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Convergence of Energy Policies between the EU and Ukraine under the Green Deal Policy

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Abstract: EU countries declared the strategic goal to achieve energy independence and increase energy efficiency. In this case, EU countries have provided a vast range of incentives, mechanisms, and directives to promote energy efficiency. Ukraine as a potential candidate should provide a convergent policy with EU countries to increase energy efficiency. The paper aims to estimate energy efficiency based on the revealed convergent and divergent determinants of energy policies among the EU and Ukraine. The data are compiled from the World Energy Statistics Yearbook, the European Statistical Office, the International Energy Agency, SolAbility agencies, and State Statistics Service of Ukraine. The study applies σ- i β-convergence theory to determine the convergent and divergent determinants of the country's energy efficiency. The empirical results allow concluding that Ukraine has an average level in the integrated energy efficiency index of the national economy, and the highest value of this index was in 2008. The highest values of energy efficiency were in Sweden and Denmark among EU countries. Besides, the findings confirm that the Ukrainian government should pay attention to divergent determinants (expenditure for environmental protection, pricing for energy resources, etc.) to improve the country's energy efficiency.

Keywords: energy efficiency; energy consumption; energy governance; national economy; carbon-neutral model; integrated method; σ-convergence; β-convergence; sustainable development

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1. Introduction

Energy security depends on energy efficiency, which is formed due to the rational use of resources and introducing and developing innovative technologies in all spheres of a country's economy [1]. Considering the studies [2–5], energy efficiency is positioned as one of the most important indicators of a country's competitiveness. Thus, in Norway, which is a leader in energy efficiency, the Energy Efficiency Fund (FEE) [6] was created in the country in the 1980s; it still accumulates all possible energy efficiency initiatives. For Ukraine, which is going through a difficult stage of independent socioeconomic development, the declared priority of energy-saving policy has not been supported by an effective form and mechanisms of interaction among the government, business, and scientific potential in implementing innovative energy-saving technologies for a long time. Since Ukraine's policy is aimed at the European integration process and support for the Green Deal Policy [7], it is necessary to define the main directions in which Ukraine has a multivector development policy. In particular, convergent indicators of the energy efficiency of the national economy include those that are directly correlated with the indicators of the EU countries, and divergent indicators include those that, according to calculations, need to be improved or change the policy of their operation to comply with the international standards.

It should be noted that the EU countries became hostages of energy dependence under the condition of a stable increase in using alternative energy sources, but this turned out to be insufficient. At the same time, since 16 March 2022, Ukraine has joined the European energy system ENTOS-E [8]. In the future, it will exclude the possibility of exchanging energy resources and diversify the use of energy resources in EU countries [9]. It is noted that the EU countries react slowly to shock situations, especially in the energy sector; this is caused by the maximum share of long-term contracts for the purchase of energy resources of the aggressor country and paying minimal attention to energy risks [9,10]. Therefore, the energy policy of the EU countries and Ukraine should be modified, minimizing the asynchrony of policies and considering the speed of response of the state energy policy to exogenous and endogenous changes. For this, it is necessary to understand which indicators Ukraine should focus on to promote energy efficiency under the accepted Green Deal Policy. The paper aims to estimate the energy efficiency and define the convergence of the relevant policies between the EU and Ukraine (as a candidate for EU membership) to ensure the country's energy efficiency. The paper contributes to the theoretical landscape of energy efficiency estimation by the development approach which considers the synchrony and the speed of response of the state energy policy in the EU and Ukraine based on σ- i β-convergence theory.

Considering the discussion, the paper has the following structure: Section 2 analyzes the theoretical foundations of the influence of economic, energy and environmental determinants on the level of energy efficiency; Section 3 explains the methods used to identify the level of asynchrony and the speed of response of the state energy policy based on the developed energy efficiency index; Section 4 explains the core empirical results of the research and Section 5 concludes and discusses the obtained results of the research.

2. Literature Review

2.1. Energy Efficiency: Approaches to Assessment

The concept of energy efficiency in the scientific field is considered in the context of many subject areas. The results of the analysis of the theoretical framework of energy efficiency showed that the scholars applied a vast range of methods to estimate the energy efficiency of the country, e.g., the Pedroni cointegration test [11], the method of least squares [2], the method of integral estimates [9], comparative analysis [12–15], SBM-DEA and Malmquist Productivity Index [16], etc. It is appropriate to pay attention to the results of the research [12], which confirms the statistical significance of the institutional determinants' influence on the energy efficiency gap. At the same time, past studies [13–16] analyzed the influence of various factors on the development of the energy efficiency of the national economy. In particular, in research [14], calculations are carried out with the help of multiple correlation-regression analyses regarding the impact of social, environmental and economic indicators on the level of energy efficiency. The results indicate the weaknesses in the development of the national economy in the context of many components. The prior studies [16–18] determine the power of influence on the level of energy efficiency during the introduction of renewable energy in the EU-27. A Markov switching regression model for three regimes was chosen for the calculations. It is necessary to note the content of the research [19] regarding the identification of the positive impact of clustering various spheres of consumption on the level of energy efficiency of the country's national economy. The study of energy efficiency is also relevant today in the context of the implementation of sustainable development goals in the country's national economy [20]. For example, scientists are investigating the impact of energy efficiency development within the framework of sustainable development and the impact on the health of the country's population [21].

2.2. Energy Efficiency and Environmental Determinants

The authors [22], within the framework of the scientific discussion, investigate the issues related to searching for and improving the existing approaches for assessing the impact of CO_2 on the state of the environment and the economic stability of the country, which will allow for the opening of new directions (providing carbon financing for economic entities, developing energy management, etc.) [23,24] in increasing the country's competitiveness and energy security. The study [25] examines the clustering method as one of the tools for solving the ecological and economic problems of waste management and the development of energy-independent regions at the expense of renewable energy sources and ecological innovations. The results of the study record the possibility of reducing the energy load on the country's fuel and energy complex and, accordingly, increasing the level of energy security and independence in the future [26]. Additionally, the authors [27] prove the hypothesis, which states that increasing the level of energy efficiency, using alternative energy sources and the strategy of sustainable development regarding energy saving has a positive effect on the level of waste reduction in countries. The basic research [28] also reveals a high correlation between the level of ozone concentration, the reliability and efficiency of the country's energy system and the level of the population's morbidity. According to the results of the study, the scientists [29] emphasize that due to the country's flexible energy efficiency policy, there is an opportunity to reduce carbon dioxide emissions and ozone concentration, which in turn will positively affect the quality of the environment and the health of the population. The authors of [30] proposed a new Air Resource Co-Benefit (ARCoB) model for assessing the comprehensive social benefits of policies to reduce greenhouse gas emissions and change ozone concentrations.

2.3. Energy Efficiency and Economic Determinants

Referring to the authors [31], the share of household expenditures on housing and communal services was also used as an indicator while studying the energy efficiency of the housing stock of Ukraine as a determinant of influence on the level of analyzing dynamics. At the same time, scientists [32] consider the indicator of the share of household expenditures on housing and communal services in the context of adaptive climate changes and increasing the level of energy efficiency. Additionally, in the work [33], the authors draw attention to the relationship between the indicator of the share of household expenditures on housing and communal services and the level of energy efficiency at the level of the region and the country. Based on the study of the green innovations' influence on the level of energy efficiency of the national economy by the authors [34], a number of economic indicators were used in the calculations, one of which is the basis of our research—the current costs of environmental protection. At the same time, the research results [35] show that environmental protection and remediation costs in China have a gradient distribution in which energy efficiency is lower and environmental costs are higher in Western China. It should be noted that there are few studies in the field of the non-energy policy influence on the level of energy efficiency of the country; in particular, the authors [36] found that the minimum wage standard significantly improves the level of energy efficiency of the national economy. Additionally, using statistical analysis with a longitudinal data set, the author [37] proved that the adoption of energy-efficient policies and the strictness of minimum wage legislation are the driving forces for the development of the country's green economy. The authors [38] developed a macroeconomic interdisciplinary model to study the economic consequences of high electricity prices and further increase energy efficiency. Additionally, research [39] demonstrates the correlation dynamics between the prices of electricity and natural gas and the level of energy efficiency of the country's national economy. At the same time, the authors [40,41] believe that the lack of favorable conditions for the large-scale development of renewable energy and the high price of electricity and natural gas are the main obstacles to reducing CO_2 in the country.

2.4. Energy Efficiency and Energy Determinants

Separately, it is necessary to pay attention to research in the field of energy management by scientists [42,43] who have developed conceptual foundations and complex approaches to the development of energy. When studying the relationship between primary energy consumption and real gross domestic product in China, India, Japan and South Korea, the author [44] focuses on the expediency of countries to increase energy efficiency. At the same time, the authors [45] considered the consequences of the country's energy efficiency development process for primary energy consumption and carbon dioxide emissions in detail using both methods of theoretical analysis and applied research. It is appropriate to pay attention to the research [46], which is based on the Divisia logarithmic average index to primary energy consumption methodology to assess progress toward European energy efficiency targets. The article [47] describes the ways of improving and coordinating the existing policy framework to increase the share of renewable energy in final energy consumption as a tool for influencing the level of energy efficiency of the national economy. At the same time, past studies [48,49] prove the statement that the reduction in energy consumption and the decarbonization index influenced the reduction in greenhouse gas emissions, as well as the increase in the intensity of using renewable resources and energy efficiency. The authors [50,51] consider the issue of reducing the coefficient of dependence of energy imports on solid fossil fuels as one of the methods to increase the level of energy efficiency and independence of the country's national economy. The results of the publication [52] are the basis for the development of an energy-efficient and ecological development strategy as a tool for reducing the dependence on fossil fuels. Given the results of the systematization of scientific publications [53,54] and the proposal by the authors regarding the scientific and methodological approaches to assessing the level of energy efficiency of the national economy, it was revealed that the absence of a single unified and generally acceptable toolkit for assessing energy efficiency, which is related to the interdisciplinary nature of the indicator [55], as well as the development vectors of the studied countries.

Considering the above, the paper aims at analysing the convergence of energy policy between the EU and Ukraine, taking into account the key stimulating and disincentive determinants of the energy efficiency of the national economy.

3. Materials and Methods

Based on the papers [56–58] three core dimensions of energy efficiency were considered to calculate integrated indicators of energy efficiency. It was calculated as the arithmetic average of the subindices of the convergent and divergent components of the energy efficiency policy of the national economy by Formula (1). The list of subindices of the convergent and divergent components of the energy efficiency policy is shown in Table 1.

$$I_i^{EE} = \sum_{i=1}^{n} \left(k_i^c, k_i^d \right) / n \quad (1)$$

where k_i^c is the subindex of the convergent component of the i-th year; k_i^d is the subindex of the divergent component of the i-th year and n is the number of sub-indexes.

Table 1. Description of the source data for calculation integrated index of energy efficiency.

Variables	Unit of Measurement	Indicators	Explanations	Source
Environmental subindex				
Ozone concentration	units of Dobson	OCN^d	The indicator, the level of which affects climate change and is an indicator regulated by the European Green Agreement	NationMaster [59]
The amount of waste generated	thousands of tons	VGW^d	Reduction of this indicator is characterized by the introduction of closed cycles in production and efficient use of resources, which meets the requirements of the Sustainable Development Strategy and the European Green Agreement	Ukrstat/Eurostat [60,61]
CO_2 emissions per capita	tons per capita	COE^d	A key indicator, the decline of which is regulated by all development strategies both at the national level and abroad	

Table 1. *Cont.*

Variables	Unit of Measurement	Indicators	Explanations	Source
		Energy subindex		
Primary energy consumption	terawatt hours	PEC^{s}	The level of this indicator characterizes the development of the industry with the growth of economic indicators, such as GDP	World Bank [62]
A share of renewable energy in final energy consumption	in percentages	REC^{s}	One of the key indicators of energy efficiency of the national economy and, accordingly, its growth due to the EU Green Agreement	
Coefficient of dependence of energy imports on solid fossil fuels	in percentages	SEI^{d}	Reduction of this indicator will have a positive impact on the level of energy efficiency of the national economy and increase the potential of energy security of the country	NationMaster [59]
		Economic subindex		
A share of household expenditures on housing and communal services	in percentages	SHE^{d}	According to the main theses of the Sustainable Development Strategy, the population should have access to energy resources at affordable prices, which is regulated by this indicator	Ukrstat/Eurostat [60,61]
Minimum wage	EUR	AWS^{s}	This indicator is one of the key indicators of the country's level of development, which in turn affects the ability of the population to switch to more energy-efficient technologies with a view to improving the environmental situation in the country	
Cost of electricity	eurocents per 1 kW	CEL^{d}	In the long run, these indicators should decrease with the introduction of renewable energy sources	
Price of natural gas	eurocents per 1 m^3	CNG^{d}		
Current costs of environmental protection	millions ofeuros	CCE^{s}	The growth of this indicator characterizes the country's financial capacity to improve environmental conditions and preserve the country's biodiversity, which is regulated by the Sustainable Development Strategy and the European Green Agreement	World Bank [62]

Note: Stimulators—s; destimulators—d.

The object of research is Ukraine and the EU member states (27 countries) from 2000 to 2020. The description and sources are shown in Table 1.

At the same time, 1 is the reference value to which the calculated indicator should strive, and all values less than 0.5 are low.

At the next step, the study applied the σ- i β-convergence theory [63–65]. These methods allow determining the asynchrony and the speed of response of the state energy policy to exogenous and endogenous changes in the national economy. Thus, it was realized by the following steps:

- assessment of σ-convergence of energy efficiency indicators;
- assessment of the β-convergence of energy efficiency indicators;
- distribution of energy efficiency indicators of the national economy according to the concepts of σ- and β-convergence into convergent and divergent.

Similar to the articles [56,58] in the third stage, the σ-convergence of energy efficiency indicators was evaluated according to the formula:

$$\sigma_t^c = (1/n \sum_{i=1}^{n} \left(\ln DEF_{i,t}^c - \ln \overline{DEF_{i,t}^c} \right)^2)^{1/2} \quad (2)$$

where $DEF_{i,t}^c$ is the determinant of the country's energy efficiency in the t-th year and n is the number of countries used to calculate group convergence.

Based on the methodology [58] in the fourth stage, the β-convergence of energy efficiency indicators was evaluated according to the formula:

$$\ln\left(\mathrm{DEF}^{c}_{\mathrm{i,t}}/\mathrm{DEF}^{c}_{\mathrm{i,t-1}}\right) = C + \beta \ln\left(\mathrm{DEF}^{c}_{\mathrm{i,t-1}}\right) + \delta F_{it} + \varepsilon_{it} \quad (3)$$

where C is a constant; $\varepsilon_{\mathrm{it}}$ is a statistical error; F_{it} is the indicator of influence on the level of energy efficiency; β is the speed of convergence.

The limits of the β-convergence distribution are as follows: $\beta > 0$—divergent processes; $\beta \leq 0$—convergent processes.

Thus, during the calculation of σ- and β-convergence, it was concluded that the indicators of the energy efficiency of the national economy according to the concepts of σ- and β-convergence should be divided into divergent and convergent indicators with respect to the EU policy.

It should be noted that all indicators were normalized depending on the direction of their action (Formulas (4) and (5)):

$$y^{s}_{in} = \frac{y_{in} - y_{\mathrm{min}}}{y_{max} - y_{min}} \quad (4)$$

$$y^{d}_{in} = \frac{y_{max} - y_{in}}{y_{max} - y_{min}} \quad (5)$$

where y^{s}_{in} is the determinant of stimulation ($y^{s}_{in} \rightarrow 1$); y^{d}_{in} is the determinant of de-stimulation ($y^{d}_{in} \rightarrow 1$); y_{in} is the array of researched data; y_{min} is the minimum value of the data array and y_{max} is the maximum value of the data array.

The obtained normalized data, which have already been divided into divergent and convergent, form subindices of divergent and convergent energy efficiency policies of the national economy according to Formula (6):

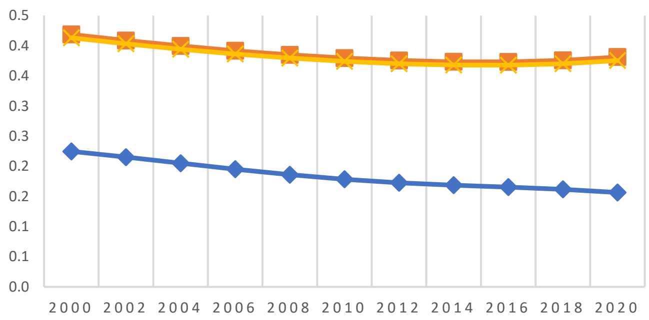
$$\mathrm{k}^{d,c}_{\mathrm{i}} = \frac{\sum^{\mathrm{n}}_{\mathrm{i=1}}\left(y^{s}_{in} + y^{d}_{in}\right)}{\mathrm{n}} \quad (6)$$

where $\mathrm{k}^{d,\,c}_{\mathrm{i}}$ are divergent and convergent subindices, respectively, and n is the number of indicators.

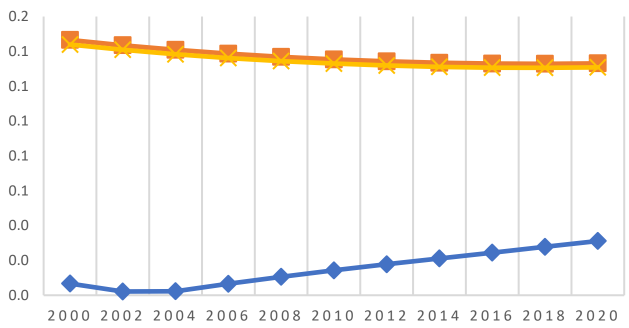
4. Results

4.1. Assessment of σ-Convergence

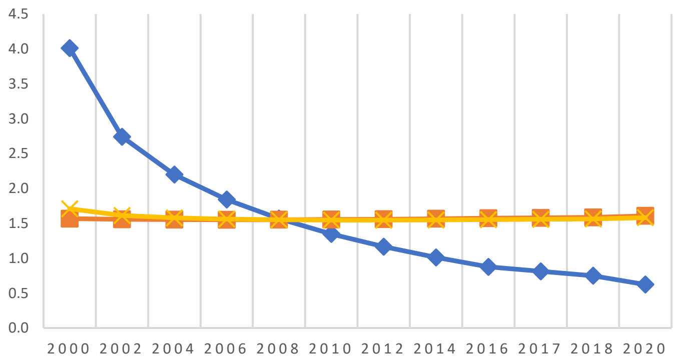
The results of the calculated σ-convergence of energy efficiency indicators by the volume of CO_2 emissions per capita (Figure 1) testify to the divergent policy of Ukraine compared to the policy of EU member states. This is caused primarily by the active introduction of renewable energy sources into the structure of the energy sector by the EU countries, the establishment of strict conditions for the industrial sector to ensure proper (compliant with standards) clean production technologies, and changes in the structure of the transport system, introducing more environmentally friendly electric cars. It is necessary to note a large gap between the indicators of the studied areas and a tendency towards the joint development of this policy regarding the stabilization of the ozone concentration (Figure 1). The results of the calculated σ-convergence of energy efficiency indicators by volume of generated waste from the calculations shown in Figure 1 testify to the formation of a convergent policy of Ukraine by the EU member states. Nevertheless, there are certain concerns about the change to a divergent direction, but this is possible only if Ukraine is not interested in the development of the economy of closed production cycles, as well as the regulation of the amount of generated waste according to current international standards. Ukraine is primarily interested in revising the policy on the regulation and transformation of generated waste, which will positively affect the level of energy efficiency [66–68] of the national economy.



(**a**)



(**b**)



(**c**)

Figure 1. Visualization of energy efficiency ecological indicators σ-convergence assessment. Note: (**a**) in terms of CO_2 emissions per capita; (**b**) by ozone concentration; (**c**) by the amount of waste generated. The ordinate axis is units; abscissa—years; blue line—Ukraine, orange line—EU countries, yellow line—Ukraine and EU countries.

According to the calculations of the assessment of the σ-convergence of energy efficiency indicators according to the minimum wage (Figure 2), it is possible to draw a conclusion about the divergent policy of Ukraine compared to the policy of the EU member states. Ukraine has the lowest minimum wage among the EU countries, while the increase in the studied indicator is irregular and insignificant, which cannot be said about the EU countries.

The findings allow (Figure 2) to conclude that the policy on the current costs of environmental protection has a divergent character. This is caused primarily by the financial inability to allocate funds for environmental protection in the appropriate amount, as well as by a developed bureaucratic and corrupt mechanism that blocks the effective activity of providing environmental protection with monetary support [69].

Taking into account the calculations of the assessment of σ-convergence of energy efficiency indicators by the cost of electricity and natural gas (Figure 2), we can draw a conclusion about Ukraine's divergent policy compared to the EU countries. The main reason for divergent policies is the diversity of policies in the process of pricing energy resources. In particular, the position of the EU is that the increase in the price of energy carriers is caused by their production from the maximum possible renewable energy, which cannot be cheap, and the non-recognition of subsidization because it is an irrational approach to energy-efficient saving. At the same time, the main topic in Ukraine is the reduction in the cost of communal services and the expansion of subsidies, which are the reasons for the inefficient use of energy and irrational use of funds.

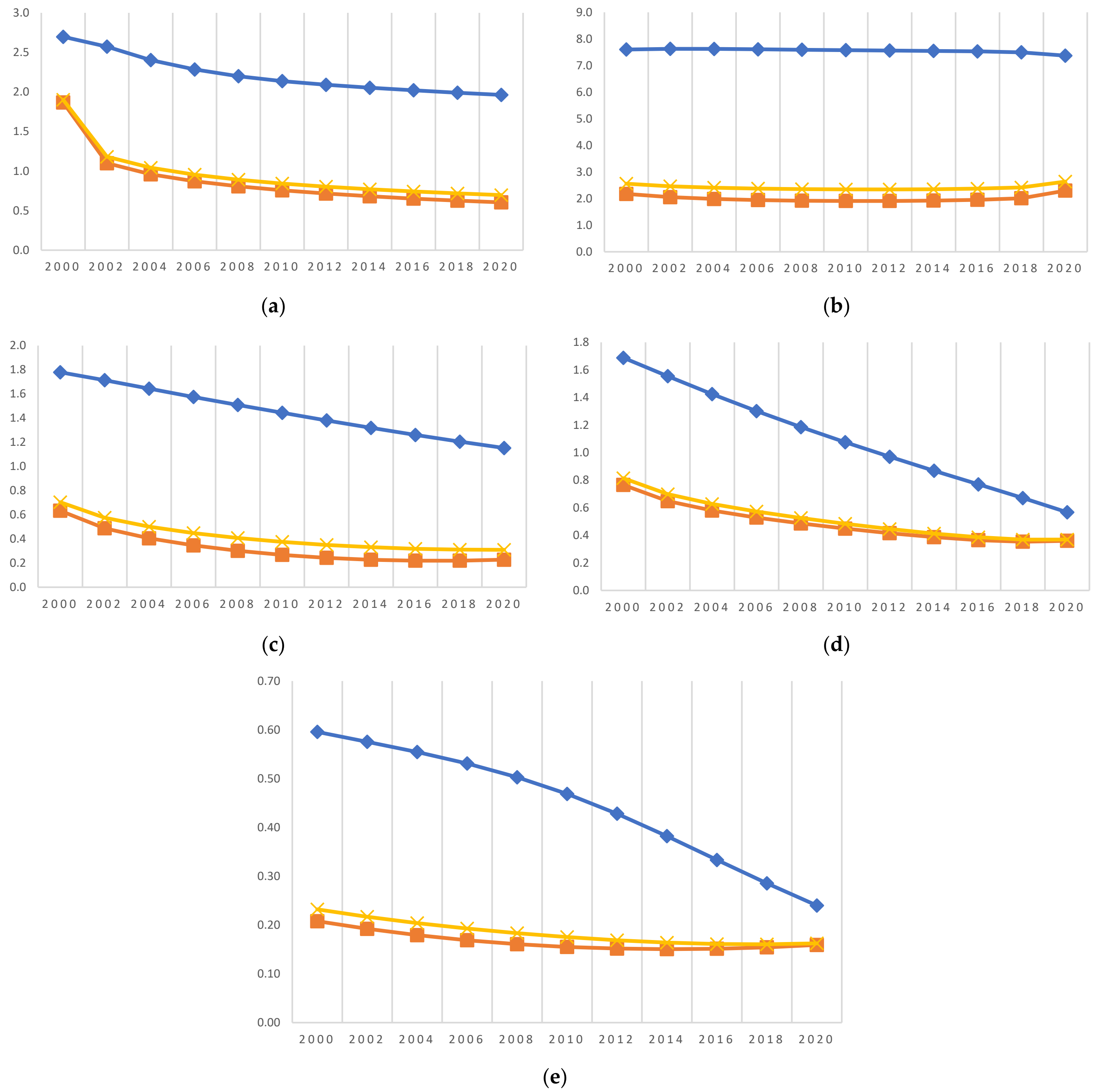


Figure 2. Visualization of energy efficiency economic indicators σ-convergence assessment. Note: (**a**) at the minimum wage; (**b**) current expenditures on environmental protection; (**c**) at the cost of electricity; (**d**) at the cost of natural gas; (**e**) by the share of household expenditures on housing and utilities; The ordinate axis is units; abscissa—years; blue line—Ukraine, orange line—EU countries, yellow line—Ukraine and EU countries.

Based on the results of the calculations of the σ-convergence of energy efficiency indicators by the share of household expenses for housing and communal services (Figure 3), it can be concluded that the policy of Ukraine is convergent with the policy of the EU member states.

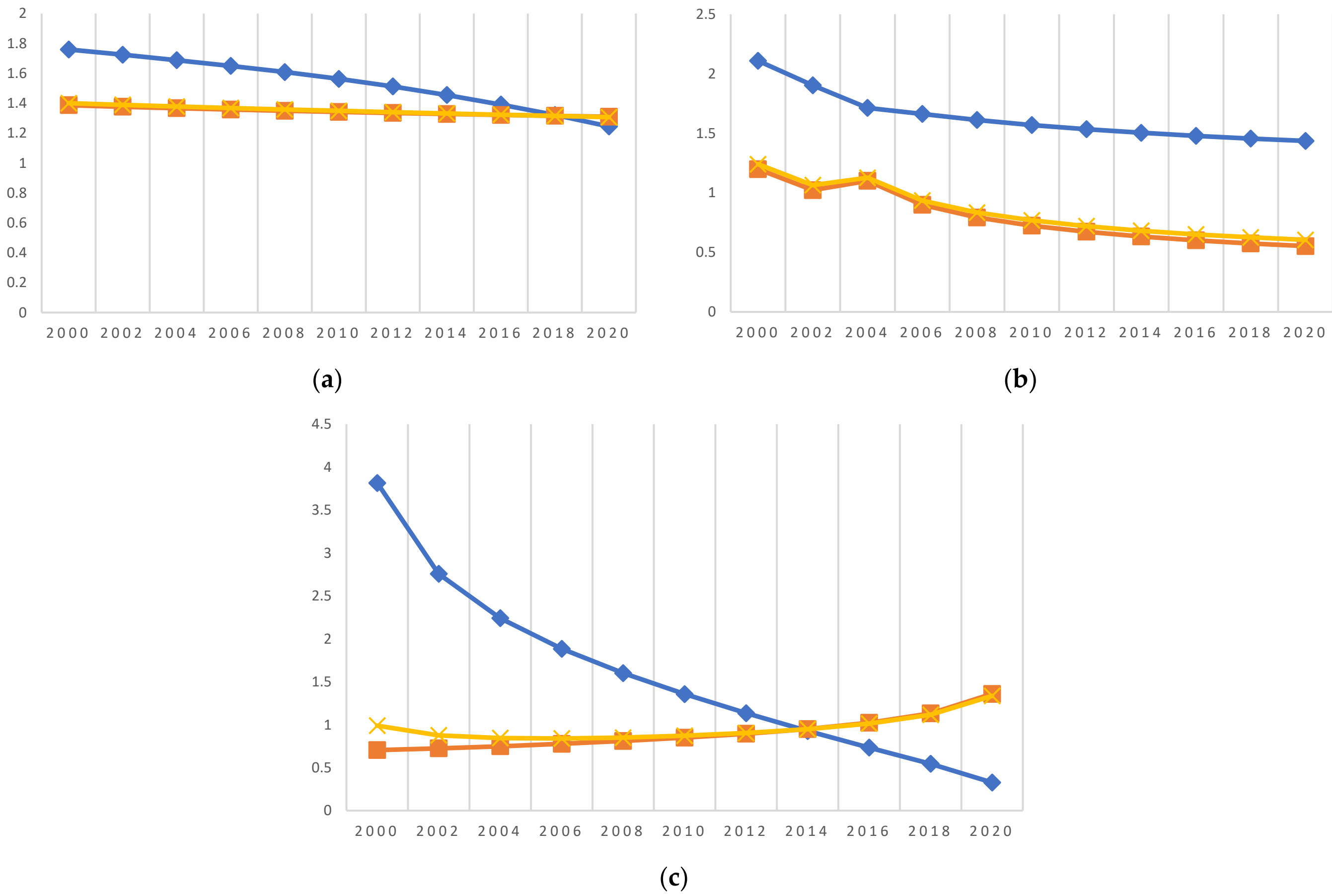


Figure 3. Visualization of energy efficiency energy indicators σ-convergence assessment. Note: (**a**) by primary energy consumption; (**b**) by the share of renewable energy in final consumption; (**c**) by the coefficient of dependence of energy imports on solid fossil fuels; blue line—Ukraine, orange line—EU countries, yellow line—Ukraine and EU countries.

According to the calculations of the assessment of σ-convergence of energy efficiency indicators by primary energy consumption and the share of renewable energy in final consumption (Figure 3), it is possible to draw a conclusion about the convergent policy of Ukraine compared to the EU countries. This is primarily due to the continuation of the EU decarbonization policy and the increase in the specific weight of renewable energy sources in the structure of the energy sector of Ukraine [70,71].

Based on the results of the calculations of σ-convergence of energy efficiency indicators based on the coefficient of dependence of energy import on solid fossil fuels (Figure 3), it is possible to conclude the divergent policy of Ukraine compared to the EU countries. The main reasons for this situation today are the political situation in the temporarily occupied territories of Ukraine, which affected the level of providing the country with its own fossil fuel, and the weak policy of decarbonization of the economy, which does not stimulate the rapid development of alternative energy sources in the energy sector system.

4.2. β-Convergence

The calculation of the value of the absolute β-convergence (Tables 2–4), made it possible to identify a number of indicators that influence the level of energy efficiency and the relationships between the rate of change of indicators and their initial values for the entire array of information by country, and which is the most statistically significant. The results of the calculations (Table 2) made it possible to note that Ukraine has its own vector of development in the sphere of reducing CO_2 emissions, unlike the EU member states which are coherent with the studies [72–74]. At the same time, the value of GDP per capita and the globalization index has a high statistical significance and influence on the policy of countries regarding the reduction in CO_2 emissions. Simultaneously, the results of the calculation assessing β-convergence of energy efficiency indicators by ozone concentration indicate a common (convergent) direction of development. The high statistical significance of the obtained results should be noted.

Table 2. The results of the calculation assessing β-convergence of energy efficiency indicators in the environmental sphere.

	Ukraine and the EU Member Countries			The EU Member Countries		
Variable	**Coef.**	**Std. Err.**	$p > \|t\|$	**Coef.**	**Std. Err.**	$p > \|t\|$
COE	0.0067444	0.0008814	0.000	0.0072551	0.0008841	0.000
F1	-1.56×10^{-7}	3.15×10^{-7}	0.000	-1.85×10^{-7}	3.20×10^{-8}	0.000
F2	3.44×10^{-6}	5.28×10^{-6}	0.514	5.21×10^{-6}	5.27×10^{-6}	0.324
F3	−0.0004557	0.0000595	0.000	−0.0005008	0.0000608	0.000
OCN	−0.0000515	0.0002505	0.007	0.0000271	0.0002554	0.005
F1	5.54×10^{-9}	3.33×10^{-9}	0.097	6.17×10^{-9}	3.43×10^{-9}	0.072
F2	1.71×10^{-6}	6.21×10^{-7}	0.006	1.66×10^{-6}	6.30×10^{-7}	0.009
F3	0.0000597	7.15×10^{-6}	0.000	0.0000645	7.46×10^{-6}	0.000
VGW	−0.0009668	0.0002807	0.001	−0.0004391	0.0001422	0.002
F1	9.66×10^{-8}	3.38×10^{-7}	0.004	1.14×10^{-7}	1.73×10^{-7}	0.000
F2	−0.0000284	7.38×10^{-6}	0.000	−0.0000243	3.73×10^{-6}	0.000
F3	−0.0002588	0.0000746	0.001	−0.0000422	0.0000384	0.272

Note: COE—emissions CO_2; OCN—ozone concentration; VGW—the amount of waste generated; F1—GDP per capita; F2—trade openness index; F3—globalization index.

Table 3. The results of the calculation assessing β-convergence of energy efficiency indicators in the economic sphere.

	Ukraine and the EU Member Countries			The EU Member Countries		
Variable	**Coef.**	**Std. Err.**	$p > \|t\|$	**Coef.**	**Std. Err.**	$p > \|t\|$
AWS	−0.0748172	0.0076215	0.000	0.0804651	0.0078424	0.000
F1	-3.10×10^{-6}	5.12×10^{-7}	0.000	-3.16×10^{-6}	5.20×10^{-7}	0.000
F2	0.0002316	0.0000832	0.006	0.0002314	0.0000839	0.006
F3	−0.0044312	0.0010716	0.000	−0.0041382	0.001089	0.000
CCE	0.0106225	0.0010957	0.000	0.0058254	0.0013096	0.000
F1	6.48×10^{-8}	1.84×10^{-7}	0.724	1.58×10^{-7}	1.80×10^{-7}	0.379
F2	0.0001565	0.0000374	0.000	0.0000877	0.000038	0.021
F3	−0.0027164	0.0004119	0.000	−0.0023974	0.0004166	0.000
CEL	0.0192067	0.000854	0.000	0.0242908	0.0009609	0.000
F1	-3.06×10^{-7}	3.50×10^{-8}	0.000	-2.85×10^{-7}	3.33×10^{-8}	0.000
F2	0.0000234	6.46×10^{-6}	0.000	0.0000194	6.10×10^{-6}	0.002
F3	−0.0001273	0.0000753	0.091	−0.0000977	0.0000716	0.173
CNG	0.1097298	0.084919	0.097	−0.1230202	0.0905341	0.175
F1	-6.07×10^{-7}	4.34×10^{-6}	0.889	-7.28×10^{-7}	4.47×10^{-6}	0.871
F2	0.0004302	0.0008171	0.599	0.0004201	0.0008339	0.615
F3	0.0027709	0.0089511	0.757	0.0020991	0.0093136	0.822
SHE	0.0074535	0.0008075	0.000	−0.0055212	0.0008675	0.000
F1	7.30×10^{-8}	1.48×10^{-8}	0.000	9.58×10^{-8}	1.48×10^{-8}	0.000
F2	−0.0000267	2.79×10^{-6}	0.000	−0.0000296	2.75×10^{-6}	0.000
F3	−0.0001438	0.0000322	0.000	−0.0001523	0.0000317	0.000

Note: AWS—minimum wage; CCE—environmental protection costs; CEL—the cost of electricity; CNG—the cost of gas; SHE—share of household expenditures on housing and utilities; F1—GDP per capita; F2—trade openness index; F3—globalization index.

Table 4. The results of the calculation assessing β-convergence of energy efficiency indicators in the energy sector.

	Ukraine and the EU Member Countries			The EU Member Countries		
Variable	**Coef.**	**Std. Err.**	***p* > |t|**	**Coef.**	**Std. Err.**	***p* > |t|**
PEC	−0.0002893	0.0000964	0.003	0.0000897	0.000104	0.389
F1	-1.05×10^{-8}	9.95×10^{-9}	0.290	-2.78×10^{-8}	9.70×10^{-9}	0.004
F2	0.000013	2.23×10^{-6}	0.000	0.0000192	2.25×10^{-6}	0.000
F3	−0.0000272	0.0000219	0.214	−0.0000765	0.0000224	0.001
REC	−0.0040503	0.0011173	0.000	−0.0041818	0.0011596	0.000
F1	-8.61×10^{-7}	1.27×10^{-6}	0.499	-1.07×10^{-6}	1.32×10^{-6}	0.417
F2	0.0002792	0.000244	0.253	0.0002878	0.0002486	0.247
F3	0.0015166	0.0027075	0.576	0.0017635	0.0028193	0.532
SEI	0.0001926	0.0005106	0.706	−0.0006947	0.000458	0.130
F1	-9.58×10^{-7}	1.77×10^{-6}	0.589	-2.73×10^{-7}	1.58×10^{-6}	0.863
F2	0.0002556	0.0003142	0.416	0.0002183	0.0002778	0.432
F3	0.0008748	0.0035393	0.805	0.0034231	0.0032054	0.286

Note: PEC—the amount of primary energy consumption; REC—the share of renewable energy in final consumption; SEI—coefficient of import dependence on fossil fuels; F1—GDP per capita; F2—trade openness index; F3—globalization index.

According to the results of the study (Table 2), a convergent process can be observed in Ukraine compared to the EU countries in the direction of reducing the amount of waste and reforming the processing industry as one of the ways to increase energy efficiency. The results of the calculations (Table 2) made it possible to note that Ukraine has a convergent vector of development with the EU countries. At the same time, among the EU member states, there are countries with divergent directions of development in the field of waste generation and waste management.

The results of the calculation of the β-convergence assessment (Table 3) of energy efficiency indicators by the volume of environmental protection expenditures made it possible to identify a divergent vector of Ukraine compared to the EU policy, which is confirmed by high indicators of statistical significance. According to the results of the study (Table 3), divergent processes are observed in Ukraine compared to EU countries in the direction of the formation of the cost of electricity. According to the results of the calculation assessing the β-convergence of energy efficiency indicators according to the cost of gas, the multivector (divergence) of the policies of Ukraine and the EU countries was revealed. According to the results of the calculation, conclusions were drawn regarding the joint policy of Ukraine and the EU in the direction of reducing the specific weight of costs for housing and communal services through an effective energy policy.

The results of the calculation assessing β-convergence of energy efficiency indicators (Table 4) indicate convergent trends in primary energy consumption both in Ukraine and the EU countries. Taking into account the results of the calculation assessing the β-convergence of energy efficiency indicators by the share of renewable energy in final consumption, a convergent policy between Ukraine and the EU was revealed. The results of the calculation assessing β-convergence of energy efficiency indicators based on the coefficient of import dependence on fossil fuels revealed divergent directions between the energy policy of Ukraine and the EU countries.

4.3. Integrated Energy Efficiency Index

In view of the preliminary calculations in the above subsections, it is relevant to adjust the target values of the specified indicators and reduce them to subindices of convergent and divergent policies of the state in the field of energy efficiency and the calculation of an integral indicator of energy efficiency, which would aim to reflect the country's energy efficiency level compared to the EU countries.

To calculate the integral index of the energy efficiency of the national economy, it is necessary to normalize the data (Formulas (5) and (6)). Appropriate calculations depend on the nature of the indicator and how it will affect the integral index. That is, as noted in the description of the research methodology, at the first stage, indicators were grouped by groups of stimulators and destimulators of the level of energy efficiency of the national economy. Step-by-step calculations of the subindices of the convergent and divergent components (Formula 7) of the integral index of energy efficiency of the national economy for Ukraine and the EU member states are shown in the figures of Figures A1 and A2. The study considers 1 to be the target value of the subindices. Taking this into account, we can conclude that in the joint policy of increasing the energy efficiency of the national economy, Ukraine has quite high results. Sweden (0.77), Denmark (0.76), and Slovenia (0.72) can be identified as reference countries for 2020.

Figure A1 shows a graphical interpretation of the dynamics of changes in the subindex of the convergent component of the integral index of energy efficiency of the national economy over the five-year period from 2000 to 2020. The graphic representation of the results calculating the subindex of the convergent component for Ukraine makes it possible to note that the policy of convergence in the direction of energy efficiency is losing its ability to positively influence the level of the subindex—this is explained by the gradual decrease in the value of the subindex of the convergent component. In view of this, one of the priority issues for Ukraine is the regulation and direction of actions to control the ozone concentration, the amount of generated waste and its effective processing, the solvency of the population and social protection of citizens, and the specific weight of renewable energy in final energy consumption.

Considering that the maximum value of the subindex is 1, and after analyzing the obtained calculations, we can conclude that in the sphere of EU divergent policy, Ukraine has rather unsatisfactory results. The most effective energy efficiency indicators of the national economy function are in Sweden (0.64), Lithuania (0.57) and Estonia (0.56). According to the figures in Figures A1 and A2, it can be seen that there is an insignificant decrease in the value of the subindex of the divergent component of Ukraine for 2020, which has a negative impact on the level of the integral index of energy efficiency of the national economy. In particular, Ukraine needs to quickly respond to divergent processes and form new policy vectors in the economic, environmental and energy spheres.

It is necessary to note that the main indicators of energy efficiency, taking into account the estimated data that inhibit the development of the energy efficiency of the national economy:

- coefficient of dependence of energy imports on fossil fuels—the country needs to develop renewable energy and its own fossil fuel deposits to ensure an appropriate level of energy independence, which will positively affect the level of energy efficiency of the national economy [2,5,15,20];
- minimum wage—increasing the level of social welfare in the country should be one of the most important goals for the state because a society that receives an adequate level of income and does not live on the edge of poverty is able to invest in the development of its own energy independence and environmental security [2,32,56,75,76].

As a result of the calculation of the integral energy efficiency index of the national economy of Ukraine and the EU countries, it can be singled out that there are several countries with a high level of energy efficiency of the national economy in accordance with the established limits (Table 5)—Sweden (0.77) and Denmark (0.76). At the same time, other countries are within the average level of energy efficiency of the national economy, but with positive dynamics of increasing the indicator.

Table 5. Results of the calculation of the integrated energy efficiency index of the national economy of Ukraine and the EU, 2000–2020.

Country	**Years**					
	2000	**2004**	**2008**	**2012**	**2016**	**2020**
Ukraine	0.74	0.74	0.73	0.73	0.73	0.72
Austria	0.65	0.63	0.64	0.65	0.67	0.66
Belgium	0.57	0.56	0.57	0.6	0.6	0.62
Bulgaria	0.67	0.66	0.66	0.68	0.69	0.7
Greece	0.67	0.68	0.69	0.71	0.7	0.69
Denmark	0.7	0.7	0.71	0.74	0.77	0.76
Estonia	0.56	0.6	0.57	0.54	0.6	0.61
Ireland	0.55	0.58	0.61	0.64	0.65	0.64
Spain	0.56	0.56	0.56	0.57	0.57	0.66
Italy	0.54	0.55	0.55	0.58	0.59	0.62
Cyprus	0.7	0.72	0.7	0.72	0.8	0.72
Latvia	0.63	0.62	0.63	0.64	0.66	0.67
Lithuania	0.73	0.71	0.69	0.68	0.67	0.66
Luxembourg	0.6	0.56	0.6	0.63	0.67	0.67
Malta	0.62	0.63	0.63	0.64	0.68	0.67
Netherlands	0.68	0.66	0.65	0.66	0.65	0.64
Germany	0.56	0.55	0.54	0.53	0.52	0.51
Poland	0.39	0.42	0.44	0.46	0.49	0.5
Portugal	0.6	0.62	0.64	0.65	0.64	0.67
Romania	0.72	0.7	0.7	0.7	0.7	0.71
Slovakia	0.61	0.61	0.62	0.63	0.62	0.65
Slovenia	0.64	0.65	0.65	0.69	0.7	0.72
Hungary	0.64	0.65	0.66	0.68	0.7	0.71
Finland	0.66	0.63	0.65	0.67	0.68	0.68
France	0.66	0.65	0.63	0.63	0.63	0.61
Croatia	0.66	0.66	0.66	0.66	0.68	0.69
Czech Republic	0.67	0.66	0.66	0.65	0.64	0.65
Sweden	0.63	0.65	0.68	0.72	0.72	0.77

Empirical calculations proved that from 2000 to 2020, Ukraine had an average level of the integrated energy efficiency index of the national economy; the highest value of this index was in 2008 (0.628), and its sharp decrease was recorded in the period 2014–2016. This can be explained by the fact that there was an aggravation of military-political conflicts in Ukraine, which significantly slowed down the process of transition of the national economy from an export-raw material to a resource-innovation model, as well as structural reforms in the direction of ensuring a green structure of energy consumption. The ratification of the European directives on energy efficiency and the updating of national programs and strategies for the development of the energy sector of the national economy based on them ensured a gradual increase in the level of the integrated index of energy efficiency in Ukraine since 2016.

5. Conclusions and Discussion

The results of the analysis of the theoretical landscape of energy efficiency assessment show that the scientific community has not accepted the universal approach for that. Thus, this study developed an approach to estimate the energy efficiency of the country based on the σ- i β-convergence theory. This approach allows for identifying the convergent and divergent policies on the promotion of energy efficiency for Ukraine and EU countries. Besides, the developed approach allows considering the volatility of convergent and divergent determinants, synchrony and the speed of response of the state policies on energy efficiency.

The results of the σ- and β-convergence calculation show that the growth of the mean square deviation of the logarithms of environmental, economic and energy parameters confirm the asynchrony of national and European energy policies Empirical calculations showed that in the period of 2000–2020, Ukraine had an average level of the integrated energy efficiency index of the national economy; the highest value of this index was in 2008 (0.628), and its sharp decrease was recorded in the period 2014–2016, which is explained by the aggravation of military and political conflicts in Ukraine. These events significantly slowed down the process of the national economy transition from the export-raw material to the resource-innovation model, as well as structural reforms in the direction of ensuring a green structure of energy consumption. It should be noted that similar results were obtained by scientists in works [58,75,76]. At the same time, the scientists [12,57] obtained opposite results based on the results of the calculation of the index of total-factor energy efficiency. Ratification of the European directives on energy efficiency and updating on their basis national programs and strategies for the development of the energy sector of the national economy ensured a gradual increase in the level of the integrated energy efficiency index in Ukraine since 2016. It is appropriate to note that, according to the results of the calculations, Denmark and Sweden are the leaders in terms of the level and dynamics of the integrated energy efficiency index. At the same time, countries such as Slovenia, Latvia, Bulgaria, Poland and others have all the opportunities and potential, taking into account the positive dynamics of the index, to develop the level of energy efficiency and increase their own energy security of the national economy in the current conditions.

Considering the empirical findings, Ukraine as a potential candidate for the EU should actively provide investigations on renewable energy and extend them among the households. Besides, in this case, green finance plays a core role in spreading renewable energy [77,78]. Ukraine has already started to reform the energy sector and relative legislation base. However, it is necessary to provide transparency and affordability of available windows for attracting green investment in green energy. In addition, the government should continue to provide green incentives such as green credits, feed-in tariffs, green taxes, etc. [77,78]. Furthermore, it is necessary to provide relevant education policies to enhance green knowledge and innovations [79,80].

It should be noted that this study has a few limitations which could be the window for future investigation. The prior study [51] shows that oil supply risk statistically significantly affects the country's energy security. At the same, time scholars [81] prove the necessity to incorporate the innovations under the assessment of the energy efficiency of the country. Besides, the efficiency of the country's government [82–85] could affect energy efficiency which justifies the necessity to incorporate this in future investigations.

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Appendix A

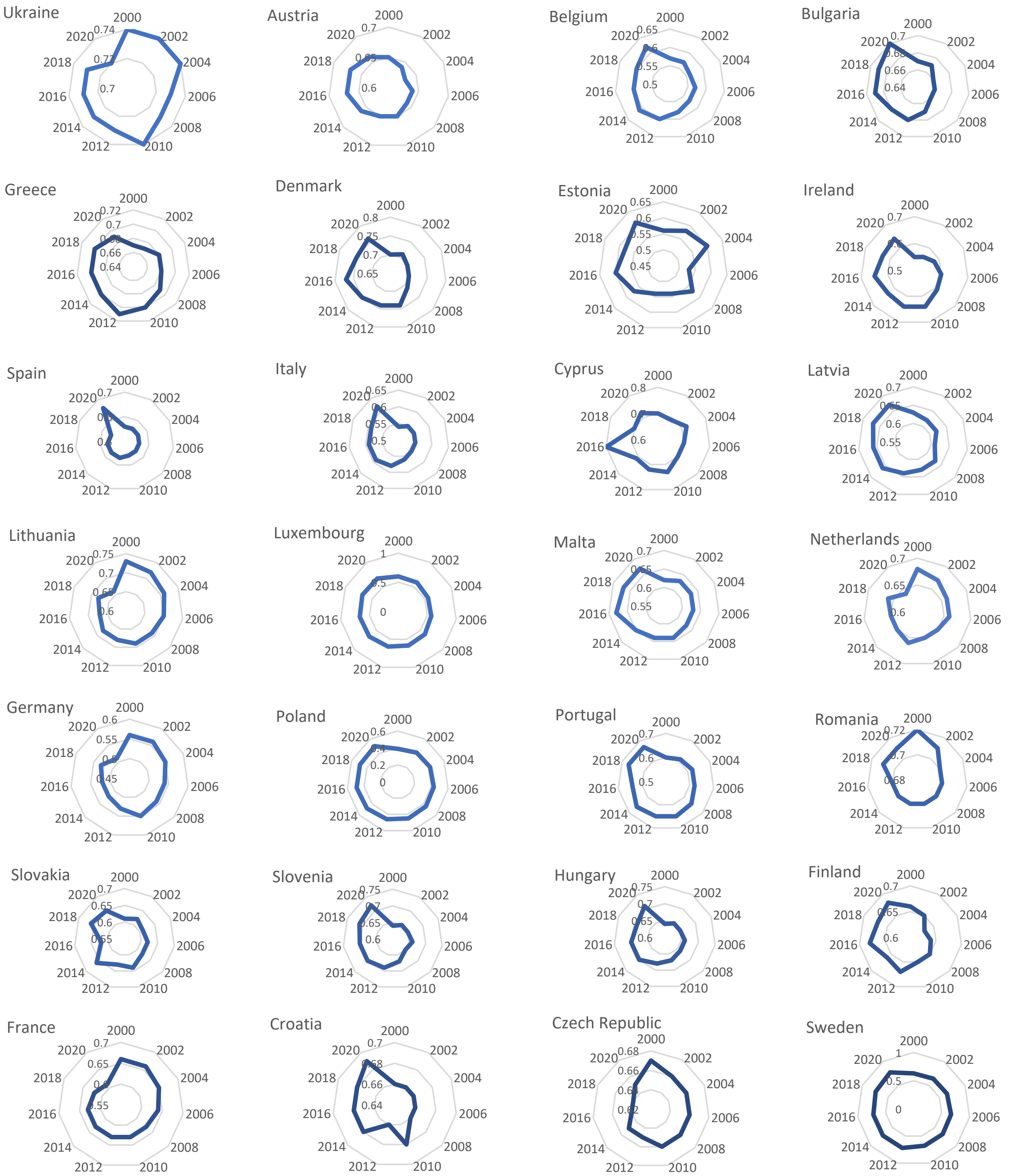

Figure A1. Results of calculating subindices of the convergent component of Ukraine and the EU countries, 2000–2020.

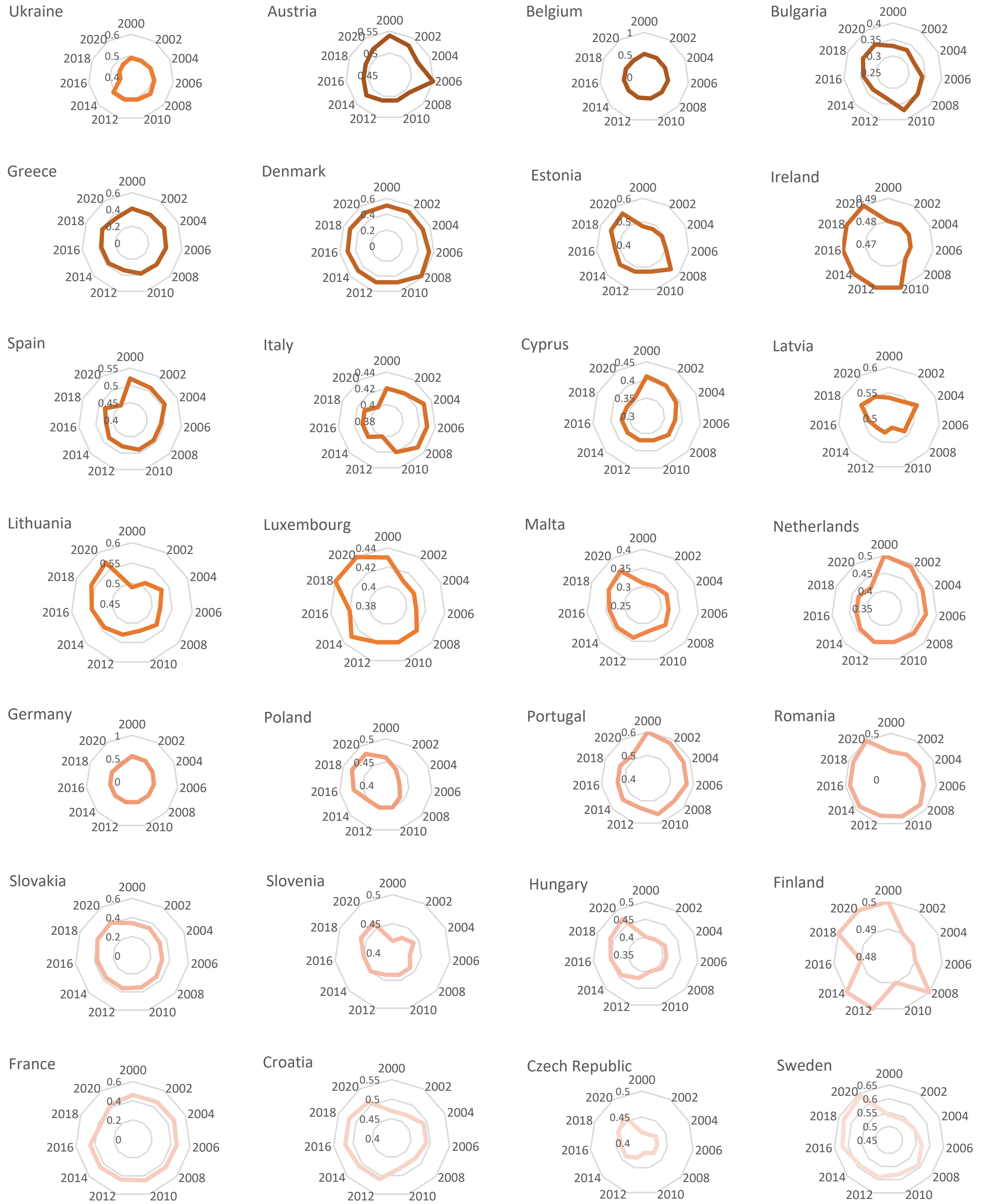

Figure A2. Results of calculating subindices of the divergent component of Ukraine and the EU countries, 2000–2020.

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