Relation between emitted CO2, asset expenditures, produced energy from renewables and energy consumption. Evidence from Bulgaria

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19 November 2020

RELATION BETWEEN EMITTED CO_2, ASSET EXPENDITURES, PRODUCED ENERGY FROM RENEWABLES AND ENERGY CONSUMPTION. EVIDENCE FROM BULGARIA

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Abstract: *The paper explores the relation between emitted CO_2 in the atmosphere, asset expenditure, produced energy from renewables and energy consumption. ARDL model was developed on the basis of data for Bulgaria (2000 – 2018). As a whole the increase in asset expenditures leads to increase in emitted carbon dioxide in the short-run and in the long-run. The increase in the produced energy from renewables leads to decrease in the emitted carbon dioxide in a long-run, while in the short-run the relation is insignificant. In a short-run the energy consumption and emitted carbon dioxide are in a positive relation: the increase in energy consumption leads to increase in the emitted pollutant.*

Keywords: *ARDL model, emitted CO_2, asset expenditures, produced energy from renewables, energy consumption*

JEL Classification: *C32, Q50*

INTRODUCTION

In this study, an autoregressive distributed lag model ([11]; [12]) was developed in order to explore the relationship between the emitted carbon dioxide in the atmosphere, asset expenditures, produced energy from renewables and energy consumption.

It was found a strong relation between energy consumption, economic growth and greenhouse gases emissions in European countries [17]. A similar research was held for Asian countries [16].

A study reveals that a positive shock on the consumption of renewable energy source decreases CO_2 emissions and a positive shock on GDP increases the emitted CO_2 [15].

The relationship between emitted carbon dioxide, GDP and energy consumption was also explored [2].

Many researchers search the relationship between real gross domestic product per capita and carbon dioxide emissions per capita in different countries [13]. Their study showed that gross domestic product per capita and the relationship of the emitted CO_2 depends on the economic development of the country.

Other authors find the relationship between climate change and urban development and they focus on the impact of urbanization on CO_2 emissions for developing countries [8].

According to a research, GDP, fossil fuel energy consumption, trade openness and urbanization, increase air pollution. And on the contrary - renewable energy consumption soften air pollution [1].

Reasons for climate change

Climate change should be stabilized by reducing the emitted global emissions which is one of the most challenging problems of our times, and is of a great concern among policy makers.

Climate change is one of the biggest environmental, social and economic threats to the planet, which has an impact on a global and regional level, creating problems of public importance. Every factor that changes the amount of input or output energy over a long period of time can cause climate change. Some of these factors are natural or internal to the climate system - volcanic

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activity, solar energy or the Earth's orbit around the sun. Other causes are external to the climate system and are called climatic factors. The scientific evidence that substantiates the relationship between the current rise in global temperatures and human activity is indisputable. The world's leading experts in the field of climate believe that human activities are the main cause of the warming observed since the mid-20th century.

Policies related to climate change

Climate change action is an area in which the EU has been very active in recent years. Various initiatives are approved and developed, which can be categorized according to the period of their validity (Table 1).

Table 1. Climate initiatives

2008-2012 Kyoto Protocol	15 countries that were members of the EU before 2004 are committed to reducing their emissions to 8% below 1990 levels for the period 2008-2012. Those that join the EU after 2004 are also making progress towards meeting the Kyoto Protocol's targets for reducing emissions by 6% or 8%.
2020	EU is committed to reducing its emissions to 20% below 1990 levels. This commitment is one of the headline targets of the Europe 2020 growth strategy and is being implemented through a package of binding legislation. The EU proposes to reduce its emissions by up to 30% by 2020, if other developed and developing countries commit to taking measures to reduce emissions.
2050	EU leaders endorsed the goal of reducing Europe's greenhouse gas emissions to 80-95% from 1990 levels as part of the efforts of developed countries. The European Commission has published a roadmap for building a European low-carbon economy

Source: adaptation by Miteva et al., 2017 [9].

Climate change mitigation measures are related to reducing greenhouse gas emissions, adapting to climate change and financing the problem of tackling climate change in developing countries, as well as the development of low-carbon technologies, the development of a low-carbon transport system emissions, forest protection.

In December 2008, the EU approved the climate and energy package, which consists of six proposals to reach the so-called 20-20-20 target by 2020 [4].

The Commission's Roadmap 2050 initiative on resource efficiency in Europe provides a long-term framework for action in various policy areas (energy, climate change, transport, industry, raw materials, agriculture, fisheries, biodiversity and regional development) [5], [6]. The Roadmap 2050 for a low-carbon economy was created in connection with the achievement of the target by 2020 to reduce emissions to 80-95%. The European Commission is setting out a plan that shows how the sectors are responsible for emissions in Europe - energy, industry, transport buildings and construction, as well as agriculture [5]. The idea behind it is the sectors to shift to a low-carbon economy in the coming decades [7]. The low-carbon economy will have a much greater need for renewable energy, energy-efficient building materials, hybrid and electric vehicles, smart grid equipment, low-carbon energy production and carbon capture, storage technologies and more. The European Energy Efficiency Directive [3] provides for mandatory energy saving measures for public buildings, including their renovation, energy saving schemes by energy companies and energy audits for all large enterprises. It lays down rules aimed at removing energy barriers in the market and overcoming market failures that hamper energy supply and use efficiency, and provides for the establishment of national indicative energy efficiency targets for 2020.

The aim of this paper is to explore the relation between emitted CO_2 in the atmosphere, asset expenditures, produced energy from renewables and energy consumption in Bulgaria.

MATERIALS AND METHODS

ARDL model was developed on the basis of data for Bulgaria (2000 – 2018).

The variables, under this research are:

- Emitted CO_2 in the atmosphere (in thousand tones): ***CO2*** (abreviation in the model). The data were derived from the National Statistical Institute, Bulgaria [10] and The World Bank [14].
- Total expenditures on acquisition of tangible fixed assets (in thousand BGN) in real numbers. The nominal values of this variable were deflated with Consumer Price Index (***Exp***). The data were derived from the National Statistical Institute, Bulgaria [10].
- Primary production of energy from renewables (in thousand toe): ***En_r***. The information is from the national statistics [10].
- Final energy consumption (in thousand toe): ***En_c***. This variable was calculated by summing final energy consumption in industry, transport, households, agriculture and forestry, and services. The source is the national statistic [10].

Stationarity of the time series was checked by Augmented Dickey-Fuller test.

The basic model from which we started is represented as follow:

(1) $$CO2_t = a_0 + a_1 Exp_t + a_2 En\_r_t + a_3 En\_c_t + e_t$$

, where e_t is the error of the regression.

We accept this model after calculating correlation coefficients between the variables.

Then the ARDL models were developed and after checking their reliability with diagnostic tests, the one with lowest Akaike information criterion was chosen for further analysis:

(2) $$d(CO2_t) = \beta_0 + d\beta_1(CO2_{t-1}) + \sum_{i=0}^{i=1} \beta_2 d(Exp_{t-i}) + \beta_3 d(En\_r_t) + \sum_{i=0}^{i=1} \beta_4 d(En\_c_{t-i}) + \beta_5 CO2_{t-1} + \\ + \beta_6 Exp_{t-1} + \beta_7 En\_r_{t-1} + \beta_8 En\_c_{t-1} + \varepsilon_t$$

, where:

d - is the first difference; β_0 - intercept; from β_1 to β_4 are the short-run coefficients; β_5 to β_8 are the long-run coefficients; ε_t - white noise;

The next equation shows the long-run model:

(3) $$CO2_t = a_1 Exp_t + a_2 En\_r_t + a_3 En\_c_t + e_t$$

The coefficients of the long-run variables were tested for co-integration with Wald test, which F-statistics was compared with the critical bounds (unrestricted intercept and no trend) [12], at 5% significance level. H_0 of Wald test was formulated as follows: $\boldsymbol{\beta_5 = \beta_6 = \beta_7 = \beta_8 = 0}$, meaning that coefficients are equal to zero, or no co-integration exists.

The next step was to develop ARDL model with error correction in order to include the residuals of the long-run model as a regressor (**Ect_CO2**):

(4) $$d(CO2_t) = \beta_0 + d\beta_1(CO2_{t-1}) + \sum_{i=0}^{i=1} \beta_2 d(Exp_{t-i}) + \beta_3 d(En\_r_t) + \sum_{i=0}^{i=1} \beta_4 d(En\_c_{t-i}) + \\ + \beta_5 Ect\_CO2_{t-1} + \varepsilon_t$$

Then the two ARDL-models ((**2**) and (**4**)) were compared according to their Akaike information criterions and that with lowest value was analyzed. Diagnostics were used to check the reliability of the model. Short-run causality was assessed with Wald test.

RESULTS AND DISCUSSIONS

The emitted carbon dioxide in the atmosphere from Bulgaria for the period 2000 – 2018 reaches its highest value in 2011 (53854 thousand tones [10]) and its lower – in 2000 (43531 thousand tones [14**]**. Two sub periods could be identified: from 2000 to 2011, where the trend is growing and after that – with downward tendency.

The real value of asset expenditures has realized growth with 87.5% for 2000 – 2018.

Energy consumption realized its lowest value in 2009 (8472 thousand toe) and reached its maximum in 2006 (9953 thousand toe). Till 2009 the tendency in energy consumption in Bulgaria is upward. The production of energy from renewables in the country constantly increases during the period of 2000 – 2018: from 776.5 to 2562.9 thousand toe, or 230% increase. The biggest share of the production is taken from primary solid biofuels during the whole period, followed by hydro, wind and solar photovoltaic (Table 2).

Table 2. Produced energy from renewables

Year	Total (Thousand toe)	Percentage from the total										
		Hydro	Wind	Solar photovoltaic	Solar thermal	Geothermal	Primary solid biofuels	Charcoal	Biogases	Renewable waste	Liquid biofuels	Ambient heat (heat pumps)
2000	776.5	29.1					70.9					
2001	688.8	20.6					79.4					
2002	825.4	22.0					78.0					
2003	948.8	27.1					72.9					
2004	1019.4	26.5	0.0				72.3					1.3
2005	1137.1	32.5	0.0			2.9	63.1					1.5
2006	1193.3	30.4	0.1			2.7	64.4				0.5	1.9
2007	1015.7	24.0	0.4			3.2	69.8				0.2	2.4
2008	1113.4	21.6	0.9			2.9	71.1				1.0	2.5
2009	1179.4	25.0	1.7	0.0		2.8	66.8		0.0		0.9	2.7
2010	1533.5	28.2	3.8	0.1	0.7	2.1	61.7		0.2		0.7	2.5
2011	1471.0	16.8	5.0	0.6	0.9	2.2	70.3		0.2	0.0	1.0	2.9
2012	1664.9	16.4	6.3	4.2	0.9	2.0	66.8		0.0	0.1	0.4	2.8
2013	1890.1	18.4	6.2	6.2	1.0	1.8	59.5		0.1	0.9	2.5	3.4
2014	1913.8	20.7	6.0	5.6	1.0	1.7	56.9		0.5	0.6	3.5	3.4
2015	2117.2	23.0	5.9	5.6	1.0	1.6	54.9		0.9	0.7	2.8	3.5
2016	1996.2	16.7	6.1	6.0	1.1	1.7	56.3		3.0	1.3	3.7	4.1
2017	1938.2	12.5	6.7	6.2	1.2	1.8	58.1		2.4	1.5	5.0	4.5
2018	2562.9	17.3	4.4	4.5	1.0	1.4	59.5		2.1	1.4	4.9	3.6

Source: National Statistical Institute (Bulgaria) [10] and own analysis

Table 3 represents correlation matrix between the emitted carbon dioxide in the atmosphere, asset expenditures, produced energy from renewables and energy consumption, comprising the period 2000-2018. The correlation coefficients suggest that the variables are proper for regression analysis.

Table 3. Correlation coefficients

Variable	CO_2	Exp	En_r	En_c
CO2	1	0.432	-0.481	0.322
Exp	0.432	1	0.123	0.550
En_r	-0.481	0.123	1	0.318
En_c	0.322	0.550	0.318	1

Source: Own analysis

According to the conducted Augmented Dickey-Fuller test for unit root, it was found that the variables: emitted carbon dioxide in the atmosphere, asset expenditures, produced energy from renewables and energy consumption, were stationary at first difference. None of them was stationary at level.

Table 4 shows the estimates of the ARDL model **(2)** for emitted CO_2. This regression is highly significant with Adjusted R^2 of 0.882, which means that 88% of the variation of the emitted carbon dioxide could be explained by this model.

Wald test for co-integration of the long-run variables indicated that they are in equilibrium (the calculated F-statistics is 5.65, or higher than the upper bound [12]).

The estimates of the long-run coefficients are represented in Table 5. The asset expenditures appeared to be significant at 5% significance level, showing that the increase in asset expenditures leads to an increase in emitted carbon dioxide in a long-run. The produced energy from renewables is highly significant, showing that the increase in the value of that variable leads to decrease in emitted carbon dioxide in a long-run.

So we can continue with the error correction model **(4)**, which estimates are represented in Table 6. Now we have two ARDL models – a model with long-run variables **(3)** and a model with an error correction **(4)**. By comparing them by Akaike information criterion we chose model **(4)** for further analysis. The diagnostic test of the error corrected model are systematized in Table 6. To find out if there is short-run causality running from the independent variables to the dependent one, a Wald test was applied: it was found that there is short-run causality running from the asset expenditures and energy consumption to the emitted CO_2. The short-run variables for energy consumption ($d(En\_c_t)$ and (En_c_{t-1})) reveal that the energy consumption and emitted carbon dioxide are in a positive relation: the increase in energy consumption leads to increase in emitted pollutant in a short-run. The conducted Wald test confirmed that the short-run coefficient of energy consumption contributes to the model ($\chi2$ = 13.14, significant at 1% level). The asset expenditures appeared to be highly significant and Wald test confirmed their contribution to the model ($\chi2$ = 45.99, significant at 1% level). Although the lag 1 of asset expenditures has negative coefficient (-0.039), as a whole the increase in asset expenditures leads to increase of emitted carbon dioxide in the short-run and in the long-run. The short-run coefficient of the produced energy from renewables is insignificant.

The error correction (Ect_CO2), known also as a speed of adjustment, is highly significant with a negative sigh of its coefficient (-0.916, significant at 1% level). This variable assumes that the emissions of carbon dioxide react with 91.6% change after shock from the independent variables.

Table 4. Estimates of model (2) with a dependent variable d(CO2)

Variable	**Coefficient**	**Standard error**
$d(CO2_{t-1})$	0.190	0.200
$d(Exp_t)$	0.055**	0.012
$d(Exp_{t-1})$	-0.039**	0.010
$d(En\_r_t)$	-3.013	3.140
$d(En\_c_t)$	3.069	1.756
$d(En\_c_{t-1})$	3.738	3.174
Constant	64154.9*	20948
$CO2_{t-1}$	-0.916**	0.246
Exp_{t-1}	0.046*	0.0127
En_r_{t-1}	-4.878*	1.376
En_c_{t-1}	-3.169	1.975
R^2/Adjusted R^2	0.956/0.882	
Standard error	1538.13	
F-statistic	12.948**	
Akaike information criterion	17.77	

*Significant at 5% level; **Significant at 1% level. Source: Own analysis

Table 5. Long-run estimates (dependent variable CO2) (model 3)

Variable	Coefficient	Standard error
Exp	0.050*	0.016
En_r	-5.326**	1.436
En_c	-3.460	2.187

*Significant at 5% level. Source: Own analysis

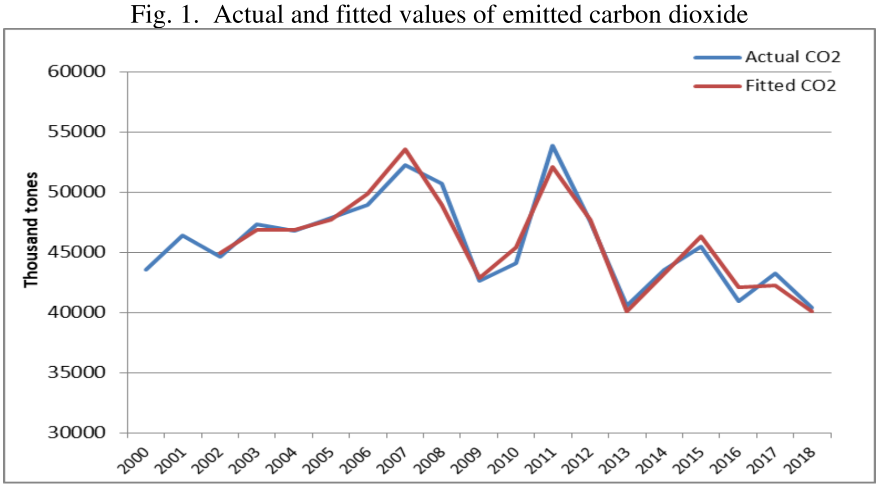
Table 6. ARDL model with error correction (model 4)

Variable	Coefficient	Standard error
$d(CO2_{t-1})$	0.191	0.112
$d(Exp_t)$	0.055**	0.008
$d(Exp_{t-1})$	-0.039**	0.008
$d(En\_r_t)$	-3.013	2.141
$d(En\_c_t)$	3.069*	1.050
$d(En\_c_{t-1})$	3.738	1.890
Constant	64157.5**	10924.4
ECT_CO2_{t-1}	-0.916**	0.157
R^2/Adjusted R^2	0.956/0.921	
Standard error	1255.88	
F-statistic	27.75**	
Akaike information criterion	17.41	
Serial Correlation LM Test (Observations*R^2 /Probability):	2.82/0.093	
ARCH Heteroskedasticity Test (Observations*R^2 /Probability):	0.288/0.591	
Jarque-Bera test (Coefficient / Probability):	0.596/0.742	
CUSUM and CUSUMSQ	The indicators fall between the 5% critical bounds	

*Significant at 5% level; **Significant at 1% level. Source: Own analysis

Figure 1 represents actual and fitted values (calculated from the model 4) of emitted carbon dioxide. The two variables fit quite well.

Fig. 1. Actual and fitted values of emitted carbon dioxide



Source: Data from the National Statistical Institute (Bulgaria) [10], The World Bank [14] and own analysis

CONCLUSIONS

As a whole the increase in asset expenditures leads to increase in emitted carbon dioxide in the short-run and in the long-run. The increase in the produced energy from renewables leads to decrease in the emitted carbon dioxide in a long-run, while in the short-run the relation is insignificant. In a short-run the energy consumption and emitted carbon dioxide are in a positive relation: the increase in energy consumption leads to increase in the emitted pollutant.

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