 (Alataş, 2021).

The results show that the technical progress is the main reason for the reduction of CO₂ emissions in the historical stage, pre-peak stage and post-peak stage (Grythe & Lopez-Aparicio, 2021).

There is an inverse U-shaped relation between patent generation and CO₂ emissions for both, more and less energy-intensive sectors, suggesting that at low levels of innovation new technologies tend to be “dirty”, but at high levels of innovation they tend to be “green”. Such dependence was found in the study of 30 provinces and 32 economic sectors in China (Li et al., 2021). Research of OECD countries over a period of almost 150 years suggests that 1% increase in transport infrastructure is associated with an increase in CO₂ emissions of about 0.4%, although dependent on the long-run estimator used (Churchill et al., 2021).

Investment in nuclear energy reduces CO₂ emissions in Canada, the Netherlands, Japan, Switzerland, Czech Republic and UK, (ii) investment in renewable energy reduces CO₂ emissions in Belgium, Canada, France, Germany, Sweden, the UK, the US, Japan, Switzerland, Finland, Czech Republic; however, it increases CO₂ emissions in the Netherlands and South Korea, and (iii) both nuclear and renewable energy consumption reduces carbon emissions for the panel estimations. The best option to reduce CO₂ emissions is to aim for a mix of nuclear and renewable energy (Saidi & Omri, 2020).

The review of the research induces the authors to formulate new hypotheses and enlarge the research sphere.

Hypothesis 1. Renewable energy is developing more intensively in the developed countries. Its development does not respond to crises.

Hypothesis 2. The development of renewable power generation improves the state of the environment; however, such effects are heterogeneous in different countries.

3. Methods

For studying the renewable power generation impact on air pollution, the methods of multivariate statistical analysis, such as the pair correlation and the cluster analysis are used. These statistical methods were implemented with the StatSoft's software package “Statistica”. The number of countries studied is 78. The study period is from 2000 to 2020. The

countries without sufficient data were excluded from the database. This study does not include African countries because the statistical data were provided by the macro-regions of the continent.

To carry out the research, the global indices of air pollution and development of renewable energy were selected: Carbon dioxide emissions or CO₂ emissions (Million tons of carbon dioxide) are those stemming from the burning of fossil fuels and the manufacture of cement (Our world in data, 2021). Renewable power generation (Terawatt-hours) is derived from natural processes that are replenished constantly (electricity and heat generated from solar, wind, ocean, hydropower, biomass, geothermal resources, and biofuels and hydrogen derived from renewable resources) (Renewable energy, 2021).

The analysis of dynamics of renewable energy development is offered to be carried out by the following algorithm: Stage 1. Determination of groups of countries homogeneous in the dynamics of renewable power generation, based on the methods of cluster analysis; Stage 2. Study of the dynamics of RPG in each selected group of countries.

4. Results and Discussion

During the implementation of the first step of the algorithm, 78 countries were divided into 3, 4 and 5 clusters based on an iterative method of clustering k-means. The hierarchical clustering method (Ward's method) gave a good visualization of the partition shown in Figure 1. During the division of countries into 3 clusters according to the dynamics of the indicator of renewable power generation, Cluster 3 includes 69 countries.

The division into 4 clusters allows obtaining such a division of countries:

Cluster 1 – China and the USA;

Cluster 2 – Brazil, Germany, India, Italy, Japan, Spain, the United Kingdom;

Cluster 3 includes 17 countries – Australia, Belgium, Canada, Chile, Denmark, Finland, France, Indonesia, Mexico, the Netherlands, Philippines, Poland, Portugal, South Korea, Sweden, Thailand, Turkey;

Cluster 4 includes 52 remaining countries.

When divided into 5 clusters, Germany is allocated to a separate cluster, and the composition of all other clusters remains unchanged. Therefore, in our opinion, it is expedient to carry out the research of dynamics of an indicator of RPG for four groups. Figure 2 shows the average values of renewable power generation for each of these four clusters. The quality of clustering by Fisher's criterion is very high (p-level = 0.0000).

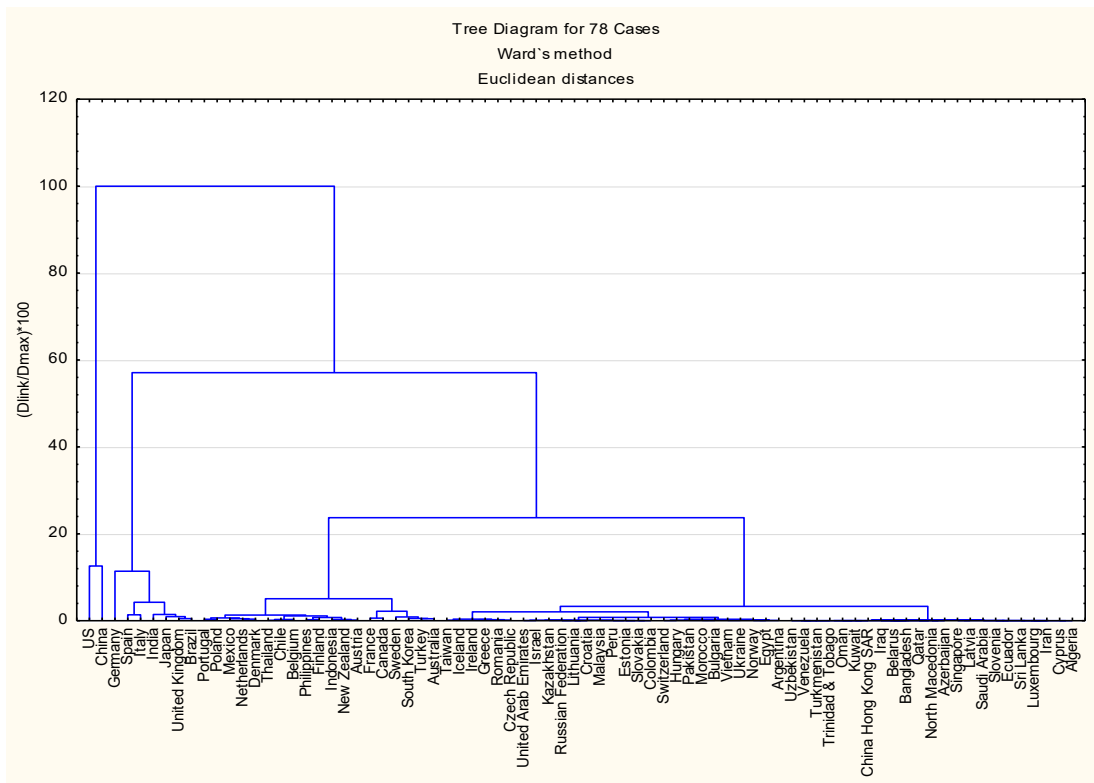


Figure 1. A Tree Diagram.
 Source: Developed by the authors

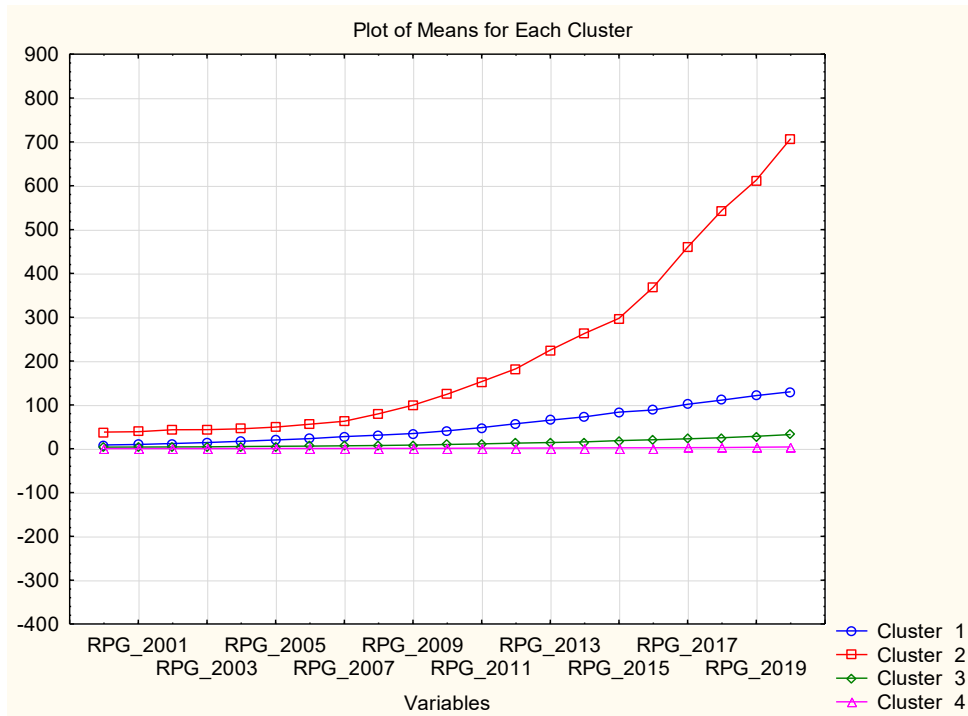


Figure 2. A Plot of means for each cluster
 Source: Developed by the authors

So, the countries from the second cluster – China and the USA – are the countries with the highest growth rate of RPG. (Figure 3)

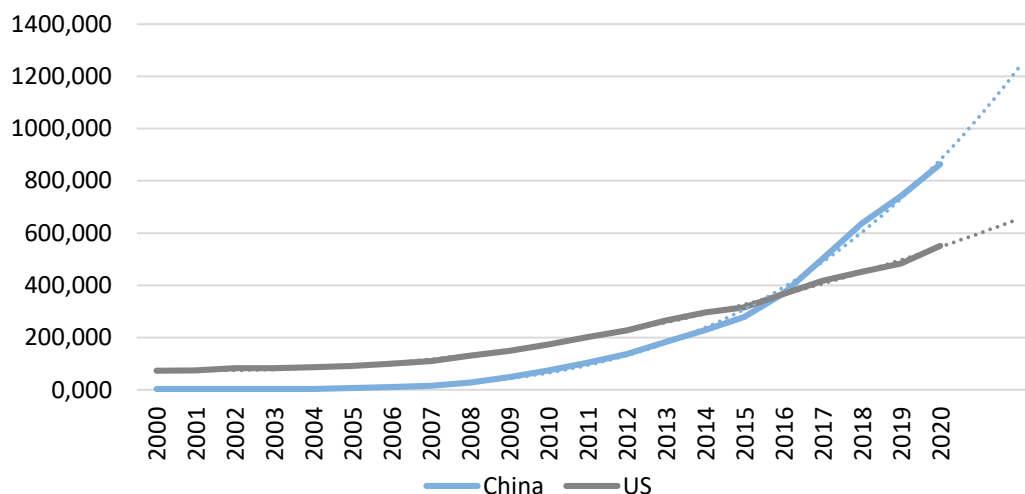


Figure 3. Dynamics of RPG for the countries of the first cluster

Source: Developed by the authors

As can be seen on Figure 3, the crisis has slowed down the dynamics of RPG in China. However, the growth rate of the indicator remains high. Moreover, in the USA, after the crisis, the development of RPG accelerated compared to the previous year 2020. Thus, for China, the basic growth rate (based on 2000) in 2020 was

$$\tau_{20} = \frac{RPG_{2020}}{RPG_{2000}} = 1216 \quad (1)$$

For the USA:

$$\tau_{20} = \frac{RPG_{2020}}{RPG_{2000}} = 777.3 \quad (2)$$

These growth rates differ significantly from each other, however, their difference from the values for other countries is even more significant. In this case, the dynamics of change in the RPG for China can be described by a polynomial of the third degree ($R^2 = 0.9976$), reflecting the change in growth acceleration, and for the United States – a polynomial of the second degree ($R^2=0.9984$), which reflects the uniformly accelerated process.

The reduction of air pollution can be achieved through the coordinated measures by the states. For example, Comprehensive control actions with multi-party coordination on provincial and even national levels have been implemented in China to minimize the adverse ecological and social impacts of pollution. Since 2013, combating PM2.5 pollution has marked a strategic transfer from emission control toward air quality management in China (Kukla-Gryz, 2009).

Let us consider the dynamics of the RPG indicator in the first cluster (Figure 4).

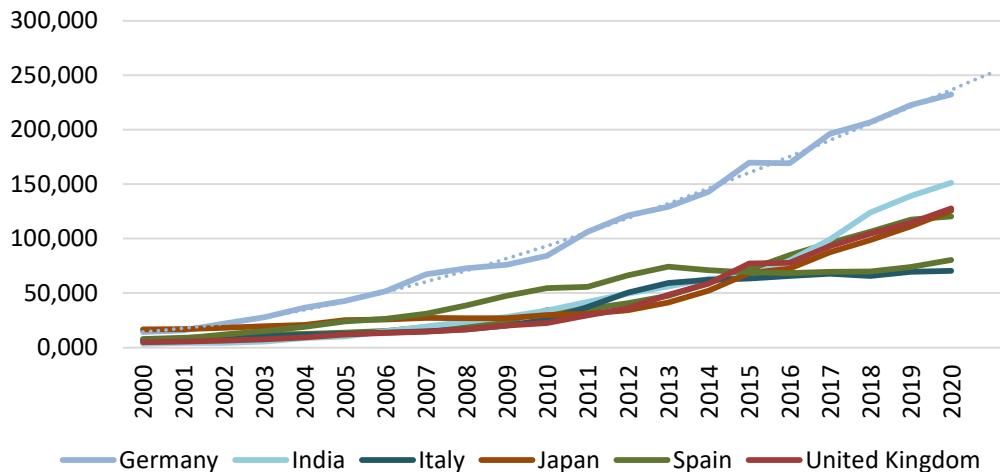


Figure 4. Dynamics of RPG for the third cluster

Source: Developed by the authors

The fastest growing renewables are in Germany. That is why this country was singled out into a separate cluster when it was divided into 5 clusters. RPG dynamics for Germany is best approximated by a third-degree polynomial ($R^2=0.9963$). Base growth rate for this country is:

$$\tau_{20} = \frac{RPG_{2020}}{RPG_{2000}} = 327.4 \quad (3)$$

The base growth rates for the rest of the countries in this cluster are in the range of 99.1 (Italy) to 213.0 (India). So, this cluster includes countries with high RPG growth rates.

Let us consider the dynamics of the RPG indicator in the third cluster. The fastest growing is in France. The dynamics of changes in the RPG indicator in this country is fairly well described by a polynomial of the second degree ($R^2 = 0.9966$). The base growth rate is 90.6. Basic growth rates for the rest of the countries in this cluster are in the range from 20.3 (Philippines) to 70.2 (Australia, Turkey). Thus, this cluster includes countries with an average RPG growth rate.

Cluster 4 includes countries with low RPG growth rates. The highest value of the basic growth rate is in Greece (20.5), and the lowest (0.2 - 0.3) is in Kuwait, Oman, Qatar, Azerbaijan.

Thus, hypothesis 1 was not confirmed, since there are developing countries with high growth rates of renewable energy (China, Brazil, India). Developed and developing countries have reacted differently to the crisis triggered by Covid-19.

To test hypothesis 2 for each of 78 countries, regression equations of the form:

$$CD_{et} = a_1RPG_t + a_0 \quad (4)$$

Let us consider the obtained results of the regression analysis. For countries from cluster 1, the results are shown in Table 1.

Table 1. Regression results for countries from cluster 1

	a_1	a_0	$ t_{a1} $	$ t_{ae} $	R^2	R	F
China	5.807	6327.544	4.25	14.02	0.4876	0.698	18.08
US	-2.314	5918.759	10.10	95.57	0.8431	0.918	102.09

Source: Developed by the authors

Comparing the calculated value of the student's statistic t_{a1} and t_{ae} with a critical value t_p (0.05;19) = 2.093 it can be concluded that the regression coefficients are statistically significant in both models. Also, both models are statistically significant according to Fisher's test.

Positive parameter value a_1 for China indicates that the intense growth of renewable power generation does not lead to a reduction in carbon dioxide emissions.

Table 2. Regression results for countries from cluster 2

	a_1	a_0	$ t_{a1} $	$ t_{ae} $	R^2	R	F
Brazil	1.288	333.757	4.72	20.69	0.5397	0.735	22.27
Germany	-0.806	871.197	8.65	73.98	0.7977	0.893	74.90
India	10.565	1156.637	10.83	17.84	0.8605	0.928	117.19
Italy	-2.180	470.031	13.05	64.02	0.8997	0.949	170.34
Japan	-1.568	1292.800	5.06	73.29	0.5740	0.758	25.60
Spain	-1.180	367.690	4.84	28.45	0.5518	0.743	23.39
The United Kingdom	-1.954	582.647	21.19	108.74	0.9594	0.979	449.10

Source: Developed by the authors

All models have statistically significant regression coefficients. Positive parameter value a_1 obtained for Brazil and India, that is, in these countries, the increase in renewable power generation is accompanied by an increase in carbon dioxide emissions.

Table 3. Results of regression analysis for countries from cluster 3

	a_1	a_0	$ t_{a1} $	$ t_{ae} $	R^2	R	F
Australia	0.278	385.203	1.00	70.26	a1	a0	1.00
Belgium	-1.617	139.289	7.29	58.93	0.7369	0.8584	53.21
Canada	0.144	550.080	0.63	85.72	0.0203	0.1424	0.39
Chile	1.618	65.626	4.72	19.72	0.5402	0.7350	22.32
Denmark	-1.757	71.245	14.64	40.20	0.9186	0.9584	214.39
Finland	-2.266	84.049	5.89	17.06	0.6465	0.8041	34.75
France	-1.923	388.302	14.88	101.90	0.9209	0.9597	221.32
Indonesia	28.366	166.058	8.93	5.28	0.8075	0.8986	79.71
Mexico	0.827	416.665	0.77	24.25	0.0303	0.1742	0.59

Continued Table 3

The Netherlands	-1.857	236.313	7.63	72.65	0.7541	0.8684	58.27
Philippines	14.034	-69.164	8.94	3.86	0.8080	0.8989	79.96
Poland	-0.258	309.502	0.88	77.69	0.0394	0.1986	0.78
Portugal	-0.768	63.365	7.01	48.29	0.7214	0.8494	49.21
South Korea	4.624	502.290	5.24	37.78	0.5908	0.7686	27.43
Sweden	-0.573	63.417	9.40	51.41	0.8231	0.9072	88.40
Thailand	4.818	214.694	5.93	27.76	0.6489	0.8056	35.12
Turkey	3.675	246.871	7.00	24.43	0.7207	0.8490	49.03

Source: Developed by the authors

Out of 52 objects of the fourth cluster, the positive value of the parameter a_1 there is in 30 countries. Moreover, a statistically significant positive parameter a_1 is for 21 countries only. Statistically significant negative parameter a_1 obtained for 18 countries from 4 clusters (Table 4).

Table 4. Results of regression analysis for some countries from cluster 4

	a_1	a_0	$ t_{a1} $	$ t_{ae} $	R^2	R	F
Austria	-0.939	72.588	4.33	41.06	0.4969	0.7049	18.76
Bulgaria	-1.547	47.880	4.36	57.46	0.5006	0.7075	19.04
Croatia	-1.620	19.400	4.75	49.81	0.5427	0.7367	22.55
Cyprus	-2.098	8.731	3.54	51.63	0.3979	0.6308	12.56
Czech Republic	-3.398	126.427	11.84	86.67	0.8806	0.9384	140.08
Greece	-3.684	110.536	14.21	63.83	0.9140	0.9561	202.04
Hungary	-3.111	57.170	5.26	37.15	0.5924	0.7697	27.62
Ireland	-1.027	46.522	6.75	54.30	0.7058	0.8401	45.57
Luxembourg	-2.041	11.520	2.11	34.09	0.1905	0.4365	4.47
North Macedonia	-8.532	8.847	7.22	76.91	0.7329	0.8561	52.15
Norway	-0.506	36.820	5.38	124.58	0.6034	0.7768	28.91
Romania	-2.487	92.029	7.36	51.49	0.7404	0.8604	54.18
Slovakia	-3.642	38.219	9.93	74.18	0.8383	0.9156	98.52
Slovenia	-4.008	15.669	3.97	41.87	0.4536	0.6735	15.77
Switzerland	-2.402	46.230	8.81	71.61	0.8035	0.8964	77.70
Trinidad & Tobago	-180.060	23.476	2.57	19.86	0.2584	0.5083	6.62
Ukraine	-18.855	300.747	4.94	30.11	0.5619	0.7496	24.37
Venezuela	-3079.51	164.328	2.72	23.14	0.2797	0.5288	7.38

Source: Developed by the authors

Ukraine is in cluster 4 (with a low rate of renewable power generation), however, the resulting model is statistically significant and parameter a_1 is negative. According to the renewed (second) nationally determined contribution to the Paris Charter on Climate Change (HOV2), Ukraine must reduce greenhouse gas emissions by 65% from the 1990 level by 2030.

5. Conclusions

Thus, although due to the crisis caused by COVID-19, the pace of the development of renewable power generation in most countries has declined, but remains positive.

According to the trend of renewable power generation, countries can be grouped into 4 clusters: with high, significant, moderate and low rates of renewable power generation development.

The level of air pollution in 84.6% of countries decreases simultaneously with the increase in renewable power generation. However, there are rare countries in which with increasing renewable power generation CO₂ emissions also increase (China, India, Brazil, Philippines, South Korea, Thailand, Turkey), which is due to the development of the economy and energy complex in the countries. In a group of countries with moderate rates of renewable power generation the rare countries are Australia, Canada, Mexico, Poland, where there is no connection between renewable power generation and carbon dioxide emissions.

Some limitations of this study are due to an insufficient database. Prospects for further research are related to the assessment of the impact of COVID-19 pandemic on the development of renewable power generation and the impact of this indicator on changes in air pollution in groups of countries.

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