Characteristics of the evolution of renewable energy production in European Union

Marian Zaharia[1*], *Rodica Manuela* Gogonea[2], *Ana* Tănăsescu[3]

[1]Petroleum-Gas University of Ploiești, marianzaharia53@gmail.com, Romania
[2]Academy of Economic Studies from Bucharest, manuela.gogonea@gmail.com, Romania
[3]Petroleum-Gas University of Ploiești, atanasescuro@yahoo.com, Romania

Abstract. Starting from the evolution of the primary energy production from renewable energy sources, in the EU-28, from 1990 to 2015, the paper emphasizes both the changes in the primary production volumes and the mutations in the share of their production in the total primary renewable energy production recorded, especially, in the second part of the analysed period. Based on them, models are identified and primary renewable energy productions for 2020 are estimated from renewable energy sources like: solid biofuels, hydropower, wind power, biogas, biodiesels and solar photovoltaic. Excepting the production of energy based on hydropower, significant increases are recorded for the other five renewable energy sources.

1 Introduction

The renewable energy production has been an objective for forty years, N. D. Mortimer [1]. The exponential growth of the energy requirement, on the one hand, as well as the sustainable development imperatives J. Andrei, J. Subic, and D. Dusmanescu [2], H. Lund [3], J. V. Andrei, R. A. Ion, G. H. Popescu, E. Nica, and M. Zaharia [4], on the other hand, have made the energy sources problem to become one of the most important concern of this beginning of millennium A. G. Simionescu, and M. C. Dragomir [5], A. L. Dumitrescu [6] for most countries of the world.

At EU level, the production and use of energy from renewable sources constitutes an important target. Thus, since 2009, the Directive 28/EC [7] provided that in 2020 at least 20% of the final energy consumption to come from renewable sources and in the Communication 572/2015 was emphasized the fact that *energy from renewable sources and the energy efficiency require new abilities and investments and create jobs in Europe*, European Commission. State of the Energy Union (website)[8]. The energy security correlated with the sustainable development of the EU Member States economies in 2030 should reduce by 40% the greenhouse gas emissions compared to 1990 levels and ensure at least 27% from energy consumption, from renewable sources, European Commission. 2030 Energy Strategy(website) [9].

Based on these considerations, the paper analyses the evolutions of primary energy productions provided, for the period between 1990 and 2015, from 15 renewable energy sources: hydropower (HP), wind power (WP), solar thermal (ST), solar photovoltaic (SP), tide, wave and ocean (TWO), solid biofuels (SB), biogas (BG), municipal waste renewable (MRW), municipal waste non-renewable (MNW), biogasoline (BGL), biodiesels (BD), other liquid biofuels (OLB), bio jet kerosene (BJK), geothermal energy (GE) and industrial waste (IW).

In the paper first part, both the evolutions of the energy production from the 15 sources that are taken into account and the change of their share in the total energy production from nonconventional sources are analysed.

In the second part of the paper, the evolutions models of the renewable energy sources with significant development of production in the second part of the analysed period are identified and statistically tested. The energy production volumes from these sources, in 2020, are estimated, based on them.

2 Methodology

For the analysis of the evolution of primary renewable energy production in the EU-28, we have used the initial data series, Primary production - all products - annual data(website) [10] corresponding to those 15 primary renewable energy sources included in the achieved analysis. These describe the evolutions of renewable energy productions for a period of 26 years

* Corresponding author: marianzaharia53@gmail.com

(1990-2015), thus the variable *n* representing the number of years is equal to 26.

We have considered the data series $Y = \{y_i\}_{i=n}$. The polynomial model (1) used to determine the evolution of analysed variables is:

$$\mathbf{y} = \hat{\mathbf{y}} + \boldsymbol{\varepsilon}, \quad \hat{\mathbf{y}} = \mathbf{a_0} + \sum_{\mathbf{j=1}}^{\mathbf{k}} \mathbf{a_j} \cdot \mathbf{t^j} \qquad (1)$$

The validation of model (1) was carried out using ANOVA methodology and *F test*. The *F statistics* is:

$$\mathbf{F_c} = \frac{\sum_{\mathbf{i=1}}^{\mathbf{n}} \left(\hat{\mathbf{y}}_\mathbf{i} - \bar{\mathbf{y}}\right)}{\mathbf{k}} \Bigg/ \frac{\sum_{\mathbf{i=1}}^{\mathbf{n}} \left(\mathbf{y}_\mathbf{i} - \hat{\mathbf{y}}_\mathbf{i}\right)}{\mathbf{n-k-1}} \qquad (2)$$

Considering that α=0.05 and according to the values of $F_{0.05,\ k,\ n\text{-}k\text{-}1}$, the test hypotheses are:

H_{0_1}: the polynomial model (1) is not statistically significant ($Fc < F_{0.05,\ k,\ n\text{-}k\text{-}1}$).

H_{1_1}: the polynomial model (1) is statistically significant ($Fc > F_{0.05,\ k,\ n\text{-}k\text{-}1}$).

The estimation of the analysed variables values for year 2020 has been carried out based on the valid models that are specific to each indicator. Taking into account the values of bilateral *t test (Student)*, the limits of the confidence intervals of estimated values, for significance threshold α, are given by the relation:

$$\mathbf{y_{2020}} \in \left[\hat{\mathbf{y}}_{\mathbf{2020}} \mp \mathbf{t}_{\frac{\boldsymbol{\alpha}}{\mathbf{2}},\mathbf{n-k-1}} \cdot \mathbf{S}_{\hat{\mathbf{y}}\mathbf{2020}} \right] \qquad (3)$$

where:

$$\mathbf{S}_{\hat{\mathbf{y}}\mathbf{2020}} = \sqrt{\frac{\sum_{\mathbf{i=1}}^{\mathbf{n}} \left(\mathbf{y}_\mathbf{i} - \hat{\mathbf{y}}_\mathbf{i}\right)^2}{\mathbf{n-k-1}} \left[1 + \frac{1}{\mathbf{n}} + \frac{\left(\mathbf{x_{2020}} - \bar{\mathbf{x}}\right)^2}{\sum_{\mathbf{i=1}}^{\mathbf{n}} \left(\mathbf{x}_\mathbf{i} - \bar{\mathbf{x}}\right)^2} \right]} \qquad (4)$$

and $t_{\frac{\alpha}{2},n-k-1}$ represents the critical values for *Student distribution* for significance threshold α and *k* independent variables. In particular, in the achieved analysed *n* is equal to 26.

The tested hypotheses are:

H_{0_2}: the estimated value is not statistically significant (the confidence interval for the variable values includes the 0 value).

H_{1_2}: the estimated value is statistically significant (the limits of the confidence interval have the same sign).

To test the statistical hypotheses, 95% Confidence level (significance threshold α=0.05) has been chosen. The unit of measure used for primary renewable energy production is thousand tonnes of oil equivalent (TOE).

The SPSS, E. Jaba, A. Grama [11] and Excel (the Data Analysis module) have been used for data processing and analysis.

3 Results and discussions

In the period between 1990 and 2015, the renewable energy production had an ascending evolution that has led us to the conclusion that the established objectives at EU level for 2020 and 2030 can be fulfilled.

3.1 Characteristics of the evolution of primary renewable energy productions

The total primary renewable energy production at EU - 28 level between 1990 and 2015 has recorded significant increases from 75584.7 TOE (TOE - thousand tonnes of oil equivalent) in 1990 to 216997.7 TOE in 2015 (an increase of 2.87 times). However, the increase was not linear. If until 2002 the annual growth rates have evolved between 5.54% in 1993 (4504.3 TOE) and 0.36% (360.9 TOE) in 1999, in the period between 2002 and 2015 the annual growth rates have evolved between a maximum value of 9.89% in 2010 and a minimum value of 1.90% in 2014 that correspond to some absolute increases of 16132.3 TOE and, respectively, 3901.9 TOE. In consequence, if in the first half of the analysed period the total renewable energy production has increased with 41.55%, in the second half of the analysed period an increased with 150.45% has been recorded.

The recorded increases significantly differ in the analysed period, by renewable energy sources (figure 1). Thus, on the one hand, in absolute values, the highest increase has been recorded at the primary production of solid biofuels (49749.7 TOE), followed by de wind power (25889.2 TOE), biogas (14946.4 TOE) and biodiesels (11070.5 TOE). On the other hand, insignificant increases have been recorded at sources like: bio jet kerosene, other liquid biofuels and tide, wave and ocean.

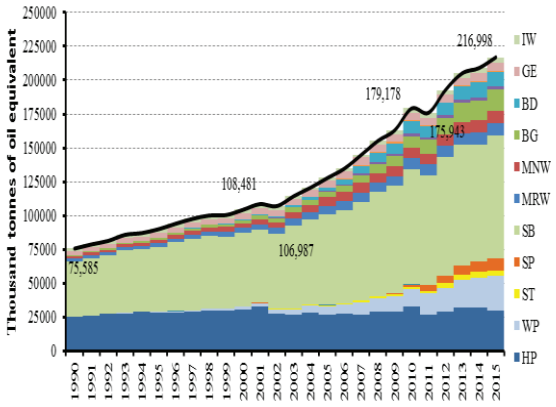

Fig. 1. Evolutions of primary renewable energy productions, in 1990-2015 period.

* Corresponding author: marianzaharia53@gmail.com

Source: elaborated by authors based on the data from Primary production - all products - annual data(website) [10]

In relative values, the differences are even higher. Thus, at the end of the first half of the analysed period, while in the case of 9 of the 15 renewable energy sources have been recorded increases between 0.7% (tide, wave and ocean) and 73.6% (municipal non-renewable waste), the primary energy production from solar thermal source was with 153% higher than in 1990 and at energy sources such as solar photovoltaic and wind power the increases were with 509.1% and, respectively, with 1348.9% higher.

Table 1. The hierarchy of renewable energy sources depending on production volume (toe)

Place	1990		1995		2000	
	Source	Prod.	Source	Prod.	Source	Prod.
1	SB	40627	SB	47646	SB	53835
2	HP	24972	HP	28547	HP	30687
3	GE	3185	GE	3439	GE	4587
4	MRW	2094	IW	3020	MRW	3801
5	MNW	2023	MRW	2661	MNW	3663
6	IW	1759	MNW	2638	IW	2395
7	BG	665	BG	1136	BG	2186
8	ST	142	WP	350	WP	1911
9	WP	67	ST	284	BD	634
10	TWO	43	BD	188	ST	427
11	BD	6	TWO	44	BGL	59
12	SP	1	BGL	24	TWO	44
13	BGL	0	OLB	10	OLB	16
14	OLB	0	SP	4	SP	10
15	BJK	0	BJK	0	BJK	0

Place	2005		2010		2015	
	Source	Prod.	Source	Prod.	Source	Prod.
1	SB	67303	SB	85467	SB	90421
2	HP	26940	HP	32408	HP	29327
3	MNW	6205	WP	12842	WP	25956
4	WP	6058	BD	8931	BG	15612
5	MRW	6025	BG	8530	BD	11077
6	GE	5309	MRW	7864	MRW	9485
7	BG	4000	MNW	7594	MNW	9189
8	BD	2499	GE	5517	SP	8799
9	IW	1633	IW	3466	GE	6466
10	ST	703	BGL	1972	ST	4252
11	BGL	480	SP	1935	IW	3780
12	OLB	394	ST	1788	BGL	2177
13	SP	126	OLB	823	OLB	414
14	TWO	41	TWO	41	TWO	42
15	BJK	0	BJK	0	BJK	1

These evolution trends are emphasized in the second part of the analysed period so that in 2015 compared to 2002 the primary energy production from renewable energy sources was of 8.31 times higher at wind power, of 8.34 times higher at solar thermal, of 11.1 times higher at biodiesels and of 13.75 times higher at biogasoline. Regarding the solar photovoltaic primary energy production, the increase has been explosive, so that in 2015 this increase was of 363.57 times higher than in 2002. The different evolutions that have been recorded by the renewable energy production in the analysed period have led to significant changes of the share of energy sources production in the total renewable energy production (figure 2).

Until the end of the first half of the analysed period significant changes are not recorded, the shares of renewable energy production from solid biofuels and hydropower representing 51.95% and, respectively, 25.64% of total.

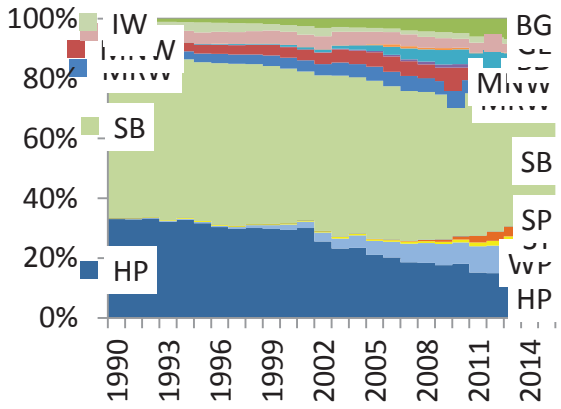

Fig. 2. Evolutions of the shares of primary renewable energy productions, by energy sources, in 1990-2015 period.

However, the changes are significant in the second part of the analysed period. Thus, in 2015, the shares of renewable energy production from solid biofuels and hydropower decrease to 41.67% and, respectively, to 13.51% of total. Due to the explosive increase, the renewable energy production based on wind power reaches to 11.96% of total. This is followed by biogas (7.19%), biodiesels (5.10%), municipal renewable waste (4.37%), municipal non-renewable waste (4.23%), solar photovoltaic (4.05%), geothermal energy (2.98%), solar thermal (1.96%) and industrial waste (1.74%).

The evolutions of the renewable energy productions by main energy sources, presented in table I, emphasize the changes that occur regarding the place occupied by the different renewable energy sources, in 1990-2015 period.

A first characteristic is represented by the fact that the energy produced based on solid biofuels and hydropower remains on the first place, for the entire analysed period.

In 1990, the main renewable energy source was municipal renewable waste (53.75% of total), followed by hydropower (33.04% from total) and geothermal energy (4.21% from total), the other 12 sources generating only 9% from the total renewable energy.

A second characteristic of the renewable energy production evolution is that the most significant advancements in the hierarchy have been recorded by the following energy sources: wind power and biodiesels with an advance of 6 places, solar photovoltaic with an

* Corresponding author: marianzaharia53@gmail.com

advance of 4 places and biogas with an advance of 3 places.

A third characteristic is that, although, the municipal renewable waste and municipal non-renewable constitute important renewable energy sources, in the production volume hierarchy they have passed from the 4th place and 5th place that were maintained until 2000 to the 6th place and 7th place in 2015, being overtaken by wind power, biogas and biodiesels. Significant regresses regarding the occupied place have been also recorded on geothermal energy and industrial waste. Although the energy production for geothermal energy has increased from 3185 TOE, in 1990, to 6466 TOE in 2015, it has passed from 3rd place to 9th place. In terms of industrial waste, it has passed from 6th place, in 1990, to 11th place in 2015.

A forth characteristic is the fact that if in 1990 the biogasoline production is practically null, in 2015 it has reached to 2177 TOE.

On the last two places, with renewable energy productions that are relatively insignificant, are placed tide, wave and ocean (approximate 43 TOE), as well as bio jet kerosene. Tide, wave and ocean energy source has passed from 10th place to 14th place, the production being relatively constant for the entire period.

3.2 Considerations regarding the primary renewable energy production for 2020

Taking into account the renewable energy productions evolutions, the growth rates, as well as the changes of the renewable energy sources rankings for 1990-2015 period, six energy sources have been chosen in order to identify evolution models and to carry out a forecast of renewable energy production.

Table 2. The parameters' values, quality and test results for quantitative model of primary renewable energy production, in 1990 - 2015 period

Variable	*k*	*Coefficients*					*Quality*	*Test results*	
		a_0	a_1	a_2	a_3	a_4	(R^2)	F_c	$F_{0.05,k,n-k-1}$
SB	3	42827	-172.56	149.96	-2.7219	-	0.981	375.131	3.05
HP	4	22165	2391.5	-262.48	10.889	-0.1496	0.446	4.222	2.84
WP	2	1665.7	-658.54	59.066	-	-	0.995	2469.518	3.42
BG	4	85.145	417.59	-56.866	3.6553	-0.0445	0.994	885.492	2.84
BD	3	1241.6	-586.96	56.941	-0.6911	-	0.973	260.717	3.05
SP	2	1795.7	-577.15	31.271	-	-	0.896	99.309	3.42

These six sources are represented by: solid biofuels (SB), hydropower (HP), wind power (WP), biogas (BG), biodiesels (BD) and solar photovoltaic (SP).

Polynomial models of the form described by the relation (1) have been tested using ANOVA methodology, based on the data series corresponding to the annual renewable energy production. Thus, second order models for variables WP and SP, third order models for variables SB and BD and, also, forth order models for variables HP and BG have been obtained.

5 of the 6 models have a value of the coefficient of determination (R squared) higher than 0.89. These values signify the fact that their models ensure a very good approximation of the real evolution of the primary renewable energy production based on solid biofuels, wind power, biogas, biodiesels and solar photovoltaic.

F statistics values corresponding to them (relation 2) are much higher than the critical values ($F_{0.05,\ k,\ n-k-1}$) that leads us to reject the null hypothesis (H_{0_1}) and to accept the alternative hypothesis (H_{1_1}). Therefore, the models are statistically significant and can be used to estimate the values of renewable energy production based on those sources.

A model with a coefficient of determination better than 0.464 cannot be obtained from the data series corresponding to variable HP. The evolutions of the primary renewable energy production based on hydropower are fluctuating from one year to another, this fact being mainly caused by the climate influences on the water flows and, implicitly, on the water level of reservoirs. Taking into account the fact that *F statistics* value (Fc=4.222) is higher than the critical value ($F_{0.05,4,21}$=2.84), the null hypothesis is also rejected (H_{0_1}) and the alternative hypothesis is accepted (H_{1_1}): the forth order polynomial model corresponding to the evolution of renewable energy production based on hydropower is statistically significant.

The evolutions of primary energy productions based on solid biofuels, hydropower, wind power, biogas, biodiesels and solar photovoltaic have been estimated starting from the polynomial models that are statistically validated. Their evolutions and the empirical data series corresponding to their productions between 1990 and 2015 period are graphically represented in figure 3.

A first characteristic that results from the evolutions of the six indicators for 2020 is the fact that the primary renewable energy production based on hydropower will be overtaken by the primary renewable energy production based on wind power.

The maintenance of the ascending trend of the primary energy production volume for the next period (2015-2020) for the other five analysed sources is the second characteristic. The estimated values as well as the results of the testing of their statistical significances are presented in table 3.

* Corresponding author: marianzaharia53@gmail.com

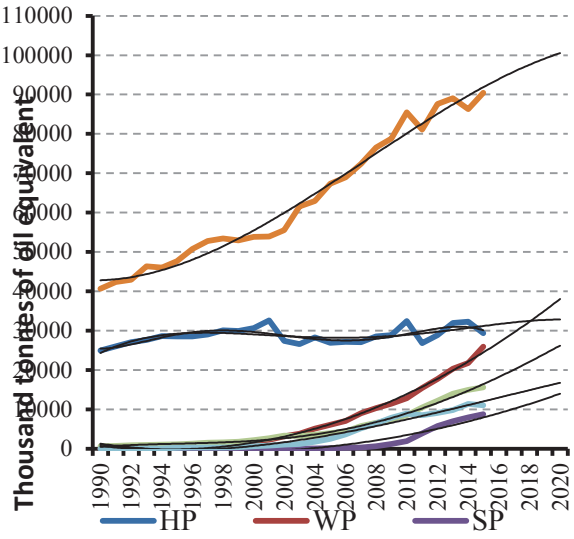

Fig. 3. Evolutions of primary renewable energy productions based on solid biofuels (SB), hydropower (HP), wind power (WP), biogas (BG), biodiesels (BD) and solar photovoltaic (SP), in the 1990-2015 period and the estimations of their values by 2020. Source: elaborated by authors

Taking into account that the minimum and maximum limits of the 95% confidence intervals have the same sign (the zero value is not included) for all the 6 estimated values, the null hypothesis is rejected (H_{0_2}) and the alternative hypothesis is accepted (H_{1_2}). Consequently, the estimated values are statistically significant.

Table 3. The estimated values of renewable energy production, in 2020, from the six sources (toe)

Variable	Estimated production	95% Confidence level		Accepted hypothesis
		Lower	Upper	
SB	100501	94867	106134	H_{1_2}
HP	32787	28958	36615	H_{1_2}
WP	38013	36675	39350	H_{1_2}
BG	26181	25254	27108	H_{1_2}
BD	16745	15935	19354	H_{1_2}
SP	13904	11685	16122	H_{1_2}

Taking into account the estimated values, it results that the renewable energy production based on biofuels will be placed, with a 95% probability, between 94867 TOE and 106134 TOE that corresponds to an increase between 4.9% and 17.3%, the most probable value of production being of 100501 TOE.

In 2020, the highest absolute increases of renewable energy compared to 2015 will be recorded by energy production based on wind power. These increases will range between 10719 TOE and 13394 TOE. At 2020 level, we estimate that the energy production based on wind power will be between 36675 TOE and 39350 TOE (relative increases between 41.3% and 51.6%).

Regarding the relative values compared to 2015, it is expected that the highest increase that ranges between 61.7% and 73.7% to be recorded by the renewable energy production based on biogas (an absolute increase between 9642 TOE and 11496 TOE), followed by biodiesels with a relative increase between 43.8% and 74.7% (an absolute increase between 4058 TOE and 8277 TOE).

Significant increases will be also recorded to the renewable energy production based on solar photovoltaic with absolute increases that belong to an interval between 2886 TOE and 7323 TOE, so that this type of renewable energy production will range between 11684 TOE and 16122 TOE that corresponds to a relative increase between 32.8% and 83.22%.

Regarding the renewable energy production based on hydropower, the increase with a maximum 7288 TOE (24.8%) of the energy production in 2020 compared to 2015 must be reservedly regarded, taking into account the limits of the used model.

4 Conclusions

From the analysis of the evolution of primary renewable energy production from the period between 1990 and 2015, it has resulted that the productions volume from those 15 analysed energy sources have increased. The increases have not been linear and as it results from the models presented, the increases have been emphasized in the second part of the analysed period. However, on the one hand, the energy produced based on solid biofuels and the one generated by hydropower have been maintained on the first place for the entire analysed period, representing in 2015 41.67% and 13.51% from the total renewable energy production at EU-28 level.

On the other hand, the increases that have been recorded significantly differ by energy source type, the highest increase being recorded on the primary production of solid biofuels (49749.7 TOE), followed by de wind power (25889.2 TOE), biogas (14946.4 TOE) and biodiesels (11070.5 TOE). The increases have been insignificant in terms of renewable energy sources like: bio jet kerosene, other liquid biofuels, as well as tide, wave and ocean.

These evolutions have determined the changing of the hierarchy of renewable energy production by sources. Thus, the most significant advancements in the hierarchy have been recorded by energy sources like wind power and biodiesels with an advance of 6 places, solar photovoltaic with an advance of 4 places and biogas with an advance of 3 places. In 2015, the productions from these sources represented 11.96 % (WP), 5.1% (BD), 4.05% (SP) and, respectively, 7.19% (BG) from the total primary renewable energy production at EU-28 level.

Although the municipal renewable waste and the municipal non-renewable waste have passed from the 4th and 5th places, in the hierarchy of the primary production volume, places that were maintained until 2000, to the 6th place and 7th place in 2015, they still represent important renewable energy sources. Thus, they ensure

* Corresponding author: marianzaharia53@gmail.com

4.27% and, respectively, 4.23% from the production recorded in 2015, at EU-28 level.

For the next period, the ascending trends of the primary energy production volume are maintained, with a 95% confidence level, for the other 5 analysed sources. Also, another important conclusion it that the primary renewable energy production based on wind power will overtake the energy production based on hydropower.

References

[1] N. D. Mortimer, "Energy analysis of renewable energy sources", *Energy Policy*, vol. 19, issue 4, pp. 374-385, May 1991.
[2] J. Andrei, J. Subic, and D. Dusmanescu, "Using dynamic programming for optimizing the investment strategy for an agricultural sheep holding: an investment case simulation", *Актуальні проблеми економіки*, vol. 4, no. 142, pp. 252-261, 2013.
[3] H. Lund, "Renewable energy strategies for sustainable development", *Energy*, vol. 32, issue 6, pp. 912-919, 2007.
[4] J. V. Andrei, R. A. Ion, G. H. Popescu, E. Nica, and M. Zaharia, "Implications of agricultural bioenergy crop production and prices in changing the land use paradigm—the case of Romania", *Land Use Policy*, vol. 50, pp. 399-407, 2016.
[5] A. G. Simionescu, M. C. Dragomir, "Using Renewable Energy for a Sustainable Development", *Annals of "Dunarea de Jos" University of Galati Fascicle I. Economics and Applied Informatics,* issue 3, pp. 39-44, 2012.
[6] A. L. Dumitrescu, "The Energy Union pillars: competitiveness, security and sustainability", *The Journal of Global Economics*, vol. 8, issue 4, 2016.
[7] European Commission, DIRECTIVE 2009/28/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL, http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32009L0028&from=en, accessed on January 2017.
[8] European Commission. State of the Energy Union, COM (2015) 572 final, https://ec.europa.eu/transparency/regdoc/rep/1/2015/EN/1-2015-572-EN-F1-1.PDF, accessed on January 2017.
[9] European Commission. 2030 Energy Strategy https://ec.europa.eu/energy/en/topics/energy-strategy, accessed on January 2017.
[10] http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=nrg_109a&lang=en Primary production - all products - annual data (nrg_109a)
[11] E. Jaba, A. Grama, *Analiza statistică cu SPSS sub Windows*, Ed. Polirom, Iași, 2004.

* Corresponding author: marianzaharia53@gmail.com