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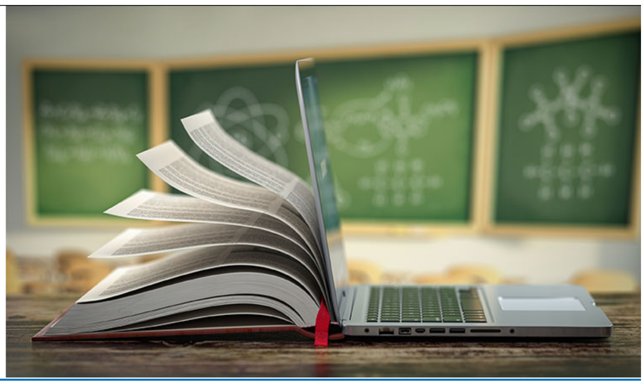

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Ecological changes during crisis period

M Kyzym[1], N Gavkalova[2], Y Lola[2], S Prokopovych[2], Pradeep Jain[2,3]

[1]Ministry of Education and Science of Ukraine, *First Deputy Minister of Education and science of Ukraine*, prospect Peremohy, 10, Kiev, UA
[2]The Simon Kuznets Kharkiv National University of Economics, *Public Administration Department*, ave. Nauki 9-A, Kharkiv, UA
[3]Ananta Medicare Ltd., *Director*, Townmead Road, London, UK

*Corresponding-email: yuliia.lola@hneu.net

Abstract. The article examines the change of the level of air pollution in world`s countries (ecological changes). We verified two hypotheses. It can be caused by an increase in the level of development of countries accompanied by a change in the level of air pollution and the countries with different rates of economic growth may observe different rates of air pollution reduction in the post-crisis period. To test the hypotheses, hierarchical agglomerative and iterative methods of cluster analysis, and econometric models were used. The annual percentage growth rate of the GDP per capita and percentage of population exposed to ambient concentrations of PM2.5 for 101 countries for 2008-2017 were considered as the research information base. The results showed both significant positive and negative effects of increasing level of economic development and air pollution of the countries with a time lag in one-two year. In addition, the results of an econometric analysis show that there are different dynamics of air pollution level for countries with high, medium and low economic growth rates. The results can be of value for the formation and adaptation of the environmental strategies.

1. Introduction

The existing economic concept of human existence has led to the challenges that are unable to be solved. The era of mass production and the period of formation of the market economy led to the allocation of large numbers of businesses seeking to pursue their own interests not taking into account the interests of society as a whole. This led to the ecological collapses faced by humanity in the 21st century. Constant growth of the world's population exacerbates this problem and requires the paradigms of socio-economic development of society under the threat of humanity destruction as a species. The most acute environmental problem is the problem of air pollution.

Ambient air pollution levels have remained high with reduction of concentrations in some part of Europe and America over the past 6 years. The highest air pollution is in the South-East Asia and Eastern Mediterranean Region, according to the World Health Organization [1]. Awareness of the scale of the danger to life on the planet has led to the emergence of such concepts as social entrepreneurship [2], ecological economy [3], and circular economy [4].

At the same time, humanity is at the stage of forming a new economic order in connection with information technologies development. Professor Klaus Schwab, the Executive Chairman of the WEF in Davos, reported about the beginning of the fourth industrial revolution in 2016 related to of mobile

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communication, artificial intelligence, robotics, self-driving cars, neuro technologies, genetics, etc. This revolution is radically changing our live, work and treat each other [5].

A feature of the fourth revolution is its fast spread. However, it is obvious that these rates will be different for different countries of the world. It increases the threat of increasing inequality in the world that will be have both technical and technological nature.

The fundamental basis of human development after the fourth industrial revolutions should become the concepts of social entrepreneurship, ecological economy and circular economy. To understand the existing ecological state of the world`s countries and their dependence on the change of the research of air pollution elasticity is an urgent problem.

2. Critical literature review

In recent years, numerous researches have been conducted on relationship between air pollution and economic development. Especially many such studies were conducted in China, which is the world leader in greenhouse gas emissions. During the past 30 years dramatic economic growth has been witnessed in China with an average annual growth rate of more than 10% [6]. This marvelous achievement in China's economy was primarily fueled by fossil fuels - particularly coal, the main source for the emission of a variety of air pollutants and car-bon dioxide (CO2). In 2017, China was responsible for 23.2% of global energy use and 27.6% of global CO2 emissions [6]. Nowadays China is searching the new industrial and environmental policy direction to reach social sustainability, economic development and environmental prevention [7].

Air quality is closely related to economic levels of countries. It was used the bivariate local indicator of spatial association (LISA). It allowed to reveal the spatial heterogeneous relationship between air quality (PM2.5) and local GDP per capita among 256 cities in China for the year 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 [8].

Accordingly [9] China is one of the most polluting centers of the century. China's carbon emissions fell by around 25% in a month.

As the pandemic leads to a decline around the world, greenhouse gas emissions are expected to decline. In general the average growth in the world economy has been fairly constant since 2010, annual growth in total greenhouse gas emissions saw a distinct drop to 0.2% in 2015. This trend did not continue in 2017. In 2018, the relatively high increase in global greenhouse gas emissions of 2.0% was not accompanied by a very high GDP growth (3.4%). Therefore, the annual increases in GDP per capita and in emissions were not well-correlated [10].

Thus, it is clear that 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 PM2.5pollution. Since 2013, combating PM2.5pol-lution has marked a strategic transfer from emission control toward air quality management in China [11].

Results of the study [12] suggest that pollution levels peak in middle income countries, and while pollution levels can generally be expected to decline in these countries as their income levels grow, pollution levels will still remain dangerously high in this group.

The estimation results [13] suggest that the influence of economic growth on air pollution intensity varies between the developing and developed countries. In the developing countries, this influence occurs through the change of the economic activity structure, while in the developed countries – on the contrary. This influence is basically direct and occurs through the sum of the scale and income effect.

Growth in household expenditures precedes pollution reduction, particularly after the expenditures of poorer households increase. There are significant spillovers from bottom-up growth in expenditures [14]. The marginal effect of income growth on forest cover per capita is the strongest at the earliest stages of economic development that weakens in more advanced economies. It present of conclusive evidence of existence of an environmental Kuznets curve for deforestation [15].

The study [16] evaluates the impact of climate and air pollution on the spread of COVID-19 in Latin America and the Caribbean region. Both income inequality and air quality were significantly associated with the spread of COVID-19.

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

Hypothesis 1. An increase in the level of economic development of countries is accompanied by a change in the level of air pollution and this change may have a certain lag period.

Hypothesis 2. In the post-crisis period, in the countries with different rates of economic growth different rates of air pollution reduction may be observed.

3. Methodology and results

For studying the influence of economic development on air pollution the methods of multivariate statistical analysis, such as the multiple regression and the cluster analysis are used. These statistical methods were implemented with the help of StatSoft's software package «Statistica».

The research algorithm includes three stages:

Stage 1. Selection of the initial variables.

Stage 2. Verification of the first hypothesis based on the correlation-regression analysis methods.

Stage 3. Verification of the second hypothesis on the basis of the correlation-regression and cluster analysis methods for the whole array of initial data and within the scope of separate groups of countries, which are similar in air pollution (PM 2,5 - mixture of solid and liquid particles) trend and GDP per capita.

To carry out the research, the global indices of economic development and ecology state were selected:

growth rate of GDP per capita founded on constant 2010 U.S. dollars [17]. GDP per capita growth rate was calculated as a percentage of GDP per capita in pre-crisis 2006.

percentage of population living in places where annual concentrations of PM2.5 are greater than 25 micrograms per cubic meter [17]. It is more harmful to human health than other pollutants.

The objects of the research are 101 countries of the world. The variables are the data for the period from 2008 until 2017. The database don`t include the countries without sufficient data. This study doesn`t include most European countries because the entire population of these countries lives in areas with air pollution levels of PM2.5 is lower than 25 micrograms per cubic meter.

The verification of the first hypothesis that the level of economic development of countries influences on the level of air pollution with a certain lag period was carried out during the implementation of the second stage of the study. The pair correlation coefficients between the time series $PM2,5_t$ (t= 2010, … , 2017) and lagged values GDP_{t-lag} per capita (lag = 0, … 2), were calculated according to the data for every 101 countries.

Fifty-three countries have the maximum absolute value of the correlation coefficient in case lag equal 2, and 20 countries – lag equal 1. For 28 countries, there is a situation where there is no time shift between changes in GDP per capita and state of air pollution. For these countries, the maximum value of the correlation coefficient is observed between the time series of $PM2.5_t$ and GDP_t per capita.

Thus, it can be noted that for most countries there is a lag between the change in the economic situation of the country and the environmental situation.

For 79 countries, the correlation coefficient between $PM2,5_t$ and GDP_t is negative (for 80 countries – between $PM2,5_t$ and GDP_{t-1}, for 81 countries – between $PM2,5_t$ and GDP_{t-2}). That is, for almost 80 % of countries, there is an inverse relationship between economic growth and air pollution.

Realization of the third stage presupposes verification of the second hypothesis that states: influence of economic development intensity of the countries on air pollution is heterogeneous and tends to increase or decrease in various countries groups. Countries disposal into homogeneous groups by values of $PM2,5_t$ (t = 2010, …, 2017) and GDP growth rate (T_t, t = 2008, …, 2017) based on cluster analysis methods.

The countries can be quite clearly allocated into two, three or five clusters (Fig. 1) based on Ward's hierarchical method.

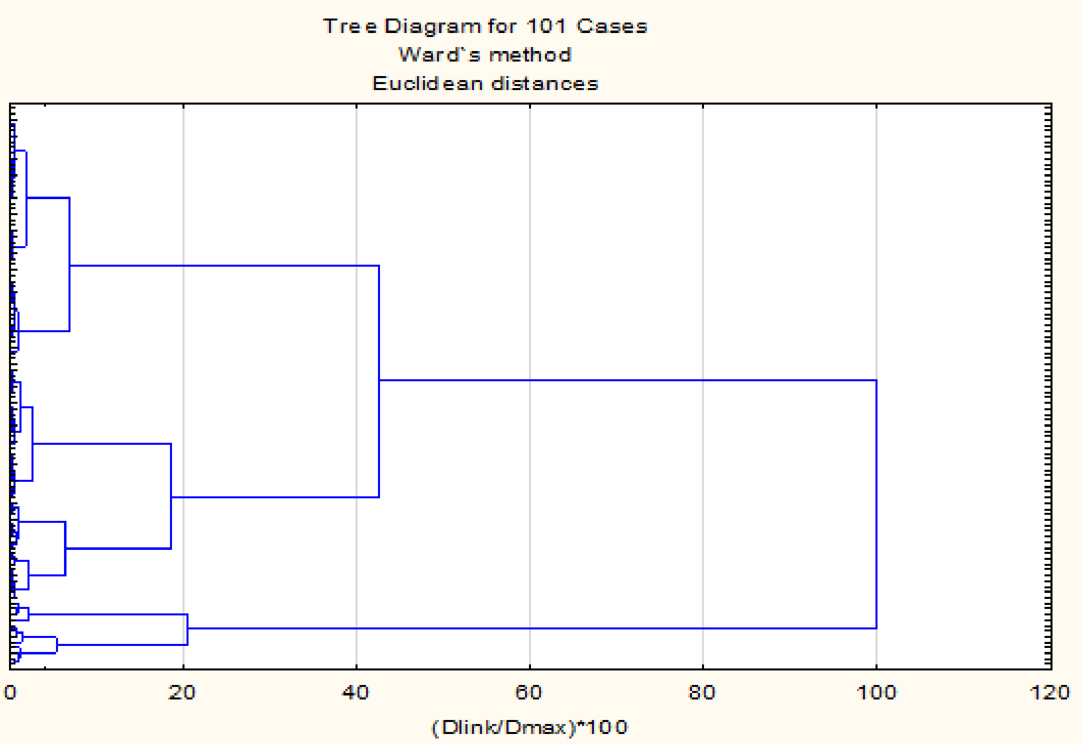

Figure 1. Tree Diagram

It is rational to divide countries into three clusters, which corresponds to the logical distribution of countries with high, medium and low level of economic growth. If we divide countries into five clusters, then the clusters with close average factor values will emerge.

Based on the iterative method of clustering k-means, the following cluster results have been obtained. Three clusters with high, medium and low levels of air pollution and different rates of economic growth were formed (Figure 2).

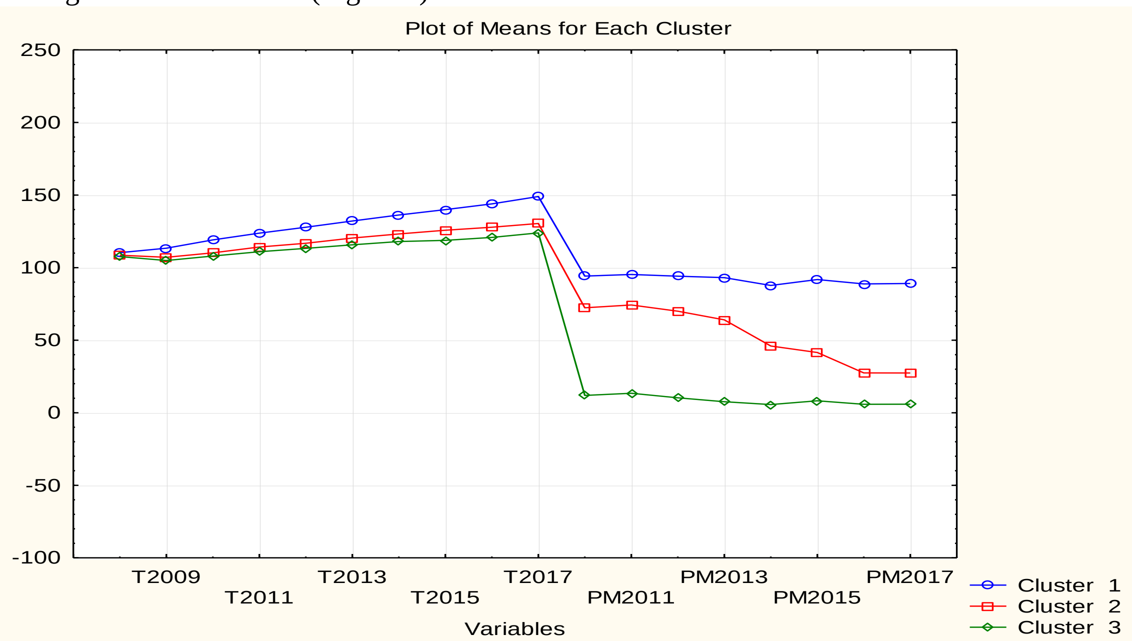

Figure 2. Plot of means for each cluster

Consider in more details the obtained homogeneous groups of countries. The first cluster includes 31 countries with the highest GDP per capita growth rates and the highest pollution levels. These countries are listed in Table 1.

Table 1. Members of Cluster Number 1, Distances from Respective Cluster Center, and Correlation Coefficients between air pollution (PM_t) and GDP per capita $_t$.

№	Country	Distance	Correlation coefficient between PM_t and GDP per capita $_t$		
			GDP per capita $_{t-2}$	GDP per capita $_{t-1}$	GDP per capita $_t$
1	Afghanistan	16,86	-0,3125	-0,2071	-0,0803
2	Armenia	7,35	-0,7989	-0,8986	-0,8510
3	Benin	18,72	0,2707	-0,0357	-0,2179
4	Bhutan	22,92	-0,8710	-0,8773	-0,9479
5	China	42,53	-0,9543	-0,9517	-0,9545
6	Egypt, Arab Rep.	12,47	-0,9066	-0,6157	-0,5139
7	Ghana	13,22	0,1586	0,1284	0,2704
8	Guinea-Bissau	19,51	-0,6252	0,2247	0,4126
9	India	11,28	-0,9538	-0,9528	-0,9631
10	Iran, Islamic Rep.	19,22	0,3012	0,1873	0,1978
11	Jordan	27,19	0,8483	0,8540	0,8541
12	Cambodia	14,43	-0,9520	-0,9281	-0,9224
13	Korea, Rep.	14,44	-0,8677	-0,8567	-0,8969
14	Lao PDR	25,22	-0,9755	-0,9761	-0,9745
15	Lebanon	16,11	-0,4149	-0,9092	-0,9974
16	Morocco	8,96	0,7715	0,7263	0,7410
17	North Macedonia	11,84	-0,9218	-0,8639	-0,8889
18	Mali	20,29	-0,0059	0,6752	0,5407
19	Myanmar	34,15	-0,8246	-0,8223	-0,8098
20	Mongolia	20,25	0,1655	0,1563	0,1904
21	Nigeria	8,54	0,0475	-0,1112	-0,4699
22	Nepal	6,15	-0,8054	-0,7124	-0,6665
23	Pakistan	18,37	-0,9191	-0,9521	-0,9828
24	West Bank and Gaza	4,62	-0,9148	-0,9380	-0,7728
25	Togo	14,51	-0,0811	-0,0876	-0,0988
26	Thailand	13,01	-0,9272	-0,8614	-0,8959
27	Tajikistan	7,47	-0,7768	-0,7454	-0,7600
28	Turkey	9,16	0,9470	0,9879	0,9866
29	Uzbekistan	18,58	-0,8605	-0,8766	-0,8779
30	Vietnam	10,88	-0,9677	-0,9692	-0,9659
31	Zambia	6,34	-0,5270	-0,5210	-0,4400
	Number of maximum values		13	6	12

The countries of this cluster are characterized by the highest rates of economic growth. 61% of countries have a time lag between economic growth and air pollution (42% of countries have a lag of 2 years and 19% – equal to 1 year). Most countries in this cluster have negative correlation coefficients. Correlation coefficients are highly positive only for such countries: Turkey (0,9879), Jordan (0,8541), and Morocco (0,7715). The second cluster includes 30 countries with an average level of air pollution and is presented in Table 2.

Table 2. Members of Cluster Number 2, Distances from Respective Cluster Center, and Correlation Coefficients air pollution (PM_t) and GDP per capita $_t$.

№	Country	Distance	Correlation coefficient between PM_t and GDP per capita $_t$		
			GDP per capita $_{t-2}$	GDP per capita $_{t-1}$	GDP per capita $_t$
1	Bosnia and Herzegovina	14,94	-0,8990	-0,9300	-0,9350
2	Belize	23,17	0,1690	0,0570	0,1600
3	Bolivia	9,05	-0,9680	-0,9840	-0,9870
4	Barbados	26,19	0,5920	0,1280	-0,5770
5	Botswana	9,11	-0,7390	-0,7360	-0,7370
6	Chile	7,55	-0,9890	-0,9420	-0,8820
7	Cuba	16,47	-0,9620	-0,9770	-0,9400
8	Georgia	22,48	-0,9120	-0,9220	-0,9040
9	Grenada	20,35	-0,4400	-0,8710	-0,9650
10	Guatemala	15,22	-0,9550	-0,9580	-0,9430
11	Guyana	10,15	-0,9750	-0,9670	-0,9540
12	Honduras	11,82	-0,9260	-0,9080	-0,9070
13	Kenya	13,94	-0,3320	-0,3020	-0,3930
14	Kyrgyz Republic	12,68	-0,7780	-0,9160	-0,9080
15	St. Lucia	24,79	0,1270	0,2190	-0,0080
16	Sri Lanka	28,72	-0,8260	-0,8000	-0,8010
17	Mexico	16,20	-0,8940	-0,8790	-0,9330
18	Montenegro	14,90	-0,7210	-0,7570	-0,7680
19	Malawi	12,31	-0,6220	-0,6070	-0,7060
20	Namibia	15,45	-0,9290	-0,8220	-0,6220
21	Peru	16,46	-0,9930	-0,9630	-0,9490
22	Poland	15,54	-0,9630	-0,9420	-0,8940
23	El Salvador	17,05	-0,9450	-0,9000	-0,9000
24	Serbia	9,97	-0,8680	-0,9170	-0,9080
25	Suriname	14,68	-0,8110	-0,1520	0,5070
26	Turkmenistan	51,33	-0,8950	-0,8940	-0,8930
27	Trinidad and Tobago	19,41	-0,2050	0,2210	0,8150
28	Tanzania	12,75	-0,7300	-0,7070	-0,7210
29	St. Vincent and the Grenadines	23,38	0,0000	-0,6890	-0,9220
30	South Africa	15,41	-0,5400	-0,3890	0,0300
Number of maximum values			15	6	9

Members of this cluster are characterized by average GDP growth rates and average air pollution levels (Fig. 2). At the same time, this is the only cluster for the countries in which there is a significant decrease in the level of air pollution in the period from 2010 to 2017. In this cluster, 70% of countries have a time lag between economic growth and air pollution (50% of countries have a lag of 2 and 20% – equal to 1). Most countries in this cluster have negative correlation coefficients. Only one country has a high positive value – Trinidad and Tobago (0,8150).

The third cluster includes 40 countries with the low level of air pollution. This cluster is presented in Table 3.

Table 3. Members of Cluster Number 3, Distances from Respective Cluster Center, and Correlation Coefficients air pollution (PM_t) and GDP per capita $_t$.

№	Country	Distance	Correlation coefficient between PM_t and GDP per capita $_t$		
			GDP per capita $_{t-2}$	GDP per capita $_{t-1}$	GDP per capita $_t$
1	Albania	14,0	-0,8337	-0,7651	-0,7297
2	Argentina	4,75	-0,5726	-0,2253	0,7217
3	Australia	7,43	-0,7659	-0,7156	-0,7112
4	Azerbaijan	25,5	-0,6200	-0,4511	-0,4788
5	Bulgaria	9,62	-0,8526	-0,8191	-0,7915
6	Belarus	16,2	-0,9467	-0,8406	-0,5404
7	Brazil	5,51	-0,8608	-0,5715	0,1513
8	Cote d'Ivoire	26,97	0,8705	0,8325	0,7898
9	Colombia	10,33	-0,9726	-0,9714	-0,9443
10	Cyprus	17,08	0,5107	0,4747	0,3337
11	Czech Republic	5,78	-0,4113	-0,7872	-0,7477
12	Germany	7,37	-0,2407	-0,7695	-0,7712
13	Ecuador	5,52	-0,9641	-0,9060	-0,7403
14	Spain	15,54	-0,6278	0,1472	0,6201
15	Guinea	21,17	0,6109	0,5360	0,5855
16	Greece	24,91	0,9426	0,8723	0,6632
17	Croatia	11,70	0,5557	-0,2813	-0,5878
18	Haiti	10,06	-0,0961	-0,7419	-0,3449
19	Hungary	10,64	-0,1798	-0,5763	-0,5606
20	Indonesia	15,44	-0,9716	-0,9665	-0,9609
21	Israel	11,11	-0,9249	-0,9503	-0,9499
22	Italy	17,48	0,6428	0,6146	0,5561
23	Jamaica	16,48	0,8142	0,3301	0,0300
24	Kazakhstan	9,85	-0,8421	-0,8148	-0,7934
25	Latvia	6,91	-0,7541	-0,8256	-0,8110
26	Madagascar	17,19	-0,2323	-0,4323	-0,7534
27	Mozambique	13,62	-0,8904	-0,8739	-0,8265
28	Malaysia	8,40	-0,8056	-0,7510	-0,7604
29	Nicaragua	7,35	-0,9694	-0,9222	-0,9012
30	Philippines	16,10	-0,9556	-0,9679	-0,9676
31	Romania	10,66	-0,2316	-0,5933	-0,6236
32	Russian Federation	3,57	-0,8456	-0,8218	-0,6559
33	Singapore	7,58	-0,2603	-0,4225	-0,4308
34	Sierra Leone	15,57	0,7677	0,5375	-0,2569
35	Slovak Republic	8,35	-0,7319	-0,8281	-0,7507
36	Slovenia	10,96	-0,1461	0,0169	-0,0534
37	Timor-Leste	23,49	-0,4291	-0,3666	-0,3854
38	Ukraine	13,71	-0,1772	-0,2337	0,3106
39	United States	11,12	-0,9240	-0,9643	-0,9606
40	Zimbabwe	12,79	-0,5953	-0,4746	-0,3164
	Number of maximum values		25	8	7

The members of this cluster are characterized by the slowest economic growth and the lowest air pollution (Fig. 2). As you can see, 82.5% of countries have a time lag between economic growth and air pollution (62.5% of countries have a lag of 2 and 20% – equal to 1). In this cluster, as in the previous two clusters, there is a predominant number of negative values of the correlation coefficients. Correlation coefficients are highly positive only for such countries: Greece (0,9426), Cote d'Ivoire (0,8705), Jamaica (0,8142), Sierra Leone (0,7677), Argentina (0,7217).

4. Conclusions

Thus, for most countries the lag in the impact of the economic growth dynamics on the level of air pollution is one-two year. The level of air pollution in 28% of the countries changes simultaneously with changes in GDP per capita growth.

In the post-crisis period, in the countries with high rates of economic growth there is a stable high level of pollution and a slow level of reduction of air pollution rates. In the group of countries with low rates of economic development, we also see a very slow decline in pollution. Countries with average GDP per capita growth have the greatest effect with a significant reduction in air pollution.

Some of the limitations of our research are related to the insufficient database. Prospects for further studies are related to the issues of assessing the influence of pandemic COVID-19 on the level of different groups of countries pollution.

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