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Environmental Determinants of a Country's Food Security in Short-Term and Long-Term Perspectives

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Abstract: About 10% of the world population suffered from hunger in 2018. Thereby, the main objective of this research is the identification of environmental drivers and inhibitors of a country's food security in the short and long run. The Food Security Index (FSI) was constructed from 19 indicators using Principal Component Analysis. Identification of the short- and long-run relationships between the FSI and environmental factors was realized with the pooled mean-group estimator for 28 post-socialistic countries for 2000–2016. Empirical research results showed that a country's food security in the short run is affected by greenhouse gas emissions but boosted by the increase of renewable energy production. Reduction of carbon dioxide emissions, electrification of rural populations, access to clean fuels, renewable energy production, arable land, and forest area growth might be essential tasks in order to ensure countries' food security in the long-run.

Keywords: food security; food availability; food access; food stability; food utilization; environmental determinants; sustainable development

1. Introduction

Global economic development at the end of the XX century led to the boosting of industrial and technological development. However, these processes also triggered numerous destructive trends, especially for the environment. In turn, the scale of the environmental problems needed cooperation of the global community to solve them, so the Agenda 21 and, recently, the Millennium Development Goals were developed in order to coordinate the efforts of different countries on the way to elimination of global damages and implementation of sustainable development. At the Millennium Summit in 2000, eight Millennium Development Goals were developed, aimed at poverty, hunger and child mortality reduction, decrease of different diseases, expansion of education, banning of gender inequality, triggering of cooperation of local community, and promotion of sustainable environment development. All of these goals have quantitative measures that needed to be achieved in order to fulfill the goals. Global community cooperation during the last decades allowed the partial fulfilment of these goals. Nevertheless, considering such achievements and newly appeared damages in 2015 at the United Nations General Assembly, the 17 Sustainable Development Goals by 2030 were introduced [1]. It is worth noting that most of the Sustainable Development Goals focus on food security or environmental issues that clarify their urgency and importance both at national (local) and supranational levels.

Elimination of hunger and different forms of malnutrition in order to overcome food insecurity continues to be an urgent global task because of the insufficient economic growth dynamics in different countries, climate change, existence of war conflicts and political instability zones, etc. Namely, according to the Food and Agriculture Organization of the United Nations (FAO) report [2] in 2000, there were 792 million people in 98 countries who met food insecurity problems, while, in 2018 [3], more than 820 million people were still suffering from hunger. Such a situation proves the extreme urgency of the need for the global community's cooperation in order to fulfill the Zero Hunger goal by 2030. Moreover, it is also essential to continue scientific research aiming at clarification of factors strengthening or worsening country food security. That might help to develop a more well thought out and scientifically grounded economic policy at both national and supranational levels.

Particularly, according to the FAO [4], nowadays, "food security exists when all people, at all times, have physical and economic access to sufficient, safe, and nutritious food that meets their dietary needs and food preferences for an active and healthy life". Moreover, in terms of the FAO approach, food security has four dimensions, namely food availability, food access, food stability, and food utilization. Food availability is about physical existence of foodstuffs of appropriate quality that might be supplied to the population. Food access characterizes the possibility of getting food considering legal, political, economic, and social conditions. Food utilization illustrates rationality and effectiveness of consumption, sanitation, and water access conditions. Food stability is about ensuring foodstuff provision at any time range, even in cases of insufficient economic situations or realization of some other risks [4]. As it becomes evident from the essence of the food security perspectives, some of them mostly dependent on economic conditions, but the majority of pillars are reliant on environmental preconditions. Consequently, environmental determinants play a crucial role in foodstuff production, distribution, and the quality of its consumption. However, the functioning of food-producing enterprises is quite often (especially in developing countries) accompanied by numerous adverse environmental effects (air pollution, soil degradation, elimination of certain species of flora and fauna, reduction of forest area, greenhouse gas emissions increase, etc.). On the contrary, spurring environmental problems would likely lead to an increase in food insecurity and disruption of sustainability of the national economy.

It should be noted that there is plenty of research that specifies the influence of social, economic, and environmental factors on a country's food security as a whole and on its perspectives separately, but they sometimes contradict each other. In addition, different groups of scientists focused on various environmental aspects and food security pillars, so it might be hard to see the situation comprehensively. Therefore, from both theoretical and empirical points of view, it is crucial to identify the impact of environmental (ecological) factors on a country's food security in the short-run and long-run perspectives using up-to-date data and scientific approaches. Specifically, this research aimed at clarifying several important issues:

(1) Identification of the relevant environmental factors that influence a country's food security (we used to think that some environmental problems might damage foodstuff production, distribution, and consumption value, but the existence of contradictory empirical research results about such an impact reveals the necessity of further theoretical and empirical findings in this direction);
(2) Comprehensiveness: As a rule, empirical research is narrow and focused on the clarification of influence of some certain environmental determinant on a country's food security or its pillars; however, we try to consider the vast majority of potential environmental factors mentioned in previous empirical research; this approach might be useful from the regulatory perspective because it could help to identify the priorities of environmental, economic, and social government policy (to some extent);
(3) Clarification of the short- and long-run impacts of environmental factors on a country's food security (basically, most of the empirical research is based on classical regression analysis and aimed at confirmation or rejection of some empirical hypothesis, but it should be taking into

consideration that environmental factors likely have no immediate influence on a country's food security; thus, it is by far more valuable to clarify this impact in different time perspectives).

Moreover, the food security concept originated in 1974 during the World Food Conference, but gained its modern features in 1996 at the World Food Summit [4]. Despite the conceptual clarification from the mid-1990s of the XX century, the possibility of tracking countries' progress in terms of food security appeared only in 2012 with the launching of the Global Food Security Index. Thus, there is no considerable amount of similar research results aimed at testing the influence of the environmental factors on a proxy of countries' food security, especially in different time perspectives.

Consequently, this research might have significant theoretical and empirical value both in terms of development of countries' environmental and food security policies and tracking of changes the environmental determinants of countries' food security.

2. Literature Review

In order to fulfill the task of comprehensiveness of the research, it is necessary to generalize potential environmental determinants influencing a country's food security (alternatively, foodstuff production, agribusiness performance, etc.) that were previously mentioned by scientists. Basically, some theoretical and empirical findings confirm the hypothesis about social, economic, or environmental factors' impacts on countries' food security as a whole or its particular perspective.

It should be noted that there is a set of scientific research that, in general terms, supports the hypothesis about the influence of environmental factors on a country's food security or its proxies. Namely, Musová, Musa, and Ludhova [5], Dwikuncoro and Ratajczak [6], and Vasa [7] researched factors influencing food purchasing (food utilization) in the Slovak Republic, Poland, and Hungary. They found out that consumer behavior is mostly driven by economic factors (quality and prices of products, household income). However, environmental factors also matter—69% of respondents mentioned that they prefer environmentally friendly goods. Moreover, Jakubowska and Radzymińska [8] found out that Czech students, who participated in the research, declare environmental motives as dominant in their consumer choices. Dabija, Bejan, and Dinu [9] also identified that consumers of Generation Z prefer green suppliers. In turn, Gadeikienė, Dovalienė, Grase, and Banytė [10], Arslan [11], Olasiuk and Bhardwaj [12], and Ahmad [13] reveal that environmental preconditions and comprehensive nutrition knowledge play an important role in ensuring sustainable consumption. Thus, this group of scientists supports the idea that environmental image and responsibility are impactful for food consumption (food utilization proxy of a country's food security).

In terms of discussing the impact of environmental determinants on the performance of food producers and foodstuff trade, i.e., food availability and partial food access, Morkūnas, Volkov, and Pazienza [14], Morkūnas et al. [15], and Tomchuk et al. [16] mentioned that economic and environmental factors have an impact for resilience of agricultural enterprises. Similarly, Handayani, Wahyudi, and Suharnomo [17], Mikhaylova et al. [18], Akhtar [19], Kheyfets and Chernova [20], Stjepanović, Tomić, and Škare [21], Cismas et al. [22], Jayasundera [23], and Harold [24] proved that green innovations positively influence business performance, sustainability of agriculture, and food security. Haninun, Lindrianasari, and Denziana [25] mentioned that environmental performance has an effect on financial performance. Ortikov, Smutka, and Benešován [26] reveal that increase of innovativeness and eco-friendliness might be among essential preconditions of an increase of competitiveness of Uzbekistan's agrarian foreign trade. However, Shuquan [27] empirically proved the existence of the relationship between international trade and countries' environmental performance (case of China). In turn, Smutka, Maitah, and Svatoš [28], Falkowski [29], and Kadochnikov and Fedyunina [30] pointed out that, in the case of Russian foodstuff imports, not environmental, but economic and political factors matter. However, in the case of Russia's exports to EU countries, political and environmental determinants play a more significant role. This block of research supports the idea that eco-friendliness and environmental responsibility are not just influencing consumers' motives, but also argue that agricultural enterprises are also driven by environmental motives. Nevertheless, these researches also allow us to conclude that environmental factors play a prior role in foodstuff trade in developed countries, but a secondary role in developing countries.

The third set of researches is mainly focused on clarification of state regulations' influence on a country's food security. In turn, Krajnakova, Navickas, and Kontautiene [31] mentioned that environmental regulation might be a trigger of a country's competitiveness and sustainability. Similarly, Grenčíková et al. [32], Bilan et al. [33–36], Lyulyov et al. [37], Akhmadeev et al. [38], Bhandari [39], Bello, Galadima, and Jibrin [40], Sokolenko, Tiutiunyk, and Leus [41], Lizińska, Marks-Bielska, and Babuchowska [42], Vacca and Onishi [43], Kostyuchenko et al. [44], and Popp et al. [45] found out that different environment-related institutional factors significantly influence countries' sustainability and food security.

Previous parts of the literature review proved the hypothesis that environmental (ecological) factors, in general terms, do influence a country's food security and its perspectives. Moreover, this allows the revelation that environmental responsibility is triggered by regulatory and institutional preconditions and is an essential determinant of consumer choice and agricultural business performance. Thus, it creates a background for more in-depth analysis regarding the identification of specific environmental factors that have impacts on a country's sustainable development and food security. In this perspective, it should be mentioned that Vasylyeva and Pryymenko [46], Mekhum [47], Lu et al. [48], Androniceanu and Popescu [49], Lyeonov et al. [50], Abdimomynova et al. [51], and Mentel et al. [52] clarify renewable energy production and consumption as among key environmental determinants. Additionally, Aitkazina et al. [53] pointed out that an increase in greenhouse gas emissions by agrarian enterprises and expansion of use of chemical fertilizers create threats for sustainable development and, consequently, a country's food security. Similarly, Sibanda and Ndlela [54], Dkhili and Dhiab [55], Mačaitytė and Virbašiūtė [56], and Odermatt [57] also argue that increase of carbon emissions negatively influences company performance, countries' food security, and sustainability. In turn, Vasylieva [58] mentioned that a country's food security is dependent on yields, rational land use, development of innovations, and infrastructure. However, Aliyas, Ismail, and Alhadeedy [59] supposed that a country's food security and agricultural sustainability are based on environmental friendliness, decrease of chemical fertilizers, and effective ecological state policy.

Consequently, a comprehensive analysis of the theoretical and empirical research results aimed at clarifying factors affecting countries' food security leads to the conclusion that economic factors are still among key determinants of foodstuff consumption (it mostly depends on prices of goods and household income) and agribusiness performance (as a key sphere of food production and distribution). At the same time, there is a considerable block of research proving that the influence of ethical, institutional, and specific environmental factors on a country's food security become more significant. In turn, among major environmental determinants affecting a country's food security, scientists mention water and soil usage, energetic issues (expansion of renewable and traditional energy production and consumption), greenhouse gas emission, fertilizer usage, etc. Nevertheless, the influence of these factors on a country's food security is revealed, but scientists have no unified position about the scale and character of such an impact, so it might be valuable, from both theoretical and practical perspectives, to identify which factors are more influential in the long run and which in the short run.

3. Materials and Methods

Previous studies [60] were mainly related to primary empirical research. Specifically, they allowed the identification of the potential blocks of environmental determinants affecting a country's food security, such as: (1) Measures concerning natural resource availability and usage; (2) energy production and consumption items; (3) fertilizer usage; (4) greenhouse gas emissions by agricultural enterprises; (5) parameters of agribusiness yield. In turn, as a result of this literature review, a set of 37 environmental determinants was collected from the World Bank DataBank [61] and the United Nations Environment Program Data Explorer [62]. Correlation analysis helped to select the most influential factors and eliminate multicollinearity problems. It allowed the choosing of 14 out of 37 environmental factors. Additionally, two of these 14 variables were eliminated because they had negative influences on regression model quality parameters. Therefore, previous research [60] helped to clarify a set of environmental factors that do have an impact on a country's food security.

The realization of this research task implied the need for several stages: (1) Construction of the comprehensive food security indicator; (2) identification of certain ecological factors influencing food security in the short and long run.

In general terms, the research was based on data collected from public sources (the World Bank DataBank [61], the United Nations Environment Programme Data Explorer [62], and the Food and Agriculture Organization of the United Nations database (FAOSTAT) [63]) for 28 post-socialistic countries (Albania, Armenia, Azerbaijan, Belarus, Bosnia and Herzegovina, Bulgaria, Croatia, Czech Republic, Estonia, Georgia, Hungary, Kazakhstan, Kyrgyz Republic, Latvia, Lithuania, Macedonia, Moldova, Montenegro, Poland, Romania, Russia, Serbia, Slovak Republic, Slovenia, Tajikistan, Turkmenistan, Ukraine, and Uzbekistan) from 2000 to 2016.

As for the first stage, it might be noted that The Economist in cooperation with the FAO have developed the Global Food Security Index, which consists of 28 measurement indicators of affordability, availability, quality, and safety of food. Nevertheless, this index has been calculated from 2012, which is too small a period for gaining reliable modeling results. That is why the Food Security Index (FSI) was constructed. The FSI consists of 19 indicators of food availability, food access, food stability, and food utilization. The FAO officially identifies these parameters as measures of food security. The descriptions of the indicators used for the FSI's construction are in Table 1.

Table 1. Measurement indicators of the Food Security Index (FSI).

Perspective of Food Security	Indicators of Food Security Measurement
Food availability	Average dietary energy supply adequacy, % (ADESA); Average value of food production, USD per capita (FoodProd); Share of dietary energy supply derived from cereals, roots, and tubers, % (CRT); Average protein supply, gr/capita/day (Protein); Average supply of proteins of animal origin, gr/capita/day (AnProt).
Food access	Rail line density, total route in km per 100 square km of land area (Railway); GDP per capita, USD (GDPpc); Prevalence of undernourishment, % (Under); Depth of the food deficit, kcal/capita/day (FoodDef).
Food stability	Cereal import dependency ratio, % (Cereals); Percentage of arable land equipped for irrigation, % (Irrig); Value of food imports over total merchandise exports, % (ImEx); Political stability and absence of violence, index (PolStab); Per capita food production variability, thousand USD (FPV); Per capita food supply variability, kcal/capita/day (FoodSup).
Food utilization	Percentage of population with access to improved drinking water sources, % (ImWater); Percentage of population with access to sanitation facilities, % (Sanit); Prevalence of obesity in the adult population (18 years and older), % (Obesity); Prevalence of anemia among women of reproductive age (15-49 years), % (Anemia).

The FAO does not clarify a certain algorithm for aggregation of food availability, food access, food stability, and food utilization indicators. Therefore, the Principal Component Analysis (PCA) in Stata software was used to realize this particular task. Namely, the eigenvalues of the first principal component were used as weighted coefficients for the FSI's construction. It is worth noting that we use the PCA method rather than the Analytic Hierarchy Process (AHP) because it is a rather complicated task for realizing pairwise judgments to prioritize measures of food security on a scale of 1 to 9. Thus, we decided to apply not a subjective, but a more objective method (PCA), which aimed at clarification of data trends and identification of weight coefficients based on them [64]. In addition, before applying the PCA, all of the above-mentioned indicators were primarily normalized considering their stimulating or unstimulating influence on the state of countries' food security. The normalization process allows us to arrange them from 0 to 1.

In turn, the second stage of the research is focused on the identification of environmental determinants influencing a country's food security in short- and long-run perspectives. As the research sample includes rather huge number of observations, both in terms of periods, countries, and independent variables (panel data sample), a pooled mean-group (PMG) estimator, developed by Pesaran, Shin, and Smith [65], was used. Traditionally, in research based on panel data with a large number of cross-sections but a small number of time observations, fixed effects are applied, as well as random effects estimators or generalized method of moments. However, an increase in the number of time observations might result in non-stationarity. As this research covers a rather large number of cross-sectional observations and time observations, it is better to apply the PMG estimator. Moreover, this research method allows us to manage the problem of non-stationarity and better fits heterogeneous panels. In addition, the PMG estimator considers both pooling and averaging approaches (it allows short-run coefficients to differ across countries, but long-run coefficients might be equal for the whole panel). Thus, it helps to mix some technical aspects from the mean group estimator and fixed effects estimator [66].

The PMG estimator allows testing of the hypothesis about the existence of influence on food security (specifically, the FSI) in the long-term and short-term perspectives of the following environmental indicators: X1—access to clean fuels and technologies for cooking (% of population); X2—access to electricity in rural areas (% of rural population); X3—agricultural methane emissions (% of total); X4—agricultural nitrous oxide emissions (% of total); X5—arable land (% of land area); X6—cereal yield (kg per hectare); X7—CO_2 emissions (metric tons per capita); X8—electric power transmission and distribution losses (% of output); X9—electricity production from renewable sources, excluding hydroelectric (% of total); X10—fertilizer consumption (kilograms per hectare of arable land); X11—forest area (% of land area); X12—renewable electricity output (% of total electricity output). The summative statistics for the set of dependent and independent variables are in Table 2.

Table 2. Summative statistics for the set of variables.

Variable	Obs	Mean	Std. Dev.	Min	Max
FSI	448	1.295	0.565	0.16	2.25
X1	476	82.774	16.484	38.07	100.00
X2	476	99.724	0.519	95.68	100.00
X3	237	36.122	16.434	0.00	75.29
X4	237	63.263	15.924	0.00	87.68
X5	464	23.172	15.259	0.58	56.23
X6	464	3310.283	1250.055	804.10	6742.3
X7	465	5.642	3.669	0.29	17.31
X8	471	13.835	7.341	1.82	72.90
X9	471	1.553	3.677	0.00	29.99
X10	364	95.155	85.911	0.84	495.23
X11	476	29.539	17.141	1.23	62.12
X12	476	29.985	30.526	0.00	100.00

Notes: X1—access to clean fuels and technologies for cooking (% of population); X2—access to electricity in rural areas (% of rural population); X3—agricultural methane emissions (% of total); X4—agricultural nitrous oxide emissions (% of total); X5—arable land (% of land area); X6—cereal yield (kg per hectare); X7—CO_2 emissions (metric tons per capita); X8—electric power transmission and distribution losses (% of output); X9—electricity production from renewable sources, excluding hydroelectric (% of total); X10—fertilizer consumption (kilograms per hectare of arable land); X11—forest area (% of land area); X12—renewable electricity output (% of total electricity output); Obs—amount of observations; Std. Dev.—Standard deviation.

Based on the results presented in Table 2, it should be noted that the number of observations differs for some variables. Nevertheless, the panel is strongly balanced, which allows us to get reliable and significant empirical research results.

4. Results

Taking into account weight coefficients (Table 3), the FSI was constructed with the PCA approach. It is also worth noting that the calculated FSI is quite representative. Its comparison with the Global Food Security Index for those 13 countries, which are matched in both samples (Belarus, Kazakhstan, Poland, Hungary, Poland, Hungary, Poland, Hungary, Russia, Serbia, Slovakia, Tajikistan, Ukraine, and Uzbekistan) for the years 2012–2016, revealed a correlation of 90.20%. Consequently, the FSI allows the characterization of the same trends as those displayed by the Global Food Security Index.

Table 3. Weight coefficients of indicators of Food Security Index.

Indicator	Eigenvalue	Indicator	Eigenvalue	Indicator	Eigenvalue
ADESA	0.2571	Under	0.2779	FoodSup	−0.0198
FoodProd	0.2452	FoodDef	0.2266	ImWater	0.2247
CRT	−0.2904	Cereals	0.1765	Sanit	0.0920
Protein	0.2994	Irrig	−0.2673	Obesity	−0.2855
AnProt	0.2761	ImEx	0.1203	Anemia	0.1908
Railway	0.2126	PolStab	0.2416		
GDPpc	0.2834	FPV	0.1295		

Analysis of the FSI level in 2016 shows that the highest level of food security is in the Czech Republic (2.25 from 2.39), and the lowest is in Tajikistan (0.16). It is also worth noting that such countries as Albania, Armenia, Azerbaijan, Bosnia and Herzegovina, Georgia, Kyrgyz Republic, Macedonia, Moldova, Serbia, Tajikistan, Turkmenistan, Ukraine, and Uzbekistan have less-than-average levels of national food security. The rest of the countries have higher-than-average levels of national food security. In terms of the characteristics of the dynamics of the FSI level, it might be highlighted that Azerbaijan (566.19%), Tajikistan (520.97%), Uzbekistan (182.79%), Armenia (178.68%), Turkmenistan (97.80%), Georgia (83.93%), and Albania (74.63%) have the best growth dynamics in comparison with 2001, while for the other countries, the growth rate fluctuates in almost the same range (about 31.66%).

The next step is the identification of the relationship between the relevant environmental determinants and the FSI. It is based on the panel data regression analysis (PMG estimator). Practically, it was implemented with the help of the "xtpmg" add-on of the Stata software. The results of the regression analysis are given in Table 4.

Therefore, the following conclusions can be made. The vast majority of the environmental factors have a statistically significant long-term impact on countries' food security (significant at the 10%, 5%, or 1% level). Environmental determinants that have no statistically significant impact on the FSI level in the long-term perspective are as follows: Agricultural methane emissions (% of total emissions) (X3); agricultural nitrous oxide emissions (% of total emissions) (X4); cereal yield (kg per hectare) (X6); electric power transmission and distribution losses (% of output) (X8). Thus, the absence of a statistically significant impact of the growth of greenhouse gas emissions by agricultural enterprises on the level of countries' food security is mostly explained by the intensified efforts of the world community on the reduction of such emissions (according to the Kyoto Protocol, countries are obliged to reduce greenhouse gas emissions by 2100). Additionally, agro-industrial enterprises provide only 10%–12% of the total emissions, while transport, industrial, construction, and energy enterprises have a greater impact on the ecosystem. The reduction in the net carbon dioxide emissions of the agro-industrial sector was largely explained by the decline of deforestation and the increase in forest plantations.

However, the increase of carbon dioxide emissions per capita from all sources of pollution (X7) remains a strong factor of the negative impact on countries' food security in the long-run perspective. Namely, an increase of this independent variable by a point results in a decrease of country food security level by 0.0886 (or 3.71% of the maximum possible FSI value).

Table 4. Results of identifying short- and long-run coefficients of environmental factors' influence on the FSI.

Variable	Coefficient	Std. Deviation	Z	P > |z|
		Long-Run Perspective		
X1	0.0105	0.0076	1.38	0.168
X2	0.0811	0.0513	1.58	0.114
X3	−0.0055	0.0127	−0.43	0.667
X4	0.0041	0.0050	0.82	0.410
X5	0.0285	0.0175	1.62	0.104 *
X6	0.0000	0.0000	0.87	0.384
X7	−0.0886	0.0248	3.57	0.000 ***
X8	0.0028	0.0019	1.40	0.161
X9	−0.0262	0.0168	−1.56	0.218
X10	0.0020	0.0009	2.23	0.026 **
X11	0.0948	0.0561	1.69	0.091 *
X12	0.0154	0.0054	2.86	0.004 ***
		Short-Run Perspective		
X1	−0.0134	0.0180	−0.74	0.457
X2	−0.0101	0.0074	−1.36	0.173
X3	−0.0109	0.0041	−2.86	0.007 ***
X4	0.0001	0.0007	0.12	0.906
X5	−0.0024	0.0049	−0.48	0.629
X6	-4.86×10^{-6}	5.20×10^{-6}	−0.93	0.350
X7	−0.0190	0.0082	−2.31	0.021 **
X8	−0.0001	0.0004	−0.31	0.755
X9	0.0181	0.0043	4.26	0.000 ***
X10	−0.0003	0.0003	−0.91	0.364
X11	0.0514	0.0619	0.83	0.406
X12	−0.0021	0.0010	−2.08	0.038 **
Cons	−3.6307	1.2189	−2.98	0.003 ***
ec	−0.2920	0.0863	−3.38	0.001 ***
Countries	28	28	28	28
Observations	476	476	476	476

Notes: X1—access to clean fuels and technologies for cooking (% of population); X2—access to electricity in rural areas (% of rural population); X3—agricultural methane emissions (% of total); X4—agricultural nitrous oxide emissions (% of total); X5—arable land (% of land area); X6—cereal yield (kg per hectare); X7—CO_2 emissions (metric tons per capita); X8—electric power transmission and distribution losses (% of output); X9—electricity production from renewable sources, excluding hydroelectric (% of total); X10—fertilizer consumption (kilograms per hectare of arable land); X11—forest area (% of land area); X12—renewable electricity output (% of total electricity output); *—significance at 10% level; **—significance at 5% level; ***—significance at 1% level.

In turn, some factors have a positive impact on the countries' food security, such as:

- Access to clean fuels and technologies for cooking (% of population) (X1)—an increase of the environmental factor by a point results in strengthening of a country's food security by 0.0105 (or 0.43% of the maximum possible FSI value);
- Access to electricity in rural areas (% of rural population) (X2)—an increase of the environmental factor by a point results in strengthening of a country's food security by 0.0811 (or 3.39% of the maximum possible FSI value), which means that further electrification of rural areas using environmentally friendly technologies should be a priority direction of public policy.

This statement is also confirmed by a positive and statistically significant impact of expanding renewable electricity output (% of total electricity output) (X12) on the country's food security in the long-run perspective. Namely, its increase by a point leads to strengthening of a country's food security by 0.0154 (or 0.64% of the maximum possible FSI value). Experts note [67–69] that the expansion of land for growing biofuel plants might have some negative consequences. It leads to the elimination of the land from the process of food production and may harm a country's food security. Consequently, this damage might not be offset by the positive environmental impact of using biofuels instead of traditional fuels.

In addition, the statistical significance of the long-term effects of arable land growth (X5) and forest area growth (X11) was confirmed at the 10% level. Particularly, an increase by a point of one of these particular environmental factors (X5 and X11) results in an increase in a country's food security by 0.0285 and 0.0948, respectively. Such a trend is quite natural, since the expansion of arable land will increase the volume of food products. However, such a scenario can have negative consequences and requires a well-thought-out and scientifically grounded approach. In particular, an intensive approach to the agricultural sector's development is preferable. It helps to ensure an increase of agricultural production without large-scale use of additional land resources. It is also equally important to use the most environmentally friendly tools for increasing agribusiness productivity and yields. While there is no widespread expansion of an intensive model of agricultural management, extensive technologies still do not lose their relevance. This is also confirmed by the statistically significant impact of the indicator "fertilizer consumption (kilograms per hectare of arable land)" (X10) on a country's food security (at the 5% level). Its increase by a point results in the FSI increase by 0.0020 (0.08% of maximum FSI value).

It is worth noting that most of the short-run coefficients are not statistically significant. However, the variables "agricultural methane emissions (% of total)" (X3) and "CO_2 emissions (metric tons per capita)" (X7) have a statistically significant negative impact on the food security index at the 1% and 5% levels, respectively. In addition, the positive impact of growth in electricity production from renewable sources is confirmed (both without hydroelectric power—variable X9 and with hydroelectric power—variable X12).

However, in most cases, the particular environmental factors are statistically significant only in short or long run. Consequently, we cannot compare statistically significant results with insignificant ones. Hence, we mainly focused only on the analysis and practical implications of only statistically significant research results. Nonetheless, it is worth noting that the increase in renewable electricity output (% of total electricity output) (X12) has a positive long-term but negative short-term influence on a country's food security. These findings might be partially explained by the specificity of the sample of countries. Namely, most of 28 post-socialistic countries have triggered more intensive economic, environmental, and technological development only for the last three decades. That is the main reason for the absence of a highly productive network of renewable energy stations. Consequently, the expansion of renewable electricity output leads to an immediate negative impact on a country's food security because of the partial elimination of land and water resources from foodstuff production and the worsening of its quality. Otherwise, in the long run, renewable energy outcompetes traditional energy production, which is more harmful to the environment and countries' food security. Familiar trends were also mentioned in the FAO report "Impacts of Bioenergy on Food Security" [70].

In turn, the increase of CO_2 emissions negatively influences a country's food security both in the short and long run. However, the scale and significance of this factor's effect become more influential in the long-term perspective.

5. Discussion

Aggregation of these empirical research results aimed at the identification of the influence of environmental (ecological) factors on a country's food security in short- and long-run perspectives allows the confirmation of trends and cohesions identified by other scientists. Specifically, Sola et al. [71] analyzed 132 articles about the influence of access to clean fuels and technologies for cooking on food security measures. Researchers mentioned that, in general, most of the scientists argued that this factor has a positive impact on food security and nutrition. However, there are no numerous empirical pieces of evidence of it. However, our research results allow us to quantitatively clarify such an impact: An increase of the factor by a point results in the strengthening of a country's food security by 0.0105 in the long run. Moreover, the FAO [72] also actively supports the idea that access to clean fuels leads to better nutrition and less environmental damage.

In addition, our empirical results about the impact of access to electricity in rural areas on food security also correlate with the FAO's findings. Namely, in publication [72], it is mentioned that access to electricity is crucial for a country's food security because electricity is necessary at each stage of foodstuff production. Moreover, access to electricity in rural areas might become a driver of agricultural productivity, efficiency, and food security.

In turn, Wambua, Omoke, and Telesia [73] found empirical pieces of evidence that lack of arable lands and other familiar resources are preconditions of food insecurity in Kenya. Mbuthia, Kioli, and Wanjala [74] highlighted the importance of the other resource factors. Namely, they revealed that the prohibition of cutting trees (forest areas) has a positive influence on household food security. Thereby, our research results form empirical evidence of the relationships that were previously identified at a theoretical level.

Moreover, Wambua, Omoke, and Telesia [73] also revealed that using animal manure or industrial fertilizers allows an increase in agricultural crops. Hence, the authors pointed out that households using fertilizers for agricultural issues did not face the problem of food insecurity even in periods of unfavorable weather and climate conditions (based on 66 households' self-assessment). In our research, the hypothesis about the long-run positive impact of fertilizer consumption on a country's food security measures was also confirmed.

In the research, it was revealed that CO_2 emissions have a negative influence on a country's food security, as was also highlighted in other research by Sibanda and Ndlela [54], Dkhili and Dhiab [55], Mačaitytė and Virbašiūtė [56], and Odermatt [57].

Finally, empirical findings about the positive influence of renewable energy output on a country's food security were also proved by other scientists' and international organizations' reports, such as the International Renewable Energy Agency (IRENA) [75]. Namely, it is noted in the report that the increase of renewable energy has crucial importance because of several reasons:

- Electricity itself plays an important role in households' everyday life and agriculture business activity, while it is necessary for foodstuff production, storing, and distribution processes;
- Renewable energy and electricity allow the decrease of consumption of fossil fuels, both for private and business purposes;
- Substitution of traditional electricity production with renewable electricity production might help to solve some environmental problems, especially in terms of reduction of greenhouse gas emission;
- Renewable energy's prevalence in comparison with traditional energy sources is more fit for the Sustainable Development Goals, especially in terms of Goal #7: "Ensure access to affordable, reliable, sustainable and modern energy for all".

In terms of the practical implications of the empirical research results, they might become a background for the development of states' economic, social, and environmental policies in order to ensure countries' food security. Moreover, it also might be useful for the identification of the strategic and operational priorities of public policy.

In terms of further research perspectives, it might be noted that certain environmental determinants may be relevant to the general level of food security, but may not have a statistically significant effect on its components. Therefore, it is also important to identify specific environmental stimulants and inhibitors in terms of ensuring food availability, food access, food stability, and food utilization.

6. Conclusions

Thus, it can be concluded that this empirical research aimed at the identification of factors affecting countries' food security in short- and long-run perspectives allows us to confirm previous empirical research results and theoretical findings (especially about the influence of CO_2 emissions, sufficiency of arable lands, forest areas, and other natural resources, access to electricity, and use of fertilizers). On the other hand, results that were revealed allowed us to obtain empirical evidence and quantitatively clarify the kinds of relationships that were identified mostly on a theoretical level (about influence of access to clean fuels and technologies for cooking).

Therefore, taking into account the results obtained regarding the impact of environmental determinants on countries' food security in short- and long-run perspectives for the 28 former socialist countries, the following can be noted:

- The main operational target in terms of ensuring a country's food security might be an intensification of efforts in reducing greenhouse gas emissions (both methane and carbon dioxide), as well as the reorientation towards the production and consumption of electricity from renewable sources rather than traditional ones, which are more destructive to the ecosystem (in countries where the use of alternative energy sources is limited, a possible solution of the problem may be reducing the number of cogeneration and nuclear power plants in favor of hydroelectric power plants);
- Among the key vectors of mitigating the long-run risks of deterioration of a country's food security can be mentioned the following: Intensification of efforts to reduce carbon dioxide emissions not only in the agricultural sector, but also in the industrial sector; continuation of rural electrification and the provision of environmentally friendly fuels and electricity sources to the population, with the reorientation from traditional sources of energy production towards alternative ones; growth of arable land (or more effective usage of the existing ones) and increasing forest areas, while moving to intensive rather than extensive agricultural management (using fewer resources in order to ensure bigger yields).

Consideration of these proposals might become a basis for the development of state policies in the field of ensuring national food security.

Despite the fact that the obtained empirical results correlate with previous empirical findings, and that, on their basis, some practical recommendations that might be used by governmental authorities while ensuring country food security were developed, there are some limitations of this research, such as: (1) The sample of Countries consists of only 28 post-socialist countries, so expansion of the sample of countries might help to get more comprehensive, complex, and reliable results; (2) other than the expansion of the country sample, it might be valuable to realize cluster analysis and specify recommendations for certain clusters; (3) as the Global Food Security Index, which is considered as a unified proxy of countries' food security, covers the period starting from 2012, it is too small for reliable empirical results; thus, despite constructing our own index, a better option may be the use of the methodology of the Global Food Security Index in order to get more reliable assessments.

Moreover, this research was aimed at identification of specific environmental determinants that influence a country's food security in short- or long-run perspectives, but in order to develop efficient public policy in terms of ensuring country food security, lags of postponed impact of environmental determinants on the FSI might be specified.

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