sustainability

Article

Food Security and Transition towards Sustainability

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Abstract: In the light of linkages in various scales and targets, the complex and nuanced design of the sustainable development goals (SDG) raises more challenges in their implementation on the ground. This paper reviewed 25 food security indicators, proposed improvements to facilitate operationalization, and illustrated practical implementation. The research focused on three essential blind spots that arise from the potential interactions between sustainable food production, consumption, and domestic material consumption (DMC). Projection of latent structure regression was applied to link food security and sustainable development goals. Findings revealed that the key target in reducing trade-offs was the integration of DMC with sustainable food production and consumption. DMC was positively correlated with the creation of coherent SDG strategies and sustainable food security. Practical implications were discussed by highlighting how to achieve food security across contrasting development contexts and the challenges of addressing the links between targets and indicators within and beyond SDGs 2 and 12. The results are useful for setting a proper strategy for sustainable production and consumption that can improve the efficient use of resources in the eight Central European countries.

Keywords: sustainable development goals; domestic materials consumption; food systems; sustainability transitions; sustainable food security

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1. Introduction

For decades, food security and sustainability have been considered separate concerns, with the concept of food security having a more significant connotation with sustainability dimensions such as environmental, economic, and social–cultural aspects that interpret human well-being [1]. Food security is highly connected to food sustainability and environmental protection [2,3]. Additionally, food security exists when all people at all times have physical, economic, and social access to sufficient, safe, and nutritious food [4]. Food insecurity today is predominantly skewed in both developed and emerging countries, encompassing quantity and quality, under-, and overconsumption issues. Additionally, food security has already been adopted as a strong urban component, because a substantial part of the world's population resides in the city, posing new physical and financial access to food [5]. Several frequently interrelated sustainability concerns were included in the global food security agenda [6], where some scholars believe that countries such as Germany, the Netherlands, and Japan are the most sustainable due to less resource consumption [7]. In contrast, others claimed that the massive resource consumption of rich and industrialized countries has contributed the most to unsustainability [8].

Recently, the "New Food Equation" concept has arisen, followed by food price spikes, shrinking natural resources, land grabbing practices, social instability, and the consequences of climate change [9]. In light of these concerns, this study used the concept of the 17 UN SDGs, which were articulated in more depth. The goals comprise production, processing, transportation and distribution, food and retail markets, food prices, and economic aspects that are connected within the chain [10]. The global food chain encompasses food production and processing, transportation of goods, and food items [11]. The functionality and sustainability of the global food system need a range of preconditions to be fulfilled, such as accessibility to resources and land, the minimization of climate change and ammonia emission, adoption of organic farming, political stability, and military violence or terrorist attack prevention [12–15]. The public debate on health and nutrients dimensions, the production process and the contents of dietary supplements, access to fresh food, food sources, and other topics is now centered on food issues. With shorter food chains and transparency of food processes, solutions to the global food system are demanded. Segregation among citizens' groups is one of the crucial challenges in urban areas, which means unequal access to services, including fresh and nutritious food items. This challenge addresses food justice, which is directly concerned with socio-economic inequalities, including urban structural disparities and diverse social, cultural, economic, and spatial exclusion, which ultimately apply to social sustainability and urban resilience [16–18].

The agricultural output concentration had a detrimental influence on food supply, food security, and the long-term viability of food systems. Countries' competitiveness and the coherence of their diversification patterns boost per capita food supply and security, but they may jeopardize long-term sustainability [19]. Hugh Wenban-Smith et al. argued that rapid urbanization would cause a significant issue in terms of food security, particularly for the poorest population of towns and cities [20]. Chartres and Noble investigated how and where natural resources were under increasing strain, as well as agriculture's "ecological footprint" [21]. The identified main issues against food security were land and water constraints on food production. Existing scientific knowledge is necessary to implement new sustainable land and water management concepts and recover salinized ground [21,22].

However, the rapid depletion of energy and material resources over the past few decades is likely not sustainable in any way. A "social–ecological system" is required to achieve an accurate estimate of sustainability. This is a system that emerges through the interaction of society and the natural environment [23]. The international comparison revealed that population played a minor role in developing DMC across countries, as it remained relatively consistent over the study period. Here, DMC refers to the biomass that encompasses domestic agricultural production, forestry, and fisheries production, as well as trading of raw and processed products from these industries. The concept focused on the fundamental assumption that the efficient use of domestic material consumption improves the long-term capacity to provide adequate food. This depends on adapting and mitigating the impact of the ecosystem and socio-economic issues that threaten ecosystem resilience. In addition, this paper focused on SDG 2 and SDG 12—which aim at "zero hunger" and to "ensure sustainable consumption and production patterns". The concept of efficient production and consumption are connected with SDG 12, which links the concept of sustainable consumption and production. The sustainable production and consumption together contribute substantially to poverty alleviation and the transition towards low-carbon and green economies [24]. Additionally, a green economy is linked with food security. For example, Kinda et al. [25] found that the green economy makes a significant contribution to improving food security. Additionally, the International Food Policy Research Institute (IFPRI) [26] pointed out that intensifying food production can boost food security. Intensifying food production is also linked with sustainability. In addition, Tambovceva et al. [27] identified food security as a good driver of the green economy. In these aspects, this study linked the concept of efficient production, consumption, and food security.

After studying the literature, it can be determined that there is little research available on the topic of food security and sustainability, which formed the research gap of this article. On the other hand, the paper also encouraged further examinations of the factors influencing country-specific DMC in Central European countries. Based on the research gap, the following research question was formed: how can the integrated targets of SDG 2 and 12 achieve sustainable food security? Naturally, food security is an overall concept related to the supply and distribution of food for all citizens. Additionally, the diversity of food produced or procured and the environmental sustainability of food production systems are essential. An overview of these problems has contributed to the proposed work.

All human beings are dependent on natural resources. The production and consumption of these resources play an important role in food security status and the circular economy. Hence, it is necessary to use these scarce resources efficiently and effectively so as to fulfill our current demands and to sustain resources for future generations. Effective use of raw materials means the sustainable use of the limited resources of the Earth, and the practice of sustainable production and consumption is the solution to improving global food security. Production should be adjusted to demand and also consumption to current needs, without endangering the ability of future generations to meet their own demands. It is evident that transformation towards sustainability is required to improve food security. Based on the above mentioned, the main objective of this study was to investigate the relationship between efficient production and consumption of domestic materials that are associated with sustainable food security in the frame of EU countries. Additionally, the article extended the objectives to find concrete and often inextricably linked obstacles to sustainable food security by reflecting on the diversity of economic, social, and environmental effects of global climate change at different stages of food security.

Based on a comprehensive review of recent academic and policy literature, this article contributed to the emerging demands for a more holistic approach to food security that considers sustainability issues. The majority of researchers emphasize food production and supply rather than consumption of domestic materials that have a significant contribution to achieving food security.

The European Commission's politicians and the member states have been debating the future design of the common agricultural policy (CAP) for several years. The EU overviews the income condition of EU farmers in terms of agricultural factor income. Besides, the overall goal of the CAP is to ensure the food security and sovereignty of EU member countries. CEU countries can now be termed food secure, but their food security status is reliant on imported foods. Significantly increased population and excessive consumption of domestic material have jeopardized the EU's food security [28,29]. For this reason, in the present paper, eight CEU countries were selected and analyzed, including Austria, Belgium, Germany, the Netherlands, the Czech Republic, Hungary, Poland, and Slovakia, as the Visegrád group.

This article has the following structure. Section 2 presents the literature that was reviewed by differentiating the present research from past studies. Section 3 discusses the methodology and data analysis techniques employed, including details on the food security indicators used in the study. A summary of the results and significant findings are given in Section 4. Section 5 provides a detailed discussion of the results with implications in contrast with the literature. Finally, the conclusions, future research areas, and new challenges are discussed in Section 6.

2. Literature Review and Hypothetical Design

The literature on food security and SDGs has been extensively researched from various perspectives by many researchers. However, the current literature that shows the impact of DMC on Central European countries is not highly developed. Moreover, the hypotheses of this study are founded based on the following review concepts.

2.1. A Food Systems Perspective for Food Security and SDGs

First of all, food production and consumption are the key components of achieving food security, and the positive correlation between sustainable production and consumption and global food security has been verified in many studies [19,20,30,31]. Different factors influence food security such as food availability, accessibility, utilization, and stability, which has evolved from the refined concept of food security theory. According to the definition of the FAO "food security exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life" [32].

The food security concept is a fundamentally transdisciplinary subject that impacts both societal and environmental sectors. The United Nations' SDGs are challenged by food-related issues [33,34]. It is important to investigate the connections between food security and the SDGs to understand the food system's potential as a framework for sustainable transitions.

Food systems intersect in the "food production" sector with agricultural systems, which contain various services, technologies, and activities regulating manufacturing, distribution, transportation, accessibility, and "food consumption". Food systems have an influence on the consumption and production of foods as well as on the future attitude of people and on their opinion about how healthy and nutritious their food is [35,36]. These two narratives are the tangible obstacles to "sustainable food security" polarizing unreasonable discourse, which has been overshadowed by stress and uncertainty. The first conceptualization of food security is a production issue that needs to be addressed from the supply end of the food chain. In contrast, it should also be considered a consumption issue from the demand end. Nevertheless, the overarching concerns underpin the impact of various adaptation options on food security and SDGs. The long-term ability of the food system to provide adequate nutritious food can lead to the sustainability of food production and consumption. Although, the sustainable development (SD) and the sustainable consumption and production (SCP) concepts were gradually popularized and established at the 1992 Earth Summit UN Sustainable Development Conferences [37].

A variety of factors affect food production and consumption—for example, geographical location, demographic trends, urban development, and globalization. Additionally, socio-economic background, income level, consumer behavior, religion, and culture influence at the national, local, and household levels [38]. As part of the federal and municipal initiatives to achieve sustainable development, policies and strategies for local and regional food systems are shifting [39]. Besides, urban and rural viability can be improved via the food systems, e.g., new job creation, new food industry establishment, and reclaiming the value of regional goods [5,40].

A key attribute of the SDGs is that their goals and objectives for growth are largely interdependent yet interlinked [41]. The SDGs were argued to include congruence or synergies as well as trade-offs or contradictions with consequences for national and global perspectives. Because of its interdependencies, several issues might be alleviated at once by reaching a single goal. Tackling climate change problems, for example, will have co-benefits for energy security, health, ecosystems, and biodiversity [42]. Almost all SDGs are directly and indirectly involved with food security issues, and targets have to be achieved to solve them.

Our first conceptualization of food security as a production issue complies with SDG 2, because it claims a radical revamping of food systems and offers small-scale agricultural farmers an important role. The SDG 2 includes targets to end hunger and ensure food accessibility for all (target 2.1) and better nutrition by reducing all forms of malnutrition simultaneously (target 2.2). SDG 2 has dedicated itself to fostering sustainable agriculture and incomes of small-scale food producers (target 2.3) to accomplish that aim [34,43].

Alongside this, the second conceptualization of food security as a consumption matter conforms to SDG 12, because it gives the standalone priority of "ensuring sustainable consumption and development patterns". Eight specific targets are included in SDG 12. Sustainability is explicitly viewed through the production efficiency perspective, concerning the utilization of natural resources (12.2), food losses related to production and supply (12.3), chemical and waste management (12.4), sustainable business practices and reporting (12.6), and sustainable public procurement (12.7). The waste generation minimization goals (12.5) and the justification of subsidy for fossil fuels (12.c) may cover both production and consumption [44].

Multiple associations exist between food production, processing, supply, and consumption from a food systems perspective. Changes in food consumption, such as a preference for more meat and dairy, result in changes in production decisions and DMC in an increasingly resource-constrained world [19]. The food production and consumption patterns are directly or indirectly linked to various segments of the food system, and both have positive and negative associations that need to be considered to achieve the multiple goals of SDG 2 and SDG 12 simultaneously. Based on these concepts, Hypothesis 1 was drawn up as follows:

Hypothesis 1 (H1). *Changing production and consumption patterns has a positive impact on SDG and sustainable food security.*

2.2. Transitions towards Sustainability?

Another influential force is the transition that is also related to improving sustainable food security. Sustainability refers to meeting the current requirements without jeopardizing the future generations' ability to fulfill their demands [45]. Achieving sustainability requires a transition, because transitions of sustainability aim to solve the crucial problems of contemporary societies by connecting environmental integrity, socio-economic viability, and intergenerational justice [46]. Many studies suggest that transition towards sustainability is positively associated with sustainable food security, which increases food availability, enhanced food accessibility, efficient food utilization, and increased stability in the food system and resilience [47–49]. The inequalities in the accessibility of resources across diverse populations and cultures at local, regional, and global levels are the main concerns, therefore, calling for cross-sectoral and cross-scale societal improvements. Additionally, excessive domestic material consumption and less circular material use rate affect sustainability [50]. The old sustainability concept was related to the view that innovation, technological work, and manufactured assets will substitute natural and biological resources.

On the other hand, the interpretation of the new sustainability concept is the recognition of globally scarce resources and a reduction in overall material use [51,52]. From the new concept, it is apparent that only agricultural improvement and increases in food production are not enough to fulfill the SDG 2 target. Rather than coping with sustainability, more focus should be placed on sustainable consumption and production, which can be fulfilled by SDG 12. The main goals of SDG 12 are directly related to sustainable food security, of which the primary goal (target 12.3) is to cut 50% global food waste per capita by 2030 at both retail and consumer levels. It is also important to minimize food losses through better management of production and supply chains, including "post-harvest losses" and "to minimize food losses" for sustainable consumption and production [43].

Moreover, the transformation narrative had the most extensive concordance with the various SDGs, including SDG 2 and SDG 12. The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) assessment described the pathways and the transformation movements narrative involving shifts in relational principles towards resource-saving lifestyles such as food and energy and non-GDP growth. Extreme poverty coupled with resource scarcity and unequal access to resources can lead to unsustainable natural resource usage and negative impacts on GDP. These interconnected factors contribute to high poverty rates and impede people's ability to establish local strategies to deal with increasingly severe episodic or chronic food, water, energy, and physical security shortages [53].

By integrating traditional and indigenous knowledge with modern technological advancements, different innovative types of agriculture were being developed, for example, agroecology, agroforestry, organic cultivation, urban agriculture, transportation, and energy models. All of these reduced the impact on the environment, atmosphere, and water. In particular, enhancing quality of life by adopting SDGs was complemented by focusing on employment creation and reducing social inequalities [54].

The historical evolution of concepts of food sustainability has been connected to food security. The international discourse was primarily implemented by concepts of sustainable development [1]. The statement included multiple facets, such as sustainable agriculture, sustainable diets, and sustainable food systems. For sustainable food production and transition, a systematic and comprehensive solution is advisable. Food analysis cannot differentiate between production and packaging, transport, recycling, and waste management without compromising the capability, current and future expense, advantages, contradictions, and dilemmas. A transition to sustainable consumption involves a deep commitment to establishing an interdisciplinary research strategy that incorporates the values of sustainable agriculture, climate, social, and health challenges. To achieve a sustainable lifestyle, diet and technology for consumption and food production structures must improve [55].

However, integrated strategies, actions of SDGs, and transition towards sustainability will ensure sustainable management, and efficient use of DMC and natural resources in production and consumption process will aid in achieving sustainable food security [50]. Therefore, it was logical to propose Hypothesis 2:

Hypothesis 2 (H2). *Efficient use of domestic materials has a positive influence on SDGs and sustainable food security.*

3. Materials and Methods

3.1. Analytical Procedure

The study was conducted in three steps: (a) variables were selected based on the most relevant indicators from previous literature and classified under the food security pillars and SDG (SDG 2 and 12) based on their importance; (b) principal component analysis (PCA) was used to determine the most important component and whether the covariates are significantly related to their factors or not; (c) projection of latent structure regression (PLSR) was used to test the significance of the variables on the first two latent vectors (food security block and Sustainable Development Goal block).

Ibukun et al. [56], Odhiambo et al. [57], Lamichhane et al. [58], Vysochyna et al. [59], Yao et al. [60], Chatterjee et al. [61], and Suantika et al. [62] used a PCA and PLSR model to estimate the impact of food security and SDGs in different circumstances.

3.2. Empirical Methods

The principal method underlying this study was the PLSR method, which is designed to relate two blocks of variables (X and Y). For our purpose, a simple multiple linear regression could have been used, but in our case, there were too many well-correlated dependent and independent variables. PLSR can overcome these difficulties (many variables and collinearities). In the PLSR model, there are two individual "outer" relations for X and Y blocks and an "inner" relation that connects the two blocks. The mathematical representation of the method is as follows:

Suppose I observations and J variables are given in X block where x_{ij} denotes the i-th observation for the j-th variable and $\mathrm{X}_{I\times J}$ is an $(I \times J)$ matrix, $X^{(j)}$ denotes the j-th column of X. Suppose further that the same number of observations exist in Y and K variables where y_{ik} denotes the i-th observation for the k-th variable and $Y_{I\times K}$ is a $(I \times K)$ matrix.

The outer relation for X block is:

$$X_{I\times J} = \sum_{l=1}^{L} t_{I\times 1}^{(l)} \cdot p'^{(l)}_{1\times J} + E_{I\times J} = TP' + E \tag{1}$$

The outer relation for Y block is:

$$Y_{I\times K} = \sum_{l=1}^{L} u_{I\times 1}^{(l)} \cdot q'^{(l)}_{1\times K} + F_{I\times K} = UQ' + F \tag{2}$$

where E and F are two ($I \times J$) and ($I \times K$) error matrices, T and U are the so-called ($I \times L$) and ($I \times L$) "score" matrices for X and Y, respectively, and $t^{(l)}$ and $u^{(l)}$ are the l-th ($I \times 1$) column vectors of T and Q. P' and Q' are ($L \times J$) and ($L \times K$) matrices that contain the so called "loadings", and $p^{'(l)}$ and $q^{'(l)}$ vectors are the l-th ($1 \times J$ and $1 \times K$) row vectors of P' and Q' where $l \in [1, L]$ and L denotes the number of latent components (dimensions). Matrix transposition is denoted by $'$ sign. The X-scores (T matrix) can also be expressed in another way as:

$$T_{I\times L} = \sum_{j=1}^{J} X_{I\times 1}^{(j)} \cdot W'^{(j)}_{1\times L} = XW' \tag{3}$$

and

$$t_{I\times 1}^{(l)} = \sum_{j=1}^{J} X_{I\times 1}^{(j)} \cdot w_{j,l} \tag{4}$$

where $W'^{(j)}$ indicates the j-th row of the $J \times L$ weight matrix for the variables in X block, and $w_{j,l}$ represents the entry (weight) in the j-th row (variable) and l-th column (latent component).

X-scores are also used as predictors of the variables in the Y block ($u_{I\times 1}^{(l)}$ in Formula (2) is replaced with $t_{I\times 1}^{(l)}$ in Formula (4)) as follows:

$$Y_{I\times K} = \sum_{l=1}^{L} \left(\left(\sum_{j=1}^{J} X_{I\times 1}^{(j)} \cdot w_{j,l} \right) \cdot q'^{(j)}_{1\times K} \right) + G = XW'Q' + G \tag{5}$$

The X variables (used as independents) are reduced to principal components and the resulting factor scores ($t^{(l)}$) are used to predict principal component scores ($u^{(l)}$) derived from Y variables (dependent variable). The predicted Y component scores are, then, used to predict the raw Y variables. The main feature of PLSR is that the technique maximizes the strength of the "inner" relation between X and Y factor scores ($t^{(l)}$, $u^{(l)}$), by choosing X-scores of the latent independents to be paired as strongly as possible with Y-scores of the latent dependent variables [63]. PLS components were computed by the most efficient technique, the nonlinear iterative partial least squares (NIPALS) method, developed by Herman Wold [64]. From a geometrical point of view, the raw X matrix is projected on a plane given by the X principal component scores and, then, related to the values of Y [65]. It is a common practice to plot the corresponding columns (as dimensions) of the W' weight and Q' loading matrices in the same coordinate system to express the relationships between the two blocks of variables.

The analysis was performed using TANAGRA 1.4.50. software [66]. Cross-validation was also performed in which the data were split to train (75%) and test (25%) samples. Model performance was measured through R-squared change and the root mean squared error rate.

Several indicators encompass the effects of sustainable development on food security. A selection of relevant indicators in each block (pillars), i.e., accessibility, availability, quality, stability, and SGG, are presented in Table 1. Table 1 shows the time coverage (2012–2019), sources, abbreviations, the related principal component, and measurement descriptions for each featured indicator and all selected Central European (CEU) countries.

Table 1. Variable measurement.

Pillar		Period	Indicator	Source *	PCA Component	Abbreviation	Measurement	Previous Literature
	Food Accessibility	2012–2018	Gross domestic product (GDP) per capita	EIU	PC1	gdppercapita	USD at PPP ** per capita	[19,50]
		2012–2018	Road infrastructure	EIU	PC4	roadinfra	Score (0–4) 4 = best	[20,36]
		2012–2018	Port infrastructure	EIU	PC1	portinfra	Score (0–4) 4 = best	[36,43]
		2012–2018	Rail infrastructure	EIU	PC1	railinfra	Score (0–4) 4 = best	[36]
	Food Availability	2012–2018	Urban absorption capacity	EIU	PC2	urbabsorb	GDP (% of real change) period of urban growth	[20]
		2012–2018	Volatility of agricultural production	EIU	PC3	volagrprod	Standard deviation (0–1)	[19]
		2012–2018	Political stability	EIU	PC2	polstab	Score (0–100) 100 = best	[19]
Food Security Block (Y) /Dependent variables/		2012–2018	Food loss	FAO	PC4	foodloss	Waste/supply (ton)	[43,47]
	Food Quality	2012–2019	Diet diversification	FAO, EIU	PC4	dietdiv	% (percent)	[18,47]
		2012–2019	Protein quality	EIU	PC1	proteinqual	Score (0–100) 100 = best	[19]
		2012–2019	Average food supply	FAO	PC1	avefoodsupply	Kcal/person/day	[19]
	Food Stability	2014 **–2019	Severe food instability	FAO	PC3	foodinst	% of the total population	[53]
		2012–2017 **	Safe drinking water	FAO	PC3	safedrink	% of the total population	[22]
		2012–2016 **	Prevalence of obesity	FAO	PC3	prevobesity	% in population (above 17 years)	[47]
		2012–2018	Public expenditure on agricultural R&D	EUROSTAT	PC3	Agric R&D	Score (1–9) 9 = highest	[19]
		2012–2019	Agricultural factor income	EUROSTAT	PC1	AFI	% (2010 = 100%)	[28]
		2015 **–2019	Domestic material consumption	EUROSTAT	PC1	DMC	Euro per kilogram	[50]
		2012–2019	Poverty proportion	EIU	PC2	povprop	% under global poverty line (USD 3.2/day)	[53]
		2012–2018 **	Municipal waste	OECD	PC3	waste	Kilograms per capita	[50]
Sustainable Development Goals Block (X) /Independent variables/		2012–2019	The area under organic farming	EUROSTAT	PC2	orgfarm	% of the total utilized agricultural area	[15,54]
		2012–2018 **	Share of renewables	EUROSTAT	PC2	renew	% in gross final energy consumption	[50]
		2012–2017 **	Circular material use rate	EUROSTAT	PC1	circularmat	%	[50]
		2012–2017 **	Ammonia emission from agriculture	EUROSTAT	PC1	ammemis	Tons	[15]
		2012–2018 **	Harmonized risk indicator for pesticides	EUROSTAT	PC2	HRI1	% (2011–2013 average = 100%)	[53]
		2014–2017 **	Rate of obesity	EUROSTAT	PC4	obesity	%	[47]

Notes: * EIU: Economist Intelligence Units [67]; EUROSTAT: Statistical Office of the European Union [68]; FAO: Food and Agricultural Organization [69]; OECD: Organization for Economic Co-operation and Development [70]; **: missing data were estimated from OLS regression.

In this study, primarily the Global Food Security Index (GFSI), Eurostat Database, and Food and Agriculture Organization (FAO) database were used to measure the effects of sustainable development on food security and simultaneously determine the impact of SDG 2 and 12 indicators on food security. However, this paper focused mainly on the EIU, FAO, EUROSTAT, and OECD's food security and SDG indicators, the most popular food security measurements, and sustainable development at the national level. The Food Affordability (FAF) dimension tests the ability and expense of people in a country to pay for food under usual situations and during food shocks, for example, GDP per capita and consumer spending on food consumption to buy food. Agricultural import tariffs and food reliance, thus, regulate the susceptibility to external price shocks. The availability and ease of access to food are determined by food accessibility (FAC) status. FAC denotes the adequacy of the national food supply, the risk of interruption of supply, agricultural infrastructure for the extension of agricultural productivity, local and innovative capability for disseminating food efforts, reducing food losses, and the uncertainty of political stability. Finally, the diversity and dietary content and the availability of average diets are included in food quality (FQ). This category is often called "food utilization", because it discusses individuals' energy, nutritional consumption, and food diversity [69].

The selected food security pillars also demonstrate the mainstreaming progression of the 2030 Agenda of Sustainable Development environmental goals [71]. It supports, for example, the monitoring of sustainable food production systems (SDG 2.4) and ensures access to reasonable, secure, and renewable energy services (SDG 7.1). Additionally, it leads to a reduction in the negative environmental effects of urbanization (SDG 11.6), to the conservation of coastal and marine areas (SDG 14.5), and the preservation and prevention of the extinction of endangered species of biodiversity (SDG 15.5).

There were 64 data points from 8 countries over eight years. The data were split to train and test samples for cross-validation. Test data were created by selecting two years (25%) randomly from each country data, and the rest (75%) formed the train data.

4. Results

According to Virginijus Sinkevičius, Environment Commissioner, in the EU food system, the long-standing supremacy of food security concerning environmental factors has been cast uncertain, indicating that conventional concerns could give way to such matters as climate changes, sustainability, or biodiversity. The European food system is dominated by challenges, including food waste, overconsumption, obesity, and cumulative environmental footprint [72]. European agriculture, manufacturing, food, and beverage sectors are highly nature-dependent and generate over EUR 7 trillion per year. At the same time, 950,000 deaths in the EU were linked with unhealthy diets in 2017 [73,74].

The major goal was to explore and highlight the production and consumption pattern and efficient use of DMC to achieve sustainable food security through SDG targets in selected CEU countries. In order to accomplish this, a model was constructed including the major SDG indicators that influence food security, and their relationships were tested using PLSR. The X matrix was the SDGs block, while the Y matrix was the food security block. First, the two blocks (SDG and food security) were studied separately using PCA to detect the inner structure. A so-called two-dimensional biplot was applied to depict the principal components as well as the scores for each country.

Figure 1 presented the two-dimensional representation of the PCA analysis results for the eight CEU countries. The first four principal components of Y (food security block) (Figure 1) explained 60% of the variance. The first component (PC1) consisting of port infrastructure (portinfra) and rail infrastructure (railinfra), GDP per capita (gdppercapita), and protein quality (proteinqual) can be considered the most important component by explaining 36% of the total variance. The second component (PC2) with 9% of the explained variance is correlated the most with urban absorption rate (urbabsorb), political stability (polstab), and prevalence of obesity (prevobesity). The third component (PC3) explained only 5% of the variance determined by the volatility of agricultural production (volagrprod), severe food instability (foodins), and the prevalence of obesity (prevobesity). The fourth component (PC4) was related mainly to diet diversity (dietdiv), road infrastructure (roadinfra), and food loss (foodloss) and contributed 10% of the total variance. The fourth component was the second most important component among all four.

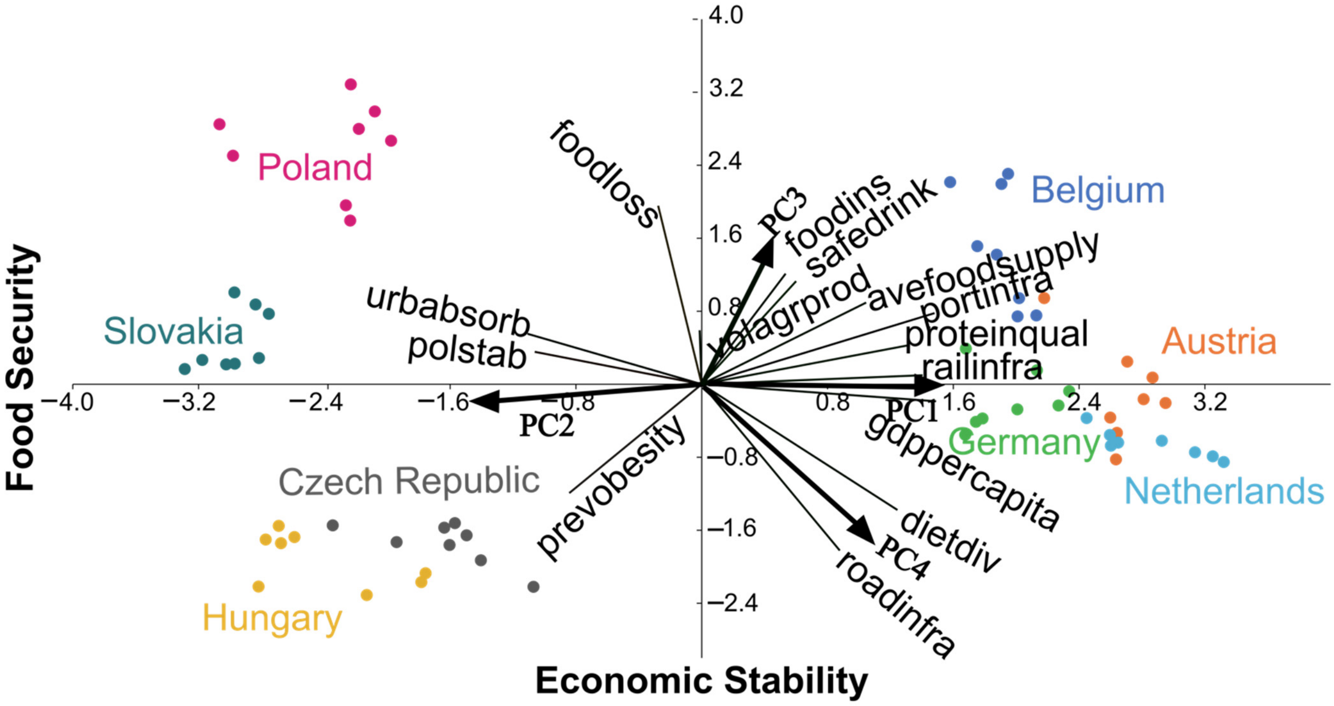

Figure 1. PCA analysis of the food security block (*Y*). Source: authors' calculation. Note: arrows represent the four principal components.

Results showed that higher-living-standard countries such as Germany, Austria, and the Netherlands' GDP per capita and protein quality mostly affected the food security block. From the global demand side, many interconnected factors obstruct the food system's sustainable food security. The interconnected factors include rising global per capita incomes with increased animal-based and processed food intake, supplemented fat diets, free trade and liberalization, lower cost of unhealthy foods, and adequate supply [75]. Urbanization triggers adverse changes in healthy dietary activities, coupled with limited energy expenditure in urban jobs, correlated with wider or normal unhealthy food choices [38]. It can also be stated that 9% of the explained variance is associated the most with urban absorption rate, political stability, and prevalence of obesity. These are significant concerns to achieve sustainable food security severely hindered by a pervasive lack of access to safe and nutritious food, particularly affecting urban residents [76]. Results also showed that in Hungary and the Czech Republic, the adherence to safe and sustainable dietary habits was sub-optimal, because the prevalence of obesity was higher and negatively affected the food security block. This block examined the nutritional quality of the average diet and food safety within the country. Based on the study findings, both countries had less access to nutritious food, and the overall quality of food supply was not satisfactory.

Figure 1 indicated that Austria, Belgium, and Germany's food security statuses were highly dependent on the average food supply, protein quality, safe drinking water, and port infrastructure. On the other hand, there was less volatility of agricultural production and severe food instability. Substantially, some environmental consequences of food production, such as water pollution and food waste, are focused in urban areas, with major repercussions for food safety. The EU aims to harness economic potential towards more sustainable systems and minimize potential health costs associated with unhealthy diets. Results also indicated that diet diversity significantly affects the health of people in the EU. Only 10% of the total variance was related to food security. This variance suggested that a limited number of people have the proper consumption ability to different foods or food groups. Therefore, they suffer from low dietary quality and nutrient inadequacy.

Poland and Slovakia had less urban absorption capacity and political stability. It can be seen from the results that these two European countries do not have a good ability to ensure food security despite urban stress.

Figure 2 presented the two-dimensional representation of the result from the PCA analysis.

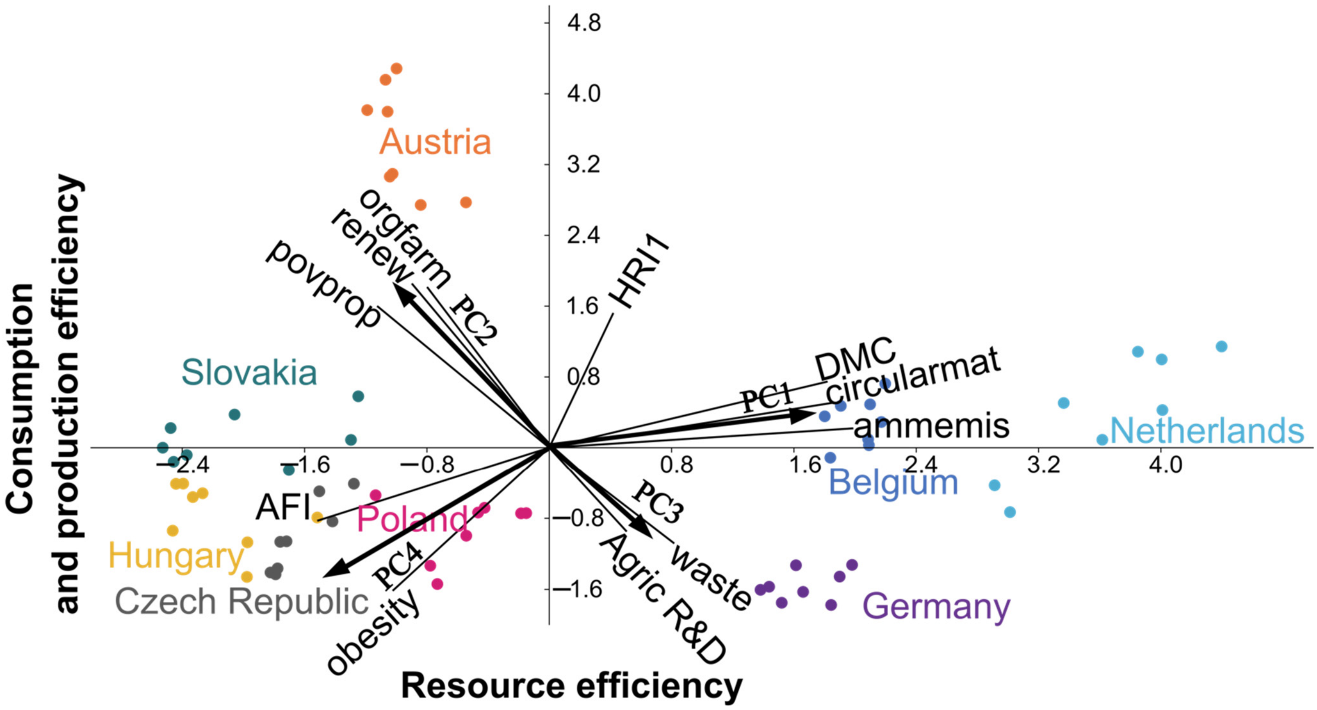

Figure 2. PCA analysis of the Sustainable Development Goal block (*X*). Source: authors' calculation. Note: arrows represent the four principal components.

The first four principal components (in the SDG block) (Figure 2) explained 83% in the PLSR. The first component (PC1) consisting of agricultural factor income (AFI), domestic material consumption (DMC), circular material use rate (circularmat), and ammonia emission (ammemis) can be considered the most important component by explaining 37% of the total variance. The second component (PC2) with 22% of the explained variance is correlated the most with organic farming, the share of renewable energy consumption, and poverty proportion. The third component (PC3) explained 18% of the variance determined by agricultural research and development (agri R&D) and municipal waste, generation, and management (waste). The fourth component (PC4) was related mainly to obesity and contributed 6% of the total variance.

In the case of Belgium and the Netherlands, the percentage of ammonia (NH_3) emission from agriculture production had less impact, indicating good manure management and that less inorganic N-fertilizers and animal manure were used on the soil.

In detail, looking at the major driving factors, it can be stated that the per capita impact of GDP (at purchasing power parity) had the greatest contributing factor in increasing DMC. Except for Hungary, in all our selected EU countries, the DMC rate has been increased significantly, adversely affecting sustainable food security.

There was also a higher value for the circular material usage rate, which means more secondary materials substitute primary raw materials and decrease primary resource extraction's environmental impact. Selected EU countries save the extraction of primary raw materials, which refers to the share of materials recovered and feedback into their economy.

Austria and Slovakia were in an advantageous position regarding the share of renewable energy consumption, using energy from renewable sources such as renewable fuels. Besides, the two countries utilized significant agricultural areas through organic farming and the production of crops and livestock. In comparison with other EU countries, more people in Slovakia live under the poverty line.

Germany, Netherlands, and Belgium were spending more on agricultural research and development. This spending means that they encompass a broad range of activities to innovate new agricultural innovation and production. The amount of municipal waste being recycled has been steadily increasing in those countries.

In most of the selected EU countries, the growth of agricultural factor income (AFI) was not in a favorable position. A substantial number of farms are not in a position to pay their variable costs. However, there are still viability challenges in the agriculture sector in Hungary, Poland, the Czech Republic, and Slovakia. It becomes noticeable when considering the capability to meet overall expenses, including own and external production factors.

The prevalence of the obesity rate was not so significant in V4 countries. Obesity rate and excess weight were low only in the cases of Hungary, Poland, the Czech Republic, and Slovakia. The reason behind this obesity rate and excess weight is malnutrition. Malnutrition occurs due to poor-quality or insufficient nutrient intake, including undernutrition (chronic or severe condition) and micronutrient deficiency.

However, concurrently worldwide, 1–1.5 billion people are overweight, and 675.7 million adults are obese, which has become a rising trend in many countries, largely due to nutritional changes towards increased sugar, animal protein, and trans-fats [77]. Considering these urging issues, there is growing concern that the Sustainable Development Goal (SDG) 2 aimed at ending hunger will not be achievable by 2030.

Furthermore, the ammonia emission explained 37% of the total variance, which showed significant impacts on the environment. Comparatively, high-income, developed EU countries emit higher ammonia (NH3). Additionally, the harmonized risk for pesticides had an impact. This emission affects the global food systems and harms the atmosphere by causing substantial destruction of natural ecosystems [78].

The major components were presented separately in Figures 1 and 2 for the food security and SDG blocks. In the next step, the two blocks were related to each other by PLSR (Figure 3). Bold acronyms denoted the variables in the SDG block, while acronyms with regular font represent the variables in the food security block.

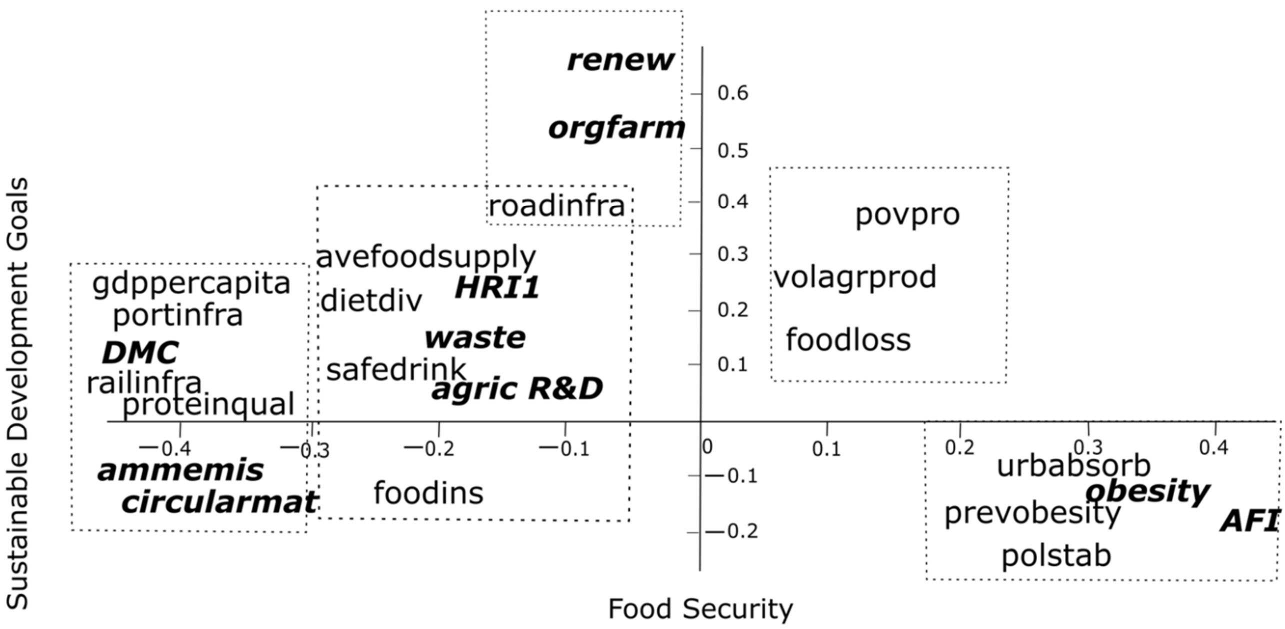

Figure 3. The PLS weights (W') and loadings (Q') for the first two PLS components.

The so-called variable importance in projection (VIP) indices in PLSR detected the most important variables in determining food security. The following VIP indices could be obtained in the order of importance: domestic material consumption (1.34), agricultural factor income (1.26), circular material use rate (1.21), ammonia emission (1.13), and obesity

(1.07). The less relevant predictors were the harmonized risk indicator for pesticides (0.59) and poverty of proportion (0.68).

The connection between SDG indicators and food security indicators was visible in Figure 3. For example, volatility in agricultural production is connected with food loss (availability) and could increase the poverty ratio. However, this was less significantly correlated with food security and SDG. Another dimension of availability was urban absorption and political stability, which was correlated with obesity rate. Rising urban absorption capacity (urbabsorb) in most developed economies has boosted scores, because of the stable political situation. Urban absorption capacity compares a country's real GDP growth rate with its urban population growth rate and is a proxy for the country's capacity to feed its population in the face of urbanization. The obesity rate in urban areas of all CEU countries continues to increase.

Switching from conventional to organic farming (orgfarm) could increase energy efficiency, because it can balance renewable energy (renew) inputs and increase productivity, which will improve food security.

Agricultural research and development (agri R&D), waste management (waste), and harmonized risk indicator of pesticides (HRI1) were correlated to food quality (diet diversity and food supply). Severe food instability (foodins) and adequate safe drinking water (safedrink) influenced the food stability status but less significantly. Overall, food production and consumption processes were significantly connected with the following factors: agri R&D, waste, dietdiv, avefoodsupply, and safedrink. The correlation between these two blocks of variables along the second component was highly significant ($r = 0.612$; $p < 0.001$), which also revealed that production and consumption have a positive impact on the SDGs and on sustainable food security and indirectly supported the first hypothesis.

The circular material rate (circularmat) and domestic material consumption (DMC) influenced food accessibility factors and correlated to ammonia emissions (ammemis). More consumption of DMC will increase emissions, and an increase in circular material use will balance the ammonia emissions. In Figure 3, DMC (with the highest VIP index of 1.34) was the most influential on both sustainable food security and SDG among the CEU countries. The correlation between these two blocks of variables along the first component was highly significant ($r = 0.935$; $p < 0.001$), which also supported the second hypothesis.

Table 2 presented the cross-validation result. The percentages of the RMSE values compared to the averages were calculated for all the dependent variables. In case of severe food instability, urban absorption rate, and volatility of agricultural production, higher rates were obtained for RMSE; the rest of the prediction can be considered acceptable, especially accessibility and quality. A paired sample *t*-test was performed for investigating the differences between the train and test data. The calculated mean difference was 0.944, and the t-statistics indicated no significant difference ($t = -0.635$; $p = 0.537$).

Table 2. RMSE values (as a percentage of the average) of the dependent variables.

Variables	Test	Train	Orig
volagrprod	26.84%	38.51%	36.30%
urbabsorb	51.46%	55.53%	54.48%
foodloss	31.32%	22.70%	21.87%
polstab	16.52%	25.71%	24.16%
roadinfra	23.55%	15.22%	15.51%
portinfra	8.04%	10.03%	9.76%
railinfra	8.74%	11.81%	11.23%
gdppercapita	9.39%	7.26%	6.89%
avefoodsupply	5.47%	6.40%	6.13%
proteinqual	6.92%	8.04%	7.87%
dietdiv	5.24%	3.79%	3.73%
severefoodins	40.94%	38.98%	37.92%
safedrinkwater	2.24%	4.94%	4.61%
prevobesity	6.41%	7.38%	7.33%

Source: authors' calculation.

5. Discussion and Implications

5.1. Discussion

A significant finding of PLS-Regression was that exposure to the domestic materials consumption rate directly affects food security, which is one of the lowest concerns in the most competitive EU countries. The other major finding was that the SDGs neglect to monitor absolute resource use patterns and instead prioritize economic development over environmental integrity. Domestic material consumption increases the natural resources used for food production and the manufacture of other useful items and commodities, which explicitly affects sustainable food security. In addition, from 2000 to 2010, the rising of DMC use from 48.7 to 71.0 billion times represents the rising use of natural resources.

The FAO showed that every year 1/3 of the food produced is lost or wasted, resulting in an economic loss of roughly 1 trillion dollars. The global volume of food wastage is projected to be 1.6 billion tons of "primary product equivalents," with 1.3 billion tons of edible food wastage [79]. Moreover, the world's food distribution is unequal. Over 820 million people are still hungry and malnourished worldwide, despite more than 2 billion people being overweight or obese. This highlights the enormous difficulty of reaching the zero hunger goal by 2030 [80].

On the other hand, the United Nations Sustainable Development Agenda aspires for a 50% reduction in food loss and waste (FLW) by 2030 [81].

The target of sustainable development for economic growth by efficient use of resources can be reached, and wastage generation should be minimized by increasing circular material use rate. Changing our production and consumption patterns will directly affect the environment, not just people's lives.

However, the variance in resource inputs of each step of the food supply chain (FSC) affects the environmental advantages of FLW reduction [81].

Surprisingly, in Figure 3, PLS-Regression explored changes in the underlying metrics of GDP and DMC rate from 2012 to 2019. Scientific evidence showed that economic growth has decoupled from capital utilization in the EU, which was interconnected by the port and rail infrastructure development. More developed infrastructure ensures the smooth distribution of food and ultimately triggers more production processes. An economic value of an average of EUR 1.34 per kilogram of domestic material is consumed in the EU. This represents a significant increment since 2012 in resource productivity efficiency. This long-term increasing trend in efficacy takes place as GDP increased faster than DMC. To achieve food security, the efficient utilization and effective management of scarce natural resources such as wood, oil, and water are necessary.

Moreover, 1.21% of the circular materials use (CMU) rate was observed between 2012 to 2017, and this is also connected with domestic material consumption and ammonia emission. Greater use of circular materials ensures resource-efficient, green, and competitive low-carbon emissions. A higher rate of CMU ensures less DMC for agricultural production. Ultimately, ammonia emissions from agriculture will decrease. However, many studies have centered on GHG emissions, which tend to be much more significant in high-income countries. Agricultural activity accounts for 80–86% of overall pollution from the food system, including indirect emissions resulting from changes in land use, with significant regional variations. [82]. Nevertheless, the recent study did not find a relevant relationship between the harmonized risk indicator for pesticides variable and food production and safety. Instead, it was revealed that the average ammonia emissions from agriculture were 1.13 tons per year in the selected EU countries between 2012 and 2017, which was primarily originating from livestock excreta. Many environmental policies linked to water and air quality revolve around livestock manure management. Therefore, reducing ammonia emissions from agriculture is a key factor in improving air and water quality and sustainable development. Ammonia and nitrogen generated as NH3 during animal protein production represent the greatest atmospheric loss of reactive nitrogen from livestock production systems. It had a direct correlation with protein quality.

Achieving food security targets through SDG and a transition towards sustainability is difficult to accomplish simultaneously due to their complexity and interdependencies on various relative factors. Consequently, this research looked into a few key characteristics that directly impact and determine the status of sustainable food security, the majority of which are linked to agricultural factor income. Results showed the agricultural factor income from 2012 to 2019 per labor unit increased by 1.26%. As a result, worldwide food production is adversely impacted by developed countries' market interference, which can afford to subsidize their domestic agriculture and export their surplus goods to developing countries, thereby displacing local farmers or food producers [83]. Additionally, public expenditure on agricultural R&D can promote mixed cropping and integrated farming systems and introduce new crops (such as soybean), which can improve overall food security status.

The average ammonia emissions from agriculture was 1.13 tons per year in the selected EU countries between 2012 and 2017, primarily originating from livestock excreta. However, reducing ammonia emissions from agriculture is a key factor in improving air and water quality and sustainable development.

Agricultural factor income measures the income generated from farming, and it significantly affected the food security status of the selected European countries and was correlated with urban absorption capacity, obesity, the prevalence of obesity, and political stability. This indicates the people can work under the stresses caused by urban growth that increased the AFI and still ensure food security. The prevalence of obesity in the urban population was also correlated with economic affluence, reflecting a potentially unfavorable outcome associated with GDP and economic growth, which was correlated with urban absorption capacity. In the chosen EU countries, the rate of obesity increased by 1.07% from 2014 to 2017. Food insecurity was intensified by political uncertainty. Political wars, refugee problems, government turmoil, and civil strife have witnessed the biggest decline in food security since 2012 in our selected EU countries.

Furthermore, marginalized rural farmers often lack the right routes for transport and other market entry mechanisms [84]. Average food supply, diet diversification, and road infrastructure were interconnected. Moreover, developed road infrastructure will ensure the average food supply and distribution adequacy, which can control severe food instability across the selected CEU countries. However, over 820 million people worldwide suffer from daily hunger, malnutrition, and less food consumption, and the lack of access to clean and adequate drinking water persists in a pressing concern [85]. Adequate quality and quantity of water are necessary for food production (fishing, crops, and livestock), processing, and manufacturing. The consistency of healthy drinking water determines the human body's effective intake of nutrients. Water stimulates industrial development, employment creation, and income generation and, ultimately, grants billions of people economic access to food.

In addition to this, the collection of municipal waste and management variations represented disparities in consumption and economic wealth patterns, which were associated with diet diversity. The amount of waste produced at the EU country level can be treated by landfilling, incineration, recycling of materials, composting, and generating electricity in waste-to-energy plants.

Moreover, a range of energy sources, including renewable and non-renewable resources, depend on organic and non-organic agriculture and food systems. The share of renewable energy was significantly correlated with the total EU area under organic farming and road infrastructures. Organic systems contribute less to GHG emissions with lower energy inputs and have a higher ability to sequester carbon in biomass. Renewable fuel sources help to reduce reliance on fossil fuel resources and mitigate environmental damage caused by pollution, but it maintains separate supply and transport chains, affected by road infrastructures. Vehicles on good road infrastructure use less energy for food carrying and distribution.

In Central European (CEU) countries, current socio-economic issues have been overlooked, such as comparatively high levels of unemployment, significant infrastructural underdevelopment, a need for enhanced transportation facilities between different parts of Europe, mass migration, the low purchasing power of the individual, standard of policies, environmental protection regulations, and so on [86,87].

The poverty of proportion was not significantly correlated with food security. Only 0.68% of people were under the global poverty line, where the average income was USD 3.2/day. The volatility of agricultural production lies in concerns about food security. Where both producers and consumers are severely and adversely affected by the low and high prices. A food price drop affects poor farmers and food producers, and a higher price prevents poor consumers from fulfilling their nutrition status. According to the most recent State of Food Security and Nutrition in the World (SOFI), around 690 million people in 2019 or 8.9 percent of the world population and over 12 million in 2018 have been chronically malnourished [80]. Indirectly, this status is affected by the price volatility of agricultural production, which ultimately affects food security.

The globalization of trade has significant impacts on biodiversity. International trade often generates loss and waste, which is threatening 30% of global species. The food produced in an area is exported and, in turn, loses natural resources but is also in a position where the cost of waste production is raised during the manufacturing processes [88]. Moreover, food loss and waste are also associated with food security and linked with the SDG 12 (targets 12.3, 12.4, and 12.5). States will minimize or eradicate unsustainable patterns in consumption and production and encourage effective SDG strategies to achieve the growth of a balanced and higher quality of life for the population. The relation between reducing food loss and waste (FLW) and nutrition is discussed explicitly in a study by Springmann published in Global Panel [89]. Kummu et al. [90] clarify variations across nations that define three groups of countries in terms of how food production relates to changes in diet, reduction in FLW, and increases in yield.

In the IPBES study and review of sustainability change pathways, it was revealed that the paradigm of the transition movements pathways has the broadest and most complete alignment with the UN-SDGs [54]. Additionally, the transition movements pathways can be divided into two groups: resource-sparing lifestyle pathways that emphasize the shift in dietary and overall patterns of consumption that eventually affect the domestic materials consumption pattern.

Transformation capability mechanisms primarily emphasize the role of local equality, deliberation, and social stability in achieving sub-regional diversification, integrated sustainable land use, and alternative livelihood. Some transition movement pathway studies highlight rules securing access to resources for susceptible groups [91]. These include innovative land use and management, such as agroecological approaches, particularly organic farming; drastically reduced energy consumption; urban built spatial framework and planning; lifestyle changes; local empowerment, social harmony and deliberation; diversification; strategies for subsistence on a sub-regional scale [54]. It is possible to connect these elements with the major SDGs, particularly SDG 2 and SDG 12, because the cross-sectoral aspects of food security issues are very evident.

5.2. Implications of this Study

The present study makes two vital contributions. First, the study investigated the risks of unsustainable production and consumption associated with food systems and the most prominent risks that have emerged due to resource deficiency in Central Europe. The dependency on imported foods and unsustainable overconsumption could also be exposed. Secondly, the excessive use of natural resources and DMC becomes the major concern of CEU countries, as this affects both food security and SDG.

The implication of the study was that policymakers should pay attention to three areas such as production and consumption exposure, the transition towards sustainability for achieving food security, and establishing global food security for reaching the targets of SDG.

One, policymakers should introduce green economies and ensure the greater use of circular materials for improving resource efficiency that benefits the environment or conserve natural resources to solve unsustainable production and consumption and environmental issues.

Two, policymakers should use legislation to create a robust social and economic welfare for CEU countries' poor farmers and need to build appropriate, decent working conditions for agro-industry labor and productive employment to promote sustainability for stabilizing individuals' food security.

Three, policymakers in CEU countries should ensure the efficient use of DMC that benefits the environment and conserves natural resources to improve the overall food security status.

The study also implied that governments, policymakers, relevant industries, consumers, and other stakeholders should pay attention to efficient controlling of DMC. Governments and policymakers should ensure the efficient use of DMC that benefits the environment and conserves natural resources to solve food security and sustainability issues and reduce the risk of food insecurity. Efficient controlling of DMC is a new aspect of inclusive food security research. This article significantly contributed to the study on food security and SDG literacy concepts. It mainly highlighted the powerful linkage between the efficient production and consumption of domestic materials that help to achieve sustainable food security. The idea of DMC is still evolving to be included as a core issue of achieving food security, both in the theoretical and practical perspectives. Hence, future research across disciplines is required to retrace and establish unique and combined indicators that reveal the potential paths of food security concerns. Present research emphasized the importance of DMC and included it in food security targets. The study's empirical findings also provided valuable recommendations for policymakers to improve food security in the CEU country context. A comprehensive and long-term plan and policy should be introduced broadly to bring awareness to use domestic material consumption among the rural and urban population and count it as a key driver of food security and SDG target achievement.

6. Conclusions

Resource depletion, ecological degradation, and climate change are influenced and triggered by present food systems. Understanding the core principle components of the SDGs' objective towards achieving food security would support the CEU countries' government, policymakers, researchers, and business leaders to redesign and reshape the strategy, rules, and regulations. Besides, authorities need to know and understand the factors affecting food security status in regions with chronic dietary and nutrition insecurity, sustaining high levels of participation.

The overall findings indicated that while there is a substantial rise in DMC trends in the selected CEU countries over the entire span because of economic growth, higher income and living standards drive an increase in food demand. In CEU countries, food security showed a significant increase, but the sustainability of resources decreased. The results illustrated the underlying gaps related to these various metrics, which have many policy ramifications. It can be argued that the success of the EU's resource utilization is so important and could be misguided by focusing only on the DMC as a predictor. The startling contrast between the DMC and other food security indicators also indicated that breaches and sourcing problems exist within the material usage of the EU.

Additionally, the findings of this study not only offered valuable information on which country performs most efficiently in terms of DMC, but also revealed that even the secondary factors (AFI, circular material usage) influenced the overall goal achievement. For example, growth in the usage of circular materials can improve the economy, while reducing waste stockpiles can help to reduce domestic material usage or increase energetic production.

Results of the analyses pointed out that it is not enough to increase the average food supply or to reduce the ammonia emission in order to achieve food security or sustainability. Rather, an adaptation of the efficient use of DMC, "sustainable intensification", intensive support on research, and development activities will accelerate the transition towards sustainability.

The key drivers of accelerating food security in Central Europe were DMC, AFI, and circular material usage, and the implementation of such efficient consumption improvements would intensify the pressure of directly consuming parties to balance their consumption behavior.

Both supply- and demand-side policies should also be adopted to find a new way to achieve sustainable food security, such as prevention of food waste, overconsumption, obesity, and cumulative environmental footprint, through policies, e.g., high R&D, collective farming, and mobilizing public and private investments. It can be concluded that it would be important to link the debate on food and nutrition security and the sustainability of the food system by reducing domestic materials consumption to make a consistent framework for the necessary transition to sustainability. It is also demonstrated that long-term food security is a key result of sustainable food systems in its availability, accessibility, utilization, and stability dimensions by exploring the relationship of efficient use of domestic materials. Our result showed that the transition towards sustainability would entail a shift from an agriculture-centered policy and analysis paradigm to a food systems policy. The investigation of the complexities of food systems in a manner that promotes collective effort should be a part of future research.

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