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Article

Sustainable Agriculture's Contribution to Quality of Life

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Abstract: The multidimensional character of sustainable agriculture mandates a systematic examination of this concept, necessitating methodological rigor for comprehensive analysis. In line with this imperative, the formulation of the composite index for sustainable agriculture was achieved through a compound, multi–stage procedural framework. This process involved the systematic grouping of 44 indicators into a specialized set, thereby delineating distinct facets within the dimensions of environmental (comprising 20 indicators), economic (comprising 16 indicators), and social (comprising 8 indicators) domains. This study aims to establish the correlation between the advancement of sustainable agriculture and quality of life, which encapsulates the circumstances of an individual's existence. The significance of probing this correlation lies in the fact that sustainable agriculture, rooted in the efficient utilization of natural, social, and economic resources, inherently influences the quality of life—a paramount objective in the realm of social development. The quality of life in this study is represented by the Quality–of–Life Index (QoL) computed by CEO World. To achieve the aforementioned objective, a combination of complex methodologies was employed, encompassing quantitative analyses (statistical, bibliometric) and qualitative analyses (analysis and synthesis). The outcomes reveal that a systemic approach is most suitable for researching sustainable agriculture. The assessment of sustainable agriculture through the composite index underscores the relevance of all three dimensions in its formulation. Results from the correlation analysis suggest a robust connection between sustainable agriculture and quality of life. Simultaneously, a prominent level of interdependence between GDPs per capita and sustainable agriculture is observed.

Keywords: sustainable agriculture; quality of life; agricultural sustainability index; organic farming; ecosystem; food system; agricultural knowledge; agricultural innovation

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1. Introduction

The functional peculiarities of agriculture determine the feasibility of achieving the fundamental objective of any country's—socioeconomic system, namely the assurance of its national security, with food security being a constituent component thereof. Among the various contemporary approaches to—socioeconomic development, the concept of developing sustainable agriculture is paramount, serving as the cornerstone in achieving food security and increasing the overall standard of living. The prerequisites for establishing an objective foundation for sustainable agriculture are multifaceted, entailing the judicious use of natural, social, and economic resources. The ultimate goal lies in reaching an adequate level of quality of life for the citizens.

The notion of "sustainable development" was introduced to the discussion agenda by the Report of the World Commission on Environment and Development: Our Common Future, which emphasizes the importance of fulfilling present needs without jeopardizing the abilities of future generations to meet their own necessities [1].

The concept of "sustainable development" has gained widespread recognition in the scientific community following the decisions made during the 1992 UN Conference on Environment and Development [2].

During this conference, a resolution was adopted, focusing on the imperative of improving the quality of life and living standards for the population. This objective was to be achieved via the efficient use of natural and material resources, along with concerted efforts to reduce environmental pollution. Simultaneously, it was argued that long–term collaboration among business sectors from different countries would ensure the economic growth of states that actively implemented investment policies and embraced new technologies [2].

In 1996, agriculture was formally integrated into sustainable development at the World Food Summit in the framework of adopting the Rome Declaration on World Food Security. Thus, the critical provisions aimed at achieving sustainable development in the agricultural sector were defined as ensuring food security, fostering the sustainable enhancement of both the quantity and quality of food production, harnessing new technologies to ensure food availability, curbing unemployment rates, alleviating poverty through increasing the income levels of the population, and promoting the rational use of natural resources and environmental protection [3].

Sustainable agriculture, as a field of research, defies clear–cut disciplinary boundaries because it is inherently a confluence of natural, social, economic, political, and even geographical phenomena/factors. Therefore, adopting a multidisciplinary approach to the concept of sustainable agriculture offers distinct advantages.

The multifaceted nature of the field under study inherently results in varying degrees of research focus on individual thematic directions. On the one hand, studies on sustainable agriculture and related issues have recently emerged as central and contemporary focal points of research [4,5]. On the other hand, the characteristics and consequences of disruptions in agriculture caused by events such as the COVID-19 pandemic and the war in Ukraine have unveiled a multitude of challenges. Addressing these challenges holds significant implications for the sustainable development trends of national economic systems [6–8].

The area of research pertaining to sustainable agriculture is notably extensive, frequently requiring the comprehensive assessment of numerous influencing factors. The ultimate challenge lies in the transformation/translation of these broad and somewhat abstract concepts into a tangible and practical assessment methodology in line with the core objectives of sustainable agriculture (the "three legs" of the sustainability stool), namely environmental health, economic profitability, and social and economic equity [9].

The primary goal of sustainable agriculture is to increase societal resource productivity through the integrated and efficient use of resources, minimizing waste. Moreover, the semantic content of sustainable agriculture extends beyond the mere organization of agricultural practice. It encompasses correlations with various complex categories, including but not limited to food security and quality of life.

Among the many challenges countries face, the development of sustainable agriculture stands as paramount. Through its integrated and efficient functioning, it bolsters the livelihoods of the population and contributes to an elevation in their standard of living and its quality. In this context, the preservation of territorial integrity and the enhancement of the quality of people's lives in harmony with the environment should become the primary objective of the agri–food policy.

Building upon the aforementioned arguments, this investigation proposes a research framework centered on increasing the population's quality of life through sustainable agriculture.

The purpose of this study is to shed light on the potential areas to be exploited in the field of sustainable agriculture and to establish the correlation between sustainable agriculture and the quality of life.

To achieve this aim, the research is guided by the following specific objectives: (1) developing the concept of sustainable agriculture through a systemic perspective, (2) building the sustainable agriculture assessment methodology, and (3) delineating the interrelationship between the sustainable agriculture index and GDP per capita and the quality of life.

To address these objectives, the following research hypotheses were formulated:

H1: *In the case of sustainable agriculture, no single relevant factor serves as the main catalyst for outcomes.*

The pursuit of sustainable agriculture necessitates a comprehensive and interconnected system that combines environmental, economic, and social resources. To achieve this, a strategy for sustainable agriculture should not only be targeted but also encompassing, stabilizing, and supportive of all its functional characteristics. In this context, adopting a systems perspective becomes essential to identify the prerequisites for transforming conventional agriculture into a sustainable one, by determining the interconnections between its multiple components. Developing a methodology for assessing complex phenomena is paramount, and constructing a Sustainable Agriculture Index can play a pivotal role in determining the factors contributing significantly to its formation. To achieve these objectives with an impact on the hypothesis, a combination of qualitative methods, such as thematic analysis, and statistical methods, will be employed to identify the mechanisms of interaction and the key factors catalyzing the main outcomes of sustainable agriculture.

H2: *There is a linear relationship between the value of the Sustainable Agriculture Index and GDP per capita.*

The development of sustainable agriculture can be conceptualized as a process that harmonizes the population's needs for agri–food products with the use of natural resources, advancements in science and technology, and institutional changes. This constructive interaction aims to preserve the environment for future generations by avoiding destructive practices. Consequently, the development of sustainable agriculture is directly tied to the efficient use of intellectual, natural, and economic resources to enhance the population's quality of life and increase food production. To sustain agricultural development over the long term, a balance among the economic, environmental, and social components is imperative. Building on these findings, the composite index serves as a valuable tool for assessing progress, though continuous monitoring is essential. Motivated by these considerations, our objective is to investigate the relationship between the Sustainable Agriculture Index and other macroeconomic parameters. To assess the hypothesis that there is a direct relationship between the Sustainable Agriculture Index and GDP per capita, we will employ a statistical method, specifically linear regression.

H3: *A mutual connection is evident between sustainable agriculture and its constituent elements on the quality of life.*

One of the objectives of sustainable agriculture is to enhance farming efficiency concurrently with improving the quality of life for citizens in a healthy and secure environment. Increasing the quality of life stands as an important goal of sustainable agriculture, encompassing accessibility and full use of material, social benefits, and spiritual values. The more diverse they are, the closer they are to distribution standards, and the more fully saturated in terms of value, the higher the quality. The assessment of these complex concepts involves constructing composite indices. To achieve our goals, we aim to discern the interrelation between sustainable agriculture and quality of life. This hypothesis will be assessed using statistical methods, specifically the Spearman correlation, to identify the link between the Sustainable Agriculture Index and the Quality–of–Life Index. It is essential to note that the outcome reflects not a simple correlation between two indicators but a more intricate relationship, representing the connection between two synthetic indices, each derived from aggregating 44 and 23 individual indicators, respectively.

The structure of the study comprises several sections. The second section encompasses a comprehensive review of the specialized literature regarding the dimensions of sustainable agriculture and assessment methodologies. The third section provides a detailed account of the materials and methods employed in the research. In the fourth section, the data and variables used in the analysis are presented. The fifth section is dedicated to the presentation of the obtained results. Subsequently, in the sixth section, the results are subjected to analysis and interpretation. Finally, the study concludes with the seventh section where the findings and insights are summarized.

2. Literature Review

The scientific community approaches the development of sustainable agriculture from a multidimensional perspective, exploring its multifaceted objectives. Sustainable agriculture ensures the country's food security, encompassing the production of agricultural raw materials, commodities, services, and the provision of public goods. Furthermore, sustainable agriculture is intertwined with objectives such as fostering economic growth, upholding environmental sustainability, and preserving cultural and historical traditions, all with the goal of improving the quality of life and living standards for the population.

In Table A1, we analyze several perspectives that can be integrated into three distinct dimensions, each emerging from the specifics of sustainable agriculture, as argued in the specialized literature.

In this regard, several publications emphasize the environmental dimension of agriculture, which can be further subdivided into two groups: –nonproductive and productive. Authors from the first group, for instance, consider the impact of agricultural intensification on air quality [10], water quality [11], soil health [12], and biodiversity [13].

The second cluster of publications focuses on the interconnections between sustainable agriculture and the environment. In this context, ecosystems are positioned at the forefront of the advancement of agricultural production [14]. For example, Rehman et al. argue the significance of investigating the interdependencies between agricultural production and other natural ecosystems. Their work highlights the potential to identify the reciprocal exchange of services within these systems [15].

The next facet of sustainable agriculture pertains to its economic dimension, which can be further subdivided into several key directions. For the most part, the authors investigate the reciprocal impacts of the environment on agricultural production and, in turn, the repercussions of agricultural practices on the environment [16]. The field of food production within sustainable agriculture has been in practice for several years, with several publications presenting evaluations, thereby identifying gaps and formulating key conclusions [17]. A noteworthy avenue within sustainable agriculture is organic farming. Scholars researching organic farming primarily focus on its distinctive features [18], as well as its performance when compared with conventional agriculture [19,20].

The third dimension of sustainable agriculture revolves around its social aspect, and this sphere finds its specialized literature divided into several thematic directions. Thus, some authors analyze the impact of sustainable agriculture on consumer behavior [21]. Others explore the attitude of consumers from different countries toward the concept of sustainability [22]. Effective human resource management is a core aspect of sustainable agriculture. Given that rural populations, typically working in this sector, have unique demographic characteristics, it is essential to manage and develop their skills. Sustainable agriculture functions at the intersection of deep regional historical and cultural traditions and the demand for advanced technologies and high qualifications [23,24]. Sustainable agriculture, as a broad domain encompassing both production and consumption, also requires research into the context of sustainability concerning nutrition [25]. Furthermore, an expanding area within the social dimension of sustainable agriculture pertains to the adoption of digital transformation of sustainable agriculture and the use of artificial intelligence [26,27]. Research in this field is characterized by its very dynamic nature and sound interdisciplinary focus. Zhou et al. ingeniously integrated environmental regulation, digital transformation, and agricultural productivity into a unified framework [28].

To have a comprehensive understanding of the publications in this multidimensional field, we conducted a bibliometric analysis using VOSviewer software 1.6.19, visualizing a network centered around the term "Sustainable Agriculture". The data used for this analysis were sourced from the international Dimensions database.

The resulting conceptual network, presented in Figure 1, reveals that the term "Sustainable Agriculture" forms a network characterized by four distinct themes. The largest cluster, depicted in red, encompasses publications relating to the sustainable development of the food system. The second cluster, represented in green, focuses on plant growth, especially from an environmental perspective. Articles associated with environmental quality, especially air and water, form the blue cluster. Many publications in this field are dedicated to China because air, water, and soil pollution threaten the health of the Chinese population and represent an enormous challenge to the ecology of this country and the world's ecosystem. The last cluster, marked in yellow, is centered around the topic of soil quality within the context of grain cultivation.

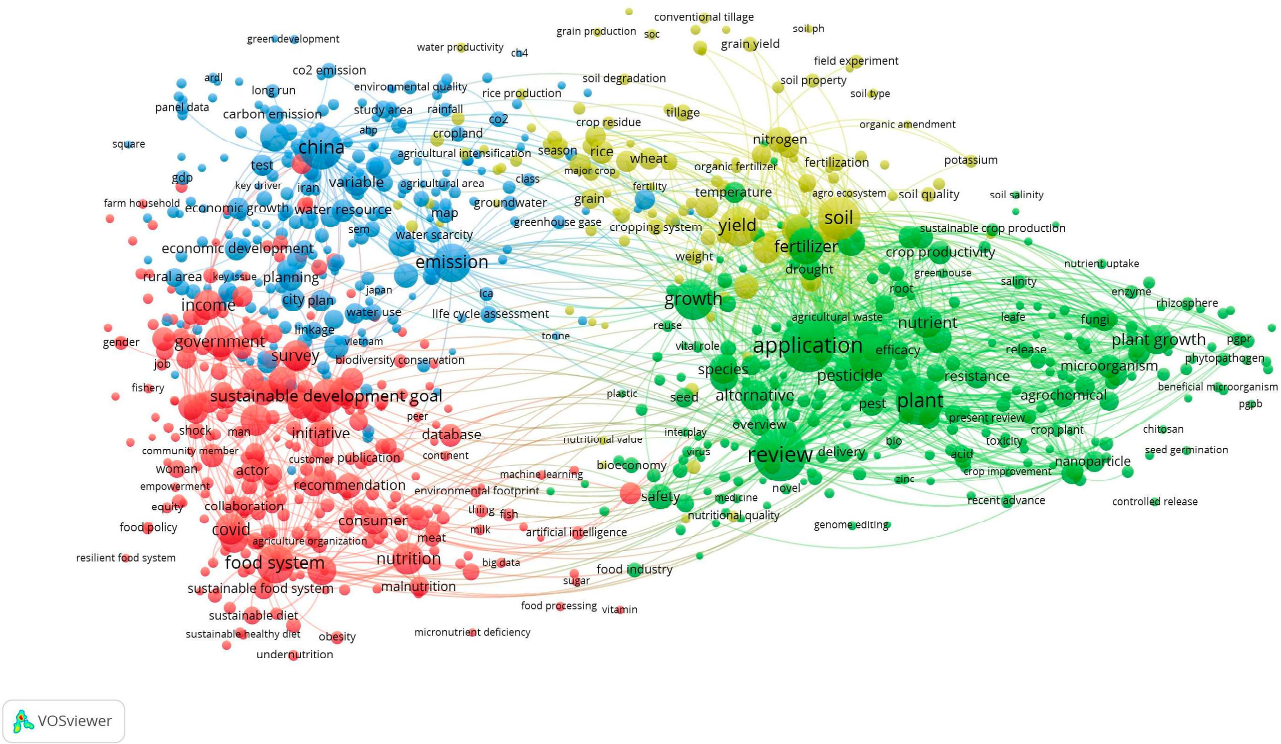

Figure 1. Network visualization of the term "Sustainable Agriculture".

Our bibliometric analysis of publications in the field of sustainable agriculture highlights that sustainable agriculture is a multifaced subject, and there is an emphasis, within specialized literature, on its environmental dimension, with the economic and social dimensions, often receiving less prominence.

Researching multidimensional concepts is inherently challenging because of the complexity of their assessment. Therefore, various studies have tackled the theoretical foundation and empirical measurement of sustainability [29,30]. The evaluation of multidimensional phenomena, especially those associated with development, requires the creation of composite indices that encompass multiple facets of the researched phenomenon [31–33]. Accordingly, sustainable agriculture can be appraised by means of composite indices, which provide quantitative assessments. The construction of composite indices allows researchers to select the indicators used to formulate the index and its scope. Thus, several composite indices are available for the evaluation of various components of agricultural sustainability [34–37]—these can be computed at various levels, ranging from a regional perspective of a country [38] to assessments at the national level (country level) [39,40], and even for multiple nations [41]. Xin et al. [41] developed a sustainable agriculture matrix, quantifying 18 indicators related to the three dimensions of sustainable agriculture, encompassing various groups of countries classified according to different criteria, such as income and geography. Given the extensive scope of sustainable agriculture, it is imperative to expand the number of indicators selected by researchers to more accurately reflect the complex nature of the field. Additionally, it is noteworthy that a country ranking was not carried out as part of the evaluation, which underscores the need for further completion and development of this research.

The methodological review of specialized studies in sustainable agriculture underscores the necessity for a deeper analysis of its social and economic dimensions in line with environmental protection. As for the evaluation of sustainable agriculture, although there are several studies in this field and several composite indices have been devised (Table A1), there remains an imperative for further in–depth research aimed at constructing a more comprehensive composite index for sustainable agriculture. Such an index should encompass a broader array of indicators that emphasize the economic and social aspects, while aligned with those of environmental protection.

The primary purposes of sustainable agriculture revolve around ensuring environmental quality, food security, and economic and social performance. These objectives serve as the foundation for achieving the goal of improving the living standards of the population. In this context, it is necessary to analyze the interconnections between sustainable agriculture and its constituent elements, along with their impact on the quality of life of the population.

3. Materials and Methods

While it has a widely accepted theoretical foundation, the conceptual framework of agricultural sustainability still falls short in elucidating the intricate phenomena that generate synergies among the three dimensions of agricultural sustainability.

The field of research into the development of sustainable agriculture is quite extensive. It frequently requires the examination of the evolution of the multitude of constituent elements and their intricate interrelationships. Therefore, it is important to approach sustainable agriculture not merely as a concept founded on three pillars (environmental, economic, and social) but as a system comprising these three dimensions that interact with one another (Figure 2).

To achieve the fundamental purpose of the study and the proposed objectives, a methodology is needed that would allow the evaluation of sustainable agriculture for its subsequent more detailed analysis. However, the diversity of environmental, economic, and –sociocultural issues, which determine the multitude of heterogeneous individual indicators that describe the processes of sustainable agriculture, unfold in different directions and have unequal significance. A more complete picture can be made based on a complex index, which makes it possible to reduce incomparable spatial and temporal data to a comparable form with the most minor loss of information.

The system of sustainable agriculture, being inherently multidimensional encompasses a combination of indicators and factors from diverse domains. To comprehensively assess the development of sustainable agriculture, an integrated approach is essential, predicated on the definition of simple indicators, the consolidation of these indicators, and the subsequent construction of a composite index.

Pursuant to the guidelines established by the Organization for Economic –Cooperation and Development (OECD), a composite index, or synthetic index, is a combination of all dimensions, objectives, individual indicators, and variables used in the assessment [42]. The development of composite indices typically involves several stages [42], as shown in Figure 3.

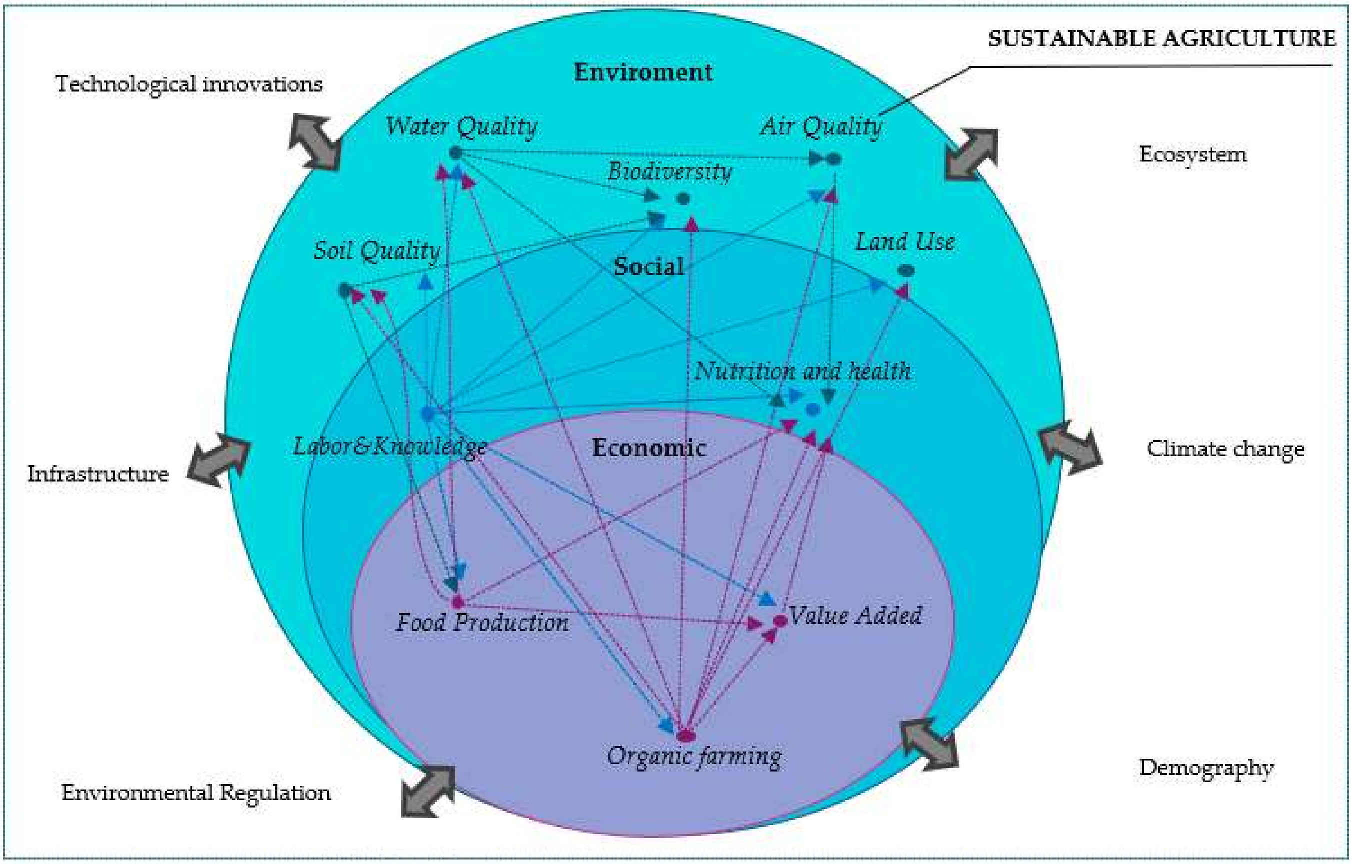

Figure 2. Linkages within the sustainable agriculture system.

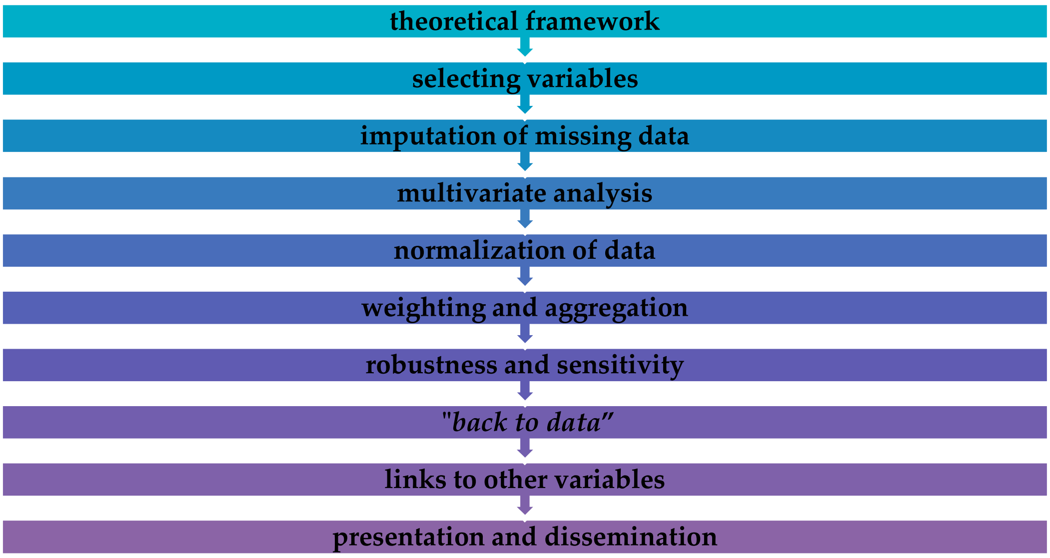

Figure 3. The process for constructing a composite index.

According to this methodology, simple indicators have quantitative values that reflect the state of the parameter in the studied subsystem. Generalizing indicators, on the other hand, provide an overview of a compartment in the subsystem and include the value of several simple indicators. Based on the value of the generalization indicator, it is possible to establish the current but preliminary assessment of the subsystem, which may necessitate further investigation. In this methodology, the composite index is an indicator that reflects the dynamics of values concerning the mean in the system, the statistical average, or the re–reference value and facilitates a direct assessment of the development of the system.

The purpose of this methodology is to quantify the integral sustainability of economic, social, and environmental values while identifying the factors that may hinder the progress of sustainable agriculture. Additionally, it aims to substantiate promising pathways for shaping the mechanism for the development of sustainable agriculture in the future.

The construction of any composite index begins with the definition of the indicator. This definition should provide a precise interpretation of what the composite index measures. Thus, the Agricultural Sustainability Index (ASI) must refer to the theoretical framework that interconnects various subgroups of fundamental indicators. The selection of indicators, along with their individual weights, reflects their respective importance within the broader dimensions of the composite index. In this context, the construction of ASIs should be based on what is intended to be measured rather than being constrained by the availability of indicators.

From a broader perspective, the sustainable agriculture system can be defined as an improvement of several critical functions:

- Minimizing the environmental impact in the agricultural production process;
- Sustaining the extensive production of agro–food products that uphold environmental safety;
- Promoting the consumption of organic farming products;
- Ensuring the increase of quality indicators and living standards under the influence of both internal and external environmental factors;
- Fostering research and innovation to optimize food production and boost labor productivity, consistent with protecting the environment.

In this context, we adhere to the notion that sustainable agriculture is a multidimensional system that can be effectively analyzed within three large dimensions: environmental, economic, and social.

ASI and its parameters were selected based on the theoretical concepts regarding the essence of the phenomenon of sustainable agriculture, the nature of the relationship between its dimensions, and the meaning of individual indicators for contrasting economic processes.

From an environmental perspective within the ASI, a –subindex of several variables is devised, comprising data related to the quality of environmental parameters. The subsequent –subindex measures the productivity of various agricultural sectors and the surplus they generate. The last dimension of the ASI quantifies the social aspects of sustainable agriculture.

An ASI is constructed by combining these three dimensions of sustainable agriculture. –Subindices are created for each category using a wide range of variables.

Additionally, it is essential to establish the selection criteria (input, output, or process) for the variables to be used. Given that the ASI is a composite index, it can include both input and output measures. For instance, it could comprise metrics such as the percentage of agricultural irrigated land (% of total agricultural land) (as an input measure) and organic export to EU and USA combined (% total agriculture export quantity) (results, i.e., as an output measure).

4. Data and Selection of Variables

The process of variable selection is one of the paramount steps in constructing any composite index. Variables should be selected based on their relevance, analytical validity, timeliness, and accessibility. However, the need for more pertinent data can constrain the ability to construct a reliable composite index. The ASI architecture is described in Table 1.

Table 1. Agricultural Sustainability Index architecture.

Subindex	Category	Variables	Source
Environment	Water Quality (WQ)	Annual freshwater withdrawal, agriculture (% of total freshwater withdrawal) [43]	World Development Indicators AQUASTAT
		Water productivity, total (constant 2015 US$ GDP per cubic meter of total freshwater withdrawal) [43]	
		Irrigation water withdrawal [44]	
		Irrigated agriculture water use Efficiency [45]	
	Air Quality (AQ)	Agricultural methane emissions (thousand metric tons of CO_2 equivalent) [46]	World Development Indicators
		Agricultural nitrous oxide emissions (thousand metric tons of CO_2 equivalent) [46]	
	Soil Quality (SQ)	Pesticides use per value of agricultural production [47]	FAOSTAT World Development Indicators
		Pesticides use per area of cropland [47]	
		Pesticides use per capita [47]	
		Fertilizer consumption (kilograms per hectare of arable land) [48]	
	Biodiversity (BD)	Bird species, threatened [49]	World Development Indicators
		Mammal species, threatened [49]	
		Plant species (higher), threatened [49]	
		Terrestrial protected areas (% of total land area) [49]	
		Fish species, threatened [49]	
	Land Use (LU)	Agricultural irrigated land (% of total agricultural land) [50]	World Development Indicators
		Agricultural land (% of land area) [50]	
		Arable land (% of land area) [50]	
		Average precipitation in depth (mm per year) [50]	
		Forest area (% of land area) [50]	
Economic	Food Production (FP)	Food production index (2014–2016 = 100) [48]	AQUASTAT FAOSTAT
		Crop production index (2014–2016 = 100) [48]	
		Livestock production index (2014–2016 = 100) [48]	
		Aquaculture production (metric kg/per capita), calculated based on [48]	
		Cereal production (metric kg/per capita) based on [48]	
		Cereal yield (kg per hectare) [48]	
		Agricultural raw materials exports (% of merchandise exports) [51]	
	Organic Farming (OF)	Organic area (% of total area) [52]	FIBL Statistics
		Organic producers [53]	
		Organic exporters [53]	
		Organic import (% total import) [54]	
		Organic export to EU and USA combined (% total agriculture export quantity), calculated based on [54,55]	
	Value Added (VA)	Agriculture, value added (% GDP) [56]	AQUASTAT FAOSTAT
		Agriculture, forestry, and fishing, value added (annual % growth) [57]	
		Agriculture, forestry, and fishing, value added per worker (constant 2015 US$) [57]	
		% of agricultural GVA produced by irrigated agriculture [56]	

Table 1. *Cont.*

Subindex	Category	Variables	Source
Social	Labor and Knowledge (LK)	Human development index [56].	AQUASTAT World Development Indicators
		Research and development expenditure (% of GDP) [58]	
		Employment in agriculture (% of total employment) (modeled ILO estimate) [59]	
		Employment in agriculture, female (% of female employment) (modeled ILO estimate) [59]	
		Employment in agriculture, male (% of male employment) (modeled ILO estimate) [59]	
	Nutrition and Health (NH)	Prevalence of undernourishment (% of the population) [60]	World Bank Open Data Health Nutrition and Population Statistics
		Prevalence of moderate or severe food insecurity in the population (%) [61]	
		Current health expenditure per capita, PPP (current international $) [62]	

Source: Authors' compilation.

The third stage of constructing the composite index is paramount and involves handling missing data. This step requires a complete dataset, usually through single or multiple imputations. There are three general methods for addressing missing data in such situations: deleting cases, single imputations, and various imputations. In compiling the ASI, we predominantly used single imputation in the instances of missing data.

Subsequently, in the fourth stage, a multivariate analysis must be conducted. As with previous stages, the nature of the database must be carefully analyzed before constructing a composite index. Like the previous ones, this stage is a preliminary one, useful in assessing the adequacy of the dataset. Moreover, it offers insights into the implications of the methodological choices in the construction stage of the composite indicator. In the development of the ASI, we segmented the information and analyzed the data in two dimensions: individual indicators and countries. At the same time, alternative methods combining cluster analysis and searching for a small representation focused on multidimensional scaling were applied. Consequently, subgroups of indicators or groups of statistically "similar" countries were identified. At the end of this stage, the multivariate analysis results were documented through the theoretical framework of the first stage.

The fifth stage, normalization, is performed prior to any data aggregation as the indicators have different units of measurement. This process entails the selection of a normalization method based on data characteristics. In our case, the normalization was performed using the min–max method.

ASI represents the rankings in quintiles of the simple average of indicators in the ASI subindices and varies on a scale from 1 to 10.

Indicators described in the subindices are reduced to a standard scale to compile the general ASI. Normalization is a crucial step due to the varied intervals of individual indicators, which render direct comparisons unfeasible. Therefore, the average index within the sustainable agriculture subindices is computed as a simple arithmetic mean.

To achieve equitable weighting of components, all elements are rescaled, and their values are recalculated to be between 0 and 10 range. For this, we use the following formula

$$V_{ic1} = \frac{V_{ic0} - min_i}{max_i - min_i} \times 10 \quad (1)$$

where: V_{ic1} is the recalculated value of indicator I for country c, V_{ic0} is the recalculated value of indicator I for country c, min_i is the lowest possible value of indicator I, and max_i is the highest potential value of indicator I [63].

Calculating the ASI can be divided into two stages. In the first stage, the –subindices of sustainable agriculture are determined, after which, in the second stage, the ASI is calculated as the arithmetic mean of the environmental –subindex, the economic –subindex, and the economic –subindex.

Index V_{ic1} is composed of the environment subindex (*envir_subind*), consisting of 20 indicators; of the economic subindex (*ec_subind*), composed of 16 indicators; and the social subindex (*soc_subind*), composed of 8 indicators. After all indicators are reduced to a total scale between 0 and 10, a subindex is calculated for sustainable agriculture according to Formulas (3)–(5):

$$envir\_subind = \frac{\Sigma_{i=1}^{20} V_{ic1}}{20} \tag{2}$$

$$c\_subind = \frac{\Sigma_{i=1}^{16} V_{ic1}}{16} \tag{3}$$

$$soc\_subind = \frac{\Sigma_{i=1}^{8} V_{ic1}}{8} \tag{4}$$

ASI_c is determined as the average of the three subindices having equal weight:

$$ASI_c = \frac{\Sigma_{i=1}^{3} V_{ic1}}{3} \tag{5}$$

where ASI_c is the Sustainable Agriculture Index for country c.

The next step involves weighting and aggregation. In the specific index under discussion, we opted for equal weighting—that is, all variables were assigned identical weights. It is important to note that equal weighting should not be misconstrued as the absence of weights; rather, it implies the uniform distribution of weights among the variables. From our standpoint, linear aggregation is the most suitable and straightforward method in terms of both implementation and interpretation.

In the context of linear aggregation, the contribution of each indicator to changes in the composite index determines its weight. In other words, an additive aggregation function allows for the separate assessment of the marginal contribution of each variable. In contrast, geometric aggregation generates greater complexity in interpreting the value of the composite index as it relies on the dynamics of a relatively extensive set of indicators. It is worth noting that in situations of comparative assessment, linear aggregation is preferred for countries with lower scores [42] (pp. 103–104).

In terms of weighting, the existing literature offers many alternative weighting methods, each accompanied by its distinct advantages and disadvantages [64–67]. In our analysis, we opted for principal component analysis (PCA), which, alongside factor analysis (FA), stands out as the most suitable technique for categorizing individual indicators according to their degree of correlation [68]. The primary objective of factor analysis is to reduce the number of variables by classifying them and determining the structure of the relationships among them. At the same time, it should be noted that the weights cannot be estimated if there is no correlation among the indicators. In our analysis, we used PCA.

Jolliffe defined PCA as a statistical procedure that orthogonally transforms the original n coordinates of a dataset into a new set of n coordinates, referred to as principal components [69] (p. 11). Following this transformation, the first principal component has the most significant possible dispersion; each subsequent component has a maximum possible dispersion, provided they are orthogonal (uncorrelated) with the preceding components.

The primary objective of PCA is to reduce the number of variables. Instead of the initial set of variables, PCA focuses on capturing the most substantial variation among the group of indicators while using the fewest possible factors. Therefore, the composite index no longer depends on the dataset size but rather on the "statistical" dimensions of the data [70]. To ensure that no single variable unduly influences the principal components, it is necessary to standardize the variables—x_s—such that mean values of 0 and unit deviations are recorded at the beginning of the analysis [71].

According to PCA, weighting is solely used to correct information redundancy that arises from correlations among two or more indicators. These weights are not indicative of the theoretical significance of the associated indicator. If no correlation is found between the indicators, PCA cannot estimate the weights [64]. Therefore, the first step in the analysis is to examine the correlation structure of the data.

From the matrix of the correlation of the ASI components (Table 2), the highest correlation is observed between the components Labor and Knowledge (LK) and Nutrition and Health (NH), marked by a coefficient of 0.900.

Table 2. The correlation of variables in the Agricultural Sustainability Index.

Variables	WQ	AQ	SQ	Bd	LU	FP	OF	VA	LK	NH
WQ	**1**	**0.335**	**−0.233**	**0.600**	−0.129	0.052	−0.016	**−0.617**	**0.644**	**0.620**
AQ	**0.335**	**1**	−0.021	**0.507**	−0.121	**−0.193**	**−0.300**	**−0.236**	0.153	0.143
SQ	**−0.233**	−0.021	**1**	−0.019	−0.063	0.025	−0.067	0.181	**−0.454**	**−0.342**
Bd	**0.600**	**0.507**	−0.019	**1**	**−0.220**	0.059	−0.160	**−0.418**	**0.373**	**0.431**
LU	−0.129	−0.121	−0.063	**−0.220**	**1**	0.048	0.185	−0.081	−0.183	−0.125
FP	0.052	**−0.193**	0.025	0.059	0.048	**1**	0.178	0.044	**0.244**	**0.331**
OF	−0.016	**−0.300**	−0.067	−0.160	0.185	0.178	**1**	−0.097	**0.231**	0.174
VA	**−0.617**	**−0.236**	0.181	**−0.418**	−0.081	0.044	−0.097	**1**	**−0.396**	**−0.374**
LK	**0.644**	0.153	**−0.454**	**0.373**	−0.183	**0.244**	**0.231**	**−0.396**	**1**	**0.900**
NH	**0.620**	0.143	**−0.342**	**0.431**	−0.125	**0.331**	0.174	**−0.374**	**0.900**	**1**

The second step identifies several latent factors (less than the number of individual indicators) serving as a representation of the dataset. Each factor depends on a set of loadings, with each coefficient quantifying the correlation between the individual indicator and the respective latent factor.

Table 3 displays the eigenvalues extracted from the correlation matrix of the 10 indicators (standardized values) constituting the ASI.

Table 3. Correlation matrix eigenvalues, Agricultural Sustainability Index.

	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10
Eigenvalue	3.515	1.800	1.157	1.003	0.795	0.599	0.428	0.370	0.255	0.077
Variability (%)	35.147	18.005	11.569	10.035	7.945	5.992	4.278	3.704	2.552	0.772
Cumulative %	35.147	53.152	64.721	74.756	82.702	88.694	92.972	96.676	99.228	100.000

PCA is conventionally used for factor extraction. In the context of factor analysis, it is customary to keep a subset of the principal components (m), particularly those with the highest value of the variation. The standard selection practice involves factors that meet the following criteria:

1. Have associated eigenvalues greater than 1;
2. Contribute individually to more than 10% of the overall variance explanation;
3. Cumulatively contribute to explaining over 60% of the total variation [64] (p. 56).

When applied to the ASI dataset presented in Figure 4, the factors with eigenvalues proximate to unity are the first five. They individually explain nearly 53% of the overall variance and cumulatively account for approximately 82% of the variance.

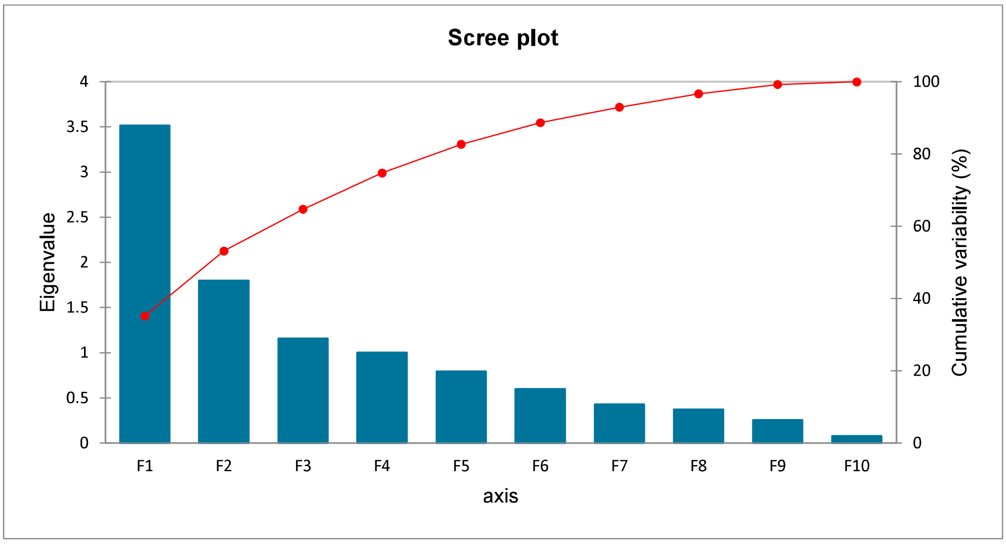

Figure 4. Factors with eigenvalues, Agricultural Sustainability Index.

Reducing the prevalence of individual indicators with substantial loadings on the same factor is achieved through rotation (usually varimax rotation). Rotation is a standard step within factor analysis. It alters factor loadings and, therefore, the interpretation of factors while preserving the analytical solutions obtained, ex– ante and ex– post rotation.

Eventually, we proceed to construct the weights of the factor loading matrix after rotation, which is based on the fact that the square of the factor loadings represents the proportion of the total unit variation of the indicator explained by the factor. The ASI dataset consists of five intermediate composites (Table 4). The first includes Water Quality (WQ: 0.740), Biodiversity (BD: 0.474), Value Added (VA: 0.750), Labor and Knowledge (LK: 0.750), and Nutrition and Health (NH: 0.728). The second intermediate composite consists of Air Quality (AQ: 0.474) and Organic Farming (OF: 0.494), the third is composed of Land Use (LU: 0.454) and Food Production (PF: 0.277), the fifth is composed of Soil Quality (SQ: 0.457). The fifth composite is irrelevant, which can be observed in Figure 4, which presents a value below unity.

Table 4. Loading factors for the Agricultural Sustainability Index based on principal components.

	Correlations between Variables and Factors:					Squared Cosines of the Variables:				
	F1	F2	F3	F4	F5	F1	F2	F3	F4	F5
WQ	0.860	−0.129	0.096	0.101	0.080	**0.740**	0.017	0.009	0.010	0.006
AQ	0.405	−0.669	0.107	0.061	−0.195	0.164	**0.447**	0.011	0.004	0.038
SQ	−0.403	−0.293	−0.336	0.676	0.281	0.162	0.086	0.113	**0.457**	0.079
Bd	0.688	−0.438	−0.119	0.272	−0.031	**0.474**	0.192	0.014	0.074	0.001
LU	−0.189	0.332	0.674	0.379	−0.443	0.036	0.111	**0.454**	0.143	0.197
FP	0.185	0.511	−0.526	0.388	−0.433	0.034	0.261	**0.277**	0.150	0.188
OF	0.076	0.703	0.149	0.210	0.488	0.006	**0.494**	0.022	0.044	0.238
VA	−0.649	0.073	−0.455	−0.278	−0.206	**0.421**	0.005	0.207	0.077	0.042
LK	0.866	0.313	−0.118	−0.199	0.030	**0.750**	0.098	0.014	0.040	0.001
NH	0.853	0.300	−0.187	−0.060	−0.066	**0.728**	0.090	0.035	0.004	0.004

Finally, we establish the factor loading matrix after rotation, rounded on the premise that the square of the factor loadings represents the proportion of the total unit variance of the indicator explained by the factor. The ASI dataset consists of five intermediary composites (as shown in Table 4). The first composite encompasses Water Quality (WQ: 0.740), Biodiversity (BD: 0.474), Value Added (VA: 0.750), Labor and Knowledge (LK: 0.750), and Nutrition and Health (NH: 0.728). The second intermediary consists of Air Quality (AQ: 0.474) and Organic Farming (OF: 0.494), the third is composed of Land Use (LU: 0.454) and Food Production (PF: 0.277), and the fifth comprises Soil Quality (SQ: 0.457). Notably, the fifth composite demonstrates a lack of relevance, as is evident in Figure 4, where its value falls below unity.

In conclusion, the principal component analysis (PCA) was applied to the Agricultural Sustainability Index (ASI) dataset, encompassing all subindices of 108 countries for the year 2020. The aim was to find the linear combinations that capture the most significant variations in the data. Greater weight was given to a series that contributes more to the direction of the standard variation. Subsequently, subindices were aggregated into higher–level indices following the same procedure. It is important to note that there is no single relevant component of sustainable agriculture. In other words, while factors like Labor and Knowledge, Water Quality, and Nutrition and Health play a significant role in sustainable agriculture in many countries, they do not singularly act as primary catalysts for results. This observation is illustrated in Figure 5.

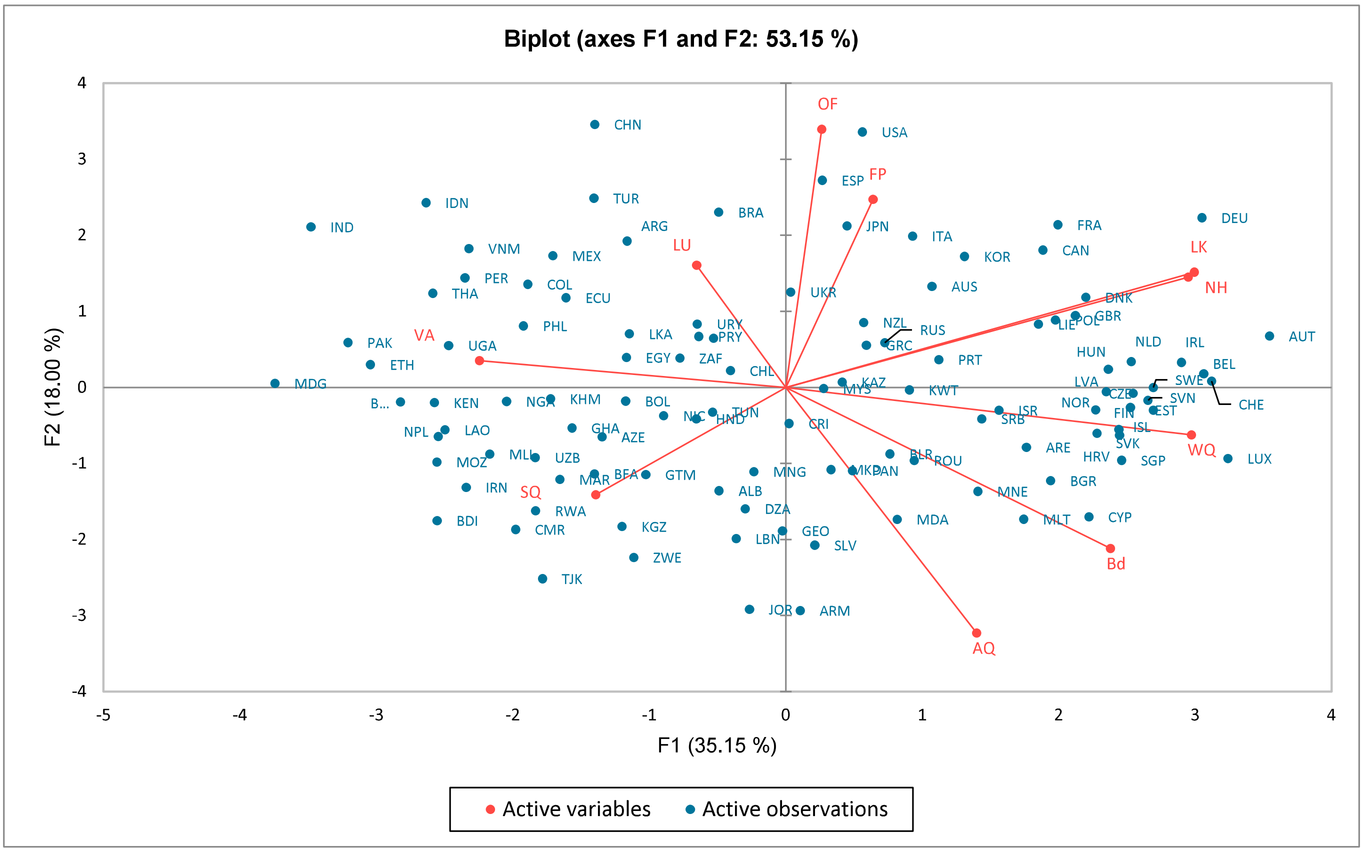

Figure 5. Principal components analysis, Agricultural Sustainability Index.

Sensitivity analysis is the eighth step in constructing the composite index and can be used to assess the robustness of the composite index. At this stage, sources of uncertainty were highlighted, and composite –subindices were developed. We conducted a comprehensive analysis of the variables detailed in Table 1 for all 108 countries during the construction of the –subindices.

According to OECD guidelines, the next step in developing the composite index involves a retrospective examination of the data [42]. The starting point of this step is that although composite indices highlight a country's overall performance and can offer valuable insights for policy development and data management, their primary function is to reveal the key determinants of either positive or unfavorable performance.

Hence, composite indices provide a launchpad for deeper analysis. Their breakdown allows for the identification and scrutiny of the country's performance by assessing the contribution of individual sub–components and indicators. In our case, the ASI comprises three –subindices, which, in turn, are divided into components that make distinctive contributions to the aggregated composite index and the resultant country ranking.

5. Results

The map of the Agricultural Sustainability Index (ASI), which encompasses 3 –subindices consisting of 10 categories and incorporates 42 individual indicators, is presented in Figure 6. This comprehensive index has been meticulously constructed for the assessment of 108 countries across the globe.

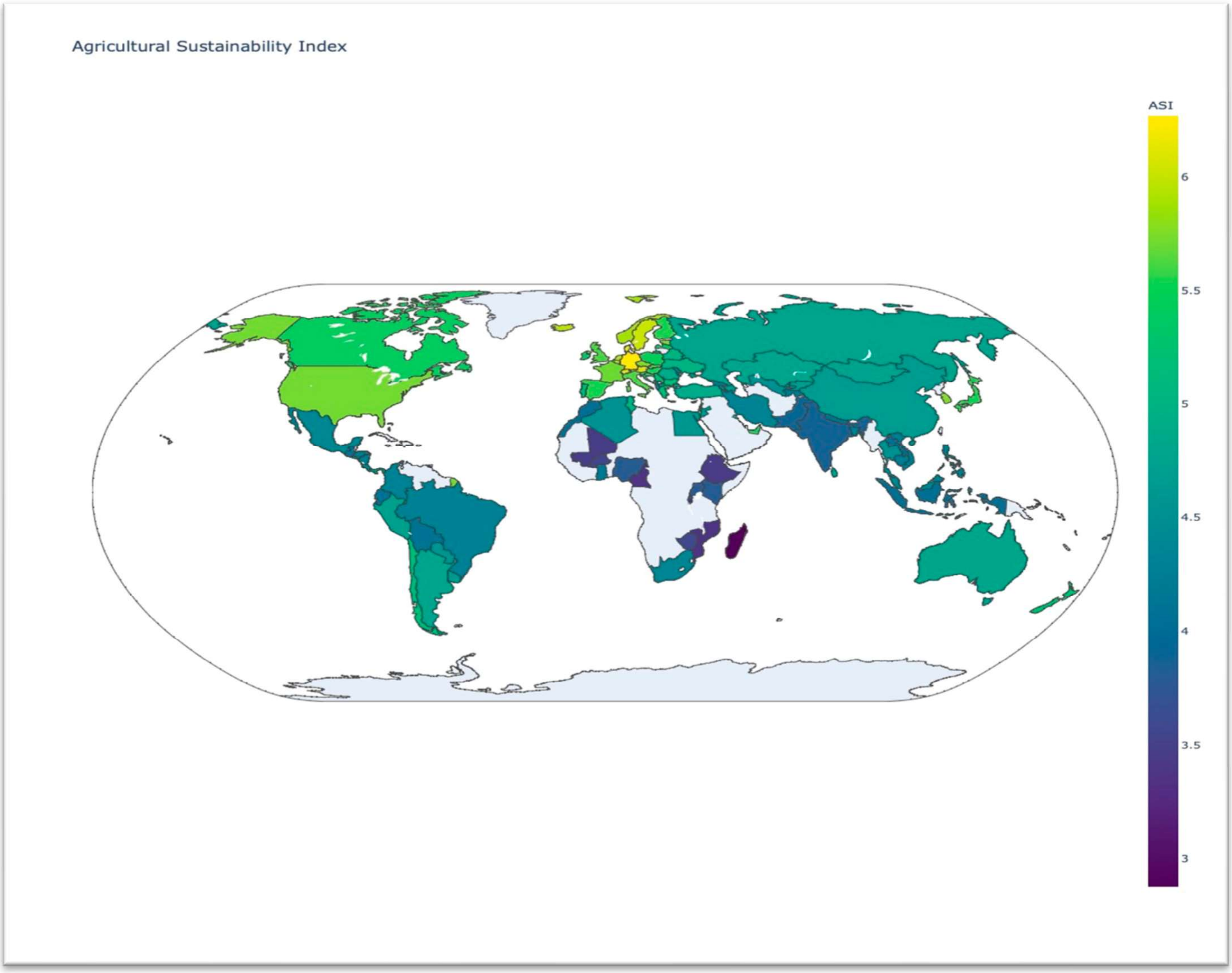

Figure 6. Agricultural Sustainability Index around the world.

The assessment of the various dimensions of sustainable agriculture via the composite index plays an essential role in determining the relationship between sustainable agriculture and quality of life.

For a more detailed analysis, the composite index was calculated for groups of countries classified by income level and disaggregated into the components of the three –subindices, which have different contributions to the final ranking.

Figure 7 illustrates that in high–income countries, indicators related to the Labor and Knowledge and Nutrition and Health components have significantly contributed to the composite index, unlike in low–income countries. At the same time, the value of Water Quality, Air Quality, Biodiversity, and Food Production components in these countries is higher than in low–income countries. In low–income countries, components like Soil Quality, Land Use, and Value Added hold more substantial importance. For the first two components, this can be attributed to the reduced use of pesticides and fertilizers in low–income countries due to cost constraints. Additionally, the Value Added component in countries with higher incomes often comes from fields with greater complexity than agriculture [72]. Interestingly, Organic Farming scored best in –low–income countries, with examples like Uganda and Ethiopia ranking second and sixth globally in the top six countries with the highest number of organic farmers [73].

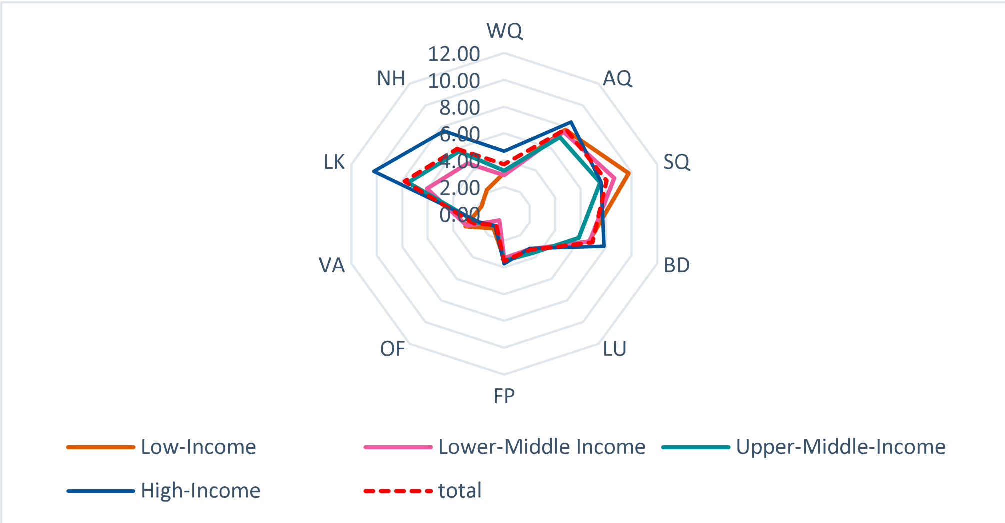

Figure 7. Radar chart of Agricultural Sustainability Index components (country groups by income level, 2020).

In this way, the ASI breakdown can clarify the overall performance of a particular country or group of countries. In addition, such an analysis assesses the correlation and causality (if possible). It determines both the primary contributors to the composite indices and the respective significance of their sub–components.

The next step in constructing the composite index is important because it measures the links with other composite indices or simple indicators.

These interdependencies, expressed as measurable variables within process–related indicators, are essential for testing the explanatory power of the ASI. We applied regression analysis to demonstrate these links between ASI and GDP per capita.

Figure 8 illustrates a clear connection between a country's GDP level and sustainable agriculture. The relationship between GDP per capita and sustainable agriculture is much more complex than a simple dependency between two variables, as the ASI is a synthetic index to which 42 individual indicators have contributed. The relationship between GDP per capita and ASI is a close one, with a variance of 83.2%. From Figure 8, we can also see that most countries are close to the trend line. Only Australia and the Kyrgyz Republic are off trend, with the former below the trend line and the latter above it.

It is worth noting that a change in GDP per capita does not necessarily lead to a change in ASI and vice versa.

Given that one of the objectives of sustainable agriculture is to enhance the quality of life, we endeavor to discern the complex connection between these two multifaceted concepts. The quality of life of the population stands as a paramount social category, delineating the structure of human needs and the feasibility of their fulfilment. Indeed, quality of life can be construed as the foremost criterion to assess the effectiveness of the –socioeconomic policies of a state.

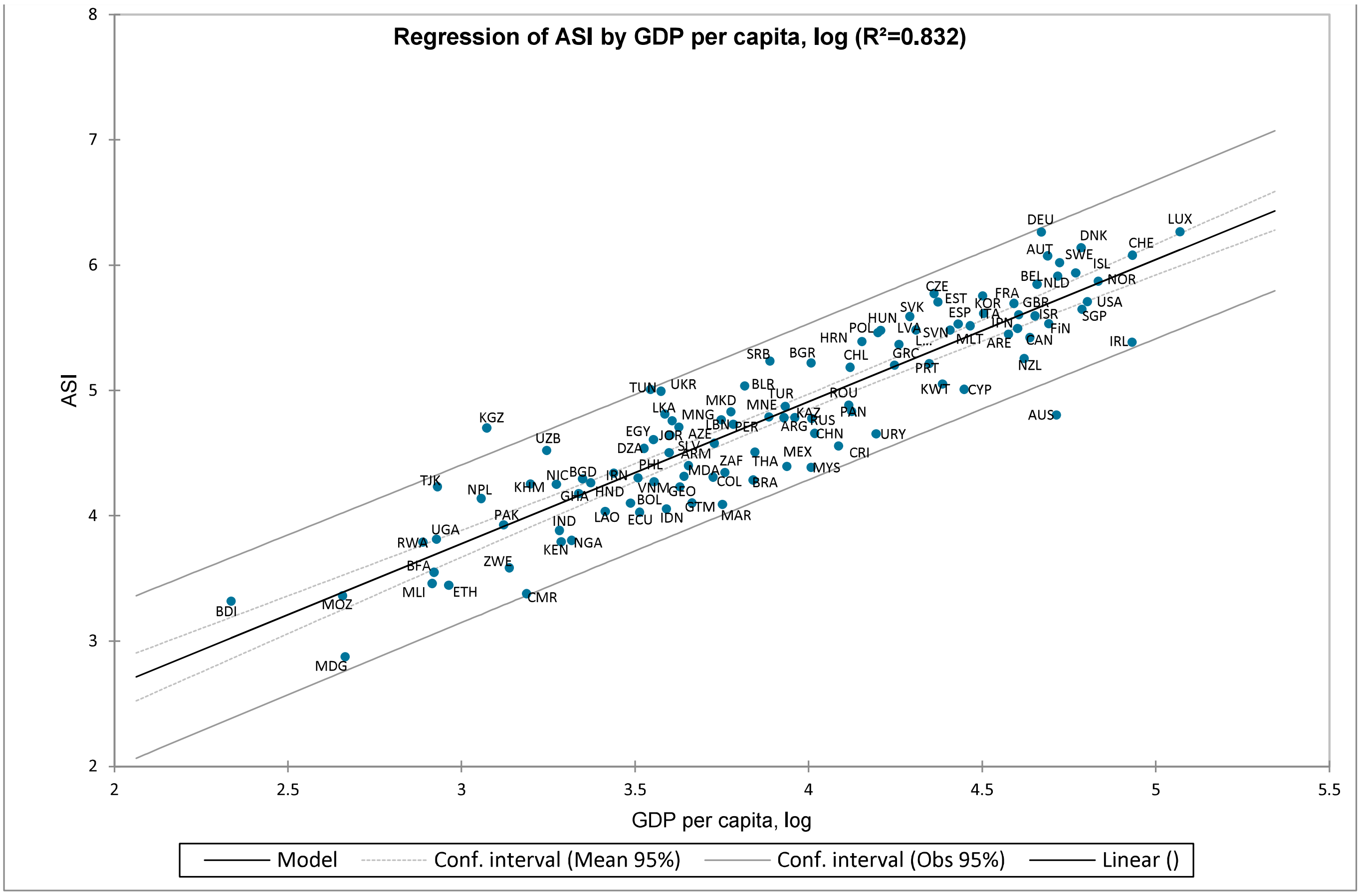

Figure 8. Interdependence between Agricultural Sustainability Index and GDP per capita, log.

The quality of life is a holistic measure of people's standards of living, encompassing the possibilities and extent of satisfaction of their material, spiritual, and social needs, along with their subjective perception of life and its various facets. Therefore, quality of life constitutes a comprehensive concept that extends beyond mere economic well–being [74].

To understand the reciprocal relationship between sustainable agriculture and quality of life, we will examine the correlation between the Quality–of–Life Index and the Sustainable Agriculture Index, including its –subindices. For the quality of life, we selected the composite Quality–of–Life Index (QoL) provided by CEO World. This index consists of three –subindices (Stability, Satisfaction, and Balance) calculated based on 23 individual indicators [75].

In Figure 9, the Spearman coefficient was used for the correlation. It is generally accepted that the strength of the correlation coefficient, as an indicator of the measure of interdependence, differs in three levels for both positive and negative correlations: $\rho > 0.01 \leq 0.29$—weak positive relationship, $\rho > 0.30 \leq 0.69$—moderate positive relationship, $\rho > 0.70 \leq 1.00$—strong positive relationship, $\rho > -0.01 \leq -0.29$—weak negative relationship, $\rho > -0.30 \leq -0.69$—moderate negative ratio, $\rho > -0.70 \leq -1.00$—strong negative ratio. The graphs in the figure are arranged according to the level of correlation [76].

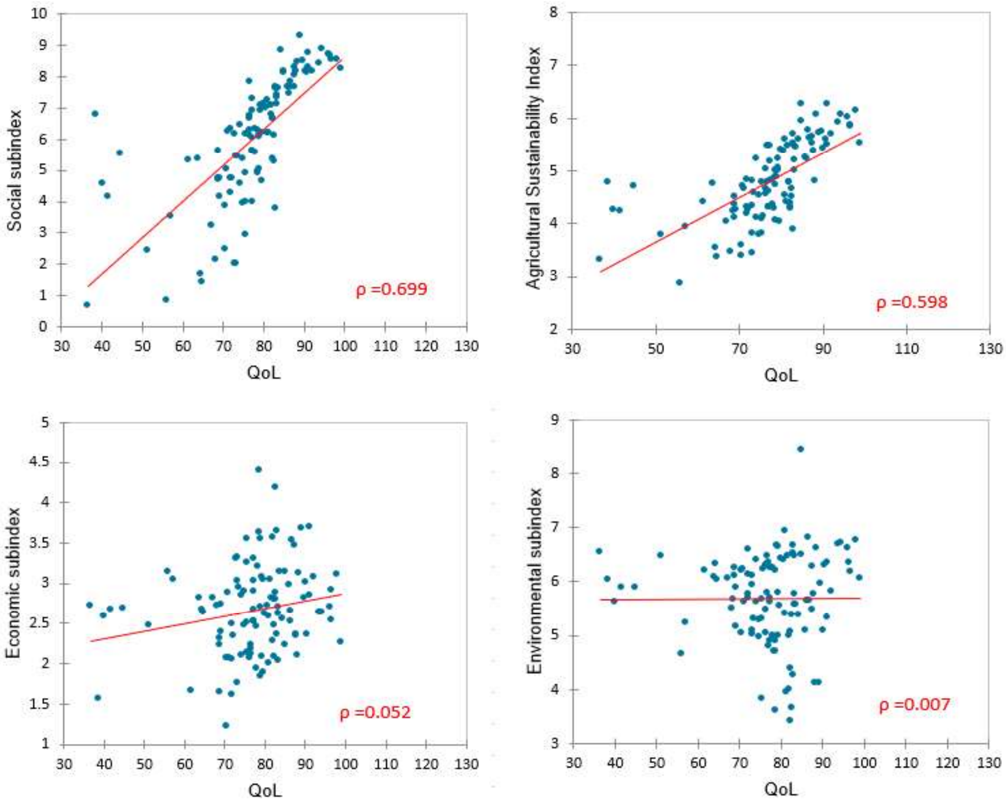

Figure 9. Correlation of Agricultural Sustainability Index with QoL.

We note that the highest correlation between QoL and the social subindex established almost falls into a strong positive relationship category. At the opposite pole are the indicators from the economic and environmental subindexes that are weakly correlated with the QoL. The Agricultural Sustainability Index has a moderately positive correlation with the Quality–of–Life Index, ρ, having a value of 0.598. The results of the mutual link analysis between sustainable agriculture and –quality of– life attest to a relatively high correlation between these two concepts

6. Discussion

Sustainable agriculture is a crucial sector of any economy, and the development level affects the environment, economic prospects, and social dimensions, including the quality of life. In this section, we will focus on elucidating and contextualizing the outcomes derived from the study within the existing scholarly landscape.

A detailed study and analysis of sustainable agriculture reveals that its development contributes to increased food security and improved quality of life for the population. The economic literature on sustainable agriculture claims that it is inextricably linked to the growth of food production, the efficient use of economic and intellectual resources, the improvement of well–being and quality of life [77], and the stable and balanced management of the environment [15,78,79]. Primarily, in the specialized literature, sustainable agriculture is analyzed as a concept based on three pillars: environmental, economic, and social [41,77,80]. In the present study, sustainable agriculture is approached from the systemic perspective, which is best included in the general framework of sustainable agriculture research and development. The adoption of a systemic approach in sustainable agriculture research provides a comprehensive framework to explore the complex interactions among its environmental, economic, and social dimensions. While the bibliometric analysis highlighted a relative scarcity of articles on economic and social aspects, the systemic perspective adopted in this study aims to fill this gap and offer a more holistic understanding of sustainable agriculture and its dimensions.

Sustainable agriculture implies a holistic concern for the system and the interaction between the whole and its components. Of course, narrow partial analysis is also acceptable, which can only be an important exploration tool. In this context, individual preferences are also largely products of the system itself. If the system changes, preferences change, too.

Applying the systems approach to sustainable agriculture from the start, we examined it as a complete system comprising its primary components (environmental, economic, and social). The elements of sustainable agriculture determine the root causes underlying the establishment of the conditions for sustainable development. This approach is founded on the heterogeneity and inconsistency of the vast fields of sustainable agriculture.

Therefore, we developed an abstract scheme of sustainable agriculture (Figure 2), highlighting the relationships inherent in the system. The scheme includes essential structural components based on the properties of the elements from which it is formed and their forms of interaction, thus ensuring the development of sustainable agriculture. Ultimately, this interaction will determine the achievement of the goals of sustainable agriculture, which include enhancing the quality of life for the population.

Indeed, the multidimensional and complex nature of sustainable agriculture poses challenges in the assessment process. Assessment is necessary to establish the correlation between sustainable agriculture and macroeconomic indicators or other composite indices, in our case GDP per capita and the Quality–of–Life Index. To address these challenges, constructing composite indices [68,81–84] becomes a valuable approach, as observed in other studies focusing on complex development phenomena, as well as different dimensions of sustainable agriculture, quantifying aspects such as ecosystems [81–84], food systems [78,85], and social and human capital [86,87]. Notably, the absence of a comprehensive index covering all three dimensions underscores the need for a holistic evaluation method that encapsulates the diverse facets of sustainable agriculture.

With this premise in mind, we have developed a composite index of sustainable agriculture, encompassing various extensive dimensions, including environmental, economic, and social. ASI is based on three –subindices (environment, economic, social), which, in turn, are divided into ten components (Water Quality, Air Quality, Soil Quality, Biodiversity, Land Use, Food Production, Organic Farming, Value Added, Labor and Knowledge, and Nutrition and Health) consisting of a large number of indicators [44]. In terms of composite indices, distinctions can be observed, with certain indices designed for specific regional scopes [38], particular states [39,40], or spanning multiple nations [81–84,88] To achieve the objectives outlined in our study, we constructed Agricultural Sustainability Indices (ASIs) for a cohort of 108 countries. This selection aligns with the constraints imposed by available statistical databases, recognizing the unavailability of comprehensive data for certain indicators across a set of countries. Regrettably, certain individual indicators lack sufficient statistical coverage for a broader spectrum of nations. An additional noteworthy aspect pertains to the breakdown of the ASI into components within the three subindices, computed for distinct country groups categorized by income levels. This analysis reveals significant insights, notably that countries in the –low–income group are leaders in Organic Farming, a pivotal component of sustainable agriculture.

The selection of a suitable weighting method is a major step in constructing composite indices. Various methods are available for this purpose, encompassing techniques such as data envelopment analysis, the analytic hierarchy process, regression approach, unobserved components models, principal component analysis (PCA), and factor analysis [64–67]. In our study, we opted for the PCA method for weighting due to its ability to group individual indicators based on their degree of correlation. This becomes particularly relevant when dealing with a substantial number of individual indicators. The implementation of PCA further underscored the systemic nature inherent in sustainable agriculture.

The exploration of the relationship between sustainable agriculture and other macroeconomic indicators is a key aspect of our study. Composite indices integrate indicators associated with processes expressed in commensurable variables. This method is fundamental as it allows for the examination of the explanatory power of the Agricultural

Sustainability Index (ASI). In our analysis, we aimed to demonstrate the reciprocal link between the ASI and the Quality–of–Life Index, as well as the interdependence between GDP per capita and the ASI.

Next, we will discuss testing and validating research hypotheses.

The first hypothesis states that no single relevant factor would have a decisive impact on ASI.

The testing of this hypothesis was conducted through principal component analysis (PCA). Subsequent to the application of this statistical method, it was revealed that Water Quality, Labor and Knowledge, and Nutrition and Health collectively play a significant role in the development of sustainable agriculture. However, it was observed that these factors are not the primary contributors to the overall outcome (Table 4). This suggests that no singular component in sustainable agriculture holds a dominant influence on the results. Instead, the development of sustainable agriculture is an outcome influenced by numerous components across the three dimensions of sustainable agriculture.

The Agricultural Sustainability Index (ASI) derived from principal component analysis (PCA) can be of significance for national public authorities. It brings to light paramount factors that have the potential to influence the level of sustainable agriculture.

The second hypothesis assumed a linear relationship between ASI and GDP per capita.

The third hypothesis indicates a reciprocal relationship between sustainable agriculture and its components with the quality of life.

The results, obtained after applying the linear regression model, establish the interconnections between the value of the Sustainable Agriculture Index and GDP per capita. Following this, it was determined that there was a close relationship between these two variables, with the variance constituting 83.2% (Figure 8). Thus, countries with a more developed economy also have a higher level of sustainable agriculture. At the same time, this finding is also helpful for the governors because it allows for predicting the ASI depending on the GDP per capita.

To assess the strength of the connections between sustainable agriculture and quality of life, we applied the Spearman correlation, which relies on the ranking of variables [89]. The Spearman coefficient is used in the case of composite indices with many individual indicators because the variables for which the relationship is calculated do not have a normal distribution. The results confirmed the hypothesis regarding the relationship between the index of sustainable agriculture and its components with the quality of life.

The results substantiate the hypothesis regarding the correlation between the Sustainable Agriculture Index and its quality–of–life components. A higher level of sustainable agriculture development corresponds to an elevated quality of life. Examining ρ for the three –subindices of sustainable agriculture reveals that the social subindex has the highest correlation coefficient ($\rho = 0.699$). This trend is attributed to the fact that the indicators in the components of this subindex (Labor and Knowledge/Nutrition and Health) are influential factors determining the quality of life. On the contrary, the low correlation coefficients between the economic subindex and the environmental subindex with the Quality–of–Life Index can be elucidated by the heterogeneous values of the components in these dimensions of the ASI. In the former case, countries in the –low–income group (e.g., Uganda and Ethiopia) exhibit high values for Organic Farming whereas countries in the –lower middle–income group (e.g., Uzbekistan and Tajikistan) exhibit high values for Value Added while their Quality–of–Life Index is low. In the latter case, the Soil Quality and Land Use components display the highest values in countries with a low Quality–of–Life Index (e.g., Uganda, Lao PDR, Bangladesh).

However, it is important to acknowledge that the analysis conducted also has its limitations, which should be discussed.

First, sustainable agriculture is a complex phenomenon consisting of three dimensions, which implies difficulties in its approach. The challenges in approaching sustainable agriculture derive from its distinct fields interacting through many links. This synergy within sustainable agriculture complicates its assessment.

Second, a significant subjective factor persists in selecting individual indicators within the dimensions of sustainable agriculture.

Third, in the process of assessing sustainable agriculture through ASI, a lack of databases was noted, especially for the Organic Farming component. At the same time, there is no coverage of the data related to the field of R&D in agriculture. To cover this area, which is extremely important for the development of sustainable agriculture, we had to include Research and Development Expenditure (% of GDP).

Fourth, some indicator values, especially in the economic –subindex, do not reflect real sustainable agriculture development levels. It is practically impossible to distinguish agricultural production resulting from sustainable agriculture from that of conventional agriculture.

Fifth, the Quality–of–Life indices calculated so far do not cover many indicators or countries (e.g., Numbeo covers only 84 countries).

Although there are challenges in assessing sustainable agriculture through the construction of a complex sustainable agriculture index, it undeniably serves as an essential step for assessing the development of sustainable agriculture in perspective. Additional analysis allows for an understanding of the interdependence between sustainable agriculture and quality of life.

Furthermore, in the theoretical framework of sustainable agriculture, there are new perspectives to explore, especially in the context of the complex systems theory. This involves the construction of comprehensive system models, models of various classes, and those specific to the properties of the system.

In the future, we aim to enhance the Sustainable Agriculture Index as new data become available. We will also conduct more in–depth investigations into the synergies within sustainable agriculture.

7. Conclusions

The development of sustainable agriculture revolves around the synergy of three primary dimensions: environmental, economic, and social. These dimensions play a crucial role in enhancing the quality and standard of living for the population. Sustainable agriculture is a critical factor in improving the quality of life. Sustainable agriculture can only be guaranteed for the long term through a balance of environmental, economic, and social components. The close relationship between the dimensions of sustainable agriculture forms an integral complex of interconnected elements that require a systemic approach for effective management.

In sustainable agriculture research, it is crucial to concentrate on identifying the connections and relationships between sustainable agriculture and its interactions with the external environment. The properties of sustainable agriculture as an integral system are shaped by the sum of the elements of its three dimensions and the characteristics of its structure and integrative connections.

Sustainable agriculture demands a long–term perspective. To achieve this, it is essential for national regulations to be aligned with the long–term development of sustainable agriculture. This alignment requires continuous collaboration among various state institutions due to the multidimensional nature of sustainable agriculture.

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Data Availability Statement: The data presented in this study are available on request from the corresponding author.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. Synthesis of specialized studies in the agricultural sustainability field.

Subject	Author/Authors	Description	Conclusion	Outcomes (Quantitative Assessments)
Ecosystem	Power, A.G. [90], Shahmohamadloo, R.S.; Febria, C.M; Sibley, P.K. [91].	Synergies between agriculture and the environment.	Agricultural intensification must be accompanied by appropriate environmental policies that prioritize significant reductions in environmental degradation.	Environment Sustainability Index [81], Environment Quality Index [82], Environmental Performance Index [83], Living Planet Index [84],
Food system	Berry, E.; Dernini, S.; Burlingame, B.; Meybeck, A.; Conforti, P. [80], Charles, H.; Godfray, J.; Garnett, T. [92] Zaharia, A.; Diaconeasa, M.C.; Maehle, N.; Szolnoki, G.; Capitello, R. [93],	Resilience of food systems (elements and outcomes) is necessary for sustainability.	Adopting sustainable agricultural practices helps maintain food production and expand sustainable consumption.	Food Sustainability Index [78], Farmer Sustainability Index [85].
Organic farming	Niggli, U. [79], Gamage, A.; Gangahagedara, R.; Gamage, J.; Jayasinghe, N.; Kodikara, N.; Suraweera, P.; Merah, O. [94].	Organic farming ensures the maintenance of a sustainable ecosystem by promoting closed production cycles that minimize the risk of environmental pollution.	The development of intensive agriculture cannot guarantee the ecological safety of food. Therefore, it is advisable to pay special attention to expanding and creating conditions for the production of ecological agricultural products.	
Social and Human Capital	Psarikidou, K.; Szerszynski, B. [95], Qiu, Y.; Zhang, Y.; Liu, M. [96].	Sustainable agriculture encompasses both production and consumption. Human resources in the production process are affected by the historical and cultural aspects of the regions, but they must also adapt to technological modernization, which requires special qualifications. The role of consumers in sustainable agriculture is shaped by their preferences, especially their interest in organic farming products, and their responsibility in terms of sustainability.	The social aspect of sustainability, whether in agriculture and other fields, can only be approached as part of a complex system where the "economic" is embedded in social relationships, and the "social" encompasses interactions between people and the material world. This perspective blurs the ontological boundaries between the economic, environmental, and social dimensions [93] (p. 37).	Social Progress Index [86], Sustainable Society Index [87].

Table A1. *Cont.*

Subject	Author/Authors	Description	Conclusion	Outcomes (Quantitative Assessments)
Agricultural knowledge and innovation	Cassman, K.G., Grassini, P. [97], Levidow, L.; Birch, K.; Papaioannou, T. [98], Lubell, M.; Niles, M.; Hoffman, M. [99].	The multidimensional nature of sustainable agriculture involves researching its components and their intricate interconnections, adding complexity to this field. To address the complex challenges related to optimizing food production and increasing labor productivity while safeguarding the environment, there is a growing emphasis on leveraging machine learning and advanced technologies.	Innovation should be a central focus sustainable agriculture research because addressing environmental issues in the face of rising demand for agricultural products requires the use of machine learning and other advanced techniques.	Global Innovation Index [100].

Source: Authors' compilation.

Table A2. Agricultural Sustainability Index, by country, 2020.

Country	Environmental Subindex	Economic Subindex	Social Subindex	Agricultural Sustainability Index
Albania	6.11	2.23	4.75	**4.36**
Algeria	5.39	2.00	6.22	**4.54**
Argentina	3.99	3.57	6.79	**4.78**
Armenia	6.20	1.66	5.34	**4.40**
Australia	4.13	2.10	8.19	**4.81**
Austria	6.61	3.12	8.49	**6.07**
Azerbaijan	6.22	2.89	5.02	**4.71**
Bangladesh	6.36	2.53	4.00	**4.30**
Belarus	6.30	2.14	6.67	**5.04**
Belgium	6.35	2.54	8.66	**5.85**
Bolivia	5.16	2.39	4.75	**4.10**
Brazil	3.41	2.80	6.65	**4.29**
Bulgaria	6.65	2.08	6.94	**5.22**
Burkina Faso	6.32	2.67	1.66	**3.55**
Burundi	6.55	2.73	0.68	**3.32**
Cambodia	5.88	2.74	4.15	**4.26**
Cameroon	5.03	1.23	3.88	**3.38**
Canada	5.08	3.01	8.19	**5.42**
Chile	5.62	3.03	6.90	**5.19**
China	3.67	4.18	6.13	**4.66**
Colombia	4.80	2.52	5.61	**4.31**
Costa Rica	5.47	2.07	6.13	**4.56**
Croatia	6.42	2.63	7.12	**5.39**
Cyprus	5.58	2.04	7.42	**5.01**
Czech Republic	6.80	2.66	7.86	**5.77**

Table A2. *Cont.*

Country	Environmental Subindex	Economic Subindex	Social Subindex	Agricultural Sustainability Index
Denmark	6.76	3.11	8.55	**6.14**
Ecuador	3.83	3.55	4.90	**4.09**
Egypt, Arab Rep.	4.88	3.31	5.64	**4.61**
El Salvador	6.24	1.65	5.62	**4.50**
Estonia	6.67	2.80	7.65	**5.71**
Ethiopia	5.01	3.31	2.02	**3.45**
Finland	6.07	2.26	8.27	**5.53**
France	5.82	3.07	8.20	**5.70**
Georgia	5.68	2.31	4.70	**4.23**
Germany	6.36	3.69	8.75	**6.27**
Ghana	5.78	2.49	4.27	**4.18**
Greece	5.77	2.71	7.13	**5.20**
Guatemala	5.62	2.10	4.59	**4.10**
Honduras	5.70	2.34	4.76	**4.26**
Hungary	6.47	2.62	7.35	**5.48**
Iceland	6.49	3.14	8.19	**5.94**
India	4.25	3.64	3.76	**3.88**
Indonesia	3.61	3.54	5.01	**4.06**
Iran, Islamic Rep.	5.09	1.76	6.17	**4.34**
Ireland	5.76	2.36	8.04	**5.39**
Israel	5.39	2.56	8.85	**5.60**
Italy	5.65	3.53	7.67	**5.62**
Japan	5.32	2.84	8.32	**5.50**
Jordan	5.63	2.07	6.24	**4.65**
Kazakhstan	5.68	2.51	6.17	**4.78**
Kenya	4.98	2.48	3.92	**3.79**
Korea, Rep.	5.96	2.81	8.50	**5.76**
Kuwait	4.98	3.08	7.09	**5.05**
Kyrgyz Republic	5.89	2.68	5.53	**4.70**
Lao PDR	6.06	2.81	3.23	**4.04**
Latvia	6.40	2.72	6.99	**5.37**
Lebanon	5.79	2.23	6.28	**4.77**
Lithuania	6.25	2.89	7.30	**5.48**
Luxembourg	8.43	2.23	8.14	**6.27**
Madagascar	4.66	3.14	0.83	**2.88**
Malaysia	4.39	2.09	6.68	**4.39**
Mali	5.50	2.72	2.16	**3.46**
Malta	6.51	2.36	7.68	**5.52**
Mexico	3.95	3.04	6.19	**4.40**
Moldova	6.60	1.61	4.74	**4.32**

Table A2. *Cont.*

Country	Environmental Subindex	Economic Subindex	Social Subindex	Agricultural Sustainability Index
Mongolia	6.07	2.82	5.38	**4.76**
Montenegro	6.02	1.57	6.78	**4.79**
Morocco	5.55	1.90	4.64	**4.03**
Mozambique	6.02	2.64	1.43	**3.36**
Nepal	6.22	3.26	2.94	**4.14**
Netherlands	6.68	2.64	8.42	**5.91**
New Zealand	5.10	2.98	7.69	**5.26**
Nicaragua	5.62	2.59	4.55	**4.25**
Nigeria	5.31	2.13	3.98	**3.80**
North Macedonia	6.12	2.05	6.32	**4.83**
Norway	6.17	2.91	8.53	**5.87**
Pakistan	5.23	3.05	3.50	**3.93**
Panama	6.25	1.94	6.31	**4.83**
Paraguay	5.32	2.96	5.47	**4.58**
Peru	4.88	4.39	4.92	**4.73**
Philippines	5.05	2.47	5.38	**4.30**
Poland	6.47	2.82	7.10	**5.46**
Portugal	5.65	2.53	7.47	**5.22**
Romania	6.67	1.85	6.13	**4.88**
Russian Federation	4.98	2.28	7.07	**4.78**
Rwanda	6.46	2.47	2.44	**3.79**
Serbia	6.40	2.85	6.45	**5.24**
Singapore	6.29	2.35	8.31	**5.65**
Slovak Republic	6.93	2.58	7.26	**5.59**
Slovenia	6.48	2.13	7.84	**5.48**
South Africa	4.99	2.47	5.59	**4.35**
Spain	5.47	3.46	7.66	**5.53**
Sri Lanka	5.93	3.04	5.47	**4.81**
Sweden	6.63	2.70	8.74	**6.02**
Switzerland	6.72	2.64	8.88	**6.08**
Tajikistan	5.88	2.68	4.15	**4.23**
Thailand	5.37	2.88	5.28	**4.51**
Tunisia	5.80	3.04	6.19	**5.01**
Turkey	4.70	3.64	6.29	**4.87**
Uganda	6.11	3.32	2.01	**3.81**
Ukraine	6.21	2.71	6.07	**5.00**
United Arab Emirates	5.57	3.15	7.64	**5.45**
United Kingdom	6.30	2.37	8.15	**5.61**
United States	4.12	3.69	9.33	**5.71**
Uruguay	5.04	2.19	6.73	**4.65**

Table A2. *Cont.*

Country	Environmental Subindex	Economic Subindex	Social Subindex	Agricultural Sustainability Index
Uzbekistan	5.29	2.89	5.38	**4.52**
Viet Nam	4.69	3.20	4.93	**4.27**
Zimbabwe	6.21	2.06	2.48	**3.59**

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