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To cite this article: N I Didenko and E S Romashkina 2018 IOP Conf. Ser.: Earth Environ. Sci. 180 012014

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Assessment of the Influence of the Extraction of Energy Resources on the Environment

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Abstract. In the paper a proposed model for evaluating the influence of energy resource extraction activities on indicators for assessing the state of the environment is considered. The model was constructed under several different assumptions. The first suggests that there exists an environment in which different processes are taking place, e.g. forests and fresh water stocks are changing along with temperature. These processes are to be assessed by endogenous variables. Moreover, each process has its own prehistory that is also being affected by each endogenous variable. The second assumption states that all the processes taking place in the environment are interrelated. The third assumption supposes that the environment is affected by external factors, primarily human activity. In the current paper the human activity of energy resource extraction was considered. The model comprised four econometric equations, each of which was considered to be an ADL model. The model represented the coefficient calculation methodology with time series stationarity and multicollinearity verification. Identification of endogenous variable lags correlated strongly with the current period variable value and verification of the significance of autocorrelation coefficients. The findings of the study allowed conclusions to be drawn, which offered directions for further investigation.

1. Introduction

The state of the environment, represented in terms of processes occurring in it [1, 2], is in a constant state of flux. Among these processes, scientists have distinguished such phenomena as ozone depletion, climate change, reduced freshwater supply, enlargement of oceanic dead zones and many others [3, 4]. When estimating these processes in figures, it can be stated that over the 24-year period from 1992 to 2016 the level of CO₂ emissions has increased by 62.1%; the temperate level raised by 167.6%; freshwater resources per capita (1000 m³) reduced by 26.1%; oceanic dead zones indicator (number of affected regions) increased by 75.3% [5].

All these adverse tendencies appear to be due to different external factors affecting the state of the environment. Among other anthropogenic (human impact) factors, the activity of extracting energy resources can be distinguished. A rapid increase in the human population of the Earth has led to the extraction of more and more raw materials to satisfy their needs [6] and resulted in an increased burden on nature beyond reasonable limits. It should be taken into account that the state of the environment is being influenced by both external factors, including anthropogenic, as well as by other processes occurring within the environment itself. This is because all processes occurring in the environment must be considered to be interrelated [7, 8]. This assumption underpins the definition of the aim of the current survey. This aim is focused on assessing the environment effect of the human activity of energy resource extraction in the context of other processes occurring within the environment itself.
2. Data

The data were collected using the National Aeronautics and Space Administration (hereinafter, NASA) [9], National Oceanic and Atmospheric Administration (hereinafter, NOAA) [10], United Nations Environment Program (hereinafter, UNEP) [11], World Energy Yearbook [12] and World Resources Institute databases [13]. The research covered the period from 2000 to 2016. The global volume of CO2 emissions indicator (including Land-Use Change and Forestry) was calculated as the global volume of CO2 emissions produced by all the countries of the world in million tonnes of carbon dioxide per year. The global mean sea level indicator contained the global mean sea level generated by all the countries of the world in millimetres. The energy resources extracting activity factor was distinguished among them as most severe one. The energy resources extracting activity was assessed with the following exogenous variables: the energy resources extracting activity was assessed with the following exogenous variables: 

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The values of the variables were presented in Table 1. The descriptive statistics of variables are shown in Table 2.

| Year | \(y_1^t\) | \(y_2^t\) | \(y_3^t\) | \(y_4^t\) | \(x_1^t\) | \(x_2^t\) | \(x_3^t\) |
|------|---------|---------|---------|---------|---------|---------|---------|
| 2000 | 27560   | 22.1    | 3510    | 0.42    | 3597    | 2509    | 4601    |
| 2001 | 28800   | 24.4    | 3517    | 0.54    | 3626    | 2536    | 4822    |
| 2002 | 29230   | 28.2    | 3524    | 0.60    | 3636    | 2617    | 4879    |
| 2003 | 29800   | 32.9    | 3531    | 0.61    | 3715    | 2705    | 5225    |
| 2004 | 30980   | 35.7    | 3538    | 0.58    | 3581    | 2792    | 5610    |
| 2005 | 31800   | 38.8    | 3545    | 0.65    | 3860    | 2863    | 5969    |
| 2006 | 33750   | 40.9    | 3550    | 0.61    | 3824    | 2931    | 6308    |
| 2007 | 32100   | 43.5    | 3556    | 0.61    | 3903    | 3057    | 6573    |
| 2008 | 33560   | 43.2    | 3561    | 0.54    | 3990    | 3152    | 6768    |
| 2009 | 32160   | 47.6    | 3567    | 0.63    | 3244    | 3072    | 6909    |
| 2010 | 34570   | 53.8    | 3572    | 0.70    | 3956    | 3324    | 7296    |
| 2011 | 35120   | 49.1    | 3577    | 0.58    | 3988    | 3388    | 7726    |
| 2012 | 36100   | 57.9    | 3584    | 0.62    | 4022    | 3452    | 7830    |
| 2013 | 36810   | 67.3    | 3590    | 0.67    | 4038    | 3525    | 7865    |
| 2014 | 37100   | 66.0    | 3595    | 0.74    | 4102    | 3278    | 7847    |
| 2015 | 39700   | 73.0    | 3600    | 0.91    | 4185    | 3563    | 7648    |
| 2016 | 41000   | 82.8    | 3607    | 0.95    | 4227    | 3629    | 7168    |

Source: data published by the National Aeronautics and Space Administration, National Oceanic and Atmospheric Administration, United Nations Environment Program, World Energy Yearbook, World Resources Institute databases [9], [10], [11], [12], [13], [15].
Table 2. Descriptive statistics for environmental assessment variables and factors

| Variable | Meaning of variable                  | Measured in                                                                 | Minimum value | Maximum Value | Mean   | Standard deviation |
|----------|--------------------------------------|------------------------------------------------------------------------------|---------------|---------------|--------|--------------------|
| $y_t^1$  | Global CO2 emissions                 | in million tonnes of carbon dioxide per year                                 | 27560         | 41000         | 33538  | 3804               |
| $y_t^2$  | Global mean sea level change         | in millimetres per year as changes relative to January 1, 1993               | 22            | 82            | 47     | 17                 |
| $y_t^3$  | Global total desertification affected areas | in millions of hectares                                          | 3510          | 3607          | 3560   | 30                 |
| $y_t^4$  | Global land and ocean temperature anomalies | with respect to the 20th century average, in °C                        | 0.42          | 0.95          | 0.64   | 0.13               |
| $x_t^1$  | Global volume of oil extraction      | in millions of tonnes per year                                              | 3244          | 4227          | 3853   | 257                |
| $x_t^2$  | Global volume of natural gas extraction | in billions of cubic metres per year                                     | 2509          | 3629          | 3082   | 371                |
| $x_t^3$  | Global volume of coal extraction     | in millions of tonnes per year                                              | 4601          | 7865          | 6532   | 1155               |

Source: data calculated by the author and initially collected from publications of the National Aeronautics and Space Administration, National Oceanic and Atmospheric Administration, United Nations Environment Program, World Energy Yearbook, World Resources Institute databases [9], [10], [11], [12], [13].

3.2. Formulation of assumptions for creating the model

The first assumption states that there is an environment in which different processes take place: forest and fresh water stocks are varying alongside changes in temperature. All of these processes are assessed using endogenous variables and have their own prehistory by which they are affected. The second assumption is that all processes taking place in the environment are interrelated; for example, changing forestation affects the level of CO2 emissions. The third assumption presupposes that the environment is affected by external factors including human activity. In the present paper, the human activity or anthropogenic factor of energy resource extraction is considered. In short form, all the assumptions made can be introduced in the following way:

\[ y_t^1 = \varphi(y_{t-j}^1; y_t^2; y_t^3; y_t^4; x_t^1; x_t^2; x_t^3) \]  \hspace{1cm} (1)

\[ y_t^2 = \varphi(y_{t-j}^2; y_t^1; y_t^3; y_t^4; x_t^1; x_t^2; x_t^3) \]  \hspace{1cm} (2)

\[ y_t^3 = \varphi(y_{t-j}^3; y_t^1; y_t^2; y_t^4; x_t^1; x_t^2; x_t^3) \]  \hspace{1cm} (3)

\[ y_t^4 = \varphi(y_{t-j}^4; y_t^1; y_t^2; y_t^3; x_t^1; x_t^2; x_t^3) \]  \hspace{1cm} (4)

3.3. Selection of appropriate model for the assumptions made

In the previous stage we supposed that there were dependences between processes occurring in the environment. These processes could be described through different types of equations. The question was what types of equations demonstrated these dependences. In order to model the assumptions, the system of econometric equations, each of which was presented in ADL model form, was considered to be the most suitable since the endogenous variables depended on both the other periods and other time series. In general form, the ADL model was represented as follows:

\[ y_{t-1}^i = \alpha_0 + \alpha_1 y_{t-1}^i + \ldots + \alpha_i y_{t-i} + \ldots + b_i y_t^k + c_j x_t^k + \varepsilon \]  \hspace{1cm} (5)

where \( y_{t-i}^i \) – value \( y_t^1 \) with lag \( t-i \), demonstrating the prehistory of the process;

\( y_t^k \) - time series showing \( k^{th} \) endogenous variable;

\( x_t^k \) - time series showing \( k^{th} \) exogenous variable.

3.4. Calculation of the model equation coefficients
The methodology of coefficients calculation included several steps: time series stationarity verification; multicollinearity test for endogenous and exogenous variables; identification of the endogenous variable lags having a strong correlation with the current period variable value and verification of the autocorrelation coefficients significance using the Ljung-Box Q-test.

3.4.1. **Time series stationary verification.** Having chosen the endogenous and exogenous variables, we checked the time series of variables for stationarity, using Dickey-Fuller test. Dickey-Fuller test supposed finding the coefficient \( a \) in the following autoregressive equation:

\[
y_t = a y_{t-1} + \varepsilon_t
\]

where \( y_t \) — time series, and \( \varepsilon_t \) — error. According to the Dickey-Fuller test, all the time series appeared to be stationary because coefficient \( |a| < 1 \) for all of them.

3.4.2. **Multicollinearity verification.** During this step all the endogenous and exogenous variables were tested for multicollinearity. Coefficients of pair correlations were found and analysed. According to the analysis carried out, no variables were excluded from the equations.

3.4.3. **Identification of the endogenous variables' lags.** During this step, the endogenous variable lags which had a strong correlation with the current period endogenous variable value, were identified. In order to determine these, the autocorrelation coefficients were first calculated. The verification of the significance of the autocorrelation coefficient was made with Ljung-Box Q-test and Box-Pierce Q-statistic. The endogenous variable lags with autocorrelation coefficient significance of more than 0.7 were included in equations. The calculations show that the endogenous variable \( y_t^1 \) is dependent on \( y_{t-7} \), since the autocorrelation coefficient equals -0.786. The endogenous variable \( y_t^2 \) showed no dependence on the values of the other periods. The endogenous variable \( y_t^3 \) was dependent on the \( y_{t-9} \), since the autocorrelation coefficient appeared to be -0.855. The endogenous variable \( y_t^4 \) showed no significant dependence on the values of the other periods. The model coefficients were calculated using the method of least squares. The significance of the regression equations and coefficients of the regression was evaluated. Finally, the model structure, including calculated coefficients, was written down as represented in system of equations 7:

\[
\begin{align*}
y_t^1 &= -337531.042 + 0.007 \times y_{t-7} + 17.085 \times y_t^2 + 100.616 \times y_t^3 + 2429.786 \times y_t^4 + \\
&+ 2.638 \times x_t^1 + 1.939 \times x_t^2 - 0.885 \times x_t^3 \\
y_t^2 &= -2527.114 + 7.337E - 0.5 \times y_t^1 + 0.728 \times y_t^3 + 5.631 \times y_t^4 + 0.001 \times x_t^1 + \\
&+ 0.007 \times x_t^2 - 0.008 \times x_t^3 \\
y_t^3 &= 3427.524 - 0.001 \times y_{t-9} + 0.001 \times y_t^1 + 0.708 \times y_t^2 + 15.925 \times y_t^4 - 0.004 \times x_t^1 - \\
&- 0.004 \times x_t^2 + 0.011 \times x_t^3 \\
y_t^4 &= -19.936 + 0.00001 \times y_t^1 + 0.003 \times y_t^2 + 0.006 \times y_t^3 - 0.00001 \times x_t^1
\end{align*}
\]

The coefficients of determination for the equations varied from 0.893 to 0.994 with F-criterion ranging from 13 to 374 and significance of 0.001 for all equations.

4. **Conclusion**

The evidence from the study allowed conclusions to be drawn concerning the network structure between variables assessing the environmental state and factors influencing the state of the environment. We report two sets of findings. The first describes the significant interrelations between the variables assessing the environment state and factors influencing this state. The second distinguishes significant interrelations between the variables assessing the processes occurring in the environment.

The first set of findings could be put down as followed. There existed a link between the global volume of oil extracted and the global volume of CO₂ emissions. A one-million-tonne increase in oil
extracted led to an increase of the global volume of CO₂ emissions by 2.636 million tonnes of carbon dioxide with probability at $p = 0.955$. The interrelations between the global volumes of natural gas, coal extracted and the global volume of CO₂ emissions appeared with probability at $p = 0.513$ and coefficients equalling $+1.939$, $-0.885$ respectively.

The interrelations between the global volumes of oil and natural gas extraction and the global mean sea level change indicator were considered to be with probability at $p = 0.246$ and $p = 0.558$ respectively; the coefficients were equal to $+0.001$, $+0.007$ respectively. Surprisingly enough, there appeared to be an inverse link between the global volume of coal extraction and the global mean sea level change indicator. A one-million-tonne rise in the amount of coal extracted led to a fall in the global mean sea level change indicator (measured as change relative to January 1, 1993) by $-0.008$ millimetres with probability at $p = 0.967$.

The interrelations between the global volumes of oil, natural gas extraction and expansion of total global desertification affected areas were considered to be with probability at $p = 0.552$ and $p = 0.333$ accordingly, with coefficients equal to $0.004$ and $-0.004$ respectively. At the same time the model demonstrated the direct link between the global volume of coal extracting and expansion of the global total desertification affected areas. A one-million-tonne increase in coal extracted appeared to be interrelated with a rise in desertification of affected areas by 0.011 million hectares with probability at $p = 0.971$.

The interrelations between the volumes of oil and natural gas extraction and the global land-ocean temperature anomalies indicator relative to the 20th century average had a probability of $p = 0.096$ and $p = 0.445$ respectively.

The second set of findings distinguishing the significant interrelations between the variables assessing the environment themselves may be described as follows. The model demonstrated a direct link between the global volume of CO₂ emissions and the expansion of the total global area affected by desertification. An increase in total global desertification with affected areas of 1 million hectares led to increase of the volume of CO₂ emissions by 100.616 million tonnes of carbon dioxide with probability at $p = 0.700$. It seems that land degradation represented in terms of processes including deforestation caused in its turn an increase in the global volume of CO₂ emissions to the environment.

The model demonstrated a direct link between the global mean sea level change indicator and expansion of the global total area affected by desertification. The expansion of the global total desertification affected areas by 1 million hectares appeared to be interrelated with the rise of global mean sea level change indicator (measured as change relative to January 1, 1993) by 0.728 millimetres with probability at $p = 0.94$.

The increase in the global land and ocean temperature anomalies change indicator (measured relative to the 20th century average) by $0.01 °C$ (1 unit was treated as a change of $0.01 °C$ with respect to the 20th century average) was interrelated with the increase in expanding the global total desertification affected areas by 15.925 million hectares with probability at $p = 0.72$.

The analysis revealed that for two variables only the prehistory assumptions were correct. It should be mentioned that only significant interrelations were highlighted in conclusions detailed in the current paper. The analysis demonstrated the methodology for assessing the influence of human activity of energy resource extraction on indicators assessing the state of the environment. The methodology could be applied in other spheres under the assumptions made. Having analysed and applied this methodology in environment sphere, the authors found it possible to apply it in their further researches in the sphere of banking sector assessment. In order to obtain results having high significance, it is recommended that a time series with more than thirty years be used. For more accurate outcomes, the number of exogenous variables should exceed the number of endogenous ones by at least three times.

**Acknowledgements**

The paper is based on research carried out with the financial support of the grant of the Russian Science Foundation (Project No. 14-38-00009, The program-targeted management of the Russian Arctic Zone development). Peter the Great St. Petersburg Polytechnic University.
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