ECONOMETRIC ANALYSIS BETWEEN TOTAL ENERGY CONSUMPTION AND CO2 EMISSIONS IN EUROPE AND ROMANIA

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Abstract: The transition to an economy with low CO2 emissions aims at a sustainable and high-performing energy sector, both nationally and at European level, in which, through the services offered to consumers, to be seen both a reduction in the bills we pay and an increase of the quality of life. Based on these considerations, in this article analyzes the correlation between total energy consumption in Europe and Romania and CO2 emissions.

Keywords: CO2 emissions, energy consumptions, econometric analysis, least squares method (LSM).

1. INTRODUCTION

One of the most current and discussed problems facing Europe (and not only) is the energy crisis. Against the background of the war provoked by Russia against Ukraine, on the taking of some not very happy governmental decisions, regarding the closure (in some countries in Europe) of some thermal power plants (see the case of Romania), as well as by the restrictive measures taken by the European Union against Russia, all this led to an extremely difficult year 2022 from an energy point of view.

Thus, according to World Energy & Climate Statistics [5], in the context of the global pandemic, global energy consumption returned with an increase of 5% in 2021, after a decrease of 4.5% in 2020. The biggest increase of energy consumption was achieved in China, with 5.2% compared to 2020, followed by the USA and India with 4.7%. And in Europe, total energy consumption increased in 2021 by 4.5% compared to the previous year, after in 2020 it decreased by 6.8% compared to 2019.

Figure 1 shows the diagram of the total global energy consumption in the period 1990-2021. As can be seen, the Asian continent has the largest increase in total energy consumption, followed by North America and Europe.

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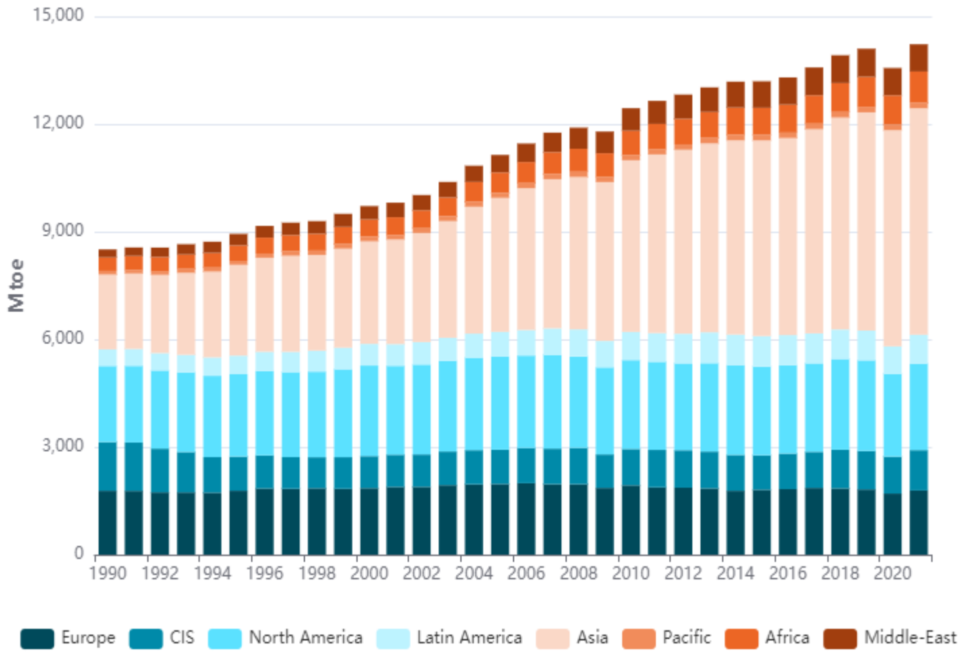


Fig. 1. Total energy consumption in world
Source: Enerdata. World Energy & Climate Statistics – Yearbook 2022 [5]

In the European Union, in order to overcome or improve the energy crisis, a series of measures have been adopted regarding the reduction of energy consumption. Thus, the "Plan of measures proposed by the EU" [6] proposes, among other things, the mandatory reduction of electricity consumption at peak hours, the regulation of the commercial margin for low-cost energy producers who make high profits, the over taxation of oil and gas companies, securing financial sources to ensure liquidity for energy companies, etc.

In Romania, total energy consumption increased in 2021 by 6.25% compared to the previous year. Regarding the measures taken by the government at the national level to reduce energy consumption [7], there are the replacement of light bulbs with LED ones, the reduction of external and internal lighting in common spaces, the disconnection of devices from the power source when they are not in use, establishing an optimal microclimate in office spaces by reducing temperatures to 21 degrees C. etc.

In this article, the total energy taken into account includes coal, gas, oil, electricity, heat and biomass.

Another stringency problem facing humanity is that of CO2 emissions from fossil fuels. Figure 2 shows the diagram of CO2 emissions worldwide, emissions from the burning of fossil fuels (coal, oil and gas).

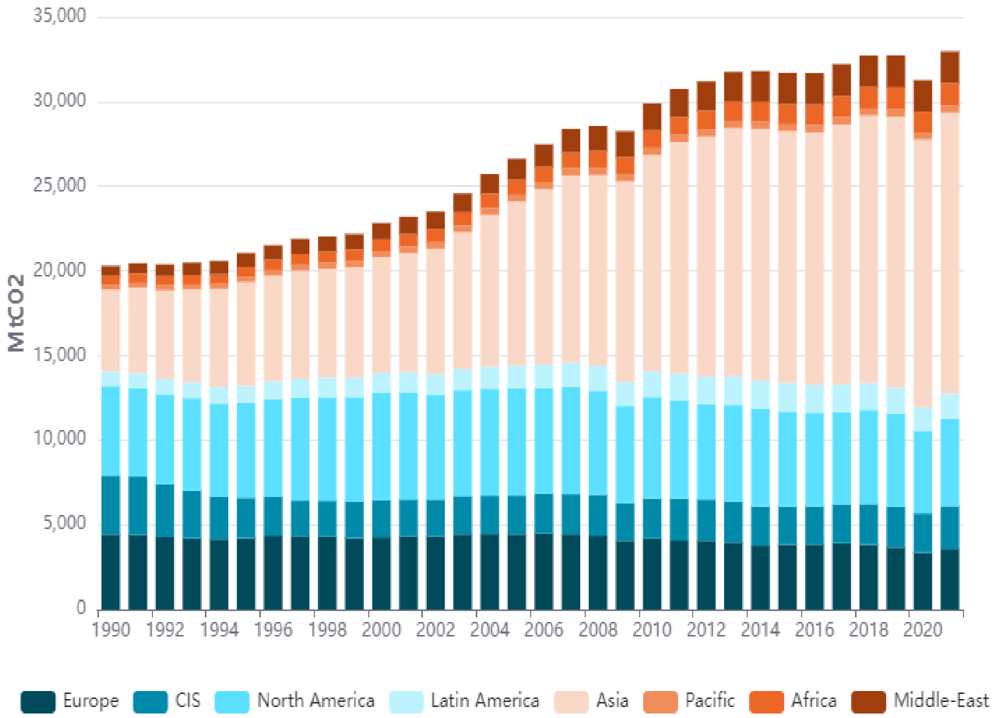


Fig. 2. CO2 emissions from fuel combustion
Source: Enerdata. World Energy & Climate Statistics – Yearbook 2022 [5]

Thus, worldwide, CO2 emissions returned by 5.4% and reached the record level of 33 GtCO2. In Europe, CO2 emissions increased by 7.1% in 2021 compared to the previous year. Against the background of the global economic recovery, in the last year under analysis, countries such as Germany, France, Italy and the Netherlands contributed to more than 70% of the increase in CO2 emissions [5].

However, according to the International Energy Agency (IEA), the EU's total CO2 emissions are expected to fall in 2022, despite the fact that emissions from burning coal will be higher. The increase in the use of coal in the EU would be only temporary and the new renewable projects that will be connected to the grid next year will increase the renewable production capacities by approximately 50 GW [8].

Unfortunately, Romania is among the EU countries with the highest increases in CO2 emissions. In Romania, CO2 emissions increased in 2021 by 4.5% compared to the previous year.

According to Eurostat [9], in 2021, Romania is among the countries whose CO2 emissions have increased more than the European average. These increases (over 50%) were caused by the increase in the use of solid fossil fuels.

Increases were also recorded in countries such as Bulgaria, Estonia, Slovakia, Poland or Spain. The only countries in which CO2 emission decreases were observed are Portugal (-5.5%) and Finland (-1.5%).

2. LITERATURE REVIEW

Being a topical subject, the specialized literature is rich, with a number of authors carrying out interesting studies on the energy sector.

Authors such as Salari et. all [2], investigates the relationship between carbon dioxide (CO2) emissions, energy consumption, and GDP in the US over the period 1997-2016. The results obtained by the authors of this study show that there is a long-term relationship, with a positive impact on CO2 emissions at the state level, of the total energy consumption, non-renewable, industrial and residential, for both static and dynamic models. On the other hand, the study shows that renewable energy consumption has a negative relationship with CO2 emissions. Based on this study, decision makers will be able to use the findings to define applicable policies to reduce CO2 emissions in the US.

Yang, et. all [1], in their paper investigates the impact of economic growth on CO2 emissions at the subsector level by employing an endogenous finite mixture model, taking renewable energy consumption as a concomitant variable and using data from 25 manufacturing subsectors in 38 countries, from 2000 to 2014.

Stoicuta O. and Stoicuta N. [3], in their paper performs the econometric analysis of the main official indicators for monitoring Romania's objectives, in accordance with Directive 2009/28/EC. In this sense, within the Eviews program, econometric models are made regarding the share of renewable energy sources in the total energy consumption used in heating/cooling; the share of energy from renewable sources in the fuel consumption used in the field of transport, as well as the share of energy from renewable sources in the final gross energy consumption.

On the other hand, Stoicuta N. and Stoicuta O., in the article [4] analyzes the evolution in time of the total electrically energy production and categories of power stations in Romania for a period of 26 years (1992-2017).

3. ECONOMETRIC ANALISYS

Starting from all the considerations above, this article analyzes the dynamics of the level of CO2 emissions according to the total energy consumption, both at European and national level, for the period 1990-2021. Also, the impact of total energy consumption on CO2 emissions from burning solid fuels is monitored. Thus, in the following table, the data series were collected for the two sizes analyzed. No changes were made to the data series, it was taken from the World Energy&Climate Statistic-Yearbook 2022 website [5].

Thus, the two econometric models to be analyzed are presented in the following:

Table 1. ***The data series of the two quantities analyzed***

Year	Total energy consumption in Europe [Mtoe]	Total energy consumption in Romania [Mtoe]	CO2 emissions in Europa [MtCO2]	CO2 emissions in Romania [MtCO2]
1990	1780	62	4418	162
1991	1777	51	4395	135
1992	1737	46	4261	124

1993	1735	46	4183	118
1994	1728	43	4138	113
1995	1781	47	4197	117
1996	1844	48	4343	121
1997	1835	45	4269	112
1998	1850	41	4275	98
1999	1833	36	4205	85
2000	1854	36	4246	87
2001	1888	37	4306	93
2002	1890	38	4302	93
2003	1938	40	4423	97
2004	1960	39	4435	96
2005	1970	39	4420	92
2006	1990	40	4469	96
2007	1964	40	4430	93
2008	1964	40	4344	92
2009	1859	35	4041	78
2010	1934	35	4175	75
2011	1875	36	4064	82
2012	1866	35	4043	79
2013	1846	32	3945	70
2014	1779	32	3776	69
2015	1808	32	3833	69
2016	1825	33	3848	68
2017	1859	33	3901	71
2018	1847	34	3820	72
2019	1817	33	3659	70
2020	1701	32	3338	66
2021	1787	34	3575	69

Dynamic Model 1. *Econometric analysis of the correlation between CO2 emissions and total energy consumption at European level*

$$CO2E\_EU_t = a_1T + a_2T^2 + a_3CTE\_EU_t + a_4CTE\_EU_t^{\,2} + a_5 + \varepsilon_{1t} \qquad (1)$$

where it was noted with:

- ✓ $\left(CO2E\_EU_t\right)_{t=\overline{1,T}}$ represents CO2 emissions at European level, measured in MtCO2 (output variable);

- ✓ $\left(CTE\_EU_t\right)_{t=\overline{1,T}}$ represents the total energy consumption at European level, measured in Mtoe (input variable);
- ✓ $t=\overline{1,T}$ the time period analyzed, between the years 1990-2021;
- ✓ T the number of terms in the series;
- ✓ ε_1 represents the residual variable.

Analyzing the two series of data and taking into account their characteristics, in the following table, various descriptive indicators specific are calculated.

Table 2. ***Descriptive indicators - Dynamic Model 1***

	Mean	**Median**	**Std. Dev.**	**Skewness**	**Kurtosis**	**Sum Sq. Dev.**
CTE_EU	1847.531	1846.5	76.60792	0.119405	2.294718	181932
CO2E_EU	4127.406	4201.0	284.6242	-0.950319	3.232963	2511340

Dynamic Model 2. *Econometric analysis of the correlation between CO2 emissions and total energy consumption at national level*

$$CO2E\_RO_t = b_1T + b_2CTE\_RO_t + b_3 + \varepsilon_{2t} \qquad (2)$$

where it was noted with:

- ✓ $\left(CO2E\_RO_t\right)_{t=\overline{1,T}}$ represents CO2 emissions at national level, measured in MtCO2 (output variable);
- ✓ $\left(CTE\_RO_t\right)_{t=\overline{1,T}}$ represents the total energy consumption at national level, measured in Mtoe (input variable);
- ✓ $t=\overline{1,T}$ the time period analyzed, between the years 1990-2021;
- ✓ T the number of terms in the series;
- ✓ ε_2 represents the residual variable.

And in this case, the main descriptive indicators of the two analyzed data series are calculated.

Table 3. ***Descriptive indicators - Dynamic Model 2***

	Mean	**Median**	**Std. Dev.**	**Skewness**	**Kurtosis**	**Sum Sq. Dev.**
CTE_RO	39.06250	37.50000	6.743874	1.420950	5.312877	1409.875
CO2E_RO	92.56250	92.00000	22.94304	1.045566	3.858429	16317.88

The graphs of the dependencies between CO2 emissions and total energy consumption, both at the European and national level, in the period 1990-2021, are represented in the following figure (graphs made in Eviews1.11).

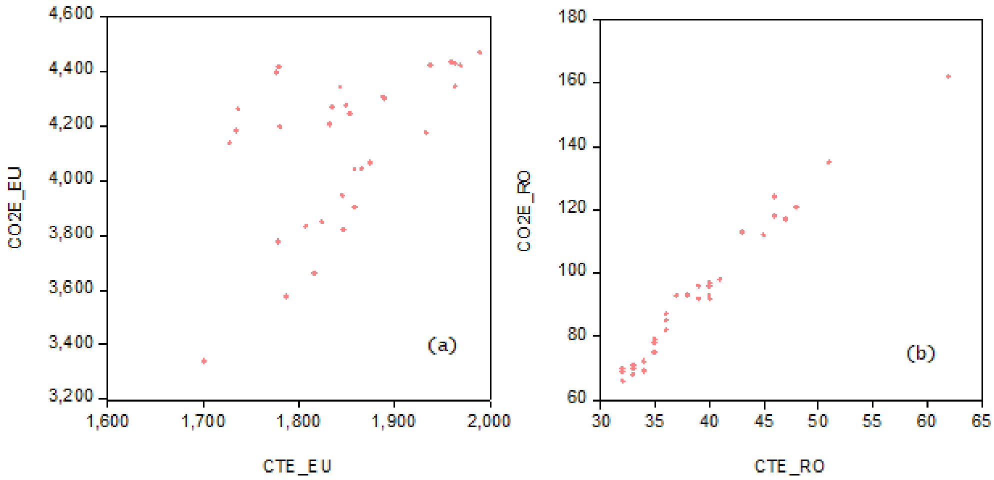


Fig. 3. Graph of the dependence between CO2 emissions and total energy consumption (a) Europe; (b) Romania

As can be seen, the first dynamic model has a non-linear trend, the data cloud being quite scattered, and the second dynamic model is one with a linear trend. Following the distribution of the points in the plane, the expressions of the two mathematical models approximating the analyzed data series are represented in relations (1) and (2).

Taking into account the above, in the next paragraph we will do the econometric analysis of the two models, starting from the results obtained in Eviews 11.1. I mentioned that the two models are obtained following the distribution of points in the plane.

Also, the results obtained for these two dynamic models give the best results, this conclusion being obtained by comparison with other models, but which were not introduced in the article.

4. RESULTS AND DISCUTION

In this paragraph, we will analyze from an econometric point of view the two models defined in relations (1), respectively (2). Thus, the parameters $a_1, a_2, ..., a_5, b_1, b_2, b_3$ of the two models are determined using the least squares method, their values being found in Table 4 for the first model, respectively in Table 5 for the second model.

Within these tables, the values of the main statistical indicators are also calculated, based on which the hypotheses specific to the econometric models will be analyzed in what follows.

Table 4. ***Estimation of parameters of Dynamic Model 1***

Dependent Variable: CO2E_EU		
Method: Least Squares (Gauss-Newton / Marquardt steps)		
Date: 11/25/22 Time: 13:50		
Sample: 1990 2021		

Included observations: 32				
CO2E_EU=a_1*T+a_2*T^2+a_3+a_4*CTE_EU+a_5*(CTE_EU)^2				
Variable	Coefficient	Std. Error	t-Statistic	Prob.
a_1	-1026.489	623.4858	-1.646371	0.1113
a_2	0.249449	0.155404	1.605164	0.1201
a_3	1054947.	624575.1	1.689063	0.1027
a_4	2.258844	4.049475	0.557811	0.5816
a_5	9.31E-05	0.001087	0.085670	0.9324
R-squared	0.983767	Mean dependent var		4127.406
Adjusted R-squared	0.981362	S.D. dependent var		284.6242
S.E. of regression	38.85710	Akaike info criterion		10.30026
Sum squared resid	40766.61	Schwarz criterion		10.52928
Log likelihood	-159.8042	Hannan-Quinn criter.		10.37617
F-statistic	409.0693	Durbin-Watson stat		1.682839
Prob(F-statistic)	0.000000			

If we following the values of the parameters $a_1, a_2, ..., a_5$ in the table above, it can be observed that the linear trend of CO2 emissions for the analyzed period determined the decrease in the level of these emissions, and the total energy consumption at the European level, has a positive influence on the dynamics of CO2 emissions.

On the other hand, if we following the values of the statistical indicators in Table 4, the following results are obtained:

- ✓ The high values of the coefficient of determination R^2 (R-squared), respectively of the adjusted demining coefficient Adjusted R-squared (close to 1) show the fact that the dynamic model 1 approximates very well the data series of the two analyzed variables;
- ✓ To verify the hypothesis of autocorrelation of the errors, the calculated value of the Durbin-Watson statistic is compared with the table values of the same statistic. In this case, for a significance threshold of 5% and for a number of 32 observations, the values from the table of the Durbin-Watson statistics are $d_1 = 1.37$ and $d_2 = 1.5$. Since the double inequality condition $d_2 < DW < 4 - d_1$ is satisfied, that is, we can conclude that the series of residuals is independent, that is, the residuals are not correlated with each other;
- ✓ To verify the hypothesis of the homoscedasticity, following the application of the White test, a calculated value of the Fisher statistic $F_{calc} = 1.67$ is obtained. This value is compared with the tabulated value $F_{0.05;1;30} = 4.171$ of the same statistic for a significance threshold of 5%. As the inequality $F_{calc} < F_{0,05;1;30}$ we can say that this hypothesis is verified;
- ✓ Regarding the performance of this model, the three indicators based on information theory were calculated. Thus, the three criteria Akaike, Schwartz

and Hannan-Quinn have sufficiently small values so that we can say that the analyzed model is a good one;

- ✓ Also, to test the validity and quality of this model, the analysis of variance is applied. The calculated value of the F statistic (found in Table 4) is greater than the tabular value of the *F* statistic, i.e. $F_{calculat} = 409.0693 > F_{0,05;1;30} = 4.171$. Therefore we can say that the analyzed model is correctly specified;
- ✓ Another observation is that the high value of the F statistic shows that the dynamics of CO2 emissions is well appreciated by the level of energy consumption.

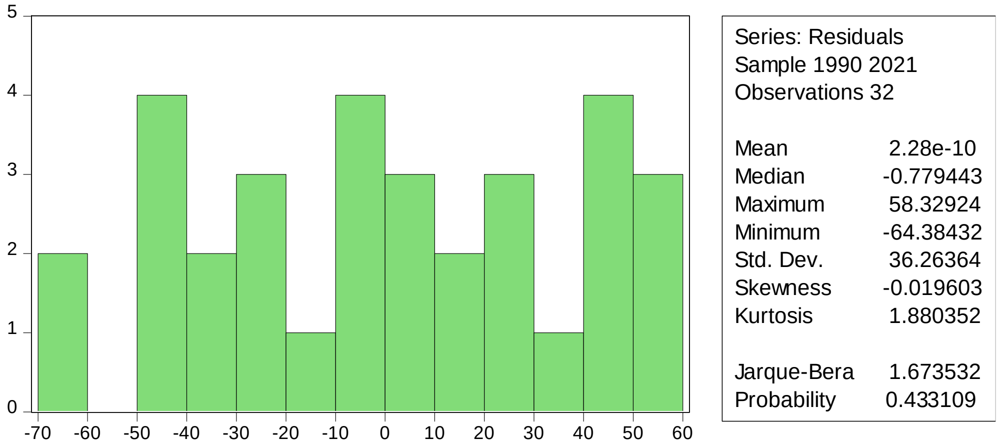


Fig. 4. The normality test from the Dynamic Model 1

In Figure 4 are represented the values of the coefficient of asymmetry (skewness) and flattening (kurtosis) and the Jarque-Bera indicator value $JB = 1.67$. Comparing the value of this statistic, with the value of the statistics $\chi^2_{2;0,05} = 5.991$, for 32 observations and a significance level of 5%, is observed that this hypothesis $JB < \chi^2_{2;0,05}$, of the normalization of residues is satisfied.

The calculated value of this test is compared to the tabulated value of the statistic $\chi^2_{2,\alpha}$, for a significance threshold of $\alpha = 5\%$, namely $\chi^2_{2;0,05} = 12,338$. If $JB = 0,078 < \chi^2_{2;0,05} = 12,338$ then the residue normalization hypothesis is accepted.

As far as Romania is concerned, based on the dynamic model 2 represented in relation (2) and the values of the characteristics and statistical indicators calculated in Table 5, we can make almost the same observations as those obtained in the case of the first Model.

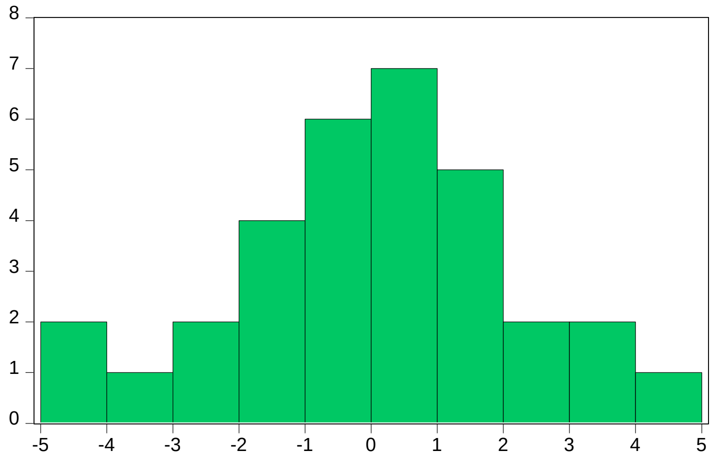
In other words, we can say that model 2 checks the assumption of autocorrelation of the residuals. Also, the hypothesis of homoscedasticity is verified, knowing that the calculated value of the *F* statistic, obtained after applying the White test, is $F_{calc} = 2.63$.

Regarding the performance of this model, one can observe the very low values (close to zero) of the three indicators Akaike, Schwartz and Hannan-Quinn.

Table 5. ***Estimation of parameters of Dynamic Model 2***

Dependent Variable: CO2E_RO				
Method: Least Squares (Gauss-Newton / Marquardt steps)				
Date: 11/25/22 Time: 13:40				
Sample: 1990 2021				
Included observations: 32				
$CO2E\_RO=b_1*T+b_2*CTE\_RO+b_3$				
	Coefficient	Std. Error	t-Statistic	Prob.
b_1	-0.612673	0.077469	-7.908664	0.0000
b_2	2.638781	0.107760	24.48758	0.0000
b_3	1218.201	158.9236	7.665323	0.0000
R-squared	0.991525	Mean dependent var		92.56250
Adjusted R-squared	0.990940	S.D. dependent var		22.94304
S.E. of regression	2.183785	Akaike info criterion		4.489056
Sum squared resid	138.2986	Schwarz criterion		4.626469
Log likelihood	-68.82490	Hannan-Quinn criter.		4.534605
F-statistic	1696.358	Durbin-Watson stat		1.571405
Prob(F-statistic)	0.000000			

In other words, analyzing the values of the parameters in Table 5, it is observed that the linear trend of CO2 emissions at the national level, for the analyzed period, determined a decrease in the level of these emissions. And as far as Romania is concerned, total energy consumption has a positive influence on the dynamics of CO2 emissions.



Series: Residuals	
Sample 1990 2021	
Observations 32	
Mean	-2.84e-14
Median	0.356787
Maximum	4.859869
Minimum	-4.270187
Std. Dev.	2.112166
Skewness	-0.076016
Kurtosis	2.839136
Jarque-Bera	0.065321
Probability	0.967867

Fig. 5. The normality test from the Dynamic Model 2

In Figure 5 are represented the values of the coefficient of asymmetry (skewness) and flattening (kurtosis) and the Jarque-Bera indicator value $JB = 0.06$. Comparing the value of this statistic, with the value of the statistics $\chi^2_{2;0,05} = 5.991$, for

32 observations and a significance level of 5%, is observed that this hypothesis $JB < \chi^2_{2;0,05}$, of the normalization of residues is satisfied.

The actual and adjusted values, are also, plotted in tandem with the residual values. The graphs are made in the Eviews 11.1 software package.

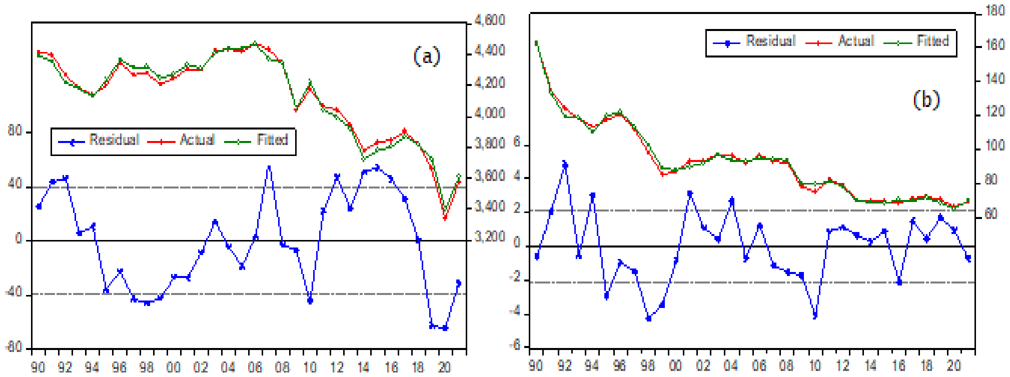


Fig. 6. Graph of the dependence between CO2 emissions and total energy consumption (a) Europe; (b) Romania

As can be seen, in both figures, the graphs of the values approximated by the two models are very close to the graphs of the real values of the two variables analyzed both at the national and at the European level.

5. CONCLUSIONS

Following the analysis of the two models applied in this work, it can be concluded that the linear trend of CO2 emissions both at the national and European level, for the analyzed period, determined decreases in the level of CO2 emissions. On the other hand, the total energy consumption, in both analyzed cases, has a positive influence on the dynamics of CO2 emissions.

Starting from these conclusions, strategic objectives can be formulated, both at national and European level in the field of the climate change and the energy, through the policies and measures applied to different sectors. In order to reduce CO2 emissions, both the EU and other European states have set ambitious objectives that aim to reduce these CO2 emissions by up to 55% by 2030.

Romania's target is to reduce these emissions by 12.7% until 2030 [10]. However, taking into account the current economic and social situation, these objectives are difficult to achieve, especially for Romania, which is on the vicinity of war of theUkraina.

On the other hand, the current energy crisis deepens even more the achievement of these objectives.

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