GREEN ENERGY IN ELECTRICITY PRODUCTION: EVOLUTION AND DETERMINING FACTORS

ENERGIA VERDE ÎN PRODUCEREA ENERGIEI ELECTRICE: EVOLUȚIA ȘI FACTORII DETERMINANȚI

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Abstract: *The research subject is green energy in Moldova. One advantage of green energy is its inexhaustibility, while natural gas and oil are distributed unevenly between countries and are exhaustible resources. This study aims to determine the economic factors influencing changes in the share of green energy in electricity production and to test the hypothesis that changes in world prices for natural gas directly affect the growth and distribution of green energy. The original aspect of the article is the testing of this hypothesis for Moldova and the study of structural changes in green energy.*

Keywords: renewable energy, electricity production structure, energy crisis, Gatev index, Ryabtsev index.

Rezumat: *Subiectul cercetării este energia verde în Moldova. Un avantaj al energiei verzi este inepuizabilitatea, în timp ce gazele naturale și petrolul sunt distribuite inegal între țări și sunt resurse epuizabile. Acest studiu își propune să determine factorii economici care influențează modificările ponderii energiei verzi în producția de energie electrică și să testeze ipoteza că modificările prețurilor mondiale la gazele naturale afectează în mod direct creșterea și distribuția energiei verzi. Aspectul original al articolului este testarea acestei ipoteze pentru Moldova și studiul modificărilor structurale în energia verde.*

Cuvinte cheie: energie regenerabilă, structura producției de energie electrică, criza energetică, indicele Gatev, indicele Ryabtsev.

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1. Introduction

Green energy (GE), a crucial component of the electricity production system, harnesses the power of various renewable energy sources. The most prevalent types, which form the focus of this study, are hydroelectricity, photovoltaic conversion of solar energy, and wind energy. In 2022, the share of green energy in the world was 29.3% of all electricity produced. The study's importance is underscored by the fact that few studies have been done on renewable energy to determine the influencing factors. In addition, no studies are analyzing changes in the structure of green energy using integral indexes of structural changes, calculating coefficients of unevenness and concentration. This research fills a crucial gap in understanding the specific factors that influence renewable energy adoption and production in Moldova, as well as the structural changes that occur, making it a significant and timely contribution to the field.

The study's results, which hold significant implications, vary from country to country. Turkish scientists have determined a one-way cause-and-effect relationship between renewable energy consumption and economic growth; if renewable energy consumption increases, it has increased economic growth in Turkey [1]. According to a study by Chinese scientists, there is a two-way cause-and-effect relationship between renewable energy production and economic performance [2]. These findings underscore the importance of understanding the economic factors influencing green energy consumption and production.

Ecuadorian and Chinese scientists have suggested that economic development will reduce fossil energy consumption and increase energy consumption from renewable sources. However, the study's results showed that economic growth does not reduce fossil energy consumption, but human capital does reduce consumption of non-renewable energy [3].

Most studies on Renewable Energy Sources (RES) examine the cause-and-effect relationship between them and the environment [4]. Vedat Kiraly believes that as renewable energy (RE) production capacity proliferates, it is necessary to minimize the need for agricultural and public areas [5].

Very little work highlights the advantages and disadvantages of GE [6]. The main disadvantages of solar and wind power plants are bird mortality, habitat loss, hazardous chemicals used in solar panels and wind turbine blades, and noise that is dangerous for humans. Therefore, building wind power plants near housing is not recommended [7]. Articles that describe the risks of transition to renewable energy are rare [8]. Most studies focus on the benefits of green energy [9], but they differ only in coverage: the benefits of solar energy [10], wind energy [11], or all of RES [12]. A population survey in the North Hungarian region found that RE is considered too expensive for low-income families to take advantage of this form of energy [13].

The paper's purpose is clear and focused: to determine the economic factors influencing changes in the share of green energy in electricity production in Moldova. It also aims to test the hypothesis that changes in world prices for natural gas directly affect the growth and distribution of green energy. By addressing these objectives, this research contributes to a deeper understanding of the dynamics of green energy production.

2. Methodological foundations of the study

This study used statistical and regression analysis. Structures' dynamics depend on changes in proportions between the components that form them. Particular statistical indicators are used to characterize changes in the structure quantitatively. The following coefficients of uneven distribution and integral coefficients of structural changes [14] will be used to analyze structural changes in green energy in Moldova.

$$K_{ud} = \frac{n \times l}{n - l} \sum (d_i - \rho)^2, \tag{1}$$

$$\rho = \frac{1}{n}, \tag{2}$$

where:

K_{ud} – the uneven distribution coefficient,

n – the number of elements of the structure,

l – the number of elements that make up the dominant group, in which 60 or more percent are concentrated,

d_i – the share of the i element in the whole,

ρ – the share of each element in the uniform distribution.

$$K_c = \frac{1}{2}\sum\left|d_i - \frac{1}{n}\right|, \tag{3}$$

where:

K_c – the concentration coefficient.

$$K_K = \sqrt{\frac{\sum(d_i - d_{i-1})^2}{n}}, \tag{4}$$

where:

K_K – Kazints coefficient or the quadratic coefficient of absolute structural changes.

$$I_G = \sqrt{\frac{\sum(d_i - d_{i-1})^2}{\sum {d_i}^2 + \sum {d_{i-1}}^2}}, \tag{5}$$

where:

I_G – Gatev index.

$$I_R = \sqrt{\frac{\sum(d_i - d_{i-1})^2}{\sum(d_i + d_{i-1})^2}}, \tag{6}$$

where:

I_R – Ryabtsev index [14].

Using software EViews 9.5, regression equations for “the share of Renewable Energy Sources in Moldova’s electricity production” were constructed, and influencing factors were identified. Data from the Report on the National Agency for Energy Regulation activity for 2013-2022 and from the National Bureau of Statistics of the Republic of Moldova were used to build the models.

The endogenous and exogenous variables of regression equations are presented in Table 1. The significance level was 5% when testing the developed regression equations.

Table 1. **Endogenous and exogenous variables**

Designation	Variables	Unit of measure
Endogenous variable		
sres	Share of Renewable Energy Sources in Moldova's electricity production	%
Exogenous variable		
pgas	Price of natural gas Europe	US$/MMBtu
poil	Price of crude oil, Brent	$/BBL
cres	Capacity of power plants operating on RES	MW
gdpcap	Gross Domestic Product (GDP) per capita according to purchasing power parity	thousand US$
growth	Index of the physical volume of GDP, previous year=100	%
cpi	Consumer price index	%
NOTE: MMBtu – Metric Million British Thermal Unit BBL – barrel of crude oil		

3. Green energy in electricity production in Moldova: evolution and structural changes

Over ten years (2013-2022), power plants' capacity to produce electricity from renewable sources has increased by 89.3 times, and the volume of electricity produced and supplied by 102.9 times (Figure 1).

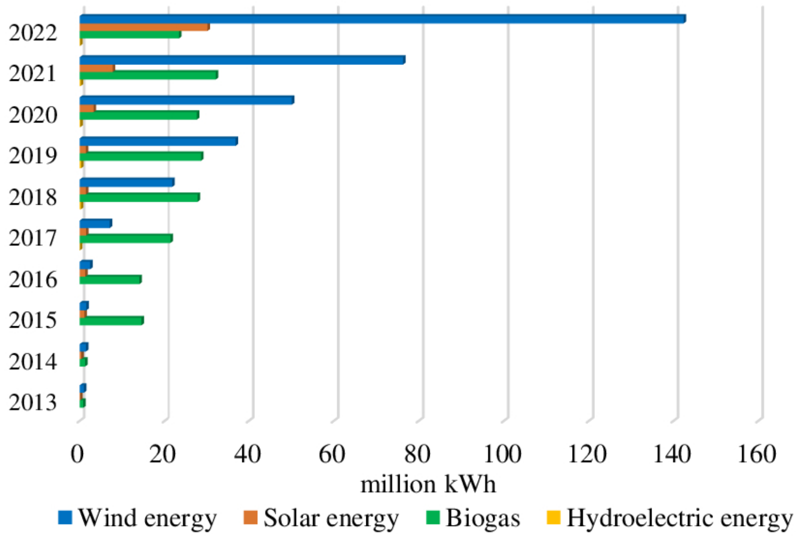

Figure 1. Production of electricity from RES, Moldova

In the first year of the analyzed period (2013), only two producers of electricity from biogas (Peasant Household "Morari V.I."; Limited Liability Company (LLC) "Tevas Grup"), two solar energy producers (LLC "Solotrans Agro"; LLC "Tasotilex") and one wind energy producer (LLC "Elteprod") were active on the territory of Moldova. Their cumulative capacity was 1.61 MW, and during the year, they produced and delivered 1.908 million kWh of electricity. The volume of electricity produced by wind generators has increased. Still, the share of wind energy in the structure of green energy decreased considerably in 2015, then it increased continuously and registered 72.5% in 2022 (Figure 2). In 2021, biogas electricity production (BEP) growth increased significantly, reaching a level of 32.24 million kW, and in 2022, a decrease of 27% was recorded. Although the volume of BEP has been growing since 2015, the share of biogas electricity production in green energy has been falling since the growth rate of BEP is less than that of wind energy.

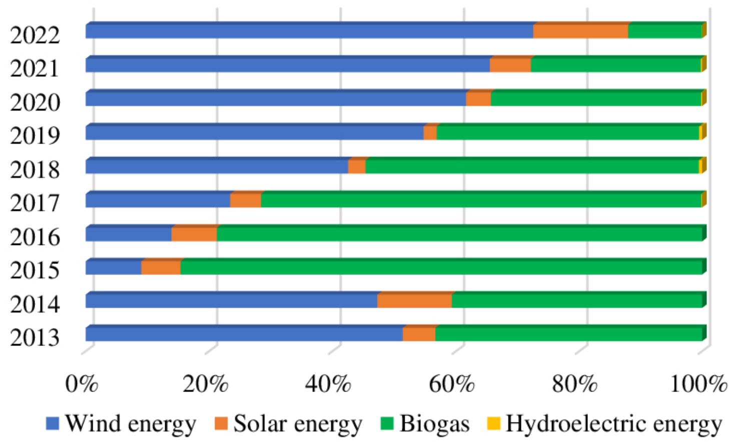

Figure 2. Structure of production of electricity from RES, Moldova

In 2014, the distribution unevenness coefficient was 0.2, which indicates relative diversity in the structure, that is, a relatively uniform distribution. However, next year, 2015, we observed increased uniformity in the structure since the empirical distribution differs from uniform. This increase in the unevenness coefficient is explained by the rise in biogas electricity production by 11.4 times. In the next three years (2016-2018), this coefficient fell as the volume of wind power production increased. Still, starting in 2019, the distribution unevenness coefficient has grown since the growth rate of wind energy is much higher than that of other types of green energy (Figure 3).

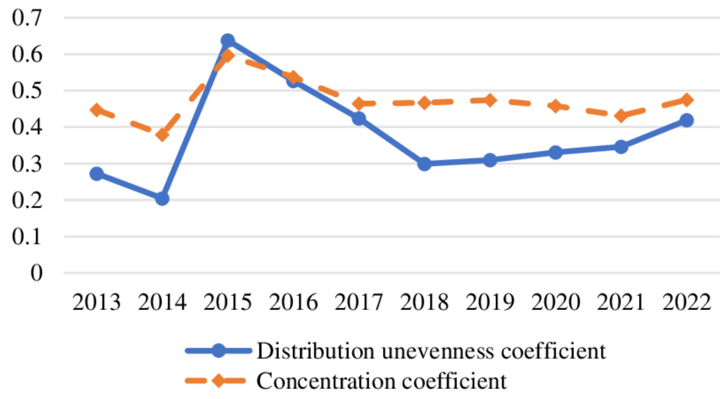

Figure 3. Distribution unevenness and concentration coefficients, Moldova

According to the Kazints coefficient, there were significant structural shifts in the structure of green energy in 2015 and 2018 (Figure 4) since levels of 0.29 (29%) in 2015 and 0.13 (13%) in 2018 were recorded. According to the criteria, if the level of the Kazints coefficient is from 2 to 10%, structural changes are substantial, and when it is more than 10%, significant structural changes occur.

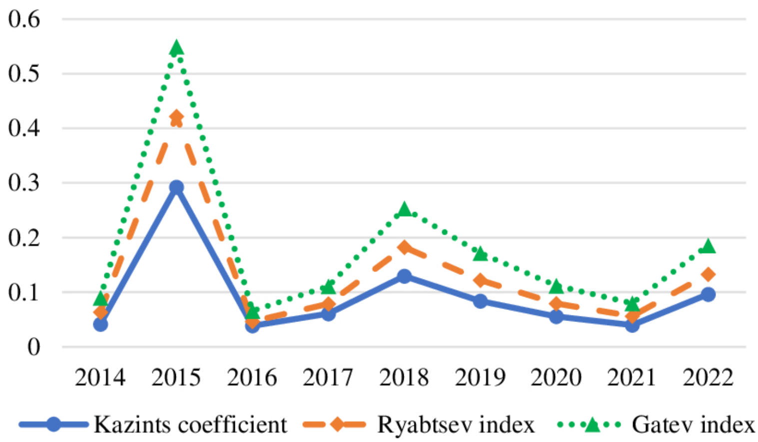

Figure 4. Kazints coefficient, Ryabtsev and Gatev indices, Moldova

Gatev index is an integral coefficient of structural differences that considers the intensity of changes in individual groups and the proportion of groups in the compared structures. The Ryabtsev index is an index of the difference between two structures. The advantage of this index is that it has a scale for assessing the significance of differences in structures. According to this scale, in 2015, there was a significant level of differences; in 2018, there was a substantial level of differences; and in 2014, 2016, and 2021 years, there were very low levels of differences. The significant difference recorded in 2015 was due to the doubling of the share of BEP in green energy (by +44 p.p.), and the substantial difference in 2018 was caused by the doubling of the share of wind energy (by +19 p.p.).

4. Determining the economic factors influencing changes in the share of green energy in electricity production

The following models were developed from one regression equation to determine the economic factors influencing the RES share level in Moldova's electricity production. There are ten observations because green energy is very young in Moldova.

Model A:

$$sres = -48 - 0.47pgas + 0.07poil + 0.14cres - 0.09growth + 0.27gdpcap + 0.51cpi \, . \tag{7}$$

Model B:

$$sres = -0.08pgas + 0.03poil + 0.1cres - 0.19growth + 0.43gdpcap + 0.14cpi \, . \tag{8}$$

Model C:

$$sres = 0.123cres - 0.124growth + 0.135cpi \, . \tag{9}$$

Model D:

$$sres = -12.274 + 0.268pgas + 1.363gdpcap \, . \tag{10}$$

Model E:

$$sres = 0.56pgas \, . \tag{11}$$

The null hypothesis that the regression parameters equal zero was tested for all models (Table 2). The null hypothesis was accepted for models

A and B, and hypothesis H1, which showed that the regression parameters differ from zero, was accepted for the last three models (C, D, and E). Further testing of the remaining models' quality showed that in model E's case, the residuals are autocorrelative since the Durbin-Watson statistic is 0.371208 (Table 3). Therefore, model F was developed, which considers the autocorrelation of the residuals.

Model F:

$$sres = 0.4pgas + [AR(1) = 0.926, UNCOND]\,. \tag{12}$$

Table 2. **Testing the null hypothesis H0 that the regression parameters are equal to zero**

Variables	**Standard error**	**t-value**	**p-value**
Model A			
c	41.48001	-1.156889	0.3311
pgas	0.352857	-1.322311	0.2778
poil	0.047342	1.487927	0.2335
cres	0.050367	2.873002	0.0639
growth	0.101904	-0.860832	0.4526
gdpcap	0.423426	0.639578	0.5679
cpi	0.319318	1.594335	0.2091
Model B			
pgas	0.118769	-0.675922	0.5362
poil	0.031256	0.898515	0.4197
cres	0.037558	2.769782	0.0503
growth	0.057110	-3.275907	0.0306
gdpcap	0.415475	1.046925	0.3542
cpi	0.053325	2.709118	0.0536
Model C			
cres	0.009002	13.68463	0.0000
growth	0.035827	-3.469615	0.0104
cpi	0.036096	3.736809	0.0073
Model D			
c	2.499671	-4.910410	0.0017
pgas	0.072146	3.720579	0.0075
gdpcap	0.231955	5.875260	0.0006
Model E			
pgas	0.091935	6.085288	0.0002

The next stage is to check models C, D, and F for heteroscedasticity of the residuals.

Table 3. **Testing the quality of models C, D, and E**

	Model C	Model D	Model E
R-squared	0.981016	0.934650	0.592462
Adjusted R-squared	0.975591	0.915978	0.592462
F-statistic	–	50.05752	–
Prob. (F-statistic)	–	0.000071	–
Akaike info criterion	3.241803	4.477944	5.908315
Schwarz criterion	3.332578	4.568719	5.938574
Hannan-Quinn criterion	3.142222	4.378363	5.875122
Durbin Watson statistic	1.005718	2.565693	0.371208

The Breusch-Pagan-Godfrey test was applied to check whether heteroscedasticity or homoscedasticity of residuals occurs. The test results showed that the null hypothesis is valid, and the regression residuals are homoscedastic (Table 4).

Table 4. **Breusch-Pagan-Godfrey test results of models C, D, and F**

Model C			
F-statistic	0.182859	Prob. F (3,6)	0.9043
Obs*R-squared	0.837706	Prob. Chi-Square (3)	0.8404
Scaled explained SS	0.391996	Prob. Chi-Square (3)	0.9419
Model D			
F-statistic	0.496621	Prob. F (2,7)	0.6285
Obs*R-squared	1.242603	Prob. Chi-Square (2)	0.5372
Scaled explained SS	0.400672	Prob. Chi-Square (2)	0.8185
Model F			
F-statistic	0.062400	Prob. F (1,8)	0.8090
Obs*R-squared	0.077397	Prob. Chi-Square (1)	0.7809
Scaled explained SS	0.011031	Prob. Chi-Square (1)	0.9164

Model F could be used to test the hypothesis that changes in world natural gas prices directly affect the growth and distribution of green energy in Moldova. Since the regression coefficient of the exogenous variable “price of natural gas Europe” in model F is positive, increasing gas prices in Europe leads to a rise in the share of green energy in electricity production in Moldova.

5. Conclusions

The structure of green energy underwent the most significant changes in 2015 and 2018. In the first case, structural changes are caused by an 11.4-fold increase in biogas electricity production, and in the second case, by the rise in wind energy by 3.1 times. In 2015, the increase in the amount of electricity produced by RES was due to the commissioning of the power plant belonging to the Joint-stock company "Sudzucker Moldova," with an installed capacity of 2.4 MW, which used biogas as fuel, obtained from organic waste from the sugar factory in Drochia.

The study's results presented in this work (Model F) prove that the energy crisis caused by rising natural gas prices in Europe was an impulse that led to an increase in green energy in Moldova by 1.7 times in 2022 compared to 2021 and by 2.4 times compared to the year preceding the energy crisis (2020). According to model D, the determining factors, the growth of which leads to an increase in the share of green energy in the volume of electricity production, are the price of natural gas in the European market and GDP per capita according to purchasing power parity. According to model C, an increase in capacity and inflation lead to a rise in the share of renewable energy sources. Still, GDP growth has a negative impact since, in today's realities, the economic development of Moldova is impossible without fossil energy sources. The growth of green energy in Moldova cannot yet meet the needs of the national economy.

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