




Article

Grand Challenges in Central Europe: The Relationship of Food Security, Climate Change, and Energy Use

Domicián Máté ^{1,2,*} , Mohammad Fazle Rabbi ³ , Adam Novotny ^{4,5} and Sándor Kovács ⁶ 

¹ College of Business and Economics, University of Johannesburg, 2006 Johannesburg, Auckland Park, South Africa

² Faculty of Engineering, University of Debrecen, 4032 Debrecen, Hungary

³ Ihrig Károly Doctoral School, University of Debrecen, 4032 Debrecen, Hungary; rabbi.mohammad@econ.unideb.hu

⁴ Faculty of Economics and Social Sciences, Eszterházy Károly University, 3300 Eger, Hungary; novotny.adam@uni-eszterhazy.hu

⁵ Nord University Business School, 8026 Bodø, Norway

⁶ Faculty of Economics and Business Management, University of Debrecen, 4032 Debrecen, Hungary; kovacs.sandor@econ.unideb.hu

* Correspondence: mate.domician@eng.unideb.hu; Tel.: +36-20-9915258

Received: 10 September 2020; Accepted: 13 October 2020; Published: 16 October 2020



Abstract: Pursuing various sustainable development goals is posing new challenges for societies, policymakers, and researchers alike. This study implements an exploratory approach to address the complexity of food security and nuance its relationship with other grand challenges, such as energy use and climate change, in Central European countries. A multiple factor analysis (MFA) suggests that the three pillars of food security relate differently to climate change: food affordability and food accessibility positively correlate with climate change, while food quality has a negative association with temperature rise. However, if countries switched to renewable energy resources, all three pillars of food security could be achieved simultaneously. The study also underlines regional inequalities regarding grand challenges and emphasizes the need for innovative local solutions, i.e., advances in agriculture systems, educational programs, and the development of environmental technologies that consider social and economic issues.

Keywords: climate change; food security; grand challenges; multiple factor analysis; regional studies; renewable energy; sustainable development goals

1. Introduction

The National Academies of Science, Engineering and Medicine (NASEM) have raised pressing global and grand challenges that environmental scientists and engineers have uniquely put together for advanced support [1]. The report highlights issues regarding the sustainability of food, fossil energy, and renewable (solar, water, biomass) resources; climate change control; pollution and waste; efficient, healthy and resilient cities; as well as informed decisions and policies. However, future goals of sustainable development face several hindrances due to the interaction of complex socio-economic issues.

Several studies attempt to explore the interactions and find the optimal balance among crucial social, economic, and environmental areas influencing the future of humanity [2–4]. Academics have long been analyzing new scenarios to explore how the world may change in the rest of the 21st century. In the 2000s, a promising effort was made to predict the trajectories of population change,

economic growth, and greenhouse gas emissions (GHGs) by the Special Report on Emissions Scenarios (SRES) [2]. Moss et al. [3] described a ‘parallel process’ of representative concentration pathways (RCPs) that may occur on a warming planet [4]. Meanwhile, various pathways have been identified to predict the future of global society, including demographic and economic features as well [5]. Shared socio-economic pathways (SSPs) are used as inputs for the climate change projections, assessed in the Intergovernmental Panel on Climate Change (IPCC) 6th Assessment Report in 2020 [6]. The new framework combines RCPs and other climate predictions in a scenario matrix architecture to support countries’ ratified policies, such as those of the Paris Agreement 2025 and 2030 [7].

Scenarios for SSPs are designed to enable researchers to explore climate impacts and adaptation requirements within baseline and mitigation narratives [8] that may address broad socio-economic trends to cover futures [9]. For instance, SSP3 as the “Rocky Road”, which faces enormous challenges in mitigating climate change, predicts the fragmented world of resurgent nationalism. The low priority given to tackling climate change seems to lead to extensive deprivation in some regions [10]. Inequalities worsen over time between industrialized and growth-intensive developing countries; thus, countries are focusing on achieving regional energy, and only SSP3 emphasizes the importance of food security related to development goals [11].

Long-term energy security, i.e., the continuous access to clean, reliable, and affordable energy in a variety of forms and services [12] and the scarcity of non-renewable energy resources worldwide, is a crucial issue of sustainable economic development [13]. As one of the critical inputs to agriculture, sustainable energy should also allow for long-term food security. Food security maintenance is a challenging concept as it deals extensively with food production, distribution, and consumption. The Rome Declaration on World Food Security (1996) reiterated the right of everyone to have access to safe and nutritious food, under the right to adequate food and the fundamental right of everyone to be free from hunger [14].

Attempts at improving food security may be supported by using renewable energy sources, which may mitigate the effects of climate change [15]. However, the impact of climate change on food security has been controversial in the literature. Alcamoa et al. [16] analyzed the effects of climate scenarios in Russia using the Global Assessment of Security (GLASS) model and argued that extreme climate events pose an increasing threat to the security of food systems and water resources. Climate change is affecting food quality due to rising temperatures and declining plant growth periods [17]. Global warming affects precipitation, which has a direct negative effect on soil moisture content and groundwater balance [18]. There are other important consequences of climate change besides water balance changes. Vişinescu and Bularda (2008) claimed the need to maintain and use river meadows as an anti-drought solution [19]. Thus, the impact of certain functions of drainage ditches on hydrological conditions, i.e., regulating water flow and nutrient retention, are likely to depend on the composition and structure of the biological communities in the ditches [20].

The link between energy use and climate change has been underestimated with the various dimensions of food security to addressing global challenges, such as eradicating hunger and developing sustainable food, agriculture, and renewable energy systems. As an exception, Hasegawa et al. [21] noted that the implementation of a stringent climate (change) mitigation policy has a more significant and adverse impact on global hunger and food consumption than the direct effects of climate change. In addition, the energy–climate–food security nexus has been examined mostly in case studies [22,23] or based on the food supply chain related to food security issues [24]. To our knowledge, no prior studies have examined regional differences taking the complexity of food security, energy use, and climate change into account.

In this paper, we propose that by examining the interrelations of the different dimensions of global challenges, we can gain novel insights into whether and how Sustainable Development Goals (SDGs) could be achieved simultaneously. The paper studies the relationship between climate change and energy use with the three different pillars of food security (affordability, accessibility, and quality). The novelty of this approach is to treat food security as a multidimensional construct, which may lead

to more nuanced findings on how key SDGs could be solved at both a regional and global level. We rely on data collected in Central European (CE) countries between 2012 and 2018. A multiple factor analysis (MFA) is applied to compute the relationship among blocks of variables. The advantage of MFA is calculating correlations between the indices in each pillar while also taking regional disparities within CE into account.

2. Materials and Method

2.1. Data and Variables

Several systematically collected groups of indicators attempt to measure the effects of human activity on the state of the planet. In this paper, groups of variables related to climate change, energy use, and food security, including food affordability (FAF), food accessibility (FAC), and food quality (FQ), were carefully selected. Table 1 presents the variables and their descriptions for CE countries. CE covers territories based on collective historical, social, and cultural identity [25]. However, it is often divided into West-Central Europe and East-Central Europe [26]. The latter contains the Visegrád Group (V4), countries that are strategic alliance partners and strongly integrated economic counterparts. The following countries were analyzed: Austria, Belgium, Germany, the Netherlands, Switzerland, and the V4 ones (the Czech Republic, Hungary, Poland, and Slovakia).

Table 1. Descriptions of indicators.

Pillar	Period	Indicator	Source *	Abbreviation	Measurement
Climate Change	2012–2017	Air pollution	W.B.	air_pollution	Micrograms per cubic meter
	2012–2018	CO ₂ emission (Cropland)	W.B., FAO	co2_crop	Gigagrams
	2012–2018	CO ₂ emission (Grassland)	W.B., FAO	co2_grass	Gigagrams
	2017–2018	Soil erosion	HWSD	soil_erosion	Score (1–4) 1 = best
	2017–2018	Forest area	W.B.	forest_change	% of the total land
	2012–2018	Temperature rise	EIU	temperature_rise	Score 0 = least vulnerable
Energy Use	2012–2015	Energy intensity level	W.B.	energy_int_level	Megajoule at PPP ** GDP
	2012–2018	Renewable electricity output	EUROSTAT	ren_electric_output	% of total output
	2012–2018	Renewable energy consumption	EUROSTAT	ren_energy_cons	% of the final energy
	2012–2018	Final energy consumption from biomass and renewable waste	EUROSTAT	final_energy_cons	Thousand tons of oil equivalent
Food Affordability (FAF)	2012–2018	Food consumption as a share of household expenditure	W.B.	food_consump	% of total household expenditure
	2012–2018	Gross Domestic Product (GDP) per capita	EIU	gdp_per_capita	USD at PPP ** per capita
	2012–2018	Agricultural import tariffs	WTO	agr_imp_tarif	% (Percent)
	2012–2018	Food import dependency	FAO	food_imp_depend	% (Percent)
Food Accessibility (FAC)	2012–2018	Average food supply	FAO	food_supply	Kcal/person/day
	2012–2018	Volatility of agricultural production	EIU	agr_prod_vol	Standard Deviation (0–1)
	2012–2018	Urban absorption capacity	EIU	urban_absorb	GDP (% of real change)-period of urban growth
	2012–2018	Population growth	W.B., EIU	population_growth	% (Percent)
	2012–2018	Road infrastructure	EIU	road_infra	Score (0–4) 4 = best
	2012–2018	Port infrastructure	EIU	port_infra	Score (0–4) 4 = best
	2012–2018	Political stability	EIU	pol_stab	Score (0–100) 100 = best
	2012–2018	Public expenditure on agricultural R&D	EIU	pub_exp_agrrd	Score (1–9) 9 = highest
Food Quality (FQ)	2012–2018	Food loss	FAO	food_loss	Waste/supply (ton)
	2012–2018	Diet diversification	FAO, EIU	diet_divers	% (Percent)
	2012–2018	Dietary availability of vegetal iron	FAO	diet_veg_iron	Mg/person/day
	2012–2018	Dietary availability of animal iron	FAO	diet_anim_iron	Mg/person/day
	2012–2018	Protein quality	EIU	protein_qual	Score (0–100) 100 = best

¹ Notes: * EIU: Economist Intelligence Units; EUROSTAT: Statistical Office of the European Union; FAO: Food and Agricultural Organization; HWSD: Harmonized World Soil Database; W.B.: World Bank; WTO: World Trade Organization. **: Purchasing Power Parity.

The climate change pillar contains various World Development Indicators (WDI) from the World Bank Dataset [27] and the Harmonized World Soil Database (HWSD) [28], collected by the Food and Agricultural Organization (FAO). The pillar includes measures of air pollution (PM_{2.5} mean annual exposure), greenhouse gas emissions (CO₂ grass- and cropland), environment-related loss of forest area and soil erosion. Temperature rise, which is also essential to measure a country's vulnerability to climate change, was added here from the Global Food Security Index (GFSI) of the Economist Intelligence Units (EIU) Database [29] and standardized to the extent possible to facilitate cross-country comparisons.

The energy usage pillar involves the energy intensity level of primary (fossil) energy, which is the ratio between energy supply and Gross Domestic Product (GDP) measured at purchasing power parity (PPP) [27]. The energy output and consumption before transformation to similar end-user fuels (renewable electricity and refined petroleum products) and other energy indices were included in this pillar from the Eurostat Energy Database [30]—namely, final energy from combustible renewables and waste, such as solid biomass and animal products, gas and liquid from biomass, and municipal waste.

Data for food security indicators were drawn mainly from the European Intelligence Unit [29] and the Food and Agricultural Organization (FAO) [31]. Food security is defined here as the state in which people at all times have physical, social, and economic access to sufficient and nutritious food that meets their dietary needs for a healthy and active life [32]. This paper uses GFSI and FAO indicators, which are the most widely used measurements of food security at the national level. To improve the transparency and validity of the pillars, insecurity indicators are added from the World Bank Global Consumption Dataset [33] and the Tariff Online Facility of World Trade Organization (WTO) [34].

FAF measures the capacity and costs of a country's people to pay for food under normal circumstances and at times of food-related shocks. For instance, GDP per capita and food consumption expenditures of consumers to purchase food. Thus, FAF contains the agricultural import tariffs and food dependence control vulnerability to external price shocks. FAC influences the supply and the ease of access to food. FAC denotes the sufficiency of the national food supply, the risk of supply disruption, the agricultural infrastructure to expand agricultural output, the local and innovation capacity to reduce food loss as well as political stability. Finally, FQ contains the variety, nutritional quality, and availability of average diets. This category is sometimes referred to as 'utilization' because it explores the energy and nutrient intake by individuals and the diversity of the diet [31].

The selected pillars also reveal the progress of the environmental targets set by the 2030 Agenda for Sustainable Development [35]. SDGs require efforts to promote renewed policies and approaches regarding the great challenges. For example, SDG 2 relates to 'End hunger, achieve food security and improved nutrition and promote sustainable agriculture' [36]. The zero-hunger challenge supports the prevention of children's stunted growth (under the age of two), full access to adequate food all year round, sustainable food production systems, increase in smallholder productivity and income, and calling for zero loss or a waste of foods. SDG 7.1 promotes ensuring access to affordable, reliable, and renewable energy resources and services, SDG 11.6 contributes to reducing the adverse environmental effect of urban development, SDG 14.5 supports to conserving coastal and maritime areas, and SDG 15.5 aims to protect and prevent the extinction of threatened species.

2.2. Statistical Analysis

MFA was first introduced by Thurstone [37] and later described as well by Escoffier and Pagès [38]. The method is useful for analyzing a group of inter-correlating variables divided into blocks. In the first stage, a traditional principal component analysis (PCA) was performed on each variable block, and in the second stage, the blocks were made comparable through normalization by using the square root of the first eigenvalue obtained from the separate PCAs [39]. In the final stage of the analysis, a global PCA was performed on the normalized blocks of variables. Observations are represented in a lower (usually two) dimensional map; the coordinates are called factor scores. MFA provides a unique

concept of partial factor scores which make it possible to position each observation by taking different groups of variables into account.

Besides balancing variable groups, MFA provides results specific to the group structure of the set of variables. For instance, the detailed groups of variables can give synthetic images and factors from separate analyses. MFA is also suitable for graphically displaying observations and their relations and hence building diverse clusters [40]. MFA is helpful to analyze different types of observations described by various groups of variables, and the method is even more valuable when the data set is large and complex [41]. It derives an integrated representation of the remarks and the relationships among groups of examined variables. The analysis was performed by FactoMiner, an R software package [42] for multivariate analysis [43].

3. Results

An MFA was conducted using the variables in Table 1. MFA first computes a series of PCAs. The relationship of the components with the global analysis was explored by computing loadings (correlations) between the components of each pillar (climate change, energy resources, and food security) and the global analysis. In this study, the analysis consists of five (T) datasets called blocks. Each block is a $(I \times J[t])$ rectangular data matrix denoted by $Y[t]$, where I is the number of observations and $J[t]$ is the number of variables of the t -th block. Each data matrix is pre-processed (centered and normalized) and denoted by $X[t]$. Each observation is assigned a ‘mass’ which reflects its importance and is stored in an $I \times I$ diagonal matrix (M). The normalized blocks are concatenated into an $I \times T$ matrix called the global data matrix (Z) [38].

A standard PCA was used to estimate the singular value decomposition of the global data Z matrix:

$$Z = U\Delta V^T \text{ with } U^T U = V^T V = I, \quad (1)$$

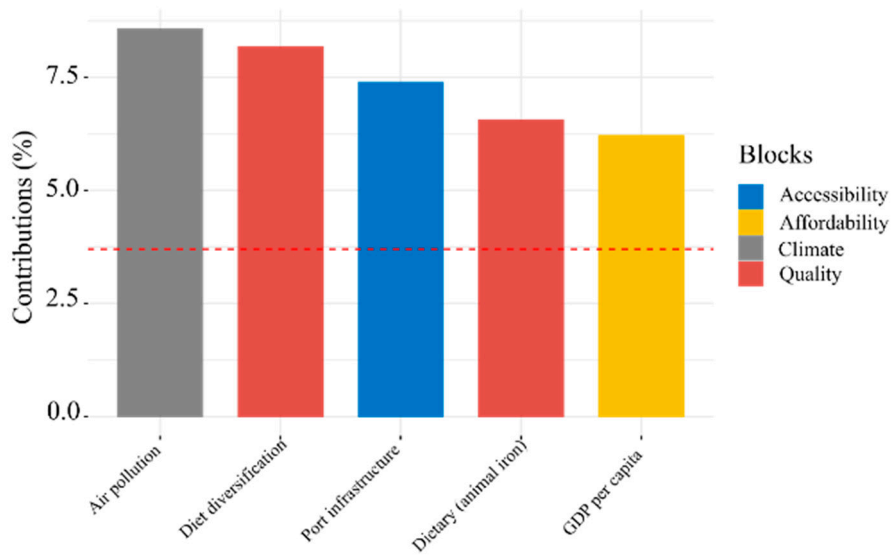
where U and V are the left and right singular vectors of Z , respectively, and Δ is the diagonal matrix of the singular values. The global (F) factor scores are obtained as:

$$F = M^{-1/2} U \Delta, \quad (2)$$

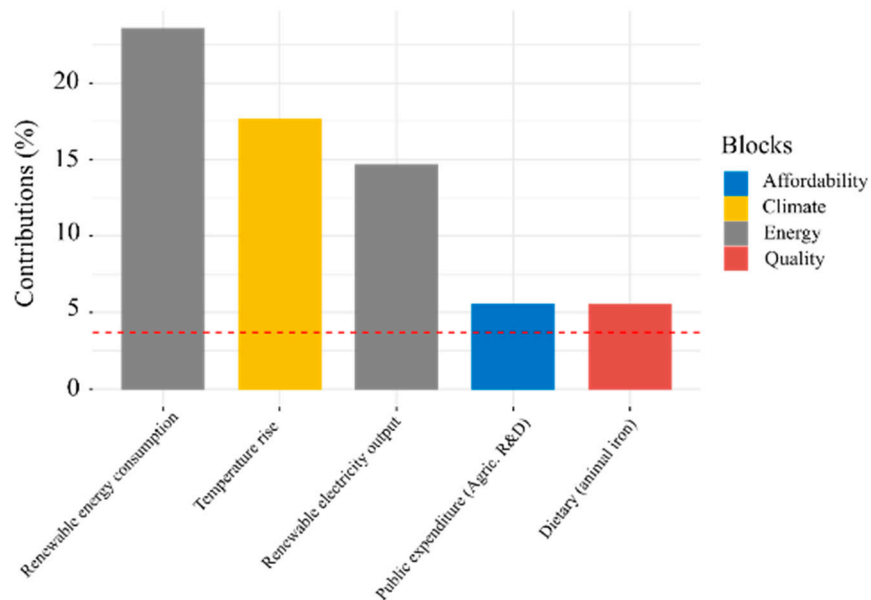
where each row represents an observation, and each column is a component (dimension). The eigenvalue of the first dimension (DIM1) corresponds to 37.8% of the inertia (Figure 1a). DIM1 is associated with air pollution, dietary diversity, port infrastructure, and GDP per capita (productivity). The second dimension (DIM2) corresponds to 13.9% of the inertia. DIM2 relatively strongly correlates with renewable energy resources, temperature rise, dietary diversity, and expenditures on agricultural R&D (Figure 1b).

3.1. Validation of Results

The validation of MFA components was carried out using several methods (Table 2): random sampling with replacement (bootstrapping), a permutation test within each block to preserve exchangeability, and exhaustive (leave-one-out) [44] and non-exhaustive (split-half) estimation [45]. These cross-validation (rotation estimation) techniques are crucial for assessing the accuracy of any predictive model in practice [46].



(a)



(b)

Figure 1. Contributions (%) of indicators and blocks to the dimensions: (a) the first dimension (DIM1) corresponds to 37.8% of inertia; (b) the second dimension (DIM2) explains 14.0% of inertia. Notes: estimation based on multiple factor analysis (MFA).

Table 2. Validation results of MFA components' explanatory power.

Component	Explained Variance (%)	Bootstrap Simulation * (p-value)	Permutation Test Within Each Block * (p-value)	Split-Half Test * (p-value)	LOO ** Validation (% of Variation)
1	37.8%	0.794	<0.001	0.320	6.9
2	14.0%	0.132	0.056	0.802	14.7
3	13.5%	0.502	<0.001	0.173	8.3

Notes: * N = 1000 iterations. ** Leave-one-out (LOO).

First, a bootstrap simulation was performed ($N = 1000$) with repetition for all indicators within each iteration. In the case of permutation tests, the permutation of the objects was applied within each block separately, resulting in a random dataset. The critical values were evaluated by the distribution of the explained variances of the MFA components. The two-sided p -values were calculated from the distributions. The null hypothesis of the test concerns to the initially explained variances are not different from the simulated ones. Both results show that the first and second components (DIM1 and DIM2) explain the largest proportion of the variance and are stable.

Regarding the split-half test, the dataset was halved into equal parts and a separate MFA was performed on each part. This process was repeated N times; the explained variance of MFA components was recorded and compared with one another by a Wilcoxon signed-rank sample test [47]. The lack of significance indicates no statistical difference between the two splits, and the second component is the most stable. In the leave-one-out cross-validation test, the MFA was executed nine times (there are nine countries in the dataset, and one country was left out each time from the analysis) to estimate the variation coefficients, i.e., the standard deviation divided by the mean. The value of the coefficient did not exceed the critical 20% in any case. Based on the results, the selected first two components were proved to be stable during validation tests and also explain a sufficient amount of variance.

3.2. Global Space and Partial Analysis

The global analysis reveals the common structure of the examined space regarding the pillars (groups of variables) in the model. It shows the relationship between the variables projecting the data set for global analysis. The projection matrix (Figure 2) contains the contributions of global factor scores (percentages).

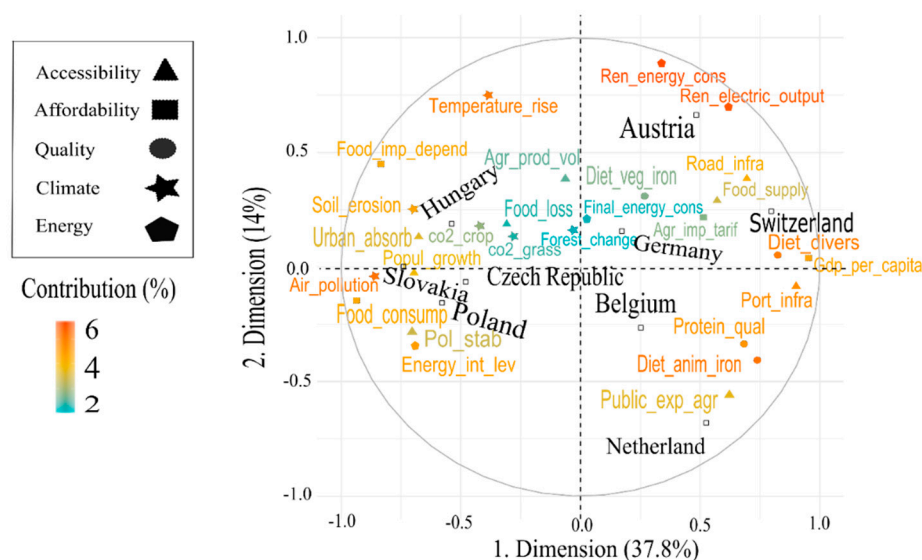


Figure 2. Individual blocks (grand challenges) and the contributions (%) of each indicator in the Central European (CE) countries to the first two dimensions (principal components). DIM1 corresponds to 37.8%, DIM2 explains 14% of inertia. Notes: estimations are based on MFA.

The global space map can be divided into four quadrants based on the two dimensions specified by the MFA. Each quadrant contains countries with different food security, climate, and energy profiles. The first quadrant (i.e., Austria, Germany, and Switzerland) can be characterized by a high level of renewable energy output and consumption, GDP per capita, food supply, and diet diversity. Germany, loading closer to the centroid, is associated with a high percentage of forest area and final energy consumption. The V4-country group forms a cluster on the other pole of the first dimension, i.e., in the second and third quadrants. The second quadrant contains Hungary, which is more strongly

associated with soil erosion and temperature rise than the other CE countries. Hungary is dominated by agricultural landscapes in the plains and intensive agricultural, especially maize production, which can be damaged by high temperatures and low rainfall. Slovakia is on the border of the second and third quadrants, described by relatively high urban absorption compared to Poland and the Czech Republic due to its topography. In Slovakia, as mountain forests cover most of the country, the agricultural production is limited by the availability of arable land. The third quadrant (Poland and the Czech Republic) is characterized by relatively high food consumption, improved energy intensity level, and political stability. Finally, the fourth quadrant (the Netherlands and Belgium) can be described by more intense public expenditure in agricultural R&D, and better food (protein) quality.

Figure 2 suggests a link between the consumption of energy resources, climate change, and food security issues. For instance, the energy intensity level of primary resources (e.g., energy supply per GDP) is associated with the climate change pillar (high air pollution, soil erosion, and temperature rise), high FAF (i.e., food consumption and import dependency), and high FAC (i.e., population growth, political stability, and urban absorption). At the other pole of DIM1, GDP per capita, as a FAF indicator, is also related to better food accessibility (i.e., higher expenditure in agriculture R&D, food supply, and port infrastructure) and improved food quality (i.e., protein quality and dietary diversity). Regarding the second dimension (DIM2), temperature rise seems to correlate with renewable energy consumption and electricity output negatively. Thus, the final energy consumption from biomass and renewables is negatively associated with GHG emissions and forest land changes.

Figure 3 shows each CE country as a single point based on the first two principal components of the global analysis. The partial points position each country from the perspective of the five different pillars. Hence, the individual and regional differences, as well as the overall status of CE countries, can be evaluated.

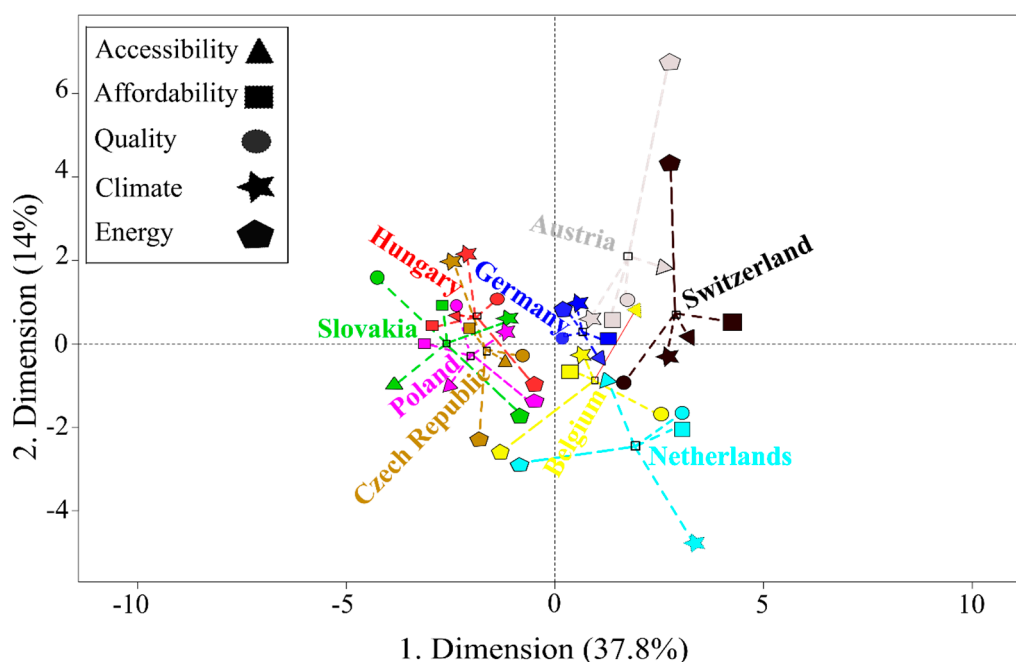


Figure 3. The contributions of each block (grand challenges) to the position of CE countries. DIM1 corresponds to 37.8%, DIM2 explains 14% of the inertia. Notes: estimations are based on MFA.

The V4 group seems to be more strongly affected by energy usage and climate change than by food security issues. Lower levels of renewable energy consumption and electricity generation can also be observed in all V4 countries. According to the partial findings, Hungary is the most exposed to the effects of climate change (especially rising temperatures). In Slovakia and Poland, on the other hand,

food accessibility (urban absorption) is more distinctive. In terms of FAF, Hungary is in the worst situation, while the Czech Republic is facing major FQ issues (dietary diversity and protein quality).

In the second dimension, Austria, Germany, and Switzerland are described by high renewable energy consumption and electricity output. The Netherlands, one of the drivers of environmental protection and sustainable food policy in the EU [48], stands out for its lower risk of climate change and higher food protein quality and dietary diversity.

4. Discussion

A key finding of the MFA is that food security can be sustained if policy measures support a stable macro-environment [49], including improved food supply, better infrastructure, and less import dependency as a precursor to higher productivity. The sustainable food economy can contribute to economic growth by increasing investments (physical and human capital) and reducing macro (price and political) instability [50]. On the other hand, stability supports poverty alleviation by reducing vulnerability to sudden shocks of food prices or food availability [51]. A crucial outcome of a rural-focused regional growth policy is to achieve food security when economic growth has raised the poor above the direct poverty line and to stabilize food prices and stocks and prevent exogenous shocks [52].

Besides, food intake plays a crucial role in productivity growth, supported by better protein quality, dietary diversity, and health in the human body [53]. The findings of the current study are consistent with those of Deolalikar [54], who found that adequate childhood nutrition can also improve educational attainment and economic growth per capita. Population growth as a socio-economic indicator is positively associated with food consumption, which supports the idea that an increased and healthier food consumption reduces mortality rates [55] and may upsurge life expectancy [56]. However, in developed countries, increased food consumption is a major cause of obesity and can reduce the expected lifetime [57].

The global MFA revealed that climate change is negatively related to dietary availability and protein quality. Interestingly, the results suggest that global warming may adversely affect water availability, crop yields, and reduce food and environmental quality in the future [58]. However, better FAC is driven by population growth, urbanization, and industrialization, and increased food consumption is a challenge to sustain the required level of food quality. The findings of the present study are consistent with Khan et al. [59], who reviewed water management and crop production in China and pointed to the need to integrate climate, energy, food, environment, and population considerations. Hepperly [60] argued that increased agricultural production leads to higher energy consumption, especially fossil fuels, and thus to higher levels of greenhouse gas emissions, pollution, deforestation, and deteriorating water and food quality.

The extent of deliberate hydrological changes in Central Europe has been enormous, from small streams and ditches to the largest rivers. However, the current droughts are not only due to climate change. The long-term frequency of extreme droughts has been stable and severe in the last two or three centuries, which were also typical in the coastal part of Poland and Silesia [61]. Another important aspect is the change in plant water conditions due to the partial closure of the stomata. The impact of transient water scarcity and shortage with increasing CO₂ concentration leads to improved water-use efficiency (WUE) and less water consumption of plants due to limited transpiration [62]. In addition, the complex effect of climate change (not just rainfall) significantly limits the growth of timber (oak and pine tree stands) in Central Europe [63]. Other trees are sensitive to extreme weather events and environmental conditions, such as heatwaves [64] and late spring frost [65]. The effect of long-term climate change, extreme frosts, and sub-optimal temperatures on the earlier occurrence of flushing and flowering fruit (wine) stages [66] and on the phenology of vegetables, for instance, potato production [67], is transforming the distribution of food supply and waste in Central Europe undesirably.

The Global Target for Sustainable Energy 2030 (Development Goal 7) is to increase the share of renewable energy sources in global energy production [68] and double the global rate of energy efficiency improvement [69]. Eco-efficiency leads to sustainability, which is closely linked to the separation of energy and material intensity, the prevention and management of food waste and air pollution, recycling, the widespread use of renewable energy, as well as the enhancement of the product life cycle and consolidation [70]. The findings of our study confirm the inverse relationship between (a) renewable energy consumption and electricity generation and (b) vulnerability to temperature rise and CO₂ emissions. Mouratiadou [71] also examined the effects of irrigation of bioenergy crops based on shared socioeconomic pathways (SSPs) and found it to be the most critical factor leading to significantly higher water demand due to climate change mitigation.

Climate change and local air pollution seem to be crucial to address regional energy policy issues in the case of CE countries. Our findings confirm that energy transformation could significantly reduce greenhouse gas emissions while ensuring sufficient energy is available through greater energy efficiency and a gradually increasing share of renewable energy sources [72]. Improving decarbonization in energy-intensive industries introduces efficiency (electrification) measures and savings from renewable energy technologies [73]. Agroforestry systems provide carbon sequestration and essential wood products against the greenhouse effect [74]. Furthermore, modern biomass heating applications and liquid biofuels are expected to double from the current energy supply level by 2050 [75]. Liu et al. [76] advocate the positive effects of biofuels on final total greenhouse gas emissions and show their advantages over fossil fuels. The production of biofuel-cellulosic biomass can also reduce crude oil consumption and pollution from fossil fuels [62].

However, air pollution is not limited to energy production and is closely linked to the food system. Along the food supply chain, agricultural production, processing, and distribution generate significant pollutants [77]. The excessive use of chemical fertilizers and animal husbandry are the primary sources of agricultural emissions [78]. In addition, the exhaust fumes from industrial waste and vehicles (aircraft, trucks) related to the food system contribute expressively to air pollution [79]. Air pollution not only reduces the supply of raw ingredients but can affect consumer demand and choice [80], and food supply will eventually change food prices [81].

5. Conclusions

The main objective of this study was to examine the interrelations of climate change, energy use, and food security, i.e., food affordability, accessibility, and quality, to shed light on novel research perspectives on grand challenges and Sustainable Development Goals (SDGs). A multiple factor analysis (MFA) was used to calculate correlations between the aforementioned pillars while also taking regional disparities within CE countries into account. The advantage of MFA is that it analyzes different types of observations described by various groups of variables, and the method is even more valuable when the data set is large and complex.

Contrary to previous approaches, we consider the complexity of food security, which is necessary for exploring the subtle interconnections of socio-economic and environmental issues. We found that the different pillars of food security are likely to have different impact on other sustainable development goals, namely: (a) higher FAF and FAC are associated with climate change and higher energy intensity level of primary resources; (b) better FQ couples with lower temperature rise and higher output per capita; (c) temperature rise is adversely related to renewable energy consumption and electricity output. At the regional level, we also found that (d) the V4 group seems to be relatively more affected by energy usage and climate change than by food security issues; (e) Austria, Germany, and Switzerland make better use of renewable energy; (f) the Netherlands stands out for its lower risk of climate change and higher food protein quality and dietary diversity.

The methodological implication is that researchers need to consider the various dimensions of complex sustainable development phenomena when they endeavor to measure and examine the impacts of grand challenges. The findings are also important for policymakers in Central Europe

and globally, since the demand for safe and clean food and sustainable energy grows with a rising population worldwide.

Creative solutions are needed to maximize energy, food, and water supplies while reducing adverse climate impacts. For example, a unique concept of solar spectrum unbundling in food, energy, and water systems (SUFEWS) proposes to maximize crop production while simultaneously producing energy and managing waste supply by separating the solar spectrum on a plot of land. Gençer et al. [82] suggested that reflective parabolic troughs can be located above the field to accumulate solar energy from near-infrared and far-infrared light waves, while the desired solar spectrum for food production is passed to plants on the ground. Near-infrared light can be used to generate energy, and near-far and far-infrared power supply distillation or reverse osmosis is supported by hydropower treatment processes. Besides, electricity generated by solar panels can contribute to sustainable agricultural production or be exported to nearby residents.

Progress in agriculture systems is desirable, including crop and alternative food production methods, reduction of food waste, and changes in dietary diversity [83]. Optimizing productivity by managing irrigation is essential in, for example, paddy areas and can considerably reduce global methane and nitrous oxide emissions [84]. In addition, the usage of efficient agrochemicals, improved pest and disease forecasting, the adoption of modern wastewater treatment, the optimization of animal feed, and the improvement of the livestock environment should be assessed in order to improve the impact of agricultural and energy policies on food security and climate change mitigation [85–87].

Changing the diet can also be an effective tool to reduce air pollution due to the shift from animal husbandry to crop production, as raising ruminants has a greater impact on air pollution [88]. Meanwhile, meat-free protein products are diversifying, including innovative plant-based products that can be grown from animal and plant tissue cells in culture. Such products significantly increase the affordability of food and, if accepted by consumers, can reduce the constant demand for animals [89], thereby reducing the soil, energy, and water needs of animal proteins [90] and the associated adverse effects of environmental and climate change, while increasing the availability of nutrients [91].

This study calls for the improvement of educational outcomes related to sustainable food, climate change, and energy challenges in practice. Environmental education programs should rely on the integration of strict energy-saving system maintenance, big data science, and decision analysis, and redesign them into sustainable engineering projects. Therefore, the cooperation of scholars and social science experts is essential to understand the social, cultural, economic, regional, and political contexts of environmental challenges [1]. The curricula of engineering programs could be enriched with topics related to grand challenges and their interrelations, in addition to traditional focus areas, such as climate, energy, and air pollution.

There are some limitations to this study related to the method and variables chosen. The most important is omitted-variable bias, as the studied pillar variables reflect the authors' partly subjective choice. In general, sampling error may have a stronger bias on PCA results than on the correlations among observations [92]. Another potential problem is that the scope of the study appears to be broad; however, the inclusion of several indices is required to map the subtle interactions of seemingly unrelated development goals.

To conclude, exploring the effects and linkages of grand challenges should not rely on simplistic research questions [93]. Goals related to sustainable development are difficult to delineate and implement simultaneously due to their complexity and interdependence. Hence, future research has to be carried out across different disciplines and theories (e.g., economic growth, circular economy, sustainability, resource management, and climate theories) to retrace and develop indicators that reflect the status quo of our planet and potential trajectories. For example, researchers may consider the impacts of government incentives, community development, and environmental activities. The integration of sustainable economic growth, population growth, crop production, climate change, energy use, and water supply analyses is essential for a more comprehensive and reliable assessment of the food security pillars.

Author Contributions: Conceptualization, D.M. and M.F.R.; methodology and validation, S.K.; formal analysis, S.K. and D.M.; investigation, A.N.; resources, S.K. and M.F.R.; first draft preparation, S.K., A.N. and D.M.; funding, D.M. All authors have read and agreed to the published version of the manuscript.

Funding: This research was supported by ÚNKP-20-5-DE-10 New National Excellence Program of the Ministry for Innovation and Technology from the source of the National Research Development and Innovation Fund and was supported by the János Bolyai Research Scholarship of the Hungarian Academy of Sciences.

Acknowledgments: This research was supported by the János Bolyai Research Scholarship of the Hungarian Academy of Science.

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

References

1. NASEM. *Environmental Engineering for the 21st Century: Addressing Grand Challenges*; The National Academies Press: Washington, DC, USA, 2019; ISBN 978-0-309-47652-2.
2. Nakicenovic, N.; Alcamo, J.; Grubler, A.; Riahi, K.; Roehrl, R.; Rogner, H.; Victor, N. *Special Report on Emissions Scenarios*; Cambridge University Press: Cambridge, UK, 2000; ISBN 0 521 80081 1.
3. Moss, R.H.; Edmonds, J.A.; Hibbard, K.A.; Manning, M.R.; Rose, S.K.; Van Vuuren, D.P.; Carter, T.R.; Emori, S.; Kainuma, M.; Kram, T.; et al. The next generation of scenarios for climate change research and assessment. *Nature* **2010**, *463*, 747–756. [[CrossRef](#)] [[PubMed](#)]
4. van Vuuren, D.P.; Riahi, K.; Moss, R.; Edmonds, J.; Thomson, A.; Nakicenovic, N.; Kram, T.; Berkhout, F.; Swart, R.; Janetos, A.; et al. A proposal for a new scenario framework to support research and assessment in different climate research communities. *Glob. Environ. Chang.* **2012**, *22*, 21–35. [[CrossRef](#)]
5. Ebi, K.L.; Hallegatte, S.; Kram, T.; Arnell, N.W.; Carter, T.R.; Edmonds, J.; Kriegler, E.; Mathur, R.; O'Neill, B.C.; Riahi, K.; et al. A new scenario framework for climate change research: Background, process and future directions. *Clim. Chang.* **2014**, *122*, 363–372. [[CrossRef](#)]
6. Kriegler, E.; Edmonds, J.; Hallegatte, S.; Ebi, K.L.; Kram, T.; Riahi, K.; Winkler, H.; van Vuuren, D.P. A new scenario framework for climate change research: The concept of shared climate policy assumptions. *Clim. Chang.* **2014**, *122*, 401–414. [[CrossRef](#)]
7. Paris Agreement. *United Nations Treaty Collection*; Paris Agreement: Paris, France, 8 July 2016.
8. Riahi, K.; van Vuuren, D.P.; Kriegler, E.; Edmonds, J.; O'Neill, B.C.; Fujimori, S.; Bauer, N.; Calvin, K.; Dellink, R.; Fricko, O.; et al. The shared socioeconomic pathways and their energy, land use, and greenhouse gas emissions implications: An overview. *Glob. Environ. Chang.* **2017**, *42*, 153–168. [[CrossRef](#)]
9. van Vuuren, D.P.; Stehfest, E.; Gernaat, D.E.H.J.; Doelman, J.C.; van den Berg, M.; Harmsen, M.; de Boer, H.S.; Bouwman, L.F.; Daioglou, V.; Edelenbosch, O.Y.; et al. Energy, land-use and greenhouse gas emissions trajectories under a green growth paradigm. *Glob. Environ. Chang.* **2017**, *42*, 237–250. [[CrossRef](#)]
10. Dearing, J.A.; Wang, R.; Zhang, K.; Dyke, J.G.; Haberl, H.; Hossain, M.S.; Langdon, P.G.; Lenton, T.M.; Raworth, K.; Brown, S.; et al. Safe and just operating spaces for regional social-ecological systems. *Glob. Environ. Chang.* **2014**, *28*, 227–238. [[CrossRef](#)]
11. Fujimori, S.; Hasegawa, T.; Masui, T.; Takahashi, K.; Herran, D.S.; Dai, H.; Hijioka, Y.; Kainuma, M. SSP3: AIM implementation of shared socioeconomic pathways. *Glob. Environ. Chang.* **2017**, *42*, 268–283. [[CrossRef](#)]
12. The United Nations. *The Secretary-General's Advisory Group on the Energy and Climate Change (AGECC) Energy for a Sustainable Future. Report and Recommendations*; United Nations: New York, NY, USA, 2010.
13. Popp, J.; Oláh, J.; Fekete, M.F.; Lakner, Z.; Máté, D. The relationship between prices of various metals, oil and scarcity. *Energies* **2018**, *11*, 2392. [[CrossRef](#)]
14. Food and Agriculture Organization of the United Nations. In *World Food Summit-Final Report*; FAO: Rome, Italy, 13–17 November 1996.
15. Calvin, K.; Bond-Lamberty, B.; Clarke, L.; Edmonds, J.; Eom, J.; Hartin, C.; Kim, S.; Kyle, P.; Link, R.; Moss, R.; et al. The SSP4: A world of deepening inequality. *Glob. Environ. Chang.* **2017**, *42*, 284–296. [[CrossRef](#)]
16. Alcamo, J.; Dronin, N.; Endejan, M.; Golubev, G.; Kirilenko, A. A new assessment of climate change impacts on food production shortfalls and water availability in Russia. *Glob. Environ. Chang.* **2007**, *17*, 429–444. [[CrossRef](#)]

17. Fricko, O.; Havlik, P.; Rogelj, J.; Klimont, Z.; Gusti, M.; Johnson, N.; Kolp, P.; Strubegger, M.; Valin, H.; Amann, M.; et al. The marker quantification of the Shared Socioeconomic Pathway 2: A middle-of-the-road scenario for the 21st century. *Glob. Environ. Chang.* **2017**, *42*, 251–267. [[CrossRef](#)]
18. Kriegler, E.; Bauer, N.; Popp, A.; Humpenöder, F.; Leimbach, M.; Strefler, J.; Baumstark, L.; Bodirsky, B.L.; Hilaire, J.; Klein, D.; et al. Fossil-fueled development (SSP5): An energy and resource intensive scenario for the 21st century. *Glob. Environ. Chang.* **2017**, *42*, 297–315. [[CrossRef](#)]
19. Vişinescu, I.; Bularda, M. Hard changes of Danube hydrological regime and its impact on agriculture in dammed territories. *An. Inst. Natl. Cercet. Agric. Fundulea* **2008**, *76*, 101–112.
20. Herzon, I.; Helenius, J. Agricultural drainage ditches, their biological importance and functioning. *Biol. Conserv.* **2008**, *141*, 1171–1183. [[CrossRef](#)]
21. Hasegawa, T.; Fujimori, S.; Havlík, P.; Valin, H.; Bodirsky, B.L.; Doelman, J.C.; Fellmann, T.; Kyle, P.; Koopman, J.F.L.; Lotze-Campen, H.; et al. Risk of increased food insecurity under stringent global climate change mitigation policy. *Nat. Clim. Chang.* **2018**, *8*, 699–703. [[CrossRef](#)]
22. Benites-Lazaro, L.L.; Giatti, L.; Giarolla, A. Topic modeling method for analyzing social actor discourses on climate change, energy and food security. *Energy Res. Soc. Sci.* **2018**, *45*, 318–330. [[CrossRef](#)]
23. García Kerdan, I.; Giarola, S.; Hawkes, A. A novel energy systems model to explore the role of land use and reforestation in achieving carbon mitigation targets: A Brazil case study. *J. Clean. Prod.* **2019**, *232*, 796–821. [[CrossRef](#)]
24. Bhat, R.; Jöudu, I. Emerging issues and challenges in agri-food supply chain. In *Sustainable Food Supply Chains*; Elsevier: Philadelphia, PA, USA, 2019; pp. 23–37. ISBN 9780128134115.
25. Tötösy, S. *Comparative Central European Culture*; Tötösy de Zepetnek, S., Ed.; Purdue University Press: West Lafayette, IN, USA, 2002; ISBN 1557532885.
26. Kłoczowski, J. Actualité des grandes traditions de la cohabitation et du dialogue des cultures en Europe du Centre-Est. In *L'heritage Historique de la Res Publica de Plusieurs Nations*; KUL: Lublin, Poland, 2004; pp. 29–30. ISBN 83-85854-82-7.
27. The World Bank. World Development Indicators | DataBank. Available online: <https://databank.worldbank.org/data/source/world-development-indicators> (accessed on 11 May 2020).
28. Food and Agriculture Organization of the United Nations. Harmonized World Soil Database v 1.2. Available online: <http://www.fao.org/soils-portal/soil-survey/soil-maps-and-databases/harmonized-world-soil-database-v12/en/> (accessed on 11 May 2020).
29. European Intelligence Units Global Food Security Index (GFSI). Available online: <https://foodsecurityindex.eiu.com/Country> (accessed on 11 May 2020).
30. Eurostat Energy Database. Available online: <https://ec.europa.eu/eurostat/web/energy/data/database> (accessed on 11 May 2020).
31. FAOSTAT. Available online: <http://www.fao.org/faostat/en/#data/GC> (accessed on 5 March 2020).
32. Clay, E. Food security: Concepts and measurement. In *Trade Reforms and Food Security*; Food and Agriculture Organization of the United Nations, Ed.; FAO: Rome, Italy, 2003.
33. The World Bank, Global Consumption Database. Available online: <http://datatopics.worldbank.org/consumption/> (accessed on 11 May 2020).
34. WTO Tariff Download Facility: WTO Tariff Database. Available online: <http://tariffdata.wto.org/Default.aspx?culture=en-US> (accessed on 11 May 2020).
35. United Nations Development Group (UNDG). *Mainstreaming the 2030 Agenda for Sustainable Development Reference Guide to UN Country Teams*; United Nations Development Group (UNDG): New York, NY, USA, March 2017.
36. Love, P. *Debate the Issues: New Approaches to Economic Challenges*; OECD Insights, OECD Publishing: Paris, France, 2016; ISBN 9789264262119.
37. Thurstone, L.L. Multiple factor analysis. *Psychol. Rev.* **1931**, *38*, 406–427. [[CrossRef](#)]
38. Escofier, B.; Pages, J. Multiple factor analysis (AFMULT package). *Comput. Stat. Data Anal.* **1994**, *18*, 121–140. [[CrossRef](#)]
39. Abdi, H.; Williams, L.J.; Valentin, D. Multiple factor analysis: Principal component analysis for multitable and multiblock data sets. *Wiley Interdiscip. Rev. Comput. Stat.* **2013**, *5*, 149–179. [[CrossRef](#)]
40. Pagés, J.; Husson, F. Multiple factor analysis with confidence ellipses: A methodology to study the relationships between sensory and instrumental data. *J. Chemom.* **2005**, *19*, 138–144. [[CrossRef](#)]

41. Pagès, J. Multiple factor analysis. In *Multiple Factor Analysis by Example Using R*; Chapman and Hall, CRC Press: London, UK, 2014; ISBN 9781482205473.
42. European Environmental Agency R Core Team (2020). Available online: <http://www.eea.europa.eu/data-and-maps/indicators/oxygen-consuming-substances-in-rivers/r-development-core-team-2006> (accessed on 26 September 2020).
43. Husson, F.; Josse, J.; Lê, S. FactoMineR: An R package for multivariate analysis. *J. Stat. Softw.* **2008**, *25*. [[CrossRef](#)]
44. Stone, M. An asymptotic equivalence of choice of model by cross-validation and Akaike's criterion. *J. R. Stat. Soc. Ser. B.* **1977**, *39*, 44–47. [[CrossRef](#)]
45. Kohavi, R. A study of cross-validation and bootstrap for accuracy estimation and model selection. *Proc. Fourteenth Int. Jt. Conf. Artif. Intell.* **1995**, *2*, 1137–1143.
46. Allen, D.M. The relationship between variable selection and data augmentation and a method for prediction. *Technometrics* **1974**, *16*, 125–127. [[CrossRef](#)]
47. Wilcoxon, F. Individual comparisons by ranking methods. *Biom. Bull.* **1945**, *1*, 80–83. [[CrossRef](#)]
48. Solorio, I. Bridging the gap between environmental policy integration and the EU's energy policy: Mapping out the "Green Europeanisation" of energy governance. *J. Contemp. Eur. Res.* **2011**, *7*, 396–416.
49. Birdsall, N.; Ross, D.; Sabot, R. Inequality and growth reconsidered: Lessons from East Asia. *World Bank Econ. Rev.* **1995**, *9*, 477–508. [[CrossRef](#)]
50. Ramey, G.; Ramey, V.A. Cross-Country evidence on the link between volatility and growth. *Am. Econ. Rev.* **1995**, *85*, 1138–1151.
51. Timmer, C.P. The macro dimensions of food security: Economic growth, equitable distribution, and food price stability. *Food Policy* **2000**, *25*, 283–295. [[CrossRef](#)]
52. Timmer, C.P. Food security and economic growth: An Asian perspective. *Asia. Pac. Econ. Lit.* **2005**, *19*, 1–17. [[CrossRef](#)]
53. Strauss, J. *The Impact of Improved Nutrition on Labor Productivity and Human Resource Development: An Economic Perspective*; Yale University, Economic Growth Center: New Haven, CT, USA, 1985.
54. Deolalikar, A.B. Nutrition and labor productivity in agriculture: Estimates for rural South India. *Rev. Econ. Stat.* **1988**, *70*, 406–413. [[CrossRef](#)]
55. Miyamoto, K.; Kawase, F.; Imai, T.; Sezaki, A.; Shimokata, H. Dietary diversity and healthy life expectancy—An international comparative study. *Eur. J. Clin. Nutr.* **2019**, *73*, 395–400. [[CrossRef](#)]
56. Haseeb, M.; Kot, S.; Hussain, H.I.; Jermisittiparsert, K. Impact of economic growth, environmental pollution, and energy consumption on health expenditure and R&D expenditure of ASEAN countries. *Energies* **2019**, *12*, 3598. [[CrossRef](#)]
57. Walls, H.L.; Backholer, K.; Proietto, J.; McNeil, J.J. Obesity and trends in life expectancy. *J. Obes.* **2012**, *2012*, 107989. [[CrossRef](#)]
58. Kang, Y.; Khan, S.; Ma, X. Climate change impacts on crop yield, crop water productivity and food security—A review. *Prog. Nat. Sci.* **2009**, *19*, 1665–1674. [[CrossRef](#)]
59. Khan, S.; Hanjra, M.; Mu, J. Water management and crop production for food security in China: A review. *Agric. Water Manag.* **2009**, *96*, 349–360. [[CrossRef](#)]
60. Hepperly, P. Environmental, energetic and economic comparisons of organic and conventional farming systems. *Bioscience* **2009**, *55*, 573–582. [[CrossRef](#)]
61. Przybylak, R.; Oliński, P.; Koprowski, M.; Filipiak, J.; Pospieszńska, A.; Chorążyczewski, W.; Puchałka, R.; Dąbrowski, H.P. Droughts in the area of Poland in recent centuries in the light of multi-proxy data. *Clim. Past* **2020**, *16*, 627–661. [[CrossRef](#)]
62. Van De Geijn, S.C.; Dijkstra, P. Physiological Effects of Changes. In *Atmospheric Carbon Dioxide Concentration and Temperature on Growth and Water Relations of Crop Plants*; Springer: Dordrecht, The Netherlands, 1995; pp. 89–99.
63. Misi, D.; Puchałka, R.; Pearson, C.; Robertson, I.; Koprowski, M. Differences in the climate-growth relationship of scots pine: A case study from Poland and Hungary. *Forests* **2019**, *10*, 243. [[CrossRef](#)]
64. Bauweraerts, I.; Wertin, T.M.; Ameye, M.; McGuire, M.A.; Teskey, R.O.; Steppe, K. The effect of heat waves, elevated [CO₂] and low soil water availability on northern red oak (*Quercus rubra* L.) seedlings. *Glob. Chang. Biol.* **2013**, *19*, 517–528. [[CrossRef](#)] [[PubMed](#)]

65. Puchałka, R.; Koprowski, M.; Przybylak, J.; Przybylak, R.; Dąbrowski, H.P. Did the late spring frost in 2007 and 2011 affect tree-ring width and earlywood vessel size in Pedunculata oak (*Quercus robur*) in northern Poland? *Int. J. Biometeorol.* **2016**, *60*, 1143–1150. [[CrossRef](#)]
66. Leolini, L.; Moriondo, M.; Fila, G.; Costafreda-Aumedes, S.; Ferrise, R.; Bindi, M. Late spring frost impacts on future grapevine distribution in Europe. *F. Crop. Res.* **2018**, *222*, 197–208. [[CrossRef](#)]
67. Pulatov, B.; Linderson, M.L.; Hall, K.; Jönsson, A.M. Modeling climate change impact on potato crop phenology, and risk of frost damage and heat stress in northern Europe. *Agric. For. Meteorol.* **2015**, *214–215*, 281–292. [[CrossRef](#)]
68. Boulanger, P.-M. Sustainable development indicators: A scientific challenge, a democratic issue. *Surv. Perspect. Integr. Environ. Soc.* **2008**, *1*, 59–73. [[CrossRef](#)]
69. Allen, C.; Metternicht, G.; Wiedmann, T. National pathways to the Sustainable Development Goals (SDGs): A comparative review of scenario modelling tools. *Environ. Sci. Policy* **2016**, *66*, 199–207. [[CrossRef](#)]
70. Shah, I.H.; Dong, L.; Park, H.S. Tracking urban sustainability transition: An eco-efficiency analysis on eco-industrial development in Ulsan, Korea. *J. Clean. Prod.* **2020**, *262*, 121286. [[CrossRef](#)]
71. Mouratiadou, I.; Biewald, A.; Pehl, M.; Bonsch, M.; Baumstark, L.; Klein, D.; Popp, A.; Luderer, G.; Kriegler, E. The impact of climate change mitigation on water demand for energy and food: An integrated analysis based on the Shared Socioeconomic Pathways. *Environ. Sci. Policy* **2016**, *64*, 48–58. [[CrossRef](#)]
72. Gielen, D.; Boshell, F.; Saygin, D.; Bazilian, M.D.; Wagner, N.; Gorini, R. The role of renewable energy in the global energy transformation. *Energy Strateg. Rev.* **2019**, *24*, 38–50. [[CrossRef](#)]
73. Lechtenböhmer, S.; Nilsson, L.J.; Åhman, M.; Schneider, C. Decarbonising the energy intensive basic materials industry through electrification—Implications for future EU electricity demand. *Energy* **2016**, *115*, 1623–1631. [[CrossRef](#)]
74. Ramachandran Nair, P.K.; Nair, V.D.; Mohan Kumar, B.; Showalter, J.M. *Carbon Sequestration in Agroforestry Systems*; Elsevier: Philadelphia, PA, USA, 2010; Volume 108, ISBN 978-94-007-1630-8.
75. Saygin, D.; Gielen, D.J.; Draeck, M.; Worrell, E.; Patel, M.K. Assessment of the technical and economic potentials of biomass use for the production of steam, chemicals and polymers. *Renew. Sustain. Energy Rev.* **2014**, *40*, 1153–1167. [[CrossRef](#)]
76. Liu, W.; Xu, J.; Xie, X.; Yan, Y.; Zhou, X.; Peng, C. A new integrated framework to estimate the climate change impacts of biomass utilization for biofuel in life cycle assessment. *J. Clean. Prod.* **2020**, *267*, 122061. [[CrossRef](#)]
77. Sun, F.; Dai, Y.; Yu, X. Air pollution, food production and food security: A review from the perspective of food system. *J. Integr. Agric.* **2017**, *16*, 2945–2962. [[CrossRef](#)]
78. Wang, H.; Zhang, X.; Ma, Y.; Hou, Y. Mitigation potential for carbon and nitrogen emissions in pig production systems: Lessons from the North China Plain. *Sci. Total Environ.* **2020**, *725*, 138482. [[CrossRef](#)]
79. Masiol, M.; Harrison, R.M. Aircraft engine exhaust emissions and other airport-related contributions to ambient air pollution: A review. *Atmos. Environ.* **2014**, *95*, 409–455. [[CrossRef](#)]
80. Ul Haque, A.; Yamoah, F.A.; Sroka, W. Willingness to reduce food choice in favour of sustainable alternatives: The role of government and consumer behaviour. *Contrib. Manag. Sci.* **2020**, *31–51*. [[CrossRef](#)]
81. Palacios-Argüello, L.; Gondran, N.; Nouira, I.; Girard, M.A.; Gonzalez-Feliu, J. Which is the relationship between the product’s environmental criteria and the product demand? Evidence from the French food sector. *J. Clean. Prod.* **2020**, *244*, 118588. [[CrossRef](#)]
82. Gençer, E.; Miskin, C.; Sun, X.; Khan, M.; Bermel, P.; Alam, M.; Agrawal, R. Directing solar photons to sustainably meet food, energy, and water needs. *Sci. Rep.* **2017**, *7*, 3133. [[CrossRef](#)]
83. Weidner, T.; Yang, A.; Hamm, M.W. Consolidating the current knowledge on urban agriculture in productive urban food systems: Learnings, gaps and outlook. *J. Clean. Prod.* **2019**, *209*, 1637–1655. [[CrossRef](#)]
84. Nishimura, S.; Sawamoto, T.; Akiyama, H.; Sudo, S.; Yagi, K. Methane and nitrous oxide emissions from a paddy field with Japanese conventional water management and fertilizer application. *Glob. Biogeochem. Cycles* **2004**, *18*. [[CrossRef](#)]
85. Sheriff, G. Efficient waste? Why farmers over-apply nutrients and the implications for policy design. *Rev. Agric. Econ.* **2005**, *27*, 542–557. [[CrossRef](#)]
86. Dorward, L.J. Where are the best opportunities for reducing greenhouse gas emissions in the food system (including the food chain)? A comment. *Food Policy* **2012**, *37*, 463–466. [[CrossRef](#)]

87. Tuomisto, H.L.; Hodge, I.D.; Riordan, P.; Macdonald, D.W. Does organic farming reduce environmental impacts?—A meta-analysis of European research. *J. Environ. Manage.* **2012**, *112*, 309–320. [[CrossRef](#)] [[PubMed](#)]
88. Friel, S.; Dangour, A.D.; Garnett, T.; Lock, K.; Chalabi, Z.; Roberts, I.; Butler, A.; Butler, C.D.; Waage, J.; McMichael, A.J.; et al. Public health benefits of strategies to reduce greenhouse-gas emissions: Food and agriculture. *Lancet* **2009**, *374*, 2016–2025. [[CrossRef](#)]
89. Burton, R.J.F. The potential impact of synthetic animal protein on livestock production: The new “war against agriculture”? *J. Rural Stud.* **2019**, *68*, 33–45. [[CrossRef](#)]
90. Popp, J.; Lakner, Z.; Harangi-Rákos, M.; Fári, M. The effect of bioenergy expansion: Food, energy, and environment. *Renew. Sustain. Energy Rev.* **2014**, *32*, 559–578. [[CrossRef](#)]
91. Leisner, C.P. Review: Climate change impacts on food security-focus on perennial cropping systems and nutritional value. *Plant. Sci.* **2020**, *293*, 110412. [[CrossRef](#)]
92. Hotelling, H. Relations between two sets of variates. *Biometrika* **1936**, *28*, 321–377. [[CrossRef](#)]
93. Barnes, D.; Wilkerson, T.; Stephan, M. Contributing to the development of grand challenges in maths education. In Proceedings of the 13th International Congress on Mathematical Education, Hamburg, Germany, 24–31 July 2016; Kaiser, G., Ed.; Springer International Publishing: Cham, Switzerland, 2017; pp. 703–704.

Publisher’s Note: MDPI stays neutral with regard to jurisdictional claims in published maps and institutional affiliations.



© 2020 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<http://creativecommons.org/licenses/by/4.0/>).