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The Dynamics of European Food Security: Key Drivers and Measurement Framework

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1. Food Security: Concepts and Measurement

Food security is well known concept in general, however there exists many ways to look at it. Various definitions of food security and its pillars influence its quantification and insight into the current situation in the world. This term was used for the first time at the World Food Conference in 1974. At that time, it was related mostly to price stability and availability of food. Later in 1983 FAO (Food and Agriculture Organization) extended the concept of food security by pillar connected with physical access to food. On the other hand, there were still various concepts of food security and some of them were related to food sufficiency (Matkovski et. al. 2020).

The most widely used food security definition was formulated at the World Food Summit in 1996. According to this definition, food security at the individual, household, state, regional and world level is achieved, when all people always have a physical and economic approach with sufficient amounts of safe and adequate food to satisfy their needs and different preferences for active and healthy life. The World Food Summit of 2009 brought food security concept based on four dimensions: stability, accessibility, access, and use. This approach is still used by FAO. Currently can be found in literature more than 200 definition of food security and its determinants (Kumar and Sharma, 2022).

Wide discussion was held also about dimensions which should be included in food security indicators. In scientific literature, different opinions about food security definitions and its content and number of pillars can be found. For example, Wineman (2016) suggests only three components of food security, which should be quantity, quality, and stability of food. Barrett (2010) agrees with three pillars of food security but suggests availability, access, and utilization. The author sees food security as hierarchical structure of suggested three dimensions, as availability is essential but not enough to reach access and this is necessary but not sufficient for utilization.

This refers to effective use of food accessed by households or individuals. Peng and Berry (2018), argue that except for the three dimensions mentioned above, stability of previously mentioned pillars over time should be considered as an important part of food security. This approach is adopted also by The Food and Agriculture Organization (FAO) which uses these four pillars to assess the food security situation in the world. Abdullah et al. (2019) adds that food systems are vulnerable when one or more pillars of food security are insecure. Rahman (2021) continues that different indicators may be appropriate for measuring food security at distinct levels, and many modern studies add sustainability as another dimension of food security. Coates (2013) agrees with this opinion and emphasizes the need to focus on individual and household levels when assessing food security. He adds that food security should include five dimensions: nutrient adequacy, food sufficiency, safety, cultural acceptability, certainty, and stability. Different approaches were used by The Economist Intelligence Unit in definition of Global Food Security Index (GFSI), which is based on four dimensions: affordability, availability, quality and safety, sustainability, and adaptation.

1.1 Food Security Indicators

Measuring food security is a complex problem and it should not be simplified into dichotomous variable which would indicate only security or insecurity. For example, Webb et. al. (2006) emphasizes the situation when some households are food insecure, but do not experience hunger immediately, in comparison with others, who are in desperate situation. According to Cafiero (2013) that explains increasing demand for indicators, which makes a difference between chronic and transitory food insecurity. Carletto et. al. (2013) highlights the lack of consensus about food insecurity indicators used by various agencies. For example, the Global Food Security Index is only one of several measures of food insecurity introduced in the last decades. It is composed of different pillars and set of indicators in comparison with FAO approach. Izraelov and Silber (2019) notes, that list of food security indicators used by FAO and GFSI does not have much in common. On the other side, instead of using composite indicators, FAO prefers to use prevalence of undernourishment as the main food insecurity measure. This way of measuring is common especially for developing countries. Research in recent years has focused on improving estimation of prevalence rates, as many agencies measure hunger to inform policy makers (Smith and Meade 2019, Pérez-Escamilla et al. 2017, Barret 2010).

Some indicators are based on data collected from households or individuals. Poudel and Gopinath (2021) gives as examples the food Consumption score developed by World Food Program which is based on the frequency of consumption of different food groups by households, another instrument based on the number of unique foods consumed by households are the Household dietary diversity score developed by United States Agency for International Development and The Coping Strategy Index which evaluates how household copes with shortfall of food.

1.2 Global Food Security Index

The most common food and nutrition security indicators according to Pangaribowo et. al. (2013) is: the Global Food Security Index (GFSI) created by The Economist Intelligence Unit, FAO Indicator of Undernourishment, the Global Hunger Index developed by the International Food Policy Research Institute (IFPRI), The Global Poverty index in collaboration with Oxford University, The Hunger Reduction Commitment Index, anthropometric indicators, diet diversity scores and medical and biomarker indicators. Many authors claim that there exists a significant level of variability between different food security indicators (e.g., Poudel and Gopinath 2021, Pérez-Escamilla et al. 2017, Pingali 2016).

The issue of composite indicators is obvious especially at the national level. Jacobs et. al. (2004) stresses the importance of composite indicators especially for delivering information about summary performance and identification of policy priorities. Nardo et al. (2005) and Saisana et al. (2005) conducted study of composite indicators and their results suggests that weighting scheme for composite indicators should be based on statistical techniques such as data envelopment analysis or principal components, but it is also possible to use simple scheme with equal weights.

A frequently used indicator for the assessment of food security at the national level is the Global Food Security index. Since 2012, it has been used to monitor global food security development and covers over 100 countries and has become the most popular national food security measure. Index was the subject of analysis of many authors who focused on his shortcomings. For example, Thomas et al. (2017) reviewed its conceptual framework and concluded that GFSI is focused on food security determinants than its outcomes and therefore rates food security environment. Another critical review of GFSI conducted by Maričič et al. (2016) concluded that despite quality methodology and reliable data its weighting scheme is biased. As the weak spot was identified subjectively assigned weights and authors in their study recommended using the I-distance method to obtain objective unbiased weighting scheme. Despite the subjective weighting scheme, GFSI was found suitable for assessing differences in food security at national level by Chen et al. (2019), Izraelov and Silber (2019), Thomas et al., (2017).

Several authors suggested Data envelopment analysis to estimate objective weights of composite indicators at national level. This method was originally designed to measure performance of decision-making units and their ability to transform effectively inputs into production outputs. However, Lovell and Pastor (1999), Kao (2010), Liu et al. (2011), and Blancas et al. (2013) states that DEA can be applied also for the purpose to produce composite index. It is a special type of DEA without explicit inputs or outputs. This method was already applied for reassessment of Global food security index by Chen et al. (2019) to estimate objective weights at global level. Results of reassessed performance of countries was not significantly different from original index.

Original motivation behind the research published in presented study was to apply food security definition according to FAO based on data available on FAOstat and with the use of all available data produce Food security measure with application of Data Envelopment Analysis to compare European countries and to characterize current food security situation in region. The secondary motivation was to compare produced measure with Global food security index and show advantages and disadvantages of both approaches. However, in the process of research some issues related to specifics of measuring food security situation in European countries were identified.

FAO usually describes food security situation at the national level with indicator measuring prevalence of undernourishment. FAOstat also includes data about food security related indicators in four pillars: availability, access, stability, and utilization, but there is not available any composite indicator based on these variables. Food security is a concept usually related to the developing world, rather than to developed countries. Intention was to use as many variables from FAOstat as possible. But the first problematic issue in conducted research was the fact that most records in database were not available for developed countries or had just ridiculously small variability in this category. As result, from large set of food security related indicators available in FAOstat database could be used only few for the analysis of situation in European countries and the most recent available period was year 2020.

2. From Past to Present: Development of Variables in Food Security Pillars across Europe (2001-2020)

The first step in the analysis was determination of variables which could be used to evaluate actual food security situation in Europe and to construct composite indicator according to definition of food security by FAO in four pillars: availability, access, stability, and utility. The original intention was to use the largest possible number of variables. All variables should have nonzero variability in European countries and should be available at least until 2020. From the list of all available indicators in the food security section met previously mentioned requirements only 10 variables, which were supplemented by 2 variables from World bank database to ensure equal number of indicators in every pillar. (Food production index in pillar Availability and consumer price index in pillar access).

List of analyzed variables can be found in table 1. All variables were obtained for 38 European countries in the period 2012-2020. The reason for the smaller number of selected indicators was that most variables included in FAOstat database are actual especially for developing countries. Some missing values were extrapolated or interpolated to maximize the number of observations used in the analysis. The produced indicator was compared with values of Global food security index (GFSI) obtained from official website of Economist Intelligence Unit (EIU).

Tab. 1 List of analyzed variables

Pillar	Variable	Units of measuring	Source
Availability	Average dietary energy supply adequacy	percent, 3-year average	FAOstat
	Dietary energy supply used in the estimation of prevalence of undernourishment	$kcal \cdot capita^{-1} \cdot day^{-1}$	FAOstat
	Food Production Index	index variable 2014-2016=100	World bank
Access	Gross domestic product per capita	Ppp constant 2017 international $	FAOstat
	Prevalence of moderate or severe food insecurity in the total population	Percent, 3-year average	FAOstat
	Consumer price index	2010=100	World bank
Stability	Political stability and absence of violence/terrorism	Index (-2,5 weak; 2,5 strong)	FAOstat
	Per capita food supply variability	kcal/cap/day	FAOstat
	Coefficient of variation of habitual caloric consumption distribution	Real number	FAOstat
Utility	Minimum dietary energy requirement	kcal/cap/day	FAOstat
	Incidence of caloric losses at retail distribution level	percent	FAOstat
	Percentage of population using safely managed sanitation services	percent	FAOstat

Source: Author´s work

For investigation of the food security situation in Europe 12 variables were selected. These were used to create a composite index to evaluate the overall situation of food security in Europe. Before complex assessment of food security in individual countries offers this chapter information about development of selected input variables and about situation in Europe according to these individual variables. Information about development of variables is displayed in box-plot charts and situation in year 2020 is shown in map chart. Box plot displays distribution of variable for every year. The bottom and top of the chart shows minimum and maximum value. Box is created with first and third quartile. The line in the middle of the box denotes median and diamond shape in the middle denotes average value in current year.

The most of variables were retrieved from the FAOstat database, only food production index and consumer price index were obtained from database of World bank. Food security is investigated in line with the definition created by FAO which assesses three pillars of food security: Availability, Access, Stability and Utility. For each pillar three variables were selected, so it would be represented equally. In FAO database more variables can be found for each pillar, but most of them are focused on developing countries. The smaller number of variables selected for this study is caused by availability of data in FAO database and appropriateness of these variables for European conditions. The year 2020, which is the last year in the presented study, was influenced by spread of Covid19 pandemic.

2.1 Physical availability of food

Availability refers to the physical existence of a sufficient amount of food. For the analysis were selected in first pillar following variables: Average dietary energy supply adequacy, Dietary energy supply used in the estimation of prevalence of undernourishment,

Average dietary energy supply adequacy according to FAO database is defined: The indicator expresses the Dietary Energy Supply (DES) as a percentage of the Average Dietary Energy Requirement (ADER). Each country's or region's average supply of calories for food consumption is normalized by the average dietary energy requirement estimated for its population to provide an index of adequacy of the food supply in terms of calories, and Food production index. It is measured in percentages and variables are expressed as a 3-year average. The average value of this indicator at the beginning of investigated period in year 2001 was equal to 127,53% with minimum values in Montenegro (106%) and Slovakia (109%) and maximum value 148 in Ireland and 147 in Belgium. Average value grew over the whole analyzed period except for the year 2008. The development of this indicator is shown in figure 1.

At the end of analyzed period was average value slightly higher with 133,68% with minimum values in Slovakia (115%) and Bulgaria (116%). Maximum values were again in Ireland (152%) and Belgium (149%). The variability of this indicator changed over time, and at the end of the period analyzed was significantly smaller. In the chart it was slightly influenced by two minimum values which were evaluated as extremes. Variability measured by standard deviation decreased from 11,9% in 2001 to 8,4% in 2020. At the end of the analyzed period the growth of average value stopped, which was influenced by pandemic conditions.

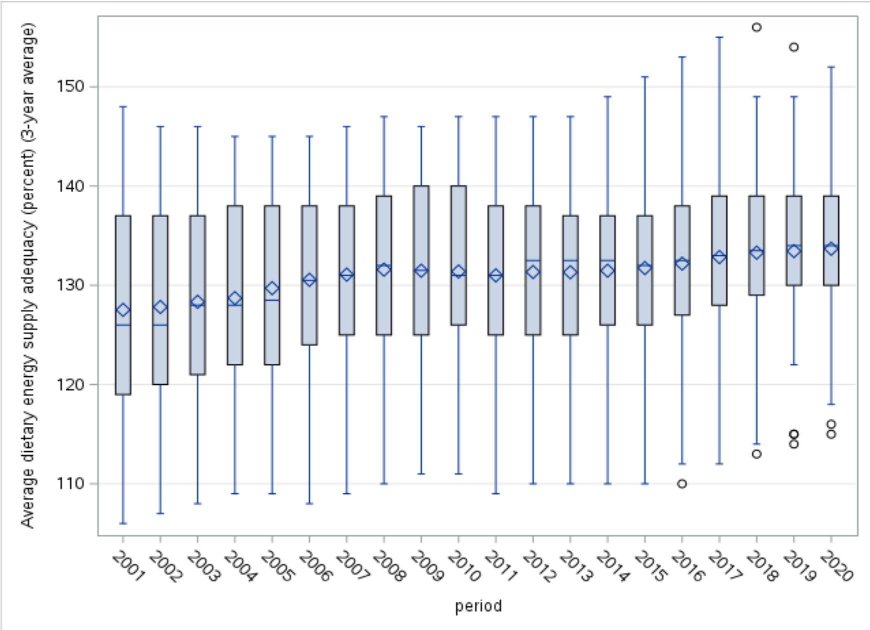

Fig.1 Development of Average dietary energy supply adequacy in years 2001-2020
Source: Author´s work based on data from FAOstat

Figure 2 shows spatial distribution of Average dietary energy supply adequacy in map of Europe. It should be noted that all European countries have levels of average dietary energy supply adequacy higher than 100%, which means that they have enough food. Countries with the smallest level are just slightly above 100%. On the other hand, too high a level of average dietary energy supply adequacy can lead to negative externalities such as large waste and prevalence of obesity.

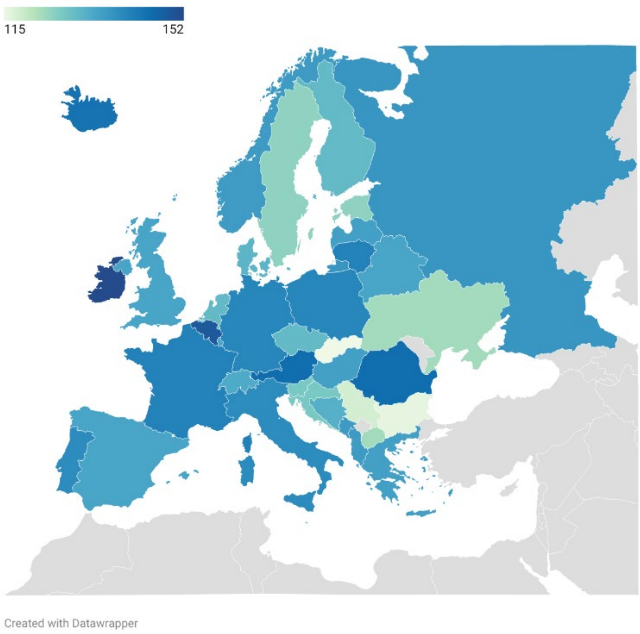

Fig.2 Average dietary energy supply adequacy in 2020
Source: Author´s work based on data from FAOstat

Countries with the smallest level of average dietary energy supply adequacy are localized in the East and South-east of Europe. Minimum value is in Slovakia in central Europe. Low values compared to rest of the Europe are concentrated in Balkan countries Bulgaria, Serbia, North Macedonia followed by Ukraine and Estonia. Surprisingly, also Sweden can be found between countries with the smallest level of average dietary energy supply adequacy with 125%. All these countries have enough food for their population and smaller value compared to the rest of Europe can be consequence of lifestyle and eating habits of population.

Values range between 115% and 152% suggests small differences between countries. However, these differences are not important due to the secure level of this indicator in all European countries. However, it could be highlighted contrast between large excess of average dietary energy supply adequacy in some European countries and developing countries in other world regions with indicator value below 100%. But. analysis of food distribution among world regions is beyond the scope of the presented study. The highest values are distributed across Ireland, Belgium, Austria and surprisingly Romania.

The second indicator evaluated within the first pillar of food security was dietary energy supply used in the estimation of prevalence of undernourishment. Its development in the analyzed period is shown in figure 3.

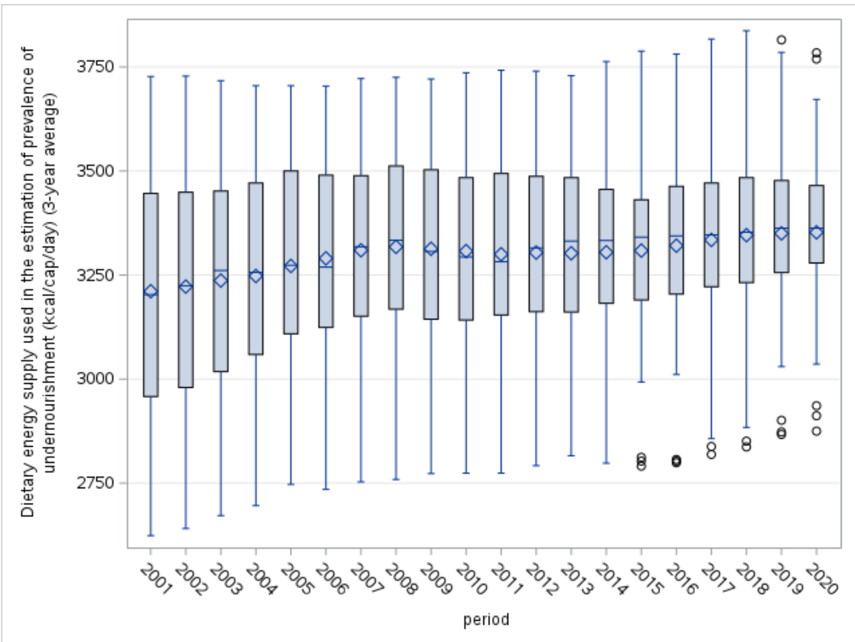

Fig.3 Development of dietary energy supply used in the estimation of prevalence of undernourishment in years 2001-2020
Source: Author´s work

This indicator is defined in FAO database as National average dietary energy supply (DES) (expressed in calories per capita per day) used in the estimation of prevalence of undernourishment. The data may be different from the DES data published in the Food Balance Sheets domain. Despite its similarity with the average dietary energy supply adequacy, results in the case of this indicator are slightly different. Its average value in 2001 was 3211,13 kcal·cap^{-1}·day^{-1}.

Development was similar in the case of average dietary energy supply adequacy with the highest value in 2008. After a slight decrease until 2011 followed continuous growth which stopped at the end of analyzed period. In the year 2020 the average dietary energy supply used in the estimation of undernourishment was equal to 3352,55 $kcal{\cdot}cap^{*-1}{\cdot}day^{-1}$. Variability measured by coefficient of variation decreased from 9% in 2001 to 6% in 2020.

The highest values in 2020 was found in Belgium (3784 $kcal.cap^{-1}.day^{-1}$), Ireland (3769 $kcal.cap^{-1}.day^{-1}$) and Austria (3672 $kcal.cap^{-1}.day^{-1}$). The smallest values were identified in Bulgaria (2875 $kcal.cap^{-1}.day^{-1}$), Slovakia (2912 $kcal.cap^{-1}.day^{-1}$) and Serbia (2936 $kcal.cap^{-1}.day^{-1}$). It is interesting, that in year 2001 were the worst countries Montenegro, Croatia, and North Macedonia, which improved their position. Spatial distribution of dietary energy supply used in prevalence of undernourishment is shown in figure 4.

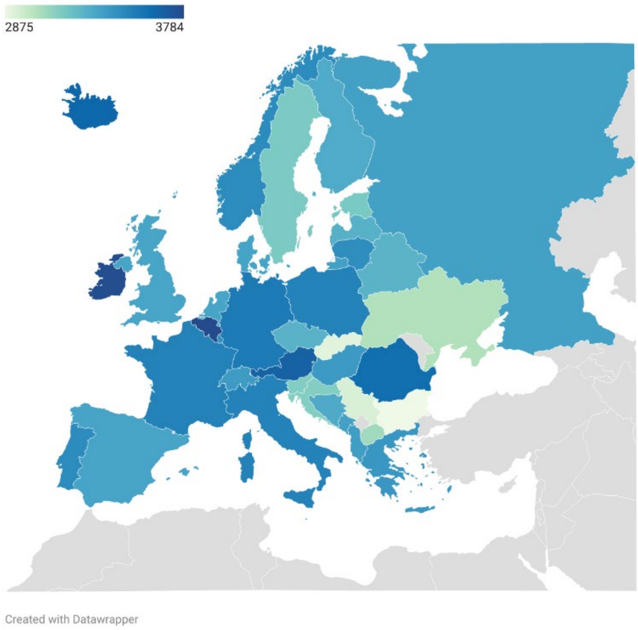

Fig.4 Dietary energy supply used in the estimation of prevalence of undernourishment in 2020
Source: Author´s work

Distribution of dietary energy supply used in the estimation of prevalence of undernourishment in the map of Europe in 2020 is like average dietary energy supply adequacy, however there can be found small differences. The smallest values are localized in south-east and east of Europe with Slovakia as the weak spot in central Europe. Dark spots in the map are again Belgium, Ireland, Austria, Iceland, and Romania.

The difference between maximum and minimum value was 90 $kcal{\cdot}cap^{-1}{\cdot}day^{-1}$. Conclusion about overall situation can be the same as in previous case. Despite the different colors on the map, the food security situation measured by this indicator is stable. Minimum values (2624 $kcal.cap^{-1}.day^{-1}$ in 2001 and 2875 $kcal.cap^{-1}.day^{-1}$ in 2020) are above minimum recommended levels. Undernourishment level was not analyzed in the presented study, as this is not currently an important problem in European regions. For most of analyzed countries was recorded prevalence of undernourishment below 2,5%. Higher values were found only in Slovakia, Serbia, Republic of Moldova, North Macedonia, Bulgaria, and Albania.

The last variable in Availability pillar was Food production index (2014-2016=100). Data for this variable was retrieved from Word Bank database. The main reason was that FAOstat data for variables in the first pillar were not available for European countries until 2020 or they have small variability in Europe. Food production index variable is defined according to World bank database as follows: Food production index covers food crops that are considered edible and that contain nutrients. Coffee and tea are excluded because, although edible, they have no nutritive value. The development of the food production index is shown in figure 5.

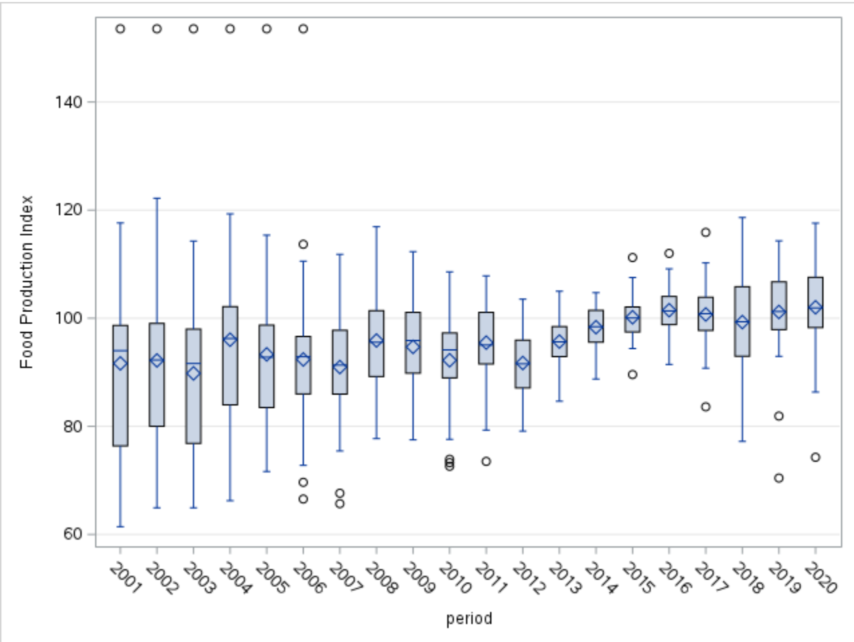

Fig.5 Development of Food production index
Source: Author´s work

Average value of Food production index continuously increased from 91,64 in 2001 to 102,022 in 2020. In 2001 were the smallest values recorded in Latvia (61), Albania (65), Ukraine (66), and Lithuania (69). The highest values of food production index in 2001 was in Slovakia (110), Italy (112), Malta (117) and Montenegro (153). It is necessary to notice that the food production index compares the current year with the period 2014-2016. Therefore, it is more a measure of change than the amount of production. According to definition this variable is related to crop production. This means that it could be used also as proxy of appropriateness of environmental conditions to crop production and its change.

The situation in 2020 was significantly different in comparison with 2001. The smallest values were found in Malta (74), Croatia (86), Bulgaria (90) and Romania (91). And the highest values were in Spain (117), Ireland (115), Bosnia and Herzegovina (114), Luxembourg (113) and Russian Federation (112). These are countries with the highest increase in their food production compared with the period 2014-2016. It is interesting that variability measured as variation coefficient of food production index decreased from approximately 20% in 2001 to 9% in 2020. This suggests convergence of food production across European countries and decreasing disparities among countries, however this result is related mainly to crop production. Although, the smallest variability of food production index among European countries was recorded in years 2014, 2015 and 2016. Distribution of food production index values across the European countries is shown in the map in figure 6.

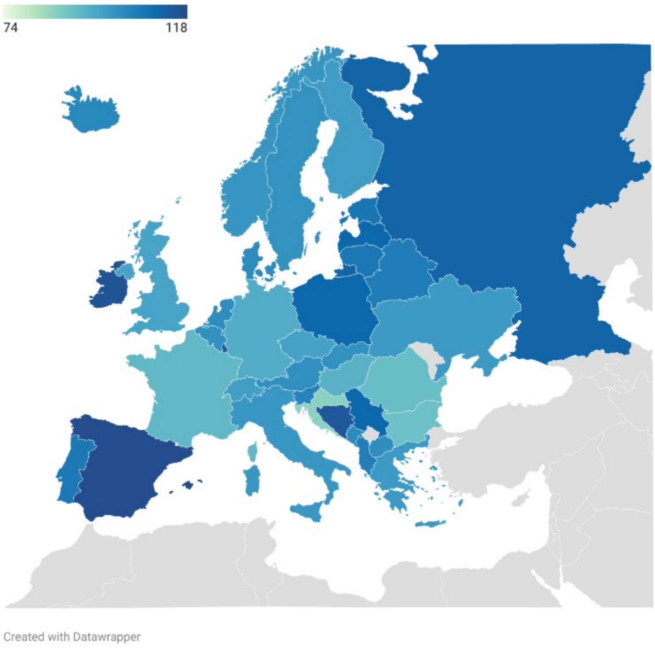

Fig. 6 Food production index in 2020
Source: Author´s work

The highest values of food production index in 2020 are concentrated in the west and southwest of Europe. There could be identified high values also in the south-east and northeast of Europe. Smaller values are concentrated in the central part of Europe. In the central part of Europe, the values of the food production index were smaller.

2.2 Economic and Physical Access to food

An important role in achieving food security has pillar 2: Accessibility. It is related to physical, social, and economic access to food. It means, that people should have sufficient resources, assets, labor, or knowledge to produce food, and market prices should be affordable. This pillar was evaluated using the following variables: Gross domestic product, Prevalence of moderate or severe food insecurity in the total population and Consumer price index. First two variables were obtained from the FAOstat database, Consumer price index was obtained from World bank database, as FAOstat did not include third variable which could be used as measure for European countries. Gross domestic product was used as the measure of income, Prevalence of food insecurity as the indicator measuring the extent of barriers to access food. The consumer price index was selected as an indicator for comparison of price levels across European countries.

Gross domestic product was measured as per capita, ppp, in constant 2017 international dollars. This indicator in FAOstat database is defined as: GDP per capita based on purchasing power

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parity (PPP). PPP GDP is gross domestic product converted to international dollars using purchasing power parity rates. An international dollar has the same purchasing power over GDP as the U.S. dollar has in the United States. GDP at purchaser's prices is the sum of gross value added by all resident producers in the economy plus any product taxes and minus any subsidies not included in the value of the products. It is calculated without making deductions for depreciation of fabricated assets or for depletion and degradation of natural resources. Data are constant in 2017 international dollars.

Gross domestic product is an important indicator of economic development and income of population. It is assumed that the population in countries with high level of GDP will not have problem with access to food regardless of its income, however there could be other barriers to access enough food also in case of sufficient income level.

Figure 7 shows development of GDP in European countries. The outlying value in box plots is Luxemburg with the highest value of GDP per capita. It is usually removed from similarly focused studies. But in this case was decided to leave it in the studied set of countries, due to application of DEA methodology. It requires the maximum possible number of decision-making units, so they can create an efficiency frontier. Outstanding performance of one decision-making unit just strengthen criteria for comparison of others, as countries are evaluated according to European standards.

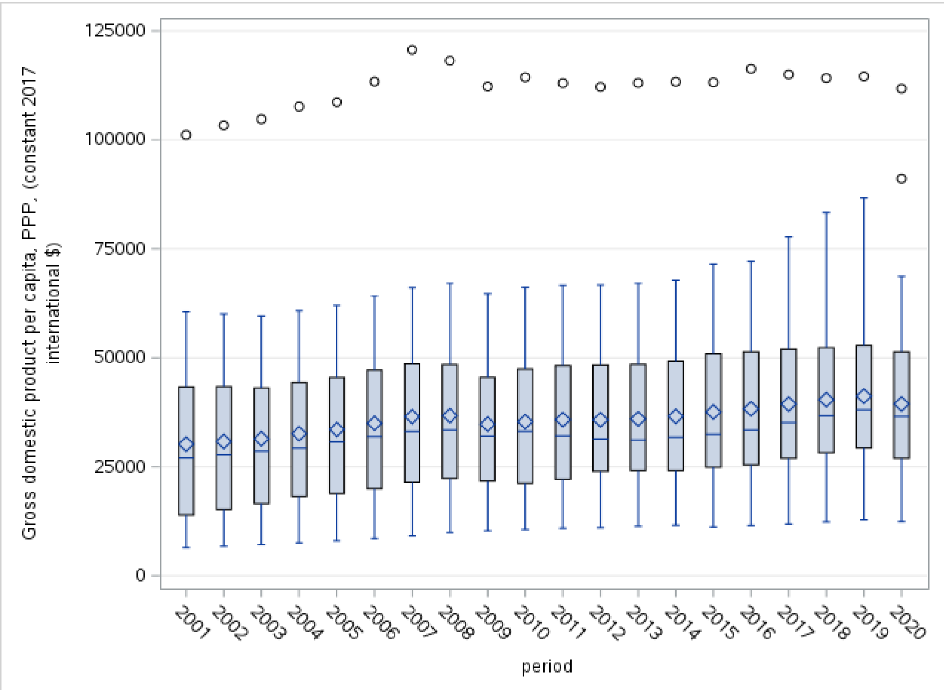

Fig. 7 Development of Gross domestic product
Source: Author´s work

The average value of GDP per capita increased from 30210 constant 2017 international dollars in 2001 to 39430 constant 2017 international dollars in 2020. The median value was smaller than average, which means that most of the analyzed countries performed below average, as the median usually lies between mode and mean. The most developed European countries in relation to GDP in 2001 were Luxembourg, Switzerland, Norway, and Ireland. The least

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developed with the smallest values of GDP per capita were in 2001 Albania, Bosnia and Herzegovina, Ukraine, Belarus, and Serbia.

Large variability in development of the analyzed countries measured as coefficient of variation decreased from 66% in 2001 to 53% in 2020. Which suggest convergence in Economic development of European countries. During the analyzed period also improved situation in least developed countries, as the minimum value in 2001 was 6441 constant 2017 international dollars per capita in Albania, and in 2020 increased to minimum of 12408 constant 2017 international dollars per capita in Ukraine. Average and median value of GDP slightly decreased in 2020 which was influenced by starting spread of Covid 19. Fig. 8 shows economic development of European countries in 2020 on the map.

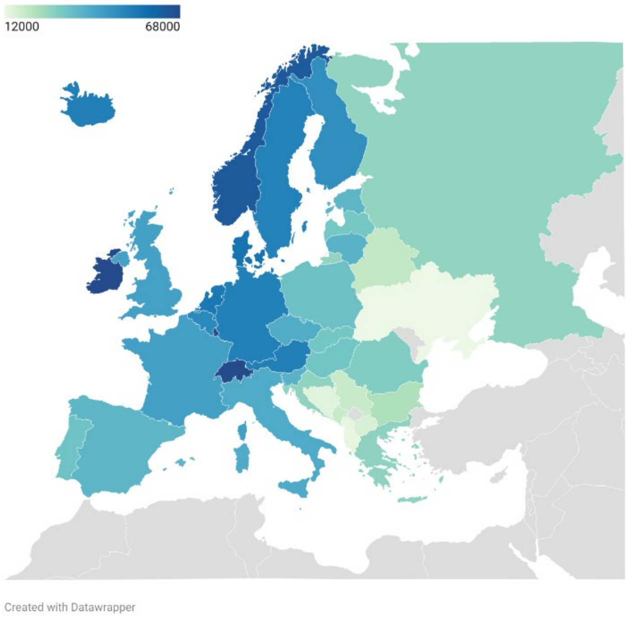

Fig. 8 Gross domestic product in 2020
Source: Author´s work

The most developed countries with the highest level of GDP per capita denoted as dark spots in the map are Luxembourg, Ireland, Switzerland, and Norway. Ireland got to second place, and in 2020 it was evaluated as the second outlying country after Luxembourg with value 91100 constant 2017 international dollars per capita. Third Switzerland evaluated as not outlying value recorded value 68670 constant 2017 international dollars per capita. Map shows how GDP per capita divides Europe into two parts with the higher values in the West and smaller values in the East. The most developed countries are in the North-west of Europe. On the other hand, countries with the smallest values of GDP per capita in 2020 were Ukraine, Albania, Bosnia and Herzegovina, North Macedonia, and Montenegro. These countries were localized primary in the East and South-east of Europe. Despite this result can be evaluated Europe as developed region compared to average GDP per capita in the world equal to 12235 dollars.

Other indicators used for evaluating the accessibility of food were prevalence of food insecurity and consumer price index. In comparison with GDP per capita, where the higher value means better access to food, high values of these indicators could mean existence of barriers in accessing enough nutrition.

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Definition of variable according to FAOstat database is following: The prevalence of severe food insecurity is an estimate of the percentage of people in the population who live in households classified as severely food insecure. The assessment is conducted using data collected with the Food Insecurity Experience Scale or a compatible experience-based food security measurement questionnaire (such as the HFSSM). The probability to be food insecure is estimated using the one-parameter logistic Item Response Theory model (the Rasch model) and thresholds for classification are made cross country comparable by calibrating the metrics obtained in each country against the FIES global reference scale, maintained by FAO. The threshold to classify "severe" food insecurity corresponds to the severity associated with the item "having not eaten for an entire day" on the global FIES scale.

In simpler terms, a household is classified as severely food insecure when at least one adult in the household has reported to have been exposed, at times during the year, to several of the most severe experiences described in the FIES questions, such as to have been forced to reduce the quantity of the food, to have skipped meals, having gone hungry, or having to go for a whole day without eating because of a lack of money or other resources. It is an indicator of lack of food access. Figure 9 shows development of Prevalence of moderate or severe food insecurity in European countries over analyzed period.

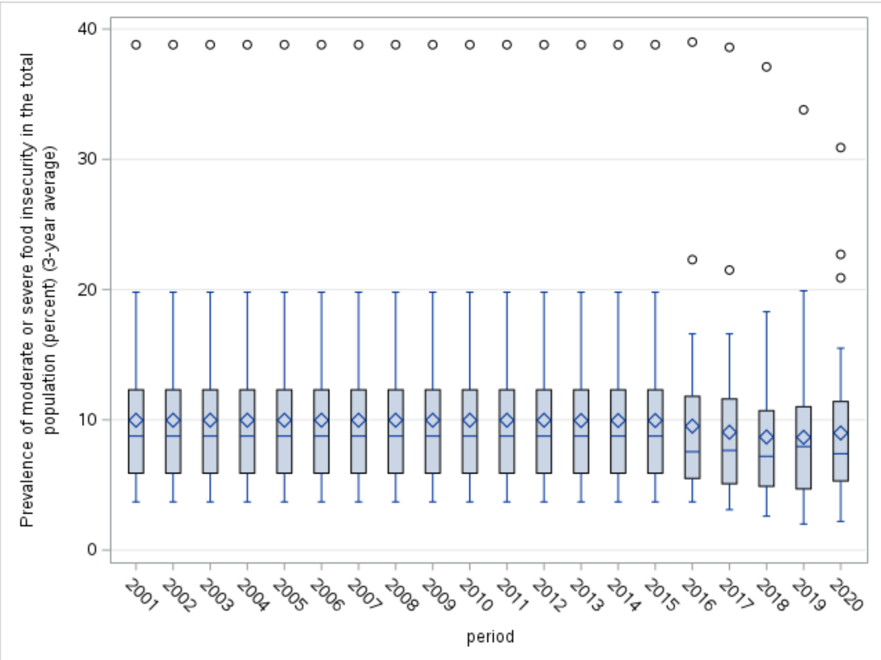

Fig. 9 Development of Prevalence of moderate or severe food insecurity
Source: Author´s work

Food insecurity does not seem to be a problem in Europe, however there are still regions where people experiencing it can be found. Based on development shown in the figure 9 there were not detected any significant changes. The average value in 2001 was 9.96% of people experiencing moderate or severe food insecurity in Europe. Outlier country with the highest recorded value over whole analyzed period was Albania, where experienced moderate or severe food insecurity 38.8% of population in 2001.This outlier value of Albania decreased over the analyzed period to 30.9% of population in 2020. Except Albania were the most food insecure countries in Europe Ukraine with 19.8%, Romania with 19.3% and Greece with 15.8% of population experiencing moderate or severe food insecurity.

Despite a small decrease in the average value over the period analyzed to 8.98% in 2020 the situation got worse in the poorest countries. Except Albania were in 2020 prevalence of moderate or severe insecurity higher than 15% in Ukraine (22.7%), North Macedonia (20.9%) and Bulgaria (15.5%) which led to detection of more outliers at the end of analyzed period. The situation was complicated even more with the start of corona crisis in 2020 which increase slightly the average prevalence of moderate or severe food insecurity in Europe compared to 2019. Large disparities between countries within this indicator are suggested also by high value of variation coefficient which was 64% at the beginning of the analyzed period and slightly increased to 65.2% in 2020. It can be concluded that despite the economic development of major parts of Europe, the situation of regions of population segments experiencing moderate or severe food insecurity is not improving. Figure 10 shows a map of prevalence of moderate or severe food insecurity in European countries in 2020.

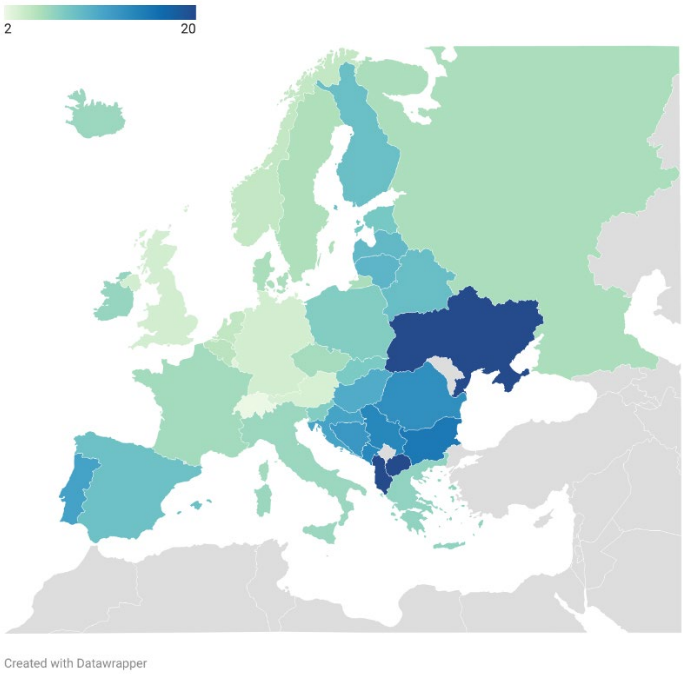

Fig.10 Prevalence of moderate or severe food insecurity in 2020
Source: Author´s work

The most endangered regions are localized in the South-east of Europe. The worst situation in western part of Europe is in Portugal (11.6% in 2020) and Spain (8.6% in 2020). On the other hand, the situation in the best performing countries improved over the period analyzed. The smallest share of population experiencing moderate or severe food insecurity in 2001 was found in Belgium (3.7%), Germany, (4.1%), Sweden (4.5%) and Luxembourg (4.7%). In 2020 were minimum values even smaller with Switzerland at the top with (2.2%), followed by Luxembourg (2.8%), Austria (3.3%), Germany and United Kingdom (both 3.5%).

Results suggest that prevalence of moderate or severe food insecurity gets worse in less developed regions of Europe, on the other hand, this problem is almost eliminated in the most developed countries. It may be argued that food insecurity is not a major problem in European

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countries and should be solved primarily in the developing world. In European segments of countries, population and regions experiencing moderate or severe food insecurity can also be found, and this problem gets worse especially in the most endangered regions. Situation is complicated even more with recent spread of covid pandemic across continent and military conflict in Ukraine.

The last variable used to evaluate accessibility of food in Europe was the Consumer price index. Data was retrieved from the World bank database. The definition of this indicator in database is the following "Consumer price index reflects changes in the cost to the average consumer of acquiring a basket of goods and services that may be fixed or changed at specified intervals, such as yearly. The Lapeyre's formula is generally used. Data are period averages." Values are expressed in the form of index, with year 2010=100. Consumer prices significantly affect the access of the population to food. In comparison with small income, it may cause serious food insecurity. Figure 11 shows the development of consumer price index in European countries over the analyzed period.

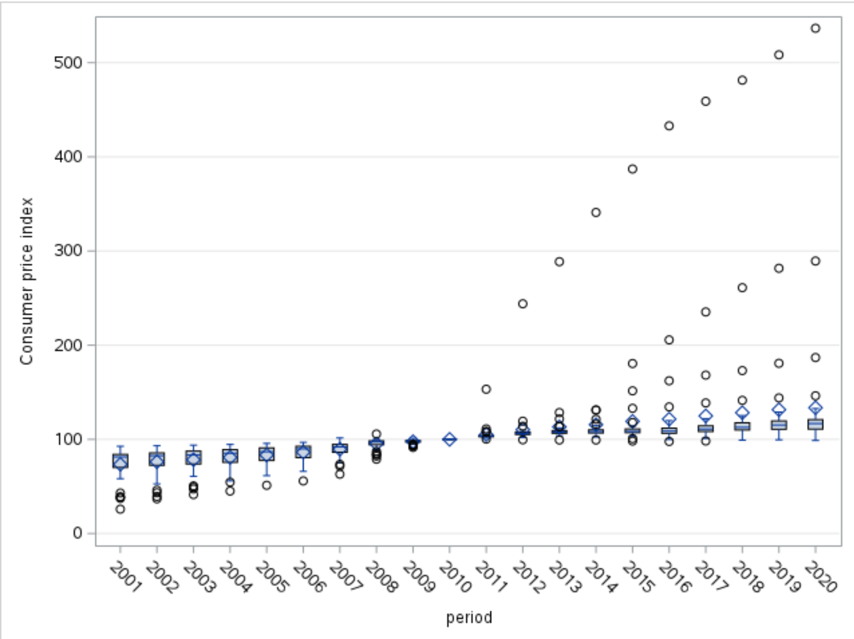

Fig.11 Development of Consumer price index in European countries
Source: Author´s work

It is obvious that the chart is visually significantly distorted by extreme values occurring since 2011. The first extreme value first observed in 2011 is Belarus with value 153. This extreme increased even more in last years to 536.54 in 2020. Since 2014 appeared another two extremes significantly increasing in recent years, which are Russian Federation and Ukraine. Their consumer price index increased from initial values 131 and 121 respectively to 186.86 and 289.35 respectively. It coincides with start of first Russian military operations in Ukraine in 2014. Another country with extremely high consumer price index in recent year was Serbia with value 146.27 in 2020.

Except these extremes can be observed continuous increase of consumer price index over analyzed period from average value 73.48 in 2001 to 133.57 in 2020. At the beginning analyzed period in 2001were the highest values recorded in Switzerland (92.65), Finland (88.3), Sweden

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(88.3) and Germany (87.39). The smallest of consumer price index in 2001 were in Belarus (25.86), Russian Federation (37.37), Serbia (38.52), Ukraine (39.01), and Romania (43).

Situation in 2020 changed significantly and smallest increase of consumer prices was recorded in Switzerland (98.82), Greece (100.68), Bosnia and Herzegovina (103.79) and Ireland (106.23). Spatial distribution of consumer price index across European countries in 2020 is shown in figure 12.

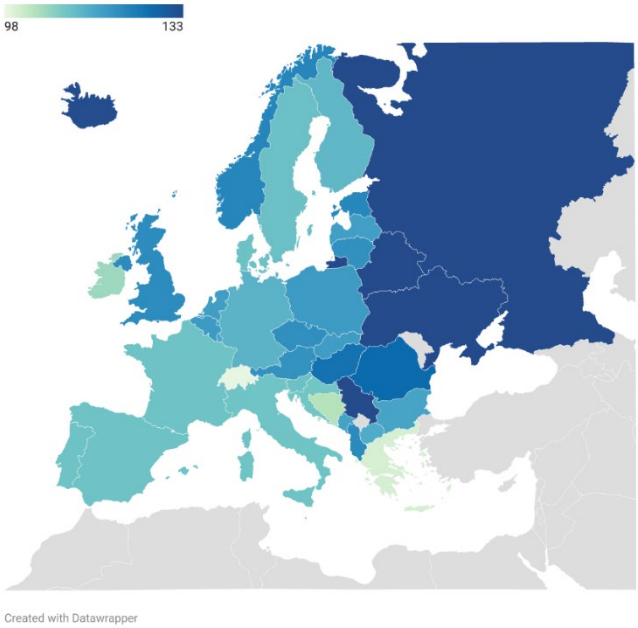

Fig.12 Consumer price index in 2020
Source: Author´s work

In the map of consumer price index is also obvious splitting into Western part with smaller increase of consumer prices and Eastern part with higher increase which reminds distribution of Gross domestic product per capita. The only European country where consumer prices were smaller than in year 2010 was Switzerland. It is interesting that in some countries with the smallest values of consumer price index in 2001 were found to have very high values in 2020. This may be linked to economic transformation in some East-European countries and liberalization of their markets. But it was strongly influenced also by Russian military operations in Ukraine and spread of coronavirus in recent years.

High consumer prices in combination with low income can be a source of food insecurity, especially in some countries of Eastern Europe. Combination of high consumer price index and low level of gross domestic product per capita in 2020 can cause further problems with food access especially in Ukraine, Albania, Serbia, Belarus, Russian Federation and Romania. It can be expected further deepening of this problem in mentioned regions in 2021 and 2022 which are not covered in this study but were significantly influenced by pandemic situation and escalation of conflict in Ukraine. Accessibility of food in Europe can be evaluated as secure compared to the developing world. On the other hand, there could be identified regions, especially in East and South-east of Europe, where it could be a serious issue. It is assumed there will be further deterioration of food accessibility in the whole region due to events in recent years. This problem should not be underestimated in the European area and help should be addressed to the most endangered regions and segments of population.

2.3 Food Utilization

According to definition by FAO, the third pillar of food security is defined as: Utilization is commonly understood as the way the body makes the most of various nutrients in the food. Sufficient energy and nutrient intake by individuals are the result of good care and feeding practices, food preparation, diversity of the diet and intra-household distribution of food. Combined with good biological utilization of food consumed, this determines the nutritional status of individuals.

Food Utilization is linked to efficient using of food resources, which refers to sanitation, waste management, but poor utilization can also cause problems with anemia or obesity in population. In practice it was not easy to find suitable variable for evaluation of food utilization in Europe. The following variables were obtained from FAOstat database: Percentage of population using safely managed sanitation services, Incidence of caloric losses at retail distribution level and Minimum dietary energy requirement. The first two variables were originally selected as part of utilization pillar by FAO. It was problematic to identify a third variable which could be used also for European countries, so minimum dietary energy requirement was selected as a measure of lifestyle and eating habits in European countries. Figure 13 shows its development over the analyzed period.

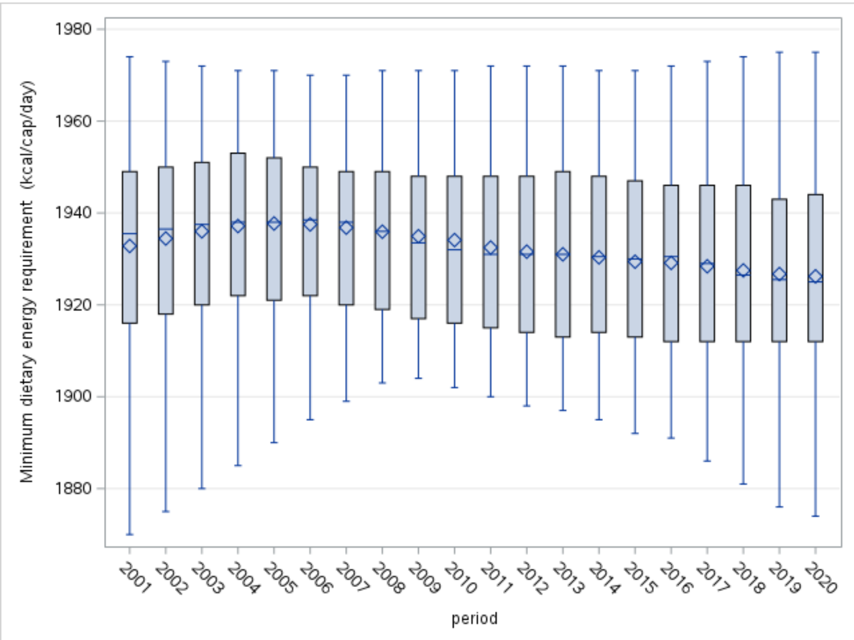

Fig.13 Minimum dietary energy requirement
Source: Author´s work

According to FAOstat is Minimum dietary energy requirement defined as follows: In a specified age/sex category, MDER is the minimum amount of dietary energy per person that is considered adequate to meet the energy needs at a minimum acceptable BMI of an individual engaged in low physical activity. If referring to an entire population, the minimum dietary energy

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requirement is the weighted average of the minimum energy requirements of the different age/sex groups. It is expressed as kilocalories per person per day.

The higher value of this variable could indicate a higher standard of living, on the other hand in poor countries it could cause a higher number of people considered undernourished. In the case of smaller value can be assumed that the country is less developed, but in rich countries it would cause a smaller number of people considered undernourished which would make it difficult to address appropriate social help. It is assumed that a higher value of minimum dietary energy requirement would be signal of better utility of food in country.

The average value of this indicator did not change substantially over the period analyzed. At the beginning in 2001 the average value was 1932.82 $kcal \cdot capita^{-1} \cdot day^{-1}$ and in 2020 it was 1926.21 $kcal \cdot capita^{-1} \cdot day^{-1}$. More interesting is the development of its variability, which decreased at the beginning of analyzed period and reached minimum in 2009, when differences among countries started to grow again. In 2001 was the smallest minimum dietary energy requirement found in Albania (1870 $kcal \cdot capita^{-1} \cdot day^{-1}$), Lithuania (1897 $kcal \cdot capita^{-1} \cdot day^{-1}$), Montenegro (1903 $kcal \cdot capita^{-1} \cdot day^{-1}$), and Serbia (1905 $kcal \cdot capita^{-1} \cdot day^{-1}$). On the other side of ranking with the highest values were Netherlands (1974 $kcal \cdot capita^{-1} \cdot day^{-1}$), Czech Republic (1971 $kcal \cdot capita^{-1} \cdot day^{-1}$), Estonia (1969 $kcal \cdot capita^{-1} \cdot day^{-1}$) and Finland (1964 $kcal \cdot capita^{-1} \cdot day^{-1}$). Figure 14 shows values of minimum dietary energy requirement in map of Europe in year 2020.

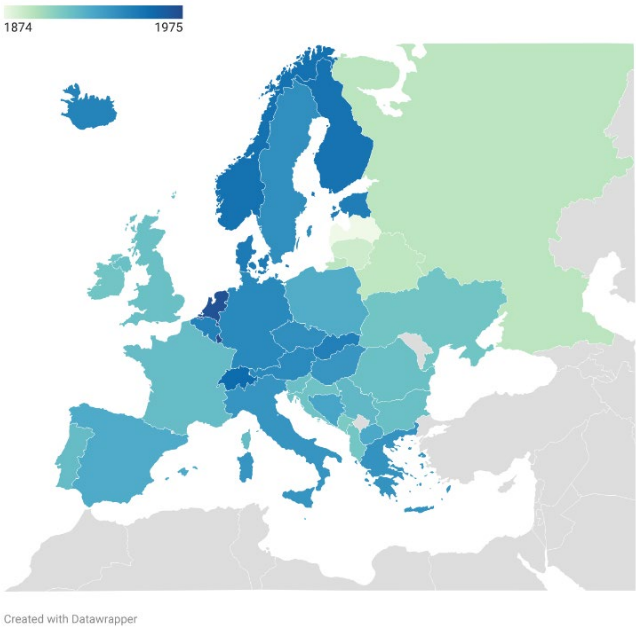

Fig.14 Minimum dietary energy requirement in 2020
Source: Author´s work

The higher values are localized in central and North Europe. Smaller values in the East. The highest values of minimum dietary energy requirement in 2020 were found in Luxembourg (1975 $kcal \cdot capita^{-1} \cdot day^{-1}$), Netherland (1971 $kcal \cdot capita^{-1} \cdot day^{-1}$), Switzerland (1957 $kcal \cdot capita^{-1} \cdot day^{-1}$) and Norway (1954 $kcal \cdot capita^{-1} \cdot day^{-1}$). Countries with the smallest values in 2020 were Latvia (1874 $kcal \cdot capita^{-1} \cdot day^{-1}$), Lithuania (1884 $kcal \cdot capita^{-1} \cdot day^{-1}$), Belarus (1888 $kcal \cdot capita^{-1} \cdot day^{-1}$) and Russian Federation (1889 $kcal \cdot capita^{-1} \cdot day^{-1}$). The variability of this indicator was relatively small and the difference between maximum and minimum dietary energy requirement in 2020 was only approximately 101 kcal·capita^{-1}·day^{-1}. It should be reminded, that variable dietary energy requirement was selected as additional variable to utilization pillar to ensure number of variables equal to other pillars. The values of these variables in European countries suggest a good level of food utilization compared to other world regions.

Another variable used in utility pillar was incidence of caloric losses at retail distribution level. It was measured in percentages. It measures how efficient food is treated at retail distribution level. Higher caloric losses at retail level are characteristic for less developed countries. In Europe can be expected small values of this variable. Figure 15 shows development of caloric losses at retail distribution level in European countries over the period analyzed.

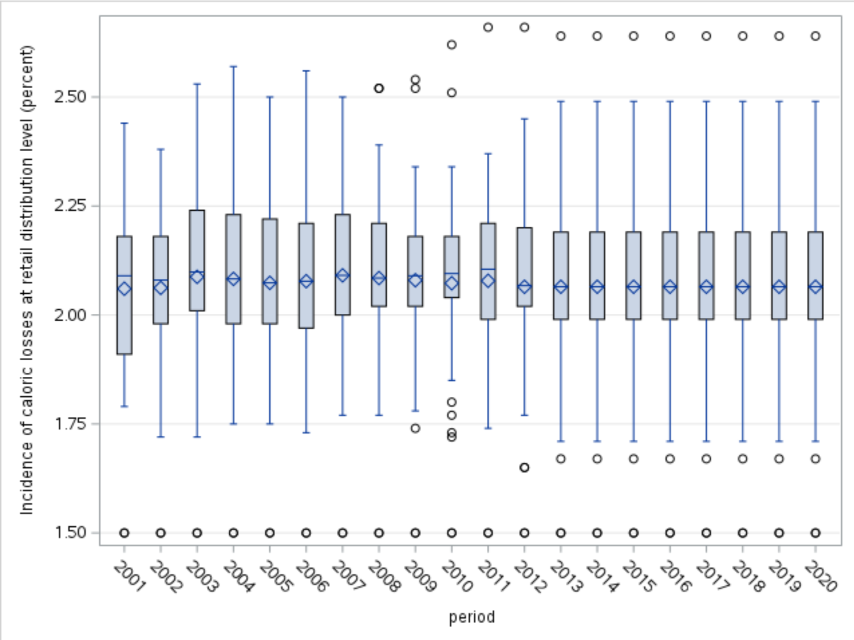

Fig.15 Incidence of caloric losses at retail distribution level
Source: Author´s work

The average value of this indicator did not change significantly over the period analyzed and at the end was like its initial level equal to 2.06%, which may be concluded in general as very small caloric loss at retail level. What had slightly changed in the period analyzed was the distribution of this variable. Its variability stays still small, equal approximately to 10% coefficient of variation. The minimum value in 2001 is equal to the minimum value in 2020 at the level of 1.5%. The maximum value recorded in 2001 was 2.44% and until 2020 slightly increased to 2.64%.

The best countries with the smallest caloric losses at retail level in 2001 were Bulgaria (1.5%), Hungary (1.5%), Czech Republic (1.79%), and Slovakia (1.8%). On the other hand, the maximum caloric losses at retail distribution level were found in Greece (2.44%), Spain (2.34%), Portugal (2.34%) and Lithuania (2.32%). Small differences between countries have not changed over the period analyzed. Distribution of caloric losses in 2020 is shown in figure 16. Despite significant differences in color shades in the figure, differences between countries are small varying 1.5% to 2.64%.

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In the case of incidence of caloric losses at retail distribution level means smaller value better result. Therefore, better countries are denoted in the figure with brighter colors. A smaller incidence of caloric losses at retail distribution level is obvious in the center of Europe. On the other hand, higher values can be found both in the Eastern and Western part. The smallest incidence of caloric losses at retail level in 2020 were recorded in Bulgaria (1.5%), Hungary (1.5%), Slovakia (1.67%) and Czech Republic (1.71%). In relation to small variability within this variable were Bulgaria and Hungary denoted as outlying small values.

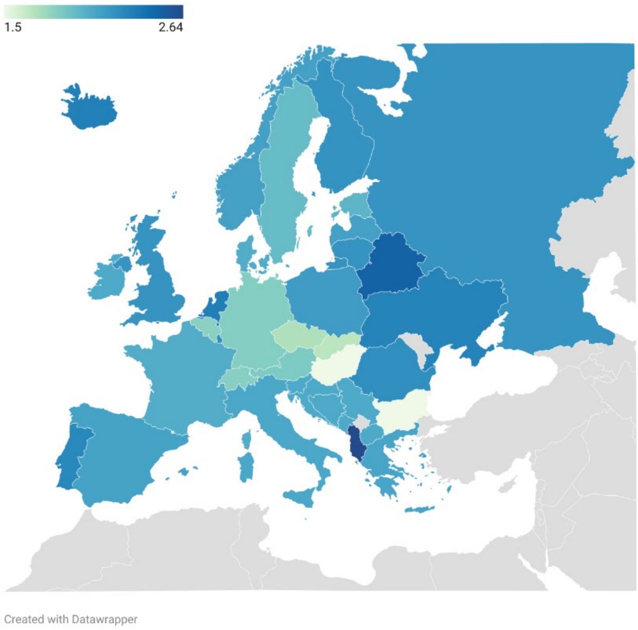

Fig.16 Incidence of caloric losses at retail distribution level in 2020
Source: Author´s work

Between the smallest caloric losses and countries with the highest values was only slight difference. The highest caloric losses in Europe were found in Albania (2.64%), Belarus (2.49%), Netherlands (2.32%), and Iceland (2.31%). Albania with 2.64% incidence of caloric losses was evaluated as the large outlier value which is obvious also in the figure. However, incidence of caloric losses in European countries can be considered at good level appropriate to developed countries. It should be noted that even a small percentage could mean large values, if it's based on large values. Retail distribution in European markets includes large amounts of food, so even a small percentage can mean substantial large value. Especially, if it would be compared with the developing world, where retail distribution does not operate so large volumes.

Last variable used to evaluate food utilization in Europe was Percentage of population using safely managed sanitation services. Data were retrieved from FAOstat and definition of this variable in data description is following: The percentage of the population using improved sanitation facilities which are not shared with other households and where excreta are safely disposed in situ or transported and treated off-site. This indicator may seem to be not up to date for European countries, but surprisingly, also in developed Europe there is still a significant number of countries with smaller value of this indicator than expected. In addition, it is the only variable in the Utility pillar of food security used for this purpose also by FAO.

Other original utility variables were not available for European countries over the whole period analyzed.

Figure 17 shows the development of percentage of population using safely managed sanitation services in European countries over the period analyzed. From the figure is obvious improvement of situation and significant increase of average value, which was equal to 66.22% at the beginning of the analyzed period in 2001 and increased to 78.92% in 2020. It is interesting that there are still extremely small values which did not improve over time. On the other hand, median value is in all years higher than mean. This suggests that values in the majority of European countries are higher than average, as median is usually localized between mode and mean. Values in 2001 were slightly smaller and the best situation was in Switzerland (99%), United Kingdom (97.7%), Netherlands (97.4%), and Germany (95.8%).

Despite of economic development of European region were in year 2001 recorded the smallest values in North Macedonia (12.9%), Bosnia and Herzegovina (17.6%), Austria (21.8%) and Serbia (22.4%).

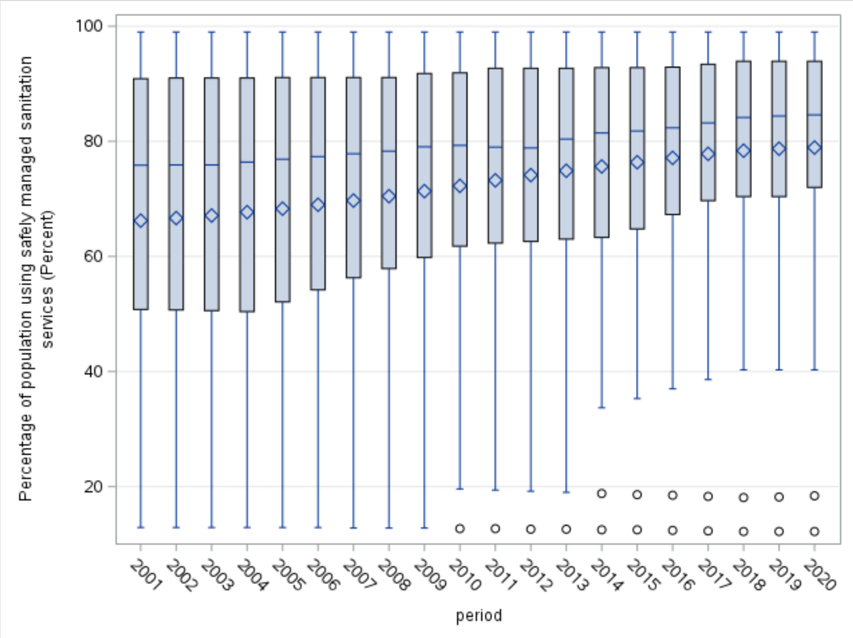

Fig.17 Percentage of population using safely managed sanitation services
Source: Author´s work

The situation significantly improved oved analyzed period and in 2020 an increased number of countries will increase with the value of this indicator above 90%. The percentage of population using safely managed sanitation services in 2020 in the map of European countries is shown in figure 18. At the top of the ranking were Austria (99%), Switzerland (99%), United Kingdom (98.1%), Netherlands (97.5%) and Germany (97.1%). The largest improvement was recorded in Austria which moved from the worst performing countries in 2001 to the top of the ranking over 20 years.

On the other hand, the situation in the worst performing countries over the last 20 years almost has not changed. The worst situation was still in North Macedonia (12.2%), Serbia (18.4%), Bosnia and Herzegovina (40.3%), Montenegro (45.4%), and Albania (47.7%). North

Macedonia and Serbia were clear outliers. All other European countries have a percentage of population using safely managed sanitation services in 2020 above 60%. In the map can be easily identified South-eastern region where is the situation with sanitation services the worst. Values shown on the map are set to range from 40% to 99%, to show also differences between more developed countries, otherwise it would be possible to identify only weak regions in the South-East.

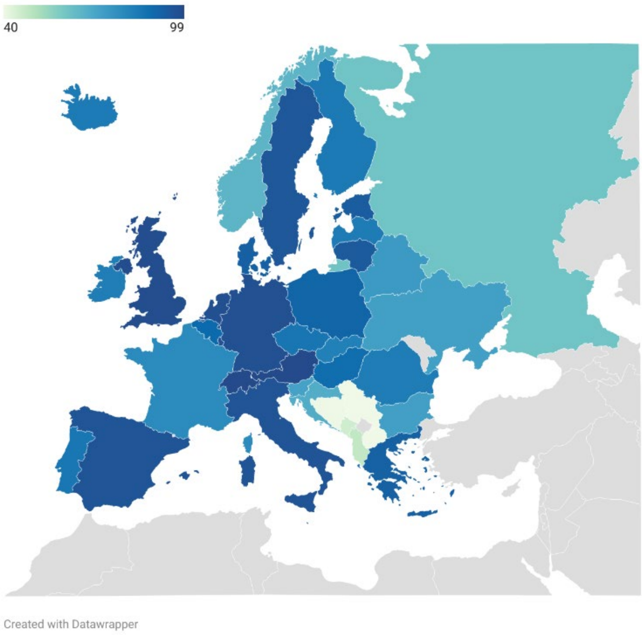

Fig. 18 Percentage of population using safely managed sanitation services in 2020
Source: Author´s work

There were found surprisingly small values also in more developed countries, for example in France (78.6%), Slovenia (71.5%), and Norway (65.4%). Except problematic region in the South-East can be identified another weaker region in the North and North-East part of Europe.

2.4 Stability of Food Availability and Access

According to definition by FAO, stability pillar of food security refers to both Availability and Accessibility dimensions. The population should have access to adequate food all the time and should not risk a loss of access to food due to unexpected crises, or cyclical events. In another words, it can be concluded that in relation to food security should be the first three pillars stable over time without significant disruptions. This pillar was again evaluated according to three variables which were part of the FAOstat suite of food security indicators labeled as part of the stability pillar: Political stability and absence of violence/terrorism, per capita food supply variability and coefficient of variation of habitual caloric consumption. These were only three variables which were useful for evaluation of developed European regions.

First and the most important variable is political stability and absence of violence/terrorism. Variable is measured in form of index, which is defined in FAOstat database as follows: Political stability and absence of violence measures perceptions of the likelihood that the government will be destabilized or overthrown by unconstitutional or violent means, including politically motivated violence and terrorism. A higher value of the index means better political stability.

In figure 19 can be seen development of index measured political stability and absence of violence over the analyzed period. There is obviously a very large variability in political stability across the European region. Variability measured by coefficient of variation was 114% in 2001 and decreased to 110% in 2020. The average value of the index decreased from 0.559 in 2001 to 0.526 in 2020. Median value was slightly higher every year than mean, which suggests that most European countries are politically stable. On the other hand, almost every year was identified some small outlying values. In year 2001 were the most politically stable countries in Europe Lithuania (1.64), Luxembourg (1.55), Spain (1.54) and Finland (1.4). On the other side of ranking with the worst political stability in region were Romania (-0.95), Netherlands (-0.52), Bosnia and Herzegovina (-0.44), Sweden (-0.36) and Ukraine (-0.3).

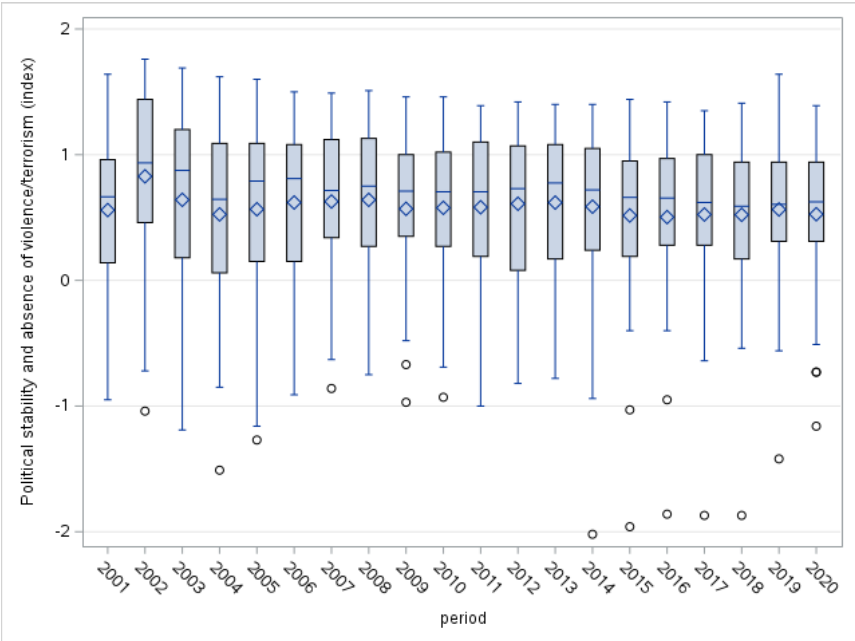

Fig.19 Political stability and absence of violence/terrorism
Source: Author´s work

The highest average political stability in Europe was recorded in 2002. Since 2014 started its continuous decrease. This was influenced by military conflict in Ukraine and refugee crisis in Europe, in 2020 decrease continued as the impact of coronavirus crisis. In following years is expected further decrease due to escalation of conflict in the Ukraine and energetic crisis in Europe.

In 2020 were the most politically stable countries in region Iceland (1.39), Norway (1.25), Luxembourg (1.23), Switzerland (1.19). The maximum value in 2020 compared to 2001 decreased, which is another sign of deteriorated political stability in the region. Countries with the worst political stability in Europe in 2020 were Ukraine (-1.16), Belarus (-0.73), Russian Federation (-0.73) Bosna and Herzegovina (-0.51) and Serbia (-0.09). Since 2014 can be identified extremely small values of this indicator. Political stability in 2020 on the map of Europe is shown in figure 20.

In the map can be seen values within range -1.16 to 1.4. The most stable region is in the center and North of Europe. Regions endangered by political instability are in the East and Southeast. The worst situation is in the East due to military conflict between and Russian Federation. Political stability is an important factor in ensuring sustainable food security. In recent period stability significantly deteriorated in the whole region. In the future it will be an important challenge to improve the quality of this indicator to ensure balanced food secure future in Europe.

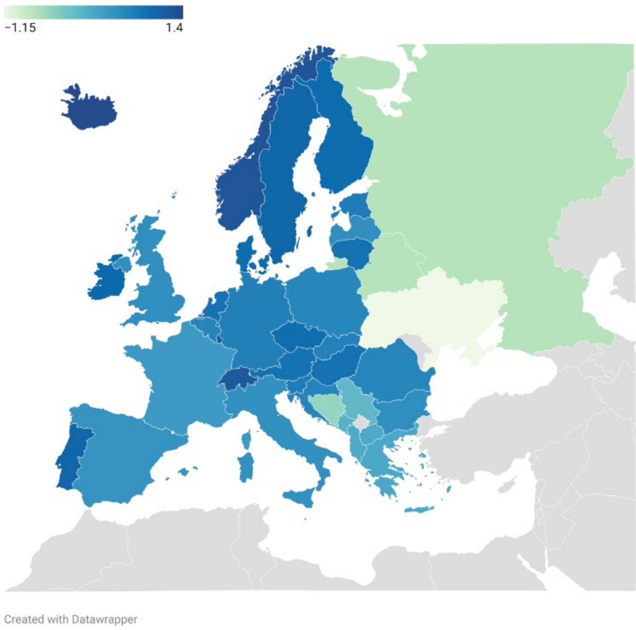

Fig.20 Political stability and a absence of violence/terrorism in 2020
Source: Author´s work

Political stability is closely related to another indicator in the last pillar, which is per capita food supply variability. This variable evaluates stability of food supply and therefore is linked to the first pillar. Even countries with a high level of food availability could be food insecure in case of poor stability of their food supply. Also in this case were data obtained from FAOstat. Description of this variable in database is following: Per capita food supply variability corresponds to the variability of the "food supply in $kcal.cap.^{1}day^{-1}$" as disseminated in FAOSTAT.

In contrast with the previous indicator, large value in this case means poor food security conditions in country, small food supply variability on the other hand means good stability and food security conditions. Development of per capita food supply variability in European countries over analyzed period is shown in figure 21. There is a positive tendency in the development of this indicator and variability of food supply is continuously decreasing and there is substantial convergence between European countries, which is demonstrated by reducing variability. There can be noticed some number of outlying values every year.

Average per capita food supply variability in 2001 was 57.84 kcal·cap^{-1}·day^{-1}. Until 2020 this value decreased to 27.84 kcal·cap^{-1}·day^{-1}. The variability of this indicator measured by coefficient of variation decreased from 68% in 2001 to 55% in 2020 but remains still large. It is interesting that average per capita food supply variability in European countries had a decreasing trend from 2001 until 2014 when it stopped and started to grow. This coincidence with start of military operations in Ukraine. 2014 was a significant inflex point for many food security indicators, which suggests that later escalation of this conflict has significant negative impact on European food security. After a small increase followed another decline in 2018. Due to coronavirus pandemic and further escalation of military conflict in Ukraine in 2022 can be expected further deterioration of stability also expressed by increasing per capita food supply variability.

The situation in individual countries between year 2001 and year 2020 significantly changed. In 2001 had the most stable food supply Luxembourg (6 kcal·cap^{-1}·day^{-1}), Iceland (21 kcal·cap^{-1}·day^{-1}), United Kingdom (22 kcal·cap^{-1}·day^{-1}) and Belgium (24 kcal·cap^{-1}·day^{-1}). Luxembourg is clear outlier with extremely small value. On the other side of ranking with the highest per capita food supply variability were Montenegro (235 kcal·cap^{-1}·day^{-1}), Czechia (110 kcal·cap^{-1}·day^{-1}), Bosna and Herzegovina (100 kcal·cap^{-1}·day^{-1}) and Slovenia (97 kcal·cap^{-1}·day^{-1}). Food supply variability in Montenegro in this year was extremely high, but it is still much smaller value than world average which is above 2000 kcal·cap^{-1}·day^{-1}.

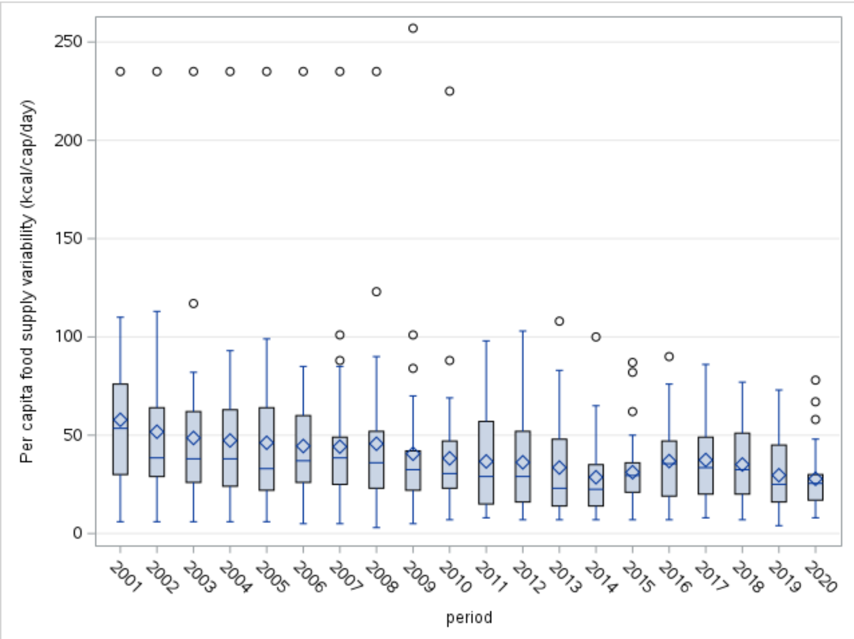

Fig.21 Per capita food supply variability
Source: Author´s work

In 2020 significantly changed performance and ranking of analyzed countries within this indicator. The smallest per capita food supply variability was recorded in Sweden (8 kcal·cap^{-1}·day^{-1}), Serbia (10 kcal·cap^{-1}·day^{-1}), Hungary (10 kcal·cap^{-1}·day^{-1}), and Finland (11 kcal·cap^{-1}·day^{-1}). Minimum values in 2020 were much smaller than in 2001, if we do not take Luxembourg result in 2001 into account. The highest per capita food supply variability was recorded in Montenegro (78 kcal·cap^{-1}·day^{-1}), Czech Republic (67 kcal·cap^{-1}·day^{-1}),

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Slovakia (58 kcal·cap^{-1}·day^{-1}), Poland (48 kcal·cap^{-1}·day^{-1}), and France (45 kcal·cap^{-1}·day^{-1}). Also, these values were significantly smaller than maximum values recorded in 2001.

In conclusion, average per capita food supply variability in Europe suggests good food security conditions. Its value decreased over time and differences between countries declined. Compared to the rest of the world the food supply variability in Europe is small. In the analyzed period it was unexpectedly increased by sudden shocks, which suggests vulnerability of the European food system. In figure 22 is shown spatial distribution of per capita food supply variability in the map of Europe. It is obvious, that in most European countries the food supply variability per capita is very small.

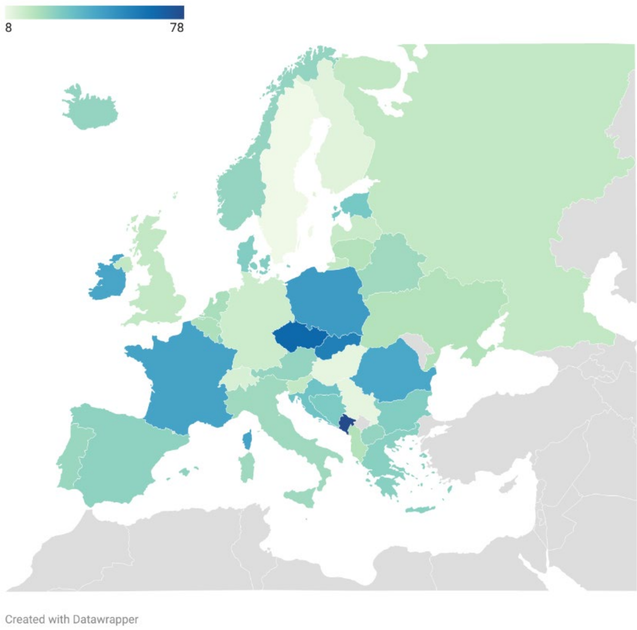

Fig.22 Per capita food supply variability in 2020
Source: Author´s work

Though, there can be identified some dark spots in the map in central Europe, France, Ireland, Romania, and the darkest point in Montenegro. Still, it should be reminded that this comparison is within European conditions. And even in case if variability of food supply in these countries is higher than in the rest of Europe, their situation in general is still food secure. However, food supply in these regions is the most volatile, which should be considered in measures taken by policy makers.

The last variable used for evaluation of stability of food security in Europe was coefficient of variation of habitual caloric consumption. It was obtained from the FAOstat database and is expressed as real number. Definition of this variable in source database was following: For many countries, the coefficient of variation, taken as an indicator of the dispersion of the food consumption distribution within the general population, is derived from available household surveys that collect data on both food consumption/acquisition and income/expenditure. When appropriate data for directly estimating the variability of food consumption are not readily available, indirect procedures are used by FAO to estimate a suitable value for this parameter.

Development of this variable over analyzed period is shown in figure 23. In general, there were not recorded significant differences between countries. At the beginning of the period analyzed in 2001 its average value was 0.207. Variability measured by coefficient of variation was only 5%. The highest coefficient of variation of habitual caloric consumption distribution in 2001 was recorded in Albania (0.25). On the other hand, the smallest value was in Bulgaria (0.19). Its values over the whole period were stable, with approximately the same variability and average value. A significant change happened at the end of analyzed period in 2020, which was influenced by corona crisis.

Average value of coefficient of variation of habitual caloric consumption in European countries and its variability significantly increased. Average coefficient of variation of habitual caloric consumption in this year increased to 0.212 and its variability measured by coefficient of variation increased to 8%. Compared to other European regions can be situation in Europe still considered as stable, but data showed its slight deterioration in pandemic year.

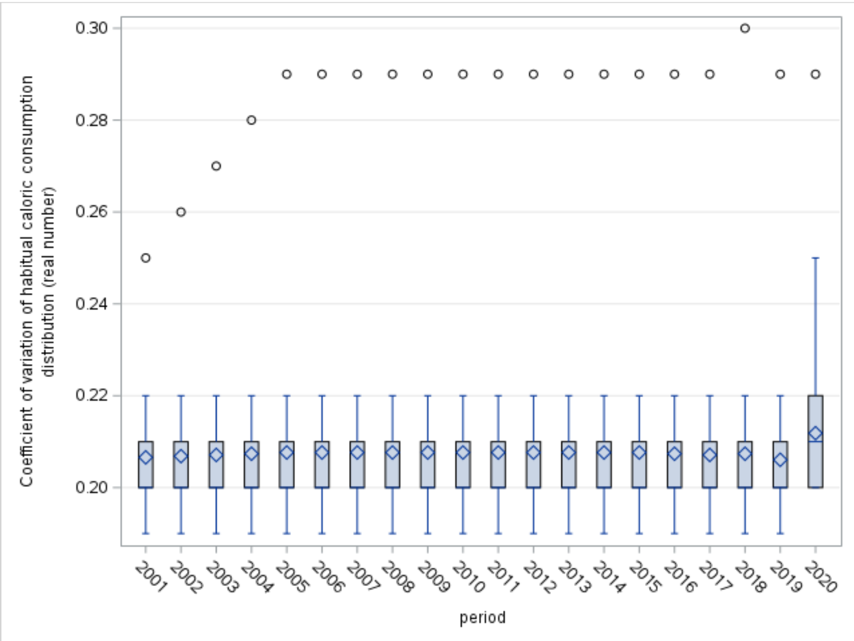

Fig.23 Coefficient of variation of habitual caloric consumption
Source: Author´s work

In most European countries the values of this indicator were similar. The highest value in 2020 was recorded in Albania (0.29). Higher values were found also in North Macedonia (0.25), Lithuania (0.23) and Ukraine (0.23). The minimum value slightly increased in comparison with previous years, and a value 0.2 was recorded in 15 European countries.

Spatial distribution of coefficient of variation of habitual caloric consumption in the map of Europe is shown on figure 24. It is obvious that the largest values are concentrated in the South-eastern and Eastern regions. However, despite the increase of overall values of this indicator in European region, its level suggests still food secure situation in region. Its increase in last years should be perceived as warning for further deterioration of food security situation in region, which is negatively influenced by fundamental factors. Even significantly deteriorated situation in Europe within this indicator would still mean food secure situation and better performance than in most other world regions.

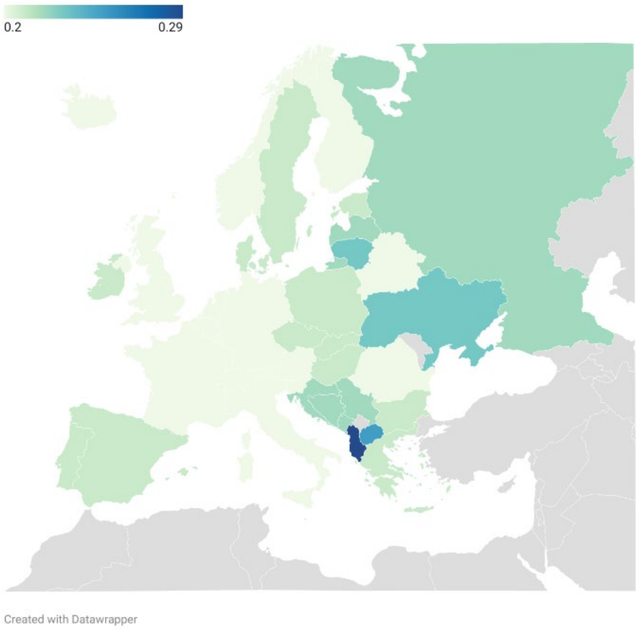

Fig.24 Coefficient of variation of habitual caloric consumption in 2020
Source: Author´s work

3. Towards a Comprehensive Composite Indicator for Food Security in Europe: Bridging the Gap between Theory and Practice

The important role of composite indicators in assessing food security was described in chapter 1.1 and 1.2. European region is specific, and all indicators mentioned in chapter 1 would evaluate it as food secure. Such conclusion is not very useful for identification of problematic areas and regions to address help and solve potential local food security problems. The specific nature of the European region requires a special approach, and composite indicators should be formulated in standard corresponding to European countries. The most suitable approach was selected Data Envelopment Analysis approach, which evaluates food security performance of each country according to best performance in region.

3.1 Methodological Framework of measuring Food Security using Data Envelopment Analysis

To obtain composite indicator with consistent ranking, it was necessary to normalize all variables according to process described by Kao (2010) and Chen et al (2019). Variables where higher values are better were normalized according to function 1. This was applied to most analyzed variables.

$$Y = \frac{y - \min(y)}{\max(y) - \min(y)} \qquad 1.$$

Variables, where smaller values mean better result, such as prevalence of moderate or severe food insecurity in the total population, consumer price index, per capita food supply variability, coefficient of variation of habitual caloric consumption and incidence of caloric losses at retail distribution level were normalized according to equation 2.

$$Y = \frac{\max(y) - y}{\max(y) - \min(y)} \qquad 2.$$

In both equations are min and max the smallest and the highest values among 38 countries for each variable.

A composite indicator of food security was created with Data envelopment analysis. Standard DEA is a method to measure efficiency of transformation of inputs into outputs for every DMU. Lovell and Pastor (1999), Kao (2010), Liu et al. (2011), and Blancas et al. (2013) and Chen (2019) suggested that DEA can be applied also in situation without explicit inputs or outputs to generate objective weights for composite indicators. The constructed indicator will be given in contrast to the Global food security index, where weights are set subjectively by the panel of experts. In the case of composite indicator would be suitable to use hierarchical DEA following structure in of individual pillars of food security as proposed by Chen (2019). In this case, it was not possible due to the few available indicators in each pillar. For construction of composite food security indicator basic DEA for aggregating indicators was used.

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Let yi (i=1,2,...M) be the indicator for each DMU j (j=1,2,...N). As proposed by Kao (2010), input-oriented DEA can be used to generate objective weights for composite indicator for *j*-th DMU by assuming input equal to one (dummy input). Then objective function has form:

$$Max\,\theta_j = \sum_{i=1}^{M} u_{ij}\, y_{ij} \quad i = 1,2,\dots M \quad j = 1,2,\dots N \qquad 3.$$

Subject to

$$\sum_{i=1}^{M} u_{ij}\, y_{ij} \leq 1\,,\ i = 1,2,\dots M \quad j = 1,2,\dots N \qquad 4.$$

Where θ is the value of composite food security index, u is the weight for variable *i* and country *j*, and y is value of variable I and country j.

According to equations 1 and 2 will be weights generated objectively without external influence the way, it will maximize value of indicator for each DMU (country in this case) and constrain will ensure, that index for all other countries will be less or equal than one (Ramathan 2006). This formulation also means that the food security index for each country will depend on the performance of all other analyzed countries in the current year. For this reason, calculation of food security composite index included data for all 38 European countries available at FAOstat (equation 4 means 38 constraints, one for every country).

According to the assumption of simple additive weighting scheme was included also constraint that sum of weights should be equal to one, formulated in equation 5.

$$\sum_{i=1}^{M} u_{ij} = 1 \quad i = 1,2,\dots M \quad j = 1,2,\dots N \qquad 5.$$

To avoid zero weights for some indicators (especially for small indicator values in maximization function) it was necessary to add constraint to restrict maximum and minimum value of weight. According to some authors these values could be decided by expert opinion. The goal of this study was to determine objective weights, so it was applied scheme suggested by Chen (2019) based on average weight without subjective element (equations 6 and 7).

$$Lb = \frac{1}{(number\ of\ indicators\ in\ composite\ index)} - 50\% \qquad 6.$$

$$Ub = \frac{1}{(number\ of\ indicators\ in\ composite\ index)} + 50\% \qquad 7.$$

Constrain for the nonzero weight of indicator has form:

$$Lb \leq u_{ij} \leq Ub \quad i = 1,2,\dots M \quad j = 1,2,\dots N \qquad 8.$$

Where *Lb* is lower bound for indicator weight, *Ub* is upper bound for indicator weight and u_{ij} is the weight of variable *i* and country *j*. In presented case with 12 indicators included in composite index was minimum weight equal to 0,0417 and maximum weight to 0,125. This means that minimum weight of one food security pillar could be 0,125 and maximum weight 0,375.

Every value of produced composite index was solution of maximization problem with 40 constraints. This was solved for 38 European countries for the period 2012-2020. The indicator only considered the performance in European countries, so the result of every country in the current year depends on the performance of all other European countries in the analyzed period. Indicator can take values between 0 and 1. Value closer to 1 means better food security performance. Despite using DEA, the estimated value of indicator is not efficiency and no country reached value equal to 1.

Conclusions were first focused on comparison of performance according to constructed index with DEA weights and ranking according to Global food security index. This could be conducted only for 26 European countries which are included in the GFSI results. Results were then used to describe characteristics of food security situation in 38 European countries in analyzed period.

The ranking of countries produced by DEA index and GFSI was compared graphically, and similarity of both results was evaluated using Pearsons's correlation coefficient. The significance in differences in rankings was verified by non-parametrical Wilcoxon signed rank test for matched samples.

3.2 Development of Composite Index and its Pillars

The produced composite indicator was based on results of DEA analysis applied for all 38 countries to estimate objective weights. Analysis was performed separately for every year in the period 2012-2020. Obtained evaluation of food security for every country therefore depends on performance of all 38 countries included in the analysis. In case, if European countries were included in analysis together with developing countries, would their result probably be homogenous. To identify problematic regions in Europe, it is essential to analyze European countries separately. Composite indicator is result of maximization of mathematical function. This means that weights were different for each country, with the highest values for best performing indicators.

Estimated weights are therefore not only an indicator of each pillar's importance, but also show the performance of every pillar in the period analyzed. Table 2 shows estimated mean weights for every pillar over the period analyzed. For simplicity of presentation, it was obtained by averaging mean weights for every analyzed year. Mode value therefore means weight, which was the most frequent mean value over the analysis period. The best evaluation measured by average weight in European countries recorded pillar Stability. This can be considered as a strength of European food security. Fluctuation of mean weight for stability over analyzed period was small, from 0.28 to 0.34. The smallest average weight in analyzed period was estimated for pillar Availability equal to 0.21. The average value of this weight in the analyzed period was between 0.18 and 0.23. This dimension was evaluated as the weakest.

The highest fluctuations were recorded in pillar Accessibility with weight equal to 0.25 which varied from 0.21 to 0.29 over analyzed period. Variability of weights measured by coefficient of variation was equal to 12.12%.

Tab. 2 Mean weights for pillars in composite DEA indicator over analyzed period

Mean weights	Mean	Mode	Median	Min	Max	CV
Availability	0.21	0.19	0.20	0.18	0.23	7.45
Accessibility	0.25	0.28	0.25	0.21	0.29	12.12
Stability	0.32	0.34	0.32	0.28	0.34	6.17
Utility	0.22	0.21	0.22	0.20	0.25	5.77

Source: Author´s work based on data from FAOstat

These weights are not directly comparable to GFSI weights, because they use slightly different dimensions: Affordability (30%), Availability (25%), Quality and Safety (22.5%) and Sustainability (22.5%). These weights are obtained by processing expert opinions. They do not change over time, on the other hand, weights obtained by DEA change every year according to actual performance of all investigated countries. Availability has slightly higher weight in GFSI. If Accessibility were compared with Affordability in GFSI, this dimension is slightly higher in GFSI. Stability and Utility are not directly comparable with the other two GFSI pillars (Sustainability and Quality and Safety). Stability has significantly higher weight than these pillars, on the other hand, average weight of Utility in analyzed period was close to them.

In produced food security measure were all indicators used in their modified and standardized version, which allowed to aggregate them to composite measure expressing development of every food security pillar. Fig. 25 shows development of pillar: Availability over analyzed period.

Availability of food in European countries in 2020 was better in comparison with 2001, however, European average availability reached two peaks in 2007 and 2011. After 2011 followed a continuous decrease until 2018. Situation improved in 2019 but beginning of corona crisis in 2020 led to further decrease in availability of Food in Europe. It is interesting, that at the beginning of analyzed period in year 2001-2006 were average value of availability index was higher than median, which suggests that the majority of analyzed countries were below average. Since 2008 was average and median similar.

In 2001 were countries with best availability of food in Europe Italy, Belgium, Ireland, France, and Austria. In 2020 remained at the top of availability ranking Ireland, Belgium, and Austria. On the other hand, the worst availability of food in 2001 was in North Macedonia, Croatia, Latvia, Bulgaria, and Ukraine. The bottom of availability ranking changed in 2020 when there could be found Bulgaria, Slovakia, Croatia, and Sweden.

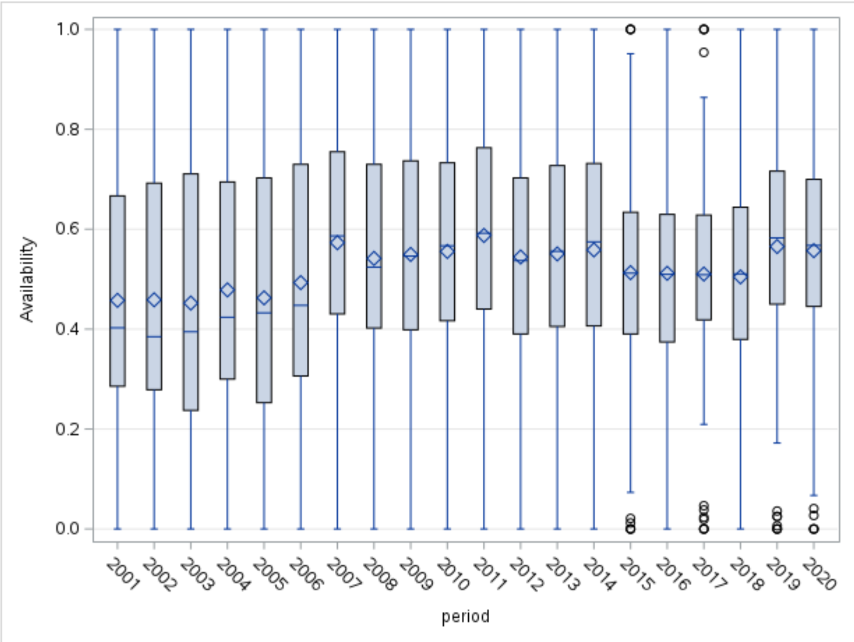

Fig. 25 Pillar availability – development over time
Source: Author´s work

It should be noted that in global perspective are all European countries food secure with enough available food, but it is also necessary to note, that availability in European countries did not improve significantly since 2011. This could affect negatively especially the most endangered regions and groups in populations.

An important part of food security is related also to accessibility. Even enough available food does not necessarily ensure food security if it will not be accessible by population. It should be noted that variable was standardized to take values between 0 and 1. Development of standardized accessibility pillar is show in Boxplot on figure 26. Compared to evaluation of availability was recorded much higher variability in accessibility of food in European countries. Development of average accessibility at the beginning of analyzed period was stable with slight growth. A significant increase in accessibility came in 2011, then continued at stable level with slight deterioration in 2020. Similar result could be found also for median value of accessibility pillar. Modal value is expected between mean and median, which leads to conclusion, that after year 2011 improved evaluation of accessibility in the most of European countries. At the beginning of analyzed period was expected modal value below average level, but at the end of this period it was higher than mean.

In 2001 was the worst accessibility of food in Albania, Greece, North Macedonia, and Lithuania. It is interesting, that countries with the best accessibility of food in 2001 were Luxembourg, Belarus, and Russian Federation. Situation changed substantially in 2020, when the worst accessibility was identified in Ukraine, Belarus, Russian Federation, Albania, and Romania. Countries ranked at the top of food accessibility in Europe in 2020 were Luxembourg, Switzerland, and Ireland.

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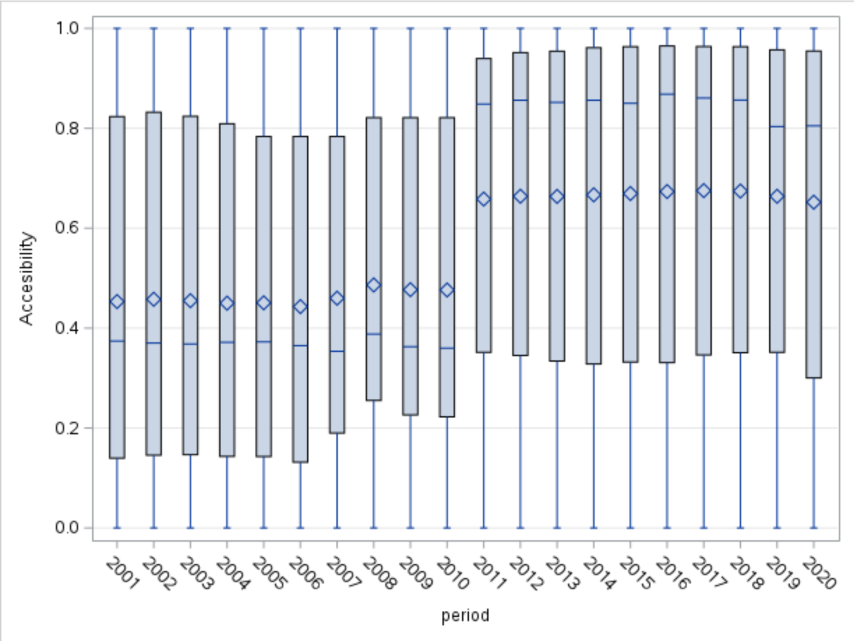

Fig. 26 Pillar accessibility – development over time
Source: Author´s work

Another important dimension of food security is the utility of food. Development of standardized values of utility pillar in European countries is shown in figure 27. The utility of food in European countries improved over the analyzed period. This improvement was continuous with a slight decrease in 2007 and 2008. After the year 2008 was recovered continuous increasing trend which stopped at the end of the analyzed period in 2020. Despite negative effects of fundamental factors in year 2020 was not found deterioration of average utility of food in European region. This suggest that slight deterioration of availability and accessibility at the end of analyzed period led to more efficient use of food.

In 2001 were countries with the worst utility of food in the Europe Serbia, Albania, and Romania. On the other side of countries ranking were Slovakia, Sweden, and Czechia. In 2020 the situation will slightly change. The worst utility of food was identified in Albania, Russian Federation and Montenegro. The best performing countries in relation to utility of food were Slovakia, Hungary, Luxembourg, and Netherlands. There was significantly high variability between European countries in relation to their utilization of food.

At the beginning of analyzed period analyzed the median value was slightly smaller than average, which suggests that modal value was even smaller, and utility of most European countries was below average. The situation stabilized at the end of analyzed period, when mean value was equal to median and distribution of utility among European countries became symmetrical. Case of Slovakia is interesting in relation to its good position in relation to utility of food, in contrast with their weak position in overall food security among European countries. Slovakia also significantly deteriorated its food security position over last 20 years despite strong utilization of food. In general, it can be concluded that utilization of food in European

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countries is at a high level and the analysis conducted identifies only weak spots in developed European regions.

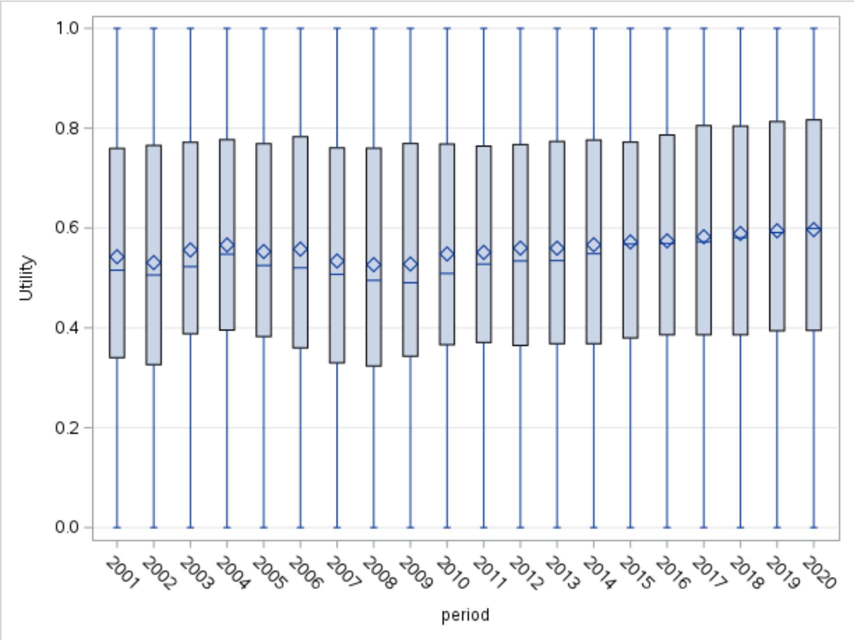

Fig. 27 Pillar utility – development over time
Source: Author´s work

The last pillar – stability is related to stability of food supply. Europe is in general considered as one of the most stable regions in the world, but especially in last years unexpected events occurred, which significantly influenced stability of food supply in region. However, compared to other world regions can be Europe still considered as stable region. Figure 28 shows development of stability pillar in European countries over time in Box plots. There could be identified some interesting facts. First, there are large differences in variability of stability pillar among European countries between years. Still, every year some extremely low values occur, however, there are no extreme highs, which suggests overall high stability in region. Another interesting sign is that the average value of cumulative index of stability is smaller every year than its median value. This suggests that mode will be higher than mean and stability in most European countries is above average.

In 2001 were the highest stability of food security found in Luxembourg, Iceland, Spain, and Finland. On the other hand, the worst stability was found in Albania with the large difference behind the rest of European region. A little better performance was found in Bosnia and Herzegovina, Montenegro, Romania, and Ukraine.

At the beginning of the analyzed period average stability value increased with the peak in 2009 and 2010 followed by decrease in 2011, 2012 and 2013. After improvement in 2014 followed another decrease until 2019. The situation will slightly improved in 2020 despite the corona crisis. Compared to other, especially developing regions can be European countries considered as stable, but development over time shows, that stability in region significantly decreased over last years and average value in 2020 was just slightly higher than in 2001.

Despite the unavailability of further data after 2020 can be assumed further decrease in overall stability of European region based on social, political, and economic events in upcoming years.

In 2020 were as the most stable countries in European region evaluated Switzerland, Norway, and Finland. On the other side of ranking according to cumulated value of stability pillar with the worst values were Montenero, Albania, Slovakia, and Poland. Especially in case of Slovakia and Poland, which are considered as developed food secure countries is interesting deterioration of their food security stability. These countries are on the Eastern border of the European union and evaluation of their stability is significantly influenced by events in the Eastern part of Europe.

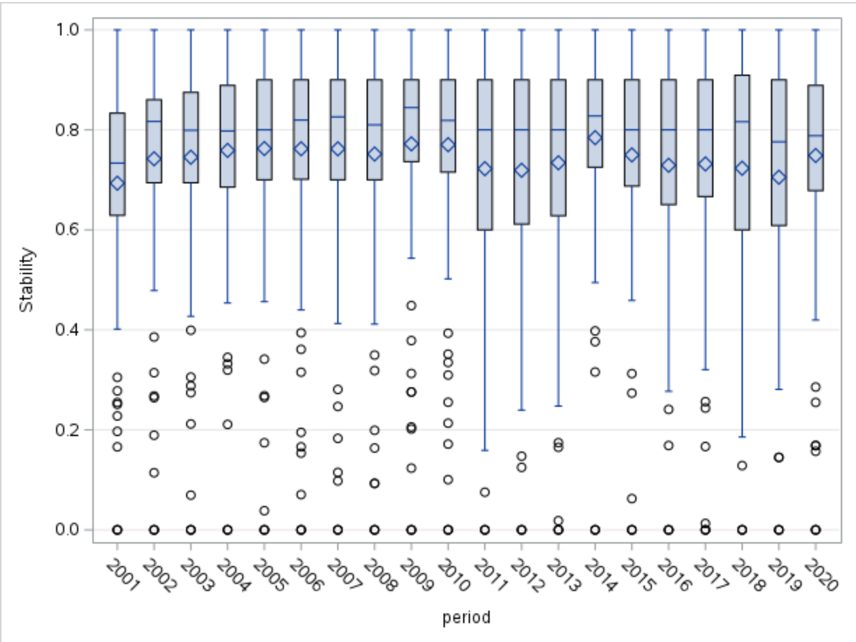

Fig. 28 Pillar stability – development over time
Source: Author´s work

Figures 29 and 30 show comparison of standardized values in food security pillars between the years 2001 and 2020. Comparison of values in food security pillars over European countries suggests that the strongest pillar in European region in 2001 was stability, with the highest average value, the smallest variability and just few outlying low values.

The weakest spots of food security in Europe in 2001 were availability and accessibility of food. Accessibility pillar also showed the highest variability, which suggests large differences among European countries in access to food. Just slightly higher average value had availability of food with much smaller variability among countries. Both pillars had median smaller than average, which suggests that modal value lies also below average and availability and accessibility of food in most European countries lies below average. Similarly, it can be concluded also in the case of food utility. Only in the case of stability was median value higher than average, which suggests that mode is also higher than mean and the most of countries in European region can be considered as stable.

In 2020 the situation will slightly change. Stability was still the strongest pillar in the European region. The weakest spot was the availability of food; however, its variability was slightly smaller with three small outlying values. The second weakest spot in 2020 was the utility of food. On the other hand, it can be concluded that the average value in every pillar increased. Positively can be perceived also change of median and mean position within availability, accessibility, and utility pillar. It means that the majority of European countries are above average within each pillar. A significant increase was recorded also in the case of median values in all pillars with the largest change in accessibility pillar.

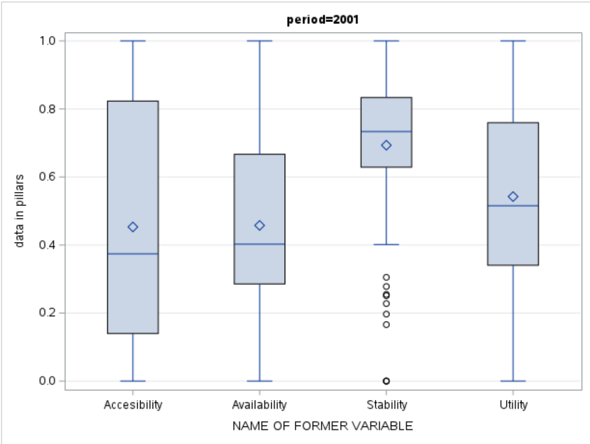

Fig. 29 Food security pillars in 2001
Source: Author´s work

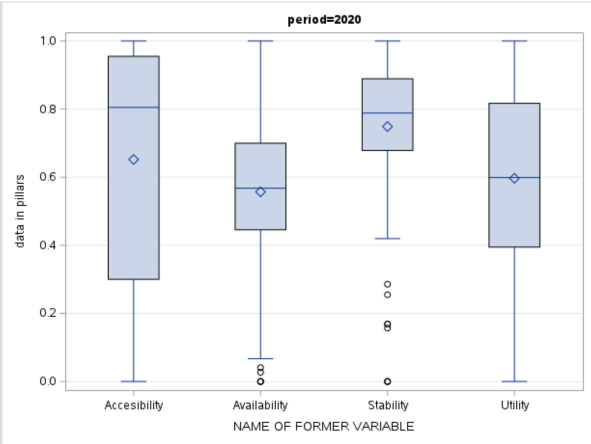

Fig. 30 Food security pillars in 2020
Source: Author´s work

Variables were cumulated into composite food security index with the use of Data envelopment analysis. This compared food security performance in every country with European standards. The development of this composite food security index can be found in figure 31.

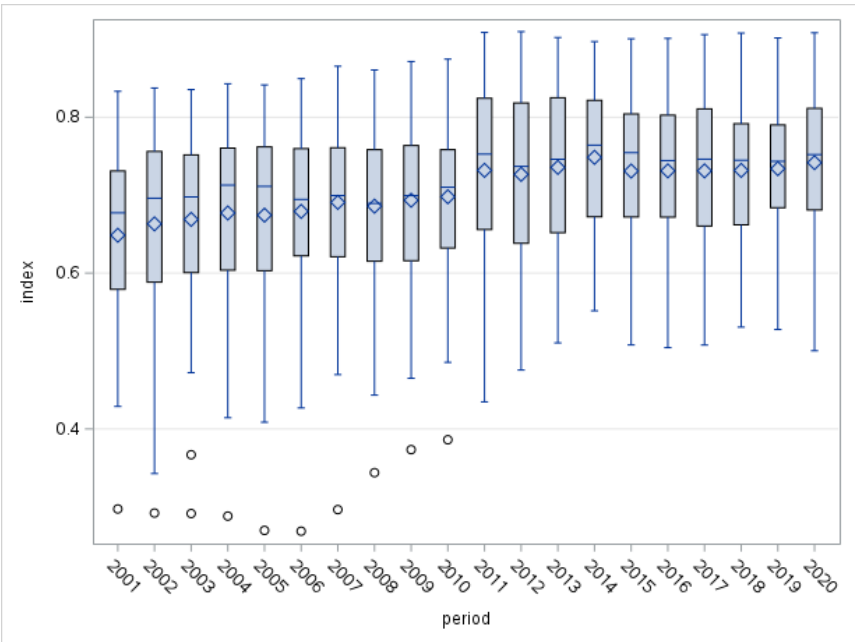

Fig. 31 Composite food security index based on DEA – development over time
Source: Author´s work

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Development of composite index shows continuous increase of food security in European region until 2014. Average value of food security index after this year stagnated. After year 2020 is expected to be a slight deterioration of food security in the region based on development of fundamental factors.

Figures 32 and 33 show the food security situation in Europe measured by composite DEA indicator. On the left side is the situation in 2001. There could be noticed significant differences between Western and Eastern Europe, low levels of food security were recorded especially in former Yugoslavian countries. On the right side is the situation in 2020. The highest level of food security was found in the central and Northern part of Europe. Local disparities among countries decreased, but regions with food security problems can still be found, especially in the East and South-east of Europe. It is important to notice that the indicator was based on benchmarking of European countries in the current year. It means that in 2020 was recorded better overall performance, on the other hand, in 2001 there were higher differences between the best performing countries and the rest of Europe. However, despite the large differences among European countries, there could be concluded a good overall level of food security in comparison to the rest of the world. The figures show that in the case of comparison of European countries with European standards, there could be still possible to find regions with food security issues.

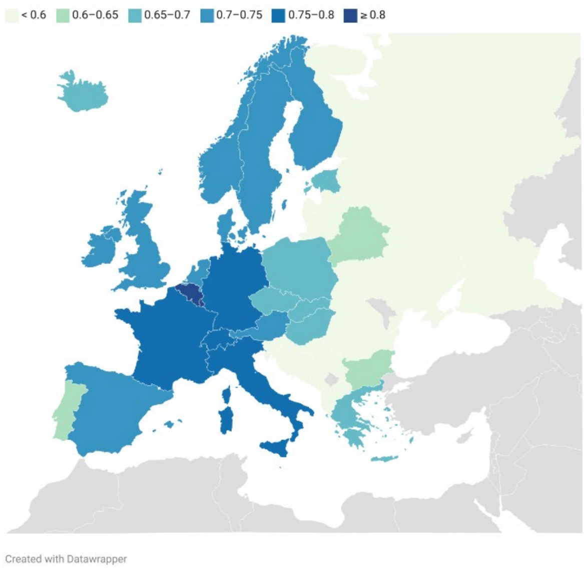


Fig.32 DEA indicator of FS in 2001
Source: Author´s work

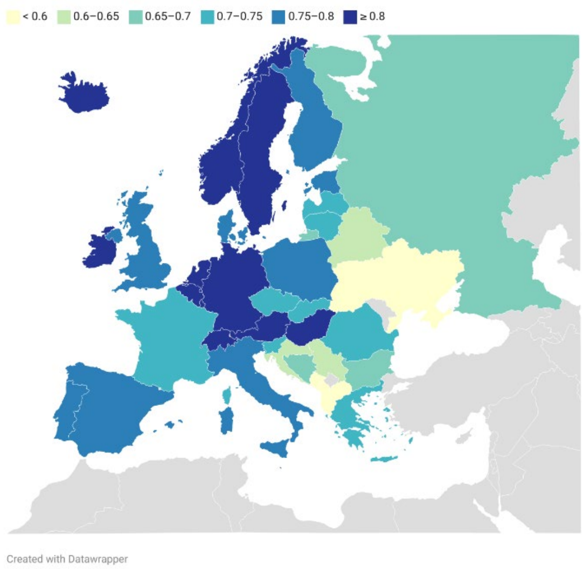


Fig. 33 DEA indicator of FS 2020
Source: Author´s work

Improvement and deterioration of food security in European countries can be assessed according to difference in countries ranking according to their performance measured by composite DEA indicator shown in figure 34. Negative difference means lower ranking at the end of analyzed period, and analogically, positive difference means improvement of position over analyzed period. Comparison of ranking is more appropriate than difference in value of indicator due to different weights estimated every year. The highest decrease in food security position between 2001 and 2020 recorded France, followed by Malta, Belarus, Italy, and Slovakia. On the other hand, the largest improvement in position recorded Iceland, Hungary, Portugal, and Latvia.

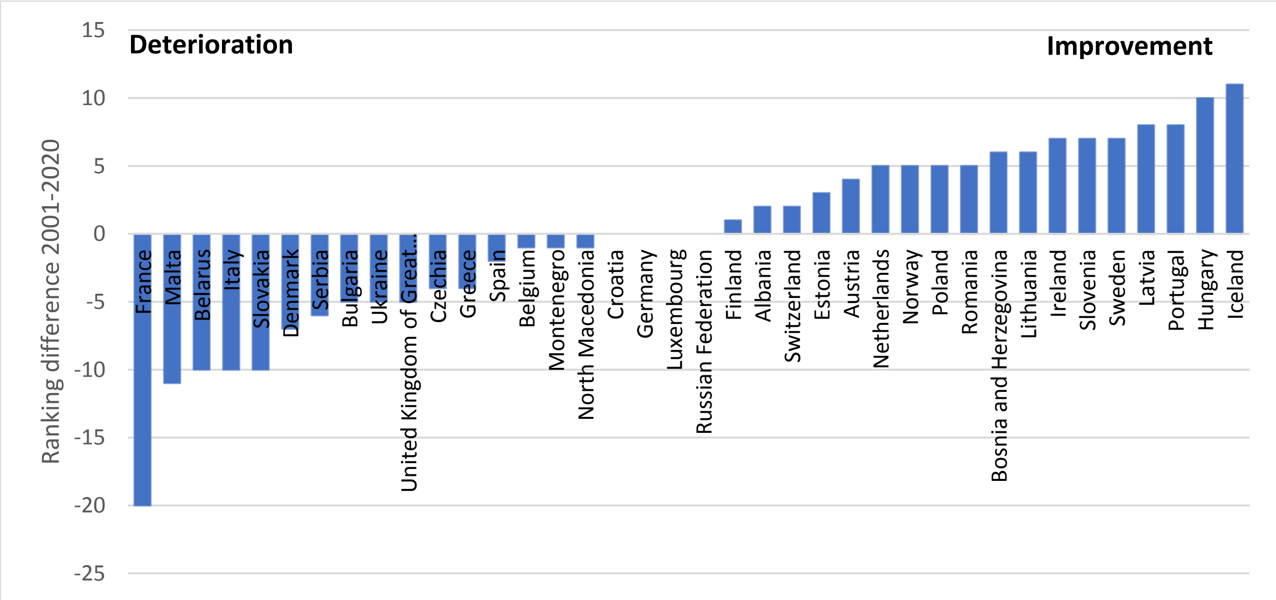


Fig. 34 Difference in countries ranking between 2001 and 2020
Source: Author´s work

3.3 Comparison of Composite DEA Indicator with Global Food Security Index

Comparison of indicators based on FAOstat data and Global food security index was difficult due to the different number of countries in both databases. The Global food security index is available for 26 European countries for the period 2012-2022. Even though FAOstat data are available only until 2020, it covers a much longer history with records for 38 European countries. This had to be considered in performed analysis. The main objective of the study was therefore to characterize the food security situation in 38 European countries according to constructed indicator based on available data from FAOstat in period of years 2012-2022. The secondary objective was to compare the performance of constructed indicator based on data envelopment analysis and data from FAOstat with Global food security index and identify its strengths and weaknesses. This could be performed only with data for 26 countries with results for both indicators. The values of both indicators are not directly comparable, but it was possible to compare countries ranking obtained by both indicators.

Table 3 shows correlations between rankings of both indicators, and their comparison using Wilcoxon signed rank test for matched samples. According to results in table was found significant correlation between constructed DEA indicator and GFSI. Correlation measured by Pearson coefficient varies between 0.62 to 0.72 which may be considered as strong relationship. DEA indicator was based on variables strongly related to food, but GFSI is based on wide set of indicators related to more aspects. This suggests that however food has an important role in GFSI, its final value depends also on other factors considered in this index. The correlation expressed by Spearman coefficients was even smaller (overall value equal to 0.63).

Despite of this fact was not identified significant differences in countries ranking. Wilcoxon signed rank test p-value in all periods was higher than 0.05. This means that there is not a significant difference in countries ranking according to GFSI and DEA composite index. Still, there are some differences which are worth highlighting.

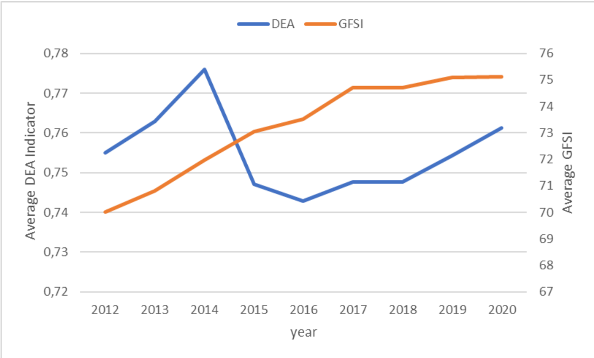
Tab.3 Comparison of rankings obtained by GFSI and DEA composite index

Ranking comparison	2012	2013	2014	2015	2016	2017	2018	2019	2020	Overall
Pearson correlation	0.64	0.62	0.72	0.71	0.69	0.69	0.73	0.69	0.72	0.77
p-value	0.0004	0.0007	<0.0001	<0.0001	0.0001	0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Spearman correlation	0.51	0.45	0.54	0.54	0.50	0.52	0.54	0.50	0.53	0.63
p-value	0.0003	0.0012	0.0001	0.0001	0.0003	0.0002	<0.0001	0.0003	0.0001	<0.0001
Wilcoxon signed rank stat	-11	6	-7.5	9	15	5	-9	3.5	6	132.5
p-value	0.77	0.87	0.84	0.79	0.66	0.87	0.93	0.93	0.87	0.89

Source: Author´s work based on data from FAOstat and EIU

Figure 35 shows development of both indicator average values compared over time in period 2012-2020. GFSI increased over all analyzed periods. On the other side, the average value of composite indicator based on DEA analysis decreased between the years 2014 and 2016. This could be caused by deterioration of average score for indicators consumer price index, political stability, food supply variability and minimum dietary energy requirement, which were mostly stable for the rest of the analyzed period. In 2014 started Russian operations in Ukraine, which could be the main cause of decline. The year 2020 was influenced by the Covid pandemic.

Weights in DEA indicator was estimated separately in every year, which may suggest that they are not directly comparable, but decrease of indicator suggest decrease of overall food security performance in European countries. Figure 36 shows comparison of variability in both indicators measured by coefficient of variation. In the case of GFSI variability did not exceed 10%, on the other hand variability of DEA did not decrease under 10%. Higher variability of DEA indicator is influenced by more countries data used in his estimation. This shows the advantage of DEA approach, which helps to identify better differences between countries within analyzed group. On the other hand, GFSI is produced at world level, which is considered also in selection of large number of input indicators, and in analysis which includes only European countries is result more homogenous.



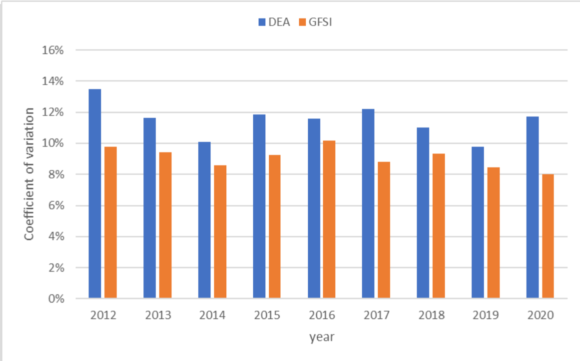


Fig.35 Average DEA and GFSI indicators over time Fig.36 Variability of DEA and GFSI
Source: Author´s work based on data from FAOstat and EIU

In addition to different variability contrast can be found also in its trend. At the beginning of the period analyzed disparity between countries measured by food security indicators decreased. Change in variability was different in the years 2016,2017 and 2018.

At the end of the analyzed period variability of GFSI decreased, in contrast to increase in variability of composite DEA indicator.

3.3.1 Comparison of Countries Ranking

Better insight into differences in rankings by both indicators offers figure 37, which displays comparison of both rankings in the year 2020. Countries lying on the orange line have the same ranking according to both indicators. This is the case of Ukraine, which food security situation was evaluated as the worst between European countries. Countries below the orange line are evaluated better by composite DEA indicator and countries above are better according to GFSI ranking. Similar conclusions can be made also for other countries at the end of both rankings. Exception is Hungary, which was ranked 21st according to GFSI, but in DEA ranking is 9th. Much higher variability can be noticed between the best evaluated countries.

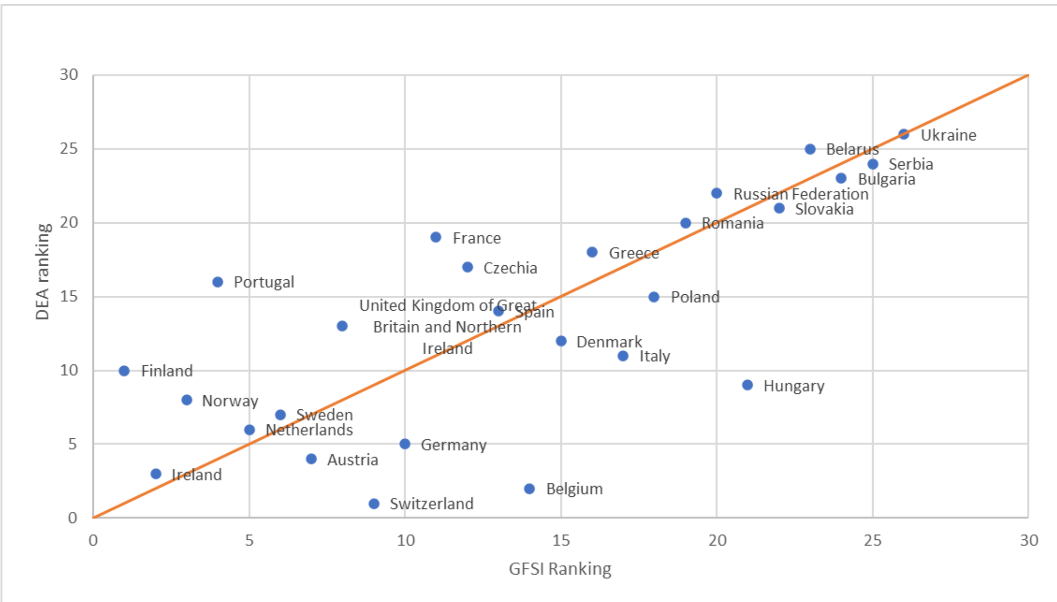


Fig. 37 Comparison of GFSI ranking and DEA ranking of 26 European countries in year 2020
Source: Author´s work based on data from FAOstat and EIU

Best countries according to GFSI ranking in 2020 were Finland, Ireland, Norway, Portugal, and Netherlands. But according to DEA ranking was Finland placed 10 and Portugal 16th. On the other hand, best countries according to DEA indicator were Switzerland, Belgium, Ireland, Austria, and Germany. Except Ireland was not included any of these countries in top 5 according to GFSI, Belgium was not even included in top 10.

Based on both indicators results can be concluded, that best food security situation in Europe is in Ireland, Netherlands, Norway, Switzerland, Finland, Austria, Sweden, and Germany which were ranked in both top 10. Figure 37 contained only comparison for the year 2020. There is an obvious difference in ranking between two food security indicators. Figure 38 can help to identify which difference in evaluation is systematic, and which occurred only in the year 2020. Figure shows average difference between ranking produced by DEA indicator and GFSI ranking for whole analyzed period of years 2012-2020. Positive values mean that countries were ranked better according to GFSI, and negative values means better assessment of countries according to DEA indicator.

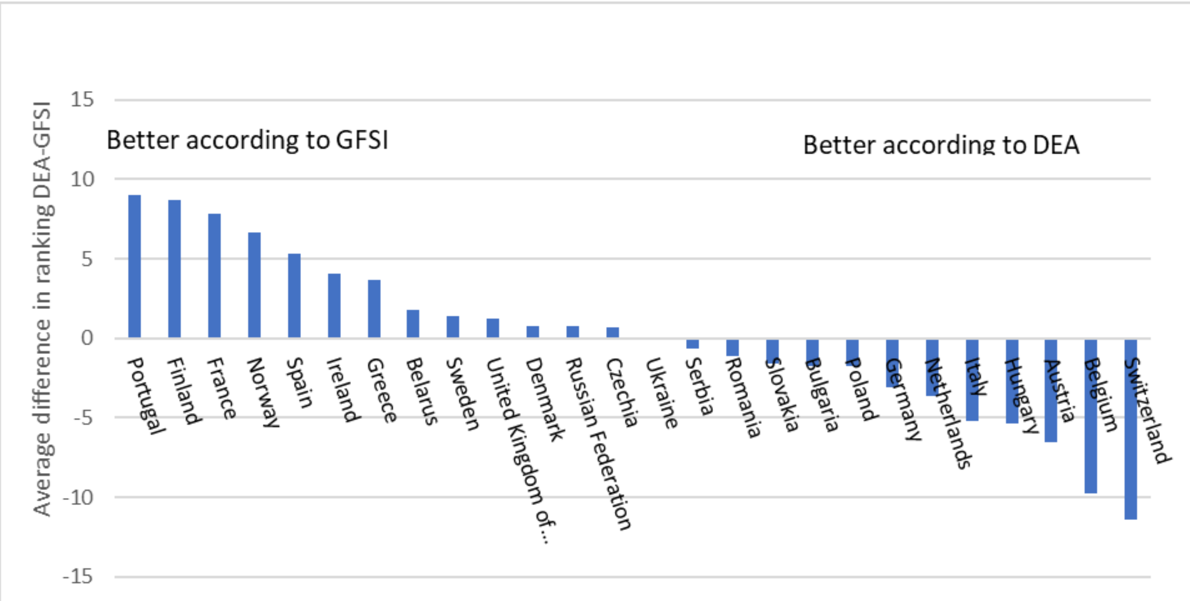


Fig. 38 Average difference between DEA and GFSI ranking for years 2012-2020
Source: Author´s work based on data from FAOstat and EIU

Systematically better rated countries by GFSI were Portugal, Finland, France, Norway, and Spain. Average differences between GFSI and DEA ranking for these countries over analyzed period was more than 5 places. On the other hand, Switzerland, Belgium, Austria, Hungary, and Italy were ranked better by DEA composite indicator. Average differences in rating of other countries between these two indicators over analyzed period of years was smaller than 5.

This is caused by the different nature of both indicators. GFSI is a more complex indicator including various aspects of food security environment such as sustainability, legislation, safety, adaptability and so on. On the other hand, DEA indicator was based primarily on variables directly linked to food security and availability, accessibility, utility, and stability of food supply.

Bad evaluation according to DEA indicator can be therefore linked to instant food security problems. On the other hand, bad evaluation based on GFSI may be caused by some aspects of food security environment which will directly affect population later, such as legislation, agricultural research, risk management or social barriers. Direct food security or insecurity perceived by population is therefore hidden in the complexity of GFSI. We suggest that present food security in countries ranked better by DEA will be better assessed also by population. On the other hand, environmental and legislative conditions in countries better evaluated by GFSI ensure better food security perspective in future.

From the methodological point of view, in situations when it is important to assess food security situation in Europe and identify weak spots can be important difference between GFSI and DEA approach also number of analyzed countries. Obvious differences can be identified in figures 39 and 40. Figure 40 shows a choropleth map with values of GFSI indicator where map of Europe includes few grey countries without which are not assessed. In contrast with figure 39 on the left side which shows result according to produced DEA indicator including almost all European countries. DEA analysis included 38 countries in contrast with 26 European countries included in GFSI result.

Previous comparison included only results for countries included in both indicators. Countries which were not included in GFSI analysis are: Albania, Bosnia and Herzegovina, Croatia, Estonia, Iceland, Latvia, Lithuania, Luxemburg, Malta, Montenegro, North Macedonia, and Slovenia. Questionable could be only the inclusion of Luxemburg, which is usually omitted from analysis as the out layer. In this case it was included to improve estimated efficiency frontier to make assessment stricter. The other 11 countries missing in GFSI are placed in Eastern and Southern Europe with level of food security situations which should be monitored.

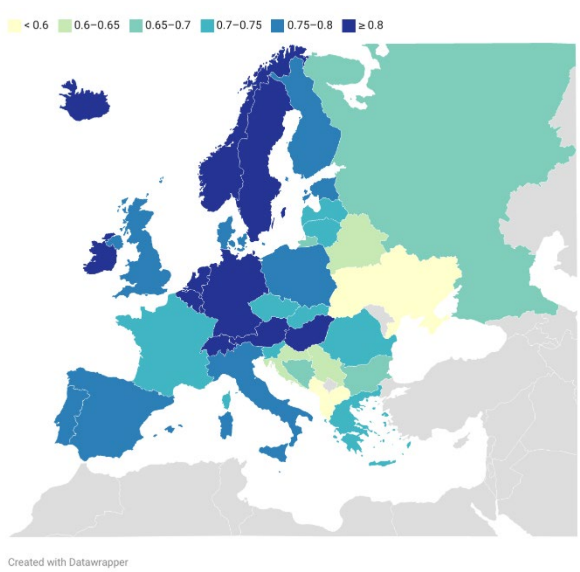


Fig. 39 DEA indicator result 2020
Source: Author´s work based on FAOstat data

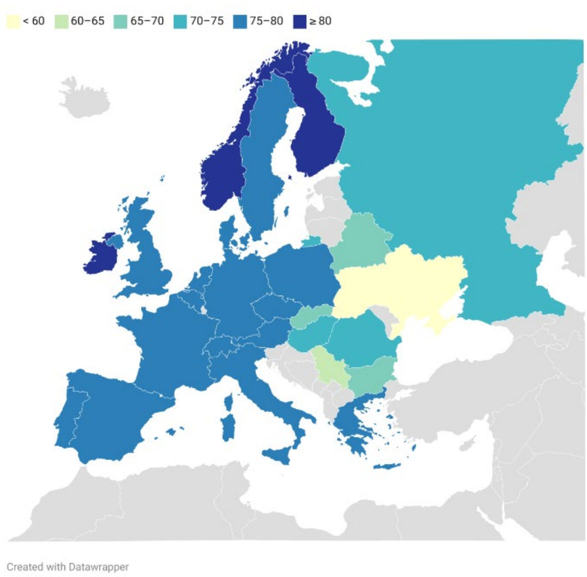


Fig.40 GFSI result 2020
Source: Author´s work based on EIU data

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Figure 39 and 40 shows food security in Europe according to DEA indicator (figure 39) and GFSI (figure 40). In figure 40 which shows GFSI result is the best result recorded in North-European countries (Finland and Norway) and Ireland. Some problems with food security can be found only in Eastern and South-Eastern countries. The rest of Europe seems to be food secure and without any significant differences. Figure 39 on the left side is more heterogenous. The top category includes more countries, not only in the North, but also in Central Europe. On the other side there were more food security categories also in the rest of Europe. Less food secure are France, Czech Republic, Slovakia, Romania and Greece, Lithuania, and Latvia. Even worse was situation in Russia, Bosnia and Herzegovina and Bulgaria. The worst food security situation in Europe according to DEA indicator in 2020 was recorded in Croatia, Serbia, Belarus, Montenegro, Albania, North Macedonia, and Ukraine.

This result shows that several countries with food security issues can be found also in Europe, and this problem should not be linked only with developing countries.

3.3.2 Comparison of Change in Food Security Performance over 2012-2020

Figures 41 and 42 show the difference in food security ranking according to both indicators over time between the years 2012 and 2020. The reason for selection of this period was that Global food security index values were published for the first time in 2012. Therefore, it was not possible to compare indicators since 2001. However, also this comparison can offer better insight into the difference in nature of both indicators. Comparison in figure 41 shows 38 countries which were included in DEA analysis. Positive values of ranking difference mean improvement of food security situation and negative values means deterioration of ranking. Countries with the best improvement of ranking according to DEA analysis since 2012 were Hungary, Iceland, Ireland, Lithuania, and Spain. On the other hand, food security situation got significantly worse in Malta, Czechia, France, Slovakia, Italy, Greece, and Montenegro.

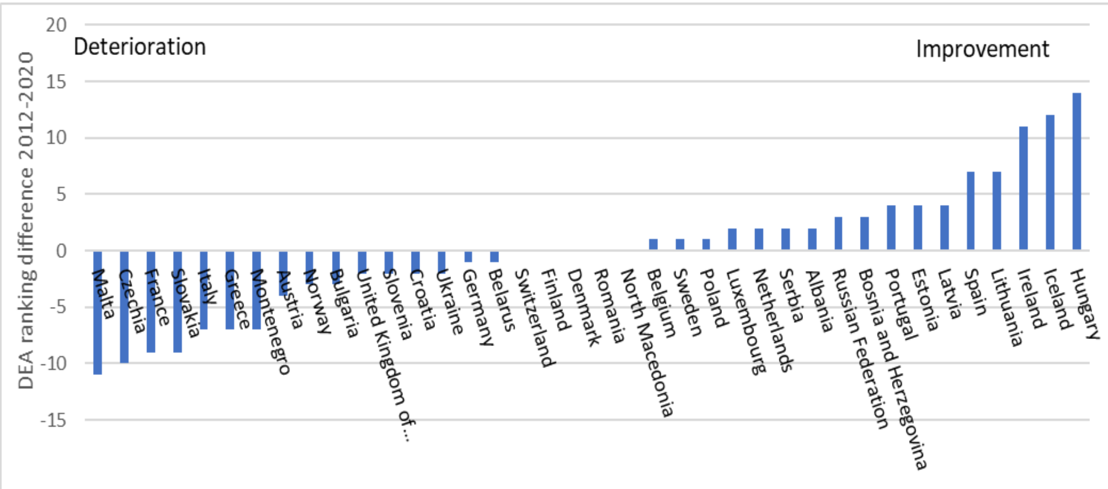

Fig. 41 Change in food security ranking between 2012-2020 measured by DEA
Source: Author´s work based on data from FAOstat

GFSI ranking included only 26 European countries, and the best improvement in ranking was recorded by United Kingdom, Netherlands and Switzerland and the largest negative change in ranking was recorded by France, Spain, and Belgium (figure 42). Ranking by GFSI indicator can be considered as more stable. According to both comparisons can be concluded significant deterioration of food security in France which decreased by 7 places in GFSI ranking and by 9 places in DEA ranking. This country recorded surprisingly bad results compared to other European countries. Values of food production index and per capita food supply variability in France belonged between 5 worst countries in Europe. Food supply variability was worse only in Montenegro, Czech Republic, Slovakia, and Poland. Both composite food security indicators confirmed also negative trend in food security of Slovakia and Italy. Large improvement of Switzerland in GFSI ranking confirmed its long-term good position according to DEA ranking. Controversial result was found in case of Spain which recorded substantial positive change in DEA ranking, but very negative change in GFSI ranking in comparison between 2012 and 2020. Result is that in 2020 was ranking of Spain according to both indicators the same. Similar situation was found also in case of Hungary, when it recorded slight deterioration in GFSI ranking, but according to DEA results it recorded the highest positive change.

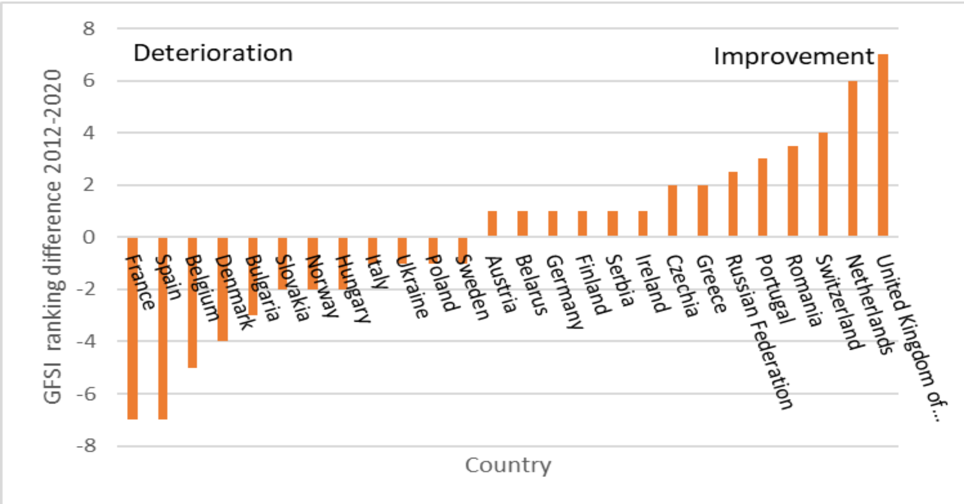

Fig. 42 Change in food security ranking between 2012-2020 measured by GFSI
Source: Author´s work based on data from EIU

Based on the findings mentioned above it can be concluded that composite indicator produced by DEA is related more directly to food and assess actual situation of food security as it can be perceived by population. On the other hand, GFSI is a more complex indicator and factors related directly to food are just one of its dimensions. Therefore, it can take longer to record direct change in food situation as it is perceived by population, as it expresses complex dimensions of food security environment.

4 Determinants of Food Security in Europe: Understanding the Drivers and Challenges

Food security is a complex problem which should be analyzed in multiple dimensions. According to Grote (2014) food security or insecurity situation is influenced by demand, supply, and market conditions. Which means, that all factors affecting these variables have a direct impact on food security.

Improving food security is according to Chavas (2017) one of the most important policy goals, however there are multiple ways to achieve it: increasing food supply, improving food access and increasing purchasing power of population. Fan and Brzeska (2016) add that the essential role in achieving food security is played in agriculture and food production. But Matkovski et al. (2020) concludes that all these ways of food insecurity reduction could be applied only in stable conditions and not in crisis conditions as was recently Covid 19 pandemic, or military conflict in Ukraine. Jambor and Babu (2017) conclude that good availability of food does not always mean good food security.

Developing countries usually have poorer stability of trade, food prices and food supply indicators which influence their food security situation. For example, Papič Brankov and Milovanovič (2015) analyzed factors influencing food security in Serbia and found that the highest impact on food security had Gross domestic product and corruption. Similar study was conducted by Kovljenič, Raletič-Jovanovič (2020) in study also performed in Serbia showed significant influence of economic development, foreign trade, population growth and investments in agriculture. Matkovski et al. (2020) analyzed factors influencing food security in EU and Balkan countries. Results suggest significant effect of added value of agriculture in GDP, agricultural production per capita, land productivity and negative impact has agricultural export.

Many studies tried to investigate the relationship between food security and trade liberalization (e.g., Feleke et al. 2005, Dorosh et al. 2009 and Pyakuryal et al. 2010) and found, that it has either insignificant or positive effects on food security. Another research conducted by Dithmer and Abdulay (2017) continued with investigation of trade influence further and confirmed, that food security is positively influenced by trade openness and economic growth. It improves especially dietary diversity and diet quality of population. In the research they used besides trade, other food security determinants measuring influence of country characteristics, economic and demographic development, variable measuring non-economic events and variable measuring economic policy.

Poudel and Gopinath (2021) compared performance of multiple food security indicators. They compared also differences in results related to food security determinants. Based on their survey, they used as explanatory variables GDP and agricultural GDP, arable land, urban population, gross capital formation, trade openness, literacy, and internet access. They assessed the influence of trade openness as insignificant. In addition to traditional sources of food security, such as economic development, and focus on resources e.g., capital and urbanization, their results highlight also important role of information access.

Several studies investigated the effect of urbanization on food security. Farrukh et al. (2022) concludes that urbanization has negative effect on food security in their analysis conducted in Pakistan. According to Li et al. (2023) urbanization can affect food security in both positive and negative ways. It depends on the economic development of the country and urbanization mode, which is present, but it does not endanger food security. Liu at al. (2021) agrees that urbanization has positive and negative aspects and suggests using its positive effects on food security especially in rural areas.

The main objective of the presented study is to determine the main factors influencing food security in European countries. To achieve it it was necessary first to produce an objective indicator for evaluation food security level in Europe and to characterize its development over analyzed period. It is assumed that the overall level of food security in Europe will be good with disparities across regions. The produced measure was used as food security output in the analysis which helped to determine the main factor influencing this outcome. This was the second objective of the presented study. Based on research studies in theoretical part was selected a wider set of considered indicators used in the modelling process. Based on its result five determinants were selected, and the influence was quantified. It is assumed that factors influencing European food security in the long run will be the same, but in the short run there will be significant differences in how they influence food security in different countries.

4.1 Identification of Food Security Factors

The added value of the presented study has more dimensions. First, the study suggests a methodological framework based on data envelopment analysis for creating objective composite indicators usable for measuring and identification of food security issues in European countries. The study also shows the development of food security and its disparities among European countries over the period analyzed. The last available year in the presented analysis is 2020, when a covid pandemic spread across Europe. Study offers deeper insight into food security conditions in European countries in this period. An important asset of the presented study lies also in the determination of the main factors influencing the food security situation in Europe in the long run, and in all individual states in the short run. Presented pooled mean group estimation can extend current knowledge in the investigated field and add new point of view to food security analysis.

The calculated food security composite DEA indicator was related to main factors influencing food security. These were considered according to results of other authors and partial results in pre-analysis. The limitation was 20 observations for one country, which means that in Pooled mean group model it was not possible to use too many variables to ensure its robustness. From a wide range of 30 available indicators were selected according to pre-analysis study results 5 final food security factors showed in table 2. Variables selection was based on results by Poudel and Gopinath (2021) and Matkovski (2020).

Tab. 4 List of variables used as food security determinants.

Shortcut	Variable	Unit	Source
Affva	Agriculture, forestry, and fishing value added	% of GDP	World Bank
Trade	Trade openness	% of GDP	World Bank
GCF	Gross capital formation	Constant LCU	World Bank
Urban	Urban population	% of total population	World Bank
Internet	Individuals using the Internet	% of population	World Bank

Source: Author´s work based on data from World Bank

Variables were used in standardized form, which allowed us to compare their importance according to estimated functional parameters. It may be questioned using cumulative Gross capital formation instead of per capita value. This was influenced by insignificance of per capita indicators of gross capital formation in pre-analysis models.

4.2 Development of selected food security factors in 2001-2020

Analysis presented in this study investigated influence of food security factors on development of composite index. Based on current scientific literature 5 factors influencing food security were selected. The number of investigated factors was determined by the number of observations for every country, so the estimated models would be as simple as possible. Analysis included following factors: Agriculture, forestry and fishing value added as the measure of agricultural productivity measured in % of GDP, Urbanization measured as % of urban population, gross capital formation expressed in constant LCU, Trade expressed as % of GDP which measures the openness of the economy, and as the last factor was selected availability of Internet expressed as the % of population with internet access which was used as the proxy of information access.

As the first factor was considered Agriculture, forestry and fishing value added expressed as % of GDP. It shows productivity of agriculture on one hand, on the other hand it could be perceived also as measure of economic development of country, as we assume that in developed countries will take this indicator smaller values. This variable can influence food security especially in regions with less developed trade, as it significantly affects self-sufficiency. Development of this variable in European countries over time is shown in figure 43.

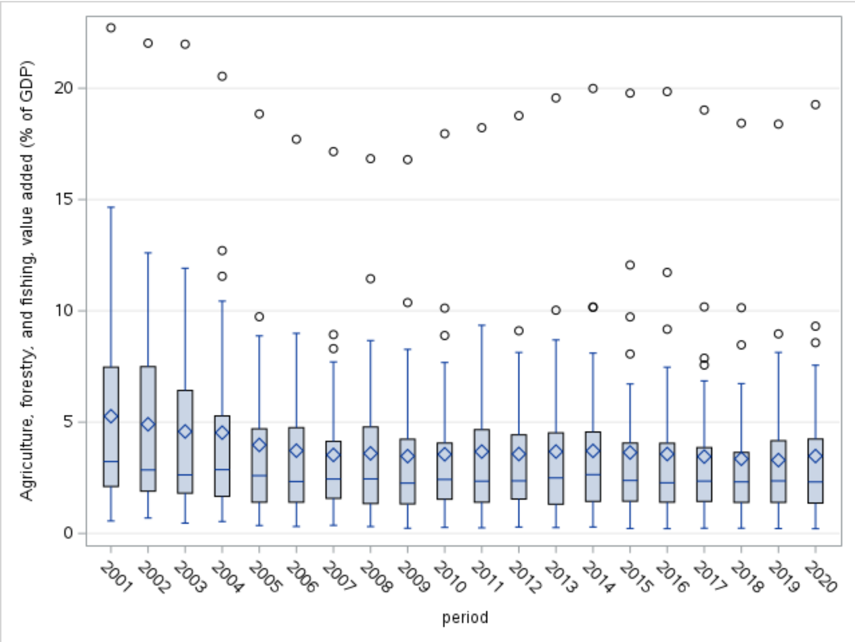

Fig. 43 Agriculture, forestry, and fishing, value added
Source: Author´s work

The average value of the indicator continuously decreased from 2001, with few countries considered as outliers with large values every year. Decreasing average value and variability suggests economic development in region which reduces share of agriculture in GDP, but it can also suggest decreasing agricultural productivity in some countries, which may not be always influenced only by development. Most European countries lay below the average value of this variable every year, which was influenced significantly by outlying values.

In 2001 was recorded the smallest value of this indicator in Luxembourg, United Kingdom, and Switzerland. In 2001 were share of agricultural, forestry and fishing value added in GDP only in these countries was smaller than 1% in whole European region. All these countries can be considered as highly developed without food security problems.

On the other side, the highest agriculture, forestry, and fishing value added in 2020 was recorded in Albania (22.7%), Serbia (14.6%), Ukraine (13.9%) and Romania (13.1%). These countries were less developed with a significant role of agricultural production in their economies. Figure 44 shows how situation changed in 2020.

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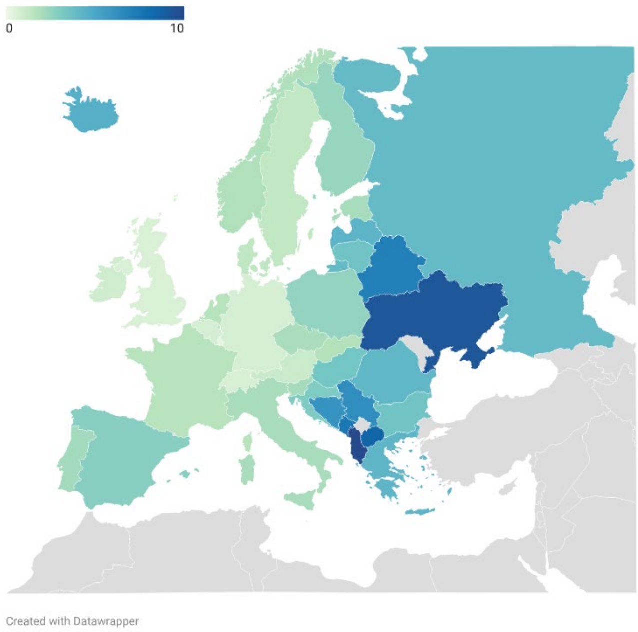


Fig. 44 Agriculture, forestry, and fishing, value added in 2020
Source: Author´s work

The number of countries where agriculture, forestry and fishing value added share was less than 1%. The smallest shares were found in Luxembourg (0.2%), Malta (0.4%), United Kingdom (0.6%), Switzerland (0.7%), Belgium (0.75%), Germany (0.75%) and Ireland (0.9%). The only European country with value higher than 10% in 2020 was Albania with 19%. Values in the rest of Europe were much smaller, which is the reason why was for the upper bound in chart selected value 7%. Another high value of this indicator was found in Ukraine (9.3%), North Macedonia (8.5%), Montenegro (7.5%), Belarus (7%), Serbia (6.3%). In the map can be seen, that higher values of agriculture, forestry and fishing, value added is in South-east of Europe. Higher in this case means approximately 10%, except Albania, which significantly exceeded this value.

Agriculture may have an important role in ensuring food security especially in difficult situations, such as pandemic situation, war in neigh borough countries, or in deteriorating trade conditions. In such a situation it can help to achieve better availability and self-sufficiency in food. On the other hand, high value of share of agriculture can indicate low development in the country. Still, it should be considered as an important indicator influencing food security.

Similarly, can be perceived also another considered factor – urbanization. High degree of urbanization is characteristic especially for developed countries, on the other hand, large extent of urbanization can be at the expense of agricultural land and countryside. This influences significantly the food security situation in a country, but the way of its impact depends on character of country. Urbanization was measured as % of urban population in countries. The development of urban population is shown in figure 45. The level of urban population in European countries was stable with a slow increasing trend of average value.

Variable exhibited large variability, which was stable over time. A significant increase was found also in minimum value. In 2001 had only two European countries share of urban population below 50%: Albania (42.4%) and Bosnia and Herzegovina (42.7%). These countries were followed by Slovenia with 50.78%. On the other hand, the highest share of urban population was recorded in Island (92.5%), Malta (92.6%) and Belgium (97.18%). These three countries were the only ones with a share of urban population above 90%.

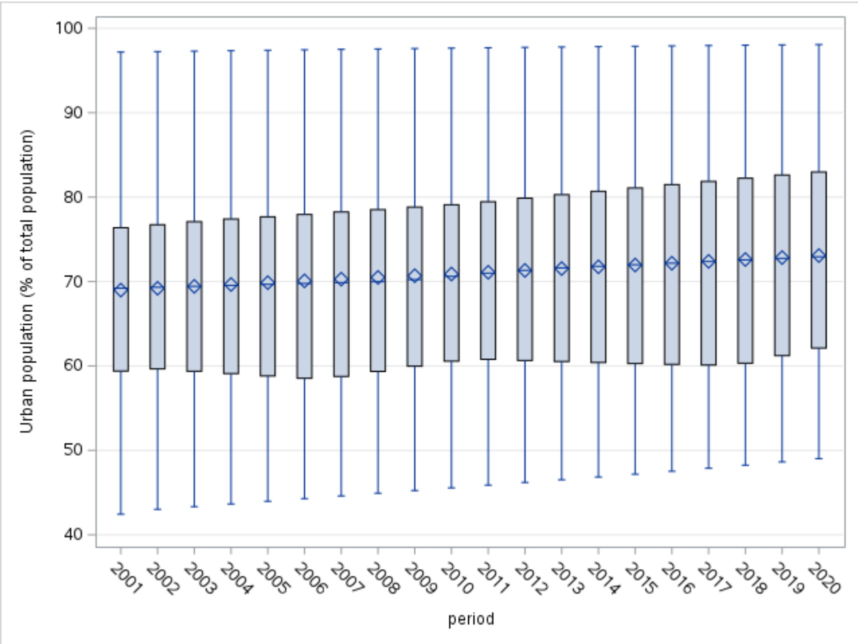


Fig. 45 Urban population
Source: Author´s work

The situation changed significantly in 2020 and can be seen in figure 46. There was only one country in the European region with share of urban population below 50%. It was Bosnia and Herzegovina with 49% of urban population followed by Slovakia (53.7%), Romania (54.2%), and Slovenia (55.1%).

The average share of urban population in European countries increased together with an increase with its minimum value from 42.4% in 2001 to 49% in 2020. On the other hand, the number of countries with a share of urban population is above 90%. In 2020 it was 5 countries: Luxembourg (91.5%), Netherlands (92.2%), Iceland (93.9%), Malta (94.7%) and the highest share of urban population was recorded in Belgium (98%).

In the map can be seen, that higher shares of urban population were found in Western and Northern European countries, on the other side, smaller share of urban population was found in Central and Eastern part of Europe. According to many contemporary studies it can be expected that the effect of urbanization on food security will be different in more and less developed regions.

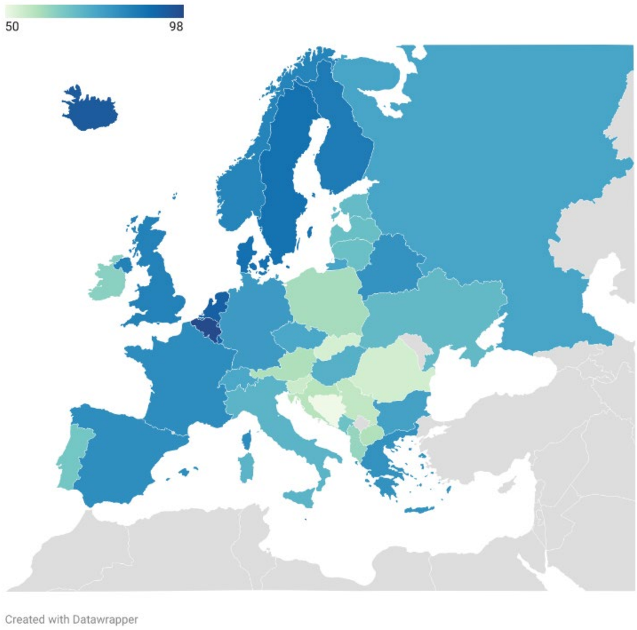


Fig. 46 Urban population in 2020
Source: Author´s work

Another variable considered as an important factor influencing food security is Gross capital formation. It is an important measure of investment which has a significant impact on the further development of each country. This variable can be expressed as absolute measure in dollars, or as comparable measure as % of GDP.

Development of this variable (% of GDP) over the analyzed period is shown in figure 47. Almost every year was recorded some outlying observations. Average gross capital formation expressed as % of GDP at the end of the period analyzed was slightly smaller than in 2001. But its median value was higher with similar variability, but extreme observations differed more from the rest of region.

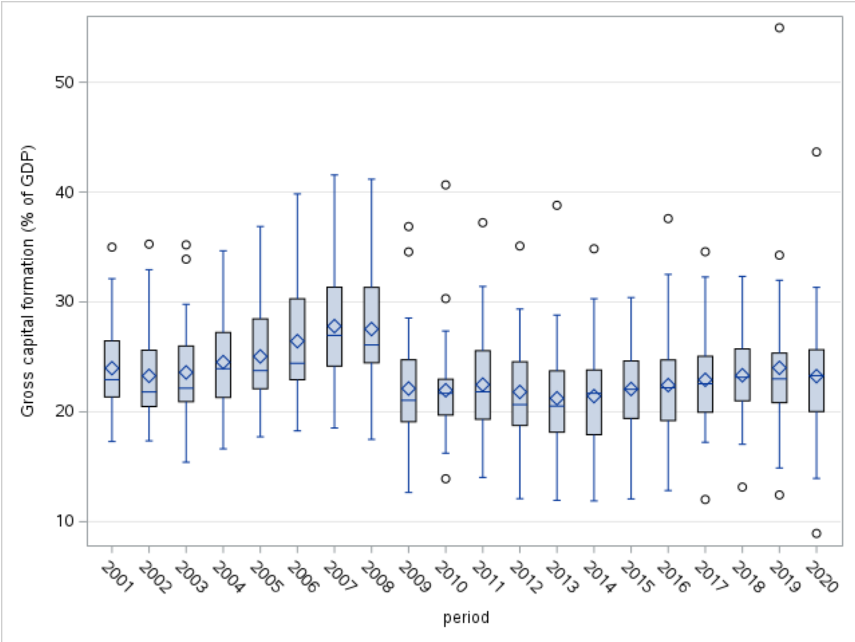
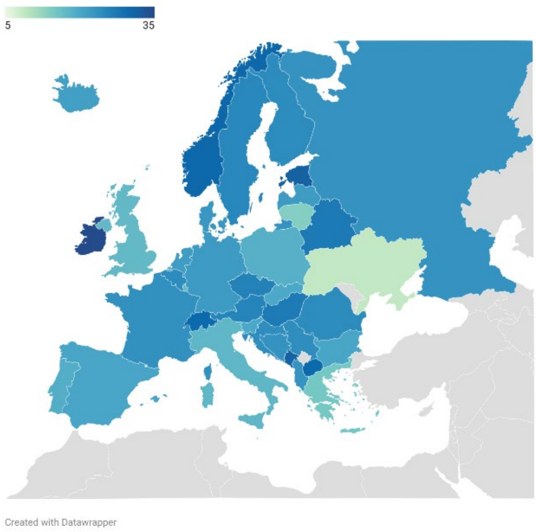


Fig.47 Gross capital formation as % of GDP
Source: Author´s work

At the beginning of investigated period average gross capital formation in the European region continuously increased until 2008. In 2009 a significant decrease and growth tendency was not recovered until the end of analyzed period. Between the years 2019 and 2020 average gross capital formation in % of GDP slightly decreased. The smallest gross capital formation in 2001 measured as % of GDP was recorded in Serbia (17%), North Macedonia (17%), and United Kingdom (18%).

On the other side of ranking with the highest values was in 2001 Albania (35%), Czechia (32%), Bosnia and Herzegovina (31%) and Slovakia (31%). If this indicator would be expressed in constant LCU, the smallest gross capital formation in 2001 would be in Malta, Estonia, Lithuania, and Latvia. On the other hand, the highest outlying values were Russian federation, Hungary, and Czech Republic. Situation changed in 2020. Gross capital formation in 2020 expressed both in % of GDP and constant LCU shown in the map of Europe is in the figures 48 and 49.



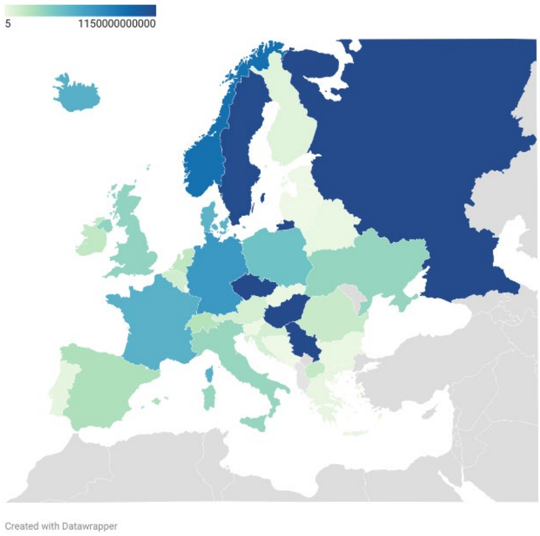


Fig. 48 Gross capital formation as % of GDP
Source: Author´s work

Fig. 49 Gross capital formation in constant LCU
Source: Author´s work

It is interesting, that at the end of analyzed period were the smallest and the highest values of gross capital formation expressed as % of GDP smaller than at the beginning of analyzed period in 2001. Year 2020 was significantly influenced by world pandemic. The smallest gross capital formation expressed as % of GDP was in Ukraine (8%), Lithuania (14%) and Greece (15%). This is a significant decrease compared to 2001 when its minimum value was 15%.

The highest gross capital formation in 2020 was in Ireland (44%), Estonia (31%), Montenegro (31%) and Norway (30%). These were the only countries in 2020 with gross capital formation above 30% of GDP. Smaller values of gross capital formation as % of GDP are localized at the East and Southeast of European region.

The situation with Gross capital formation expressed in constant LCU in 2020 would be slightly different. The smallest values in 2020 were recorded in Montenegro and Malta, which were clear low extremes compared to the rest of Europe. On the other side, large extremes in 2020 were recorded in Russian Federation and Hungary. Significantly higher values compared to the rest of European region were also in Czech Republic, Serbia, and Sweden. It could be questioned if the influence of this factor should be investigated in % of GDP or constant LCU. Values expressed in % of GDP are comparable across countries, on the other hand constant LCU includes also additional information about economic strength of country. Both these indicators were considered in the presented analysis.

Another factor significantly affecting food security in country was Trade. This variable was expressed as a % of GDP. It is expected significant impact of this variable especially on the availability of food, which can be obtained from homeland sources or imported from the outside. Volume of trade measured as % of GDP also express openness of Economy which is significant factor affecting not only food security but also overall development of countries. Development of this indicator over the analyzed period is shown in figure 50.

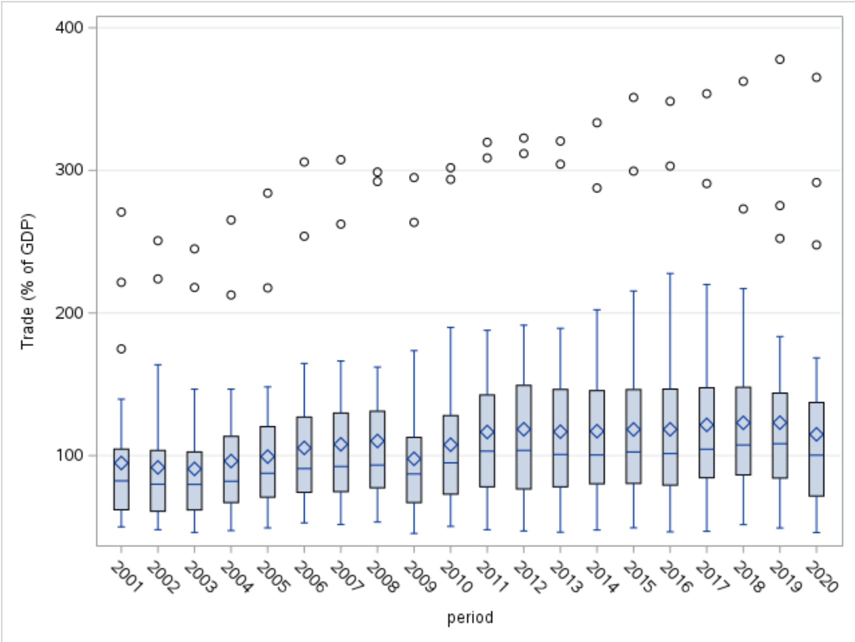


Fig. 50 Trade as % of GDP
Source: Author´s work

Based on values shown in the figure can be concluded overall high openness of European economies with some extremely high values. Average value at the beginning of analyzed period in 2001 was slightly smaller than at its end in 2020 with median under mean in both years. The average value of trade in the European region at the beginning of the period analyzed increased until 2008. After its recovery in the following period it stabilized, but at the end of analyzed period slightly decreased which can be explained as the influence of pandemic restrictions. Median value was smaller than mean over whole analyzed period. This means that the majority of European countries will be below average value. Variability among countries was significantly higher at the end of the period analyzed.

At the beginning of analyzed period in 2001 was the smallest values of trade expressed in % of GDP recorded in Italy (50%), Romania (52%) and United Kingdom (53%), and France (55%). On the other side, the highest values were recorded in Luxembourg (270%), Malta (221%), Ireland (175%), and Belgium (140%).

This is in accordance with expectation, that the value of this indicator will be smaller in large countries, but higher in small countries which depend more on international trade. Situation in 2020 describes map in the figure 51. At the end of analyzed period was minimum value of this indicator recorded in Russian federation, which is consequences of international sanctions after ignition of conflict in Ukraine in 2014. Other small trade shares in GDP were found in Italy (55%), France (57%) and United Kingdom (58%). Except Russian Federation was recorded increase in trade openness in all countries at the end of ranking compared to 2001.

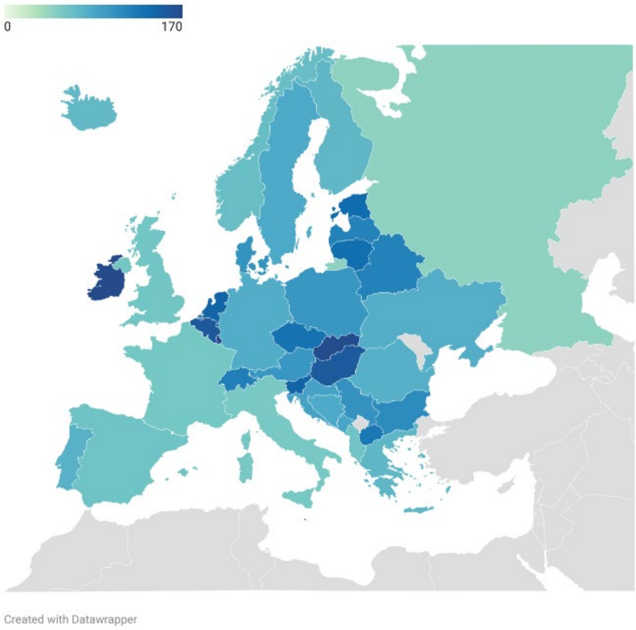


Fig. 51 Trade as % of GDP in 2020
Source: Author´s work

Increase was recorded also in countries with the highest openness of economy. At the top of ranking were again small countries: Luxembourg (365%), Malta (291%), Ireland (248%), and Slovakia (168%).

All previously mentioned factors were related mostly to availability or accessibility of food with direct impact on food security level in country. Current technical development highlights the importance of information in everyday life, which also affects the area of food security. Many authors emphasize in their studies that information access can have also an impact on food security.

As the approximation of information access in this study, variable individuals using the internet expressed as share of population. The development of this indicator is shown in figure 52. It reflects also technological development over the last 20 years. At the beginning of the period analyzed the average value of the presented indicator was only slightly above 20% with large variability, but at the end in year 2020 was average value almost 90% with small variability. Also, the position of median changed over time. In 2001 its value was much smaller than the mean, but in 2020 their values will be almost equal.

The beginning of the period analyzed in 2001 was characterized by large disparities among countries. Minimum value of variable was just 0.32% in Albania. Other very small values were found in Bosnia and Herzegovina and Ukraine (both 1.2%). Russian Federation with 2.9% of people with internet access was just slightly higher. On the other side of ranking was Norway with the maximum value for 2001 equal to 64% of population with internet access. Values above 50% were found also in Switzerland (55.1%) and Sweden (51.7%).

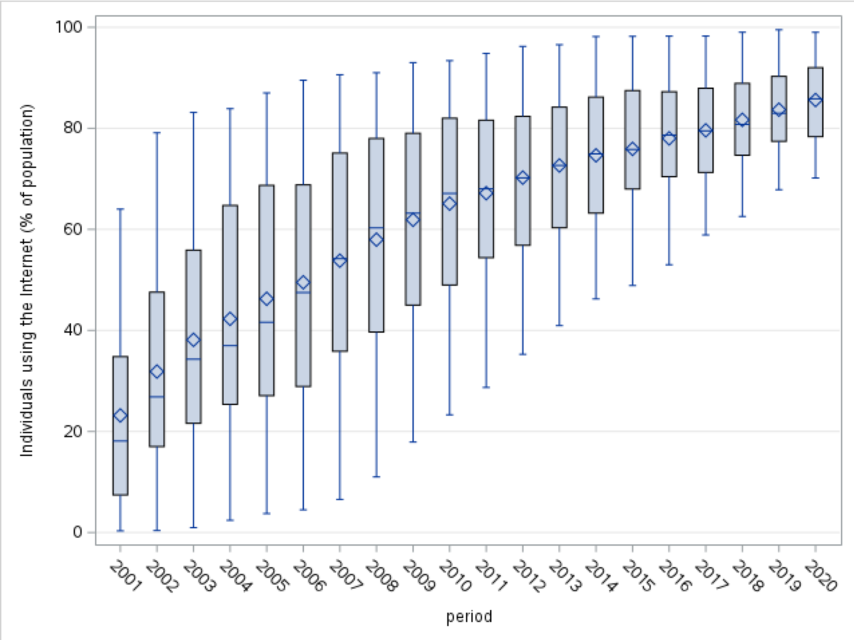


Fig. 52 Individuals using the Internet (% of population)
Source: Author´s work

The situation will substantially improve in 2020. The share of population in European countries with internet access in 2020 is in figure 53. Charts show intervals between 70% and 100%. In 2020 was the worst access to internet between European countries in Bulgaria with 70% and Italy with 70.5%. Slightly better situation was in Albania (72%) and Bosnia and Herzegovina (73%). On the other hand, almost all population can access the internet in Iceland (99%) and Luxembourg (99%). Value above 95% was recorded also in Denmark and Norway (97%). Based on the values in the map chart it can be concluded that the best internet access is in the Northern and Western parts of Europe.

In general, it can be concluded good availability of internet and information access in European region, compared to average share of population with internet access in the world, which was approximately 66% according to International Telecommunication Union. Together with other factors can be European region can be evaluated as developed food secure region. This means that European countries are in good shape according to world standards. But if they were compared only with developed countries, there would be still possible to identify weak regions and areas. Especially at the end of analyzed period when most of variables included in the analysis deteriorated. This was influence by negative development of social and political fundamental factors, but also by unexpected effects, such as covid pandemic, or spread of war in Ukraine.

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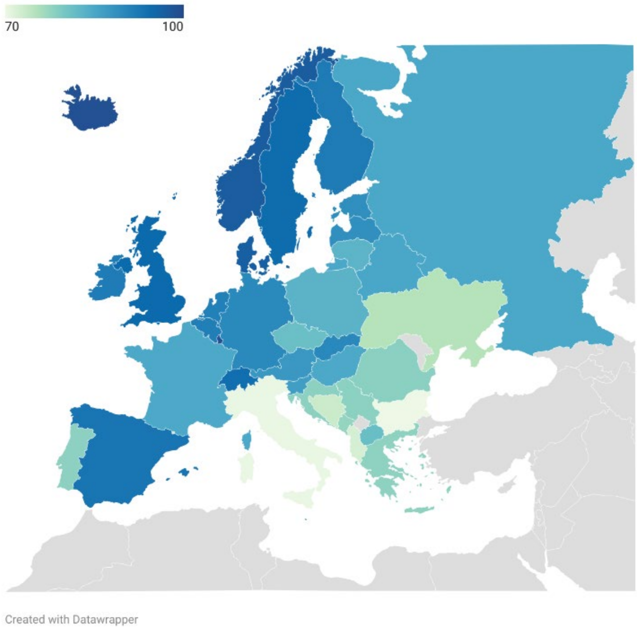

Fig. 53 Individuals using the Internet (% of population) in 2020
Source: Author´s work

4.3 A Comprehensive Methodological Framework for Estimating the Influence of Food Security Factors

The standard approach to analysis of causal relationships assumes that composite food security indicator produced as result of DEA analysis is function of considered food security factors according to equation 1.

$$y_{it} = f(x_{1it}, x_{2it}, \dots x_{5it}) for\ i = 1,2,\dots,N \quad and\ t = 1,2,\dots,T \qquad 9.$$

Where y_{it} is the value of constructed food security indicator of i-th country in time t, and x_{1it}, to x_{5it} are considered food security factors described in table 2, for i-th country in time t.

It is assumed there is a linear relationship between food security and its factors. Logarithmic transformation was not considered, because most of food security factors were expressed in percentage. To ensure comparability of estimated coefficients all explanatory variables were standardized.

Analysis assumed basic relationship between variables:

$$y_{it} = b_0 + b_1 x_{1it} + b_2 x_{2it} + b_3 x_{3it} + b_4 x_{4it} + b_5 x_{5it} + u_{it} \qquad 10.$$

Where b_0, b_1, …b_5 are estimated functional parameters, and u_{it} random error component.

Standard approach to panel data analysis is model with fixed effects or random effects which assume homogenous values of b coefficients, which are the same for all countries.

The fixed effects model is based on assumption that slope coefficients are the same for all analyzed countries, but functions differ in constant b0, which is called fixed effect. It would be obtained by following substitution in equation 2:

$$b_0 = \alpha_i \qquad 11.$$

Where α_i is time-invariant individual effect. In practice it could be obtained by introducing N-1 dummy variables.

Alternative panel approach assuming homogenous values of estimated parameters is random effects model. In contrast with the fixed effects model, it estimates individual effect as specific error component. Random effect model can be obtained by following substitution in equation 2:

$$u_{it} = e_{it} + v_{it} \qquad 12.$$

Where e_{ij} is the common random error component and v_{it} is random error specific for every cross-sectional unit which express individual heterogeneity of panel. The decision between fixed and random effects model was based on result of Hausman test, which verifies if random effects model estimate is consistent. In case of null hypothesis acceptance should be used Random effects model, otherwise should be preferred fixed effects model.

As the alternative to fixed and random effects model was used Pooled mean group model, which allows to estimate heterogenous functional parameters in short run, which are specific for every cross-sectional unit. A common approach to modelling of panel data is to estimate N separate regression and calculate mean value of coefficients, which is called the Mean Group estimator. An approach introduced by Pesaran, Shin, and Smith (1999) called Pooled Mean Group estimator allows the long run coefficients to be the same and short run coefficients and error variances to differ across groups. It assumes that there are often good reasons to expect long run equilibrium relationship between variables to be the same, but short run dynamics and error variances tend to be different.

We assume that equation 2 express long run relationships with heterogenous functional parameters. But in the short run can be estimated relationship in equations with slope coefficients specific for each cross-sectional unit according to equation 5.

$$\Delta y_{it} = \varphi_i(y_{it-1} - b_0 - b_1 x_{1it} - b_2 x_{2it} - \cdots - b_5 x_{5it}) + \delta_{1i}\Delta x_{1it} + \delta_{2i}\Delta x_{2it} + \cdots + \delta_{5i}\Delta x_{5it} + \varepsilon_{it} \qquad 13.$$

Where $\Delta y_{it}, \Delta x_{1it}, \dots, \Delta x_{5it}$ are first differences of dependent and independent variables.

φ_i denotes error correction term, which expresses how fast cross-sectional unit converges to long run equilibrium Significance of this term also confirms significance of long run relationship.

$\delta_{1i}, \delta_{2i}, \dots, \delta_{5i}$ are short run coefficients specific for each analyzed cross sectional unit.

Interpreted results include comparison of long run coefficients estimated with different methods and short run dynamics estimated with the use of Pooled mean group model.

4.4 Long Run Influence of Food Security Factors

The produced value of food security index was used in further analysis of factors influencing countries' performance. The food security index was used as a dependent variable related to factors described in table 2. Panel data were analyzed using fixed effects, random effects, and pooled mean group model, which allowed to estimate also short run dynamic in every country. Random effects estimator was not consistent according to Hausman test, which p-value was 7.5 e-10. For this reason, random effects model was not included in table 3, which shows long run influence of food security factors estimated using Pooled mean group and fixed effects model. The table includes both point and interval estimates. R-squared value of the fixed effects model was equal to 0.91. This value is not directly comparable with Pooled mean group model, where it is not possible to estimate R-squared value for its long run coefficients.

The fixed effects model included two insignificant variables: agriculture, forestry and fishing value added and gross capital formation. Significant variables were trade openness, availability of internet and urbanization. According to pooled mean group model were all considered variables significant. This difference comes from the nature of both estimators. Fixed effects model is pooled estimator assuming different intercept for each country, and Pooled mean group model estimates mean coefficient value in panel data. Interesting fact is that in pre analysis of input variables arable land was evaluated as insignificant factor according to all considered models. This suggests that intensity of food production became more important than its extensity. It should be noted that all explanatory variables were standardized, their influence can be therefore directly compared.

Tab. 5 Long run influence of food security factors

Estimator	PMG model Long run	Fixed effects model	PMG model Long run		Fixed effects model	
	Coefficients		Low95%	High95%	Low95%	High95%
AffVA	0.130***	−0,004	0.099	0.162	-0.015	0.007
Trade	0.065***	0,027***	0.054	0.077	0.016	0.038
GCF	0.021***	0,0005	0.009	0.032	-0.011	0.012
Internet	0.017***	0,021***	0.008	0.027	0.016	0.026
Urban	0.099***	0,071***	0.059	0.139	0.048	0.09

*** - significant at alpha=0.01 ** - alpha=0.05 * - alpha=0.1

Both models confirmed the significant positive influence of trade in accordance with expectations. Mean coefficient is slightly higher than pooled in fixed effects model. Trade is therefore a significant factor in food security. Goods and commodities are traded in both ways, but in general trade openness can be considered as a significant factor in ensuring a stable and sufficient food supply. Even higher positive influence on food security situation according to both models was found in case of urbanization (slightly higher according to PMG model). Despite negative expectations, this result is in accordance with other authors. Urbanization can be understood also as a measure of development and concentration of capital and human resources.

For developed countries with high level of urbanization is characteristic open economy with intensive technologically advanced agriculture. This can be reason for positive value of urbanization coefficient.

The availability of the internet was used as the measure of access to information. Both models show their significant influence on the food security situation in European countries, in accordance with expectations, with surprisingly similar estimated values. Results suggest that except traditional sources, access to information should be considered when accessing food security situations.

Different results estimated in fixed effects model and pooled mean group model for agriculture, fishing and forestry added value and gross capital formation could be explained by lack of relationship between variables in pooled set of data, but its significance in the most of separately estimated country specific models. According to pooled mean group estimator the agriculture, forestry and fishing value added the most influencing factor. Better insight could offer country specific short run models, which results are shown in figures 54 to 60.

4.5 Short run influence of food security factors

Explanatory ability of each model measured by R Squared value is shown in figure 54. The highest proportion of explained variability was in Ireland, Portugal, Serbia, and Slovenia. The food security situation in countries with the highest R Squared value is influenced by factors considered in table 3 the most. On the other hand, in countries with the smallest R Squared value is food security probably determined by other factors, or they are in specific conditions, which is the case of Luxembourg, Ukraine and Romania.

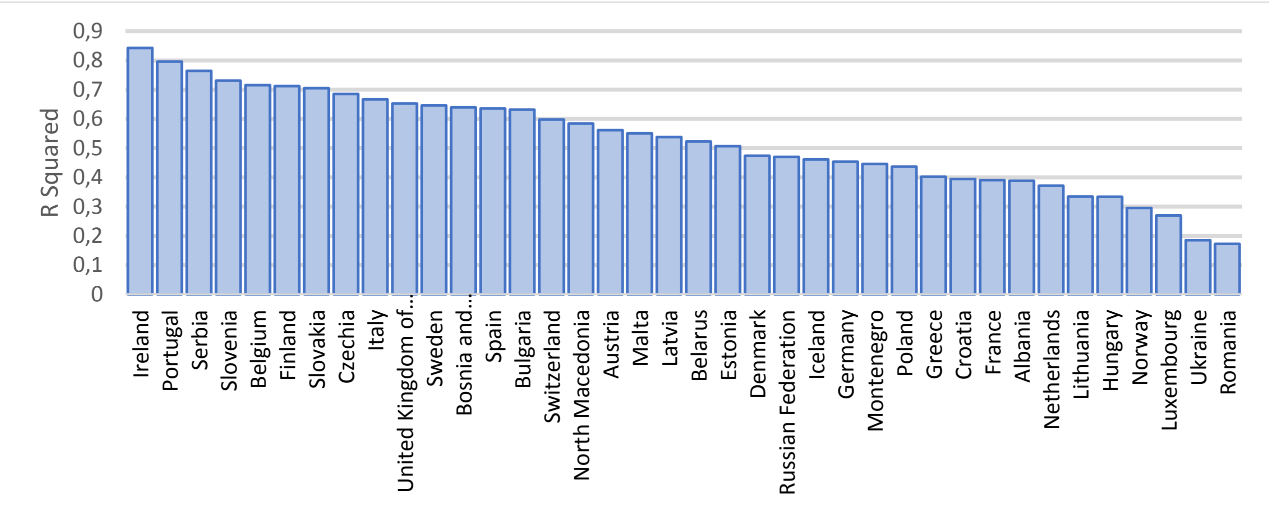

Fig. 54 R Squared values in short run estimation
Source: Author´s work

Pooled mean group model allowed to estimate long run relationship coefficients common for all analyzed countries and country specific short run effects. In short run estimation can be found error correction term.

Its value shows how fast countries converge toward long run equilibrium and its significance and negative value confirms existence of long run relationship. Figure 55 shows estimated error correction coefficients in country specific short run models.

Bars in blue denote significant coefficients. Finland, Serbia, and Portugal converge fastest to long run equilibrium, which suggests, that these European countries are the most flexible. On the other hand, Ukraine, Norway, Albania, and Iceland were on the other side of distribution with the smallest values estimated values and insignificant error correction term. This suggests just a very small speed of adjustment of their food security toward long run equilibrium in Europe, or that long run equilibrium in these countries does not correspond to the rest of the Europe. This could be actual also for Belgium, Austria, and Hungary. In case of Albania and Ukraine with poor food security performance it indicates even further deepening of disparities compared to other countries.

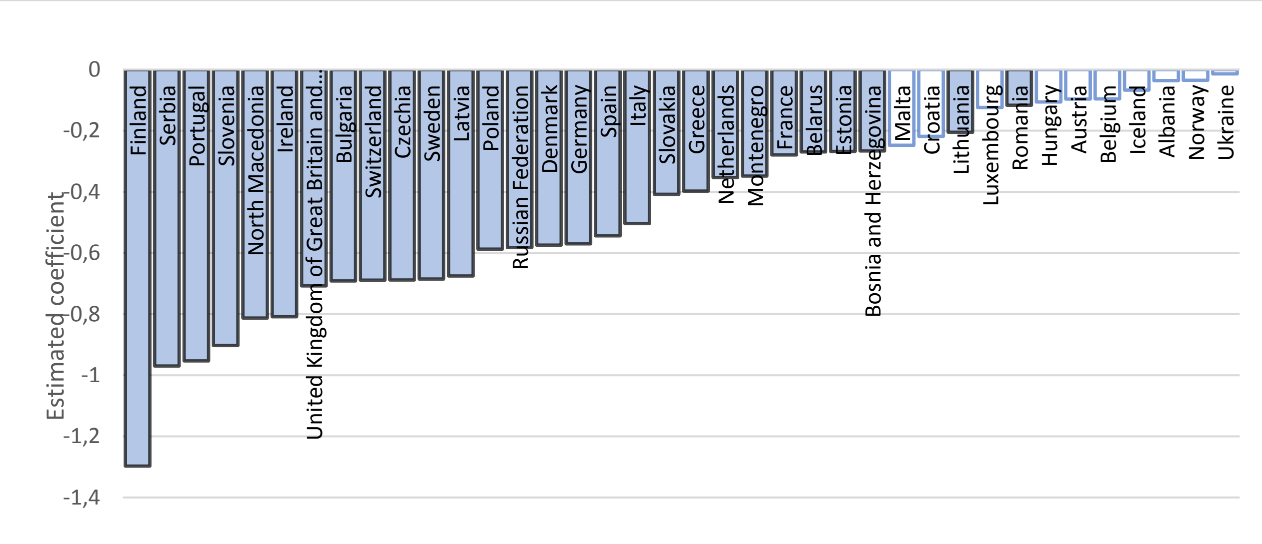

Fig. 55 Error correction term coefficient -speed of convergence to long run relationship
Source: Author´s work

Next figures show short run influence of food security factors, which were estimated as country specific. Figure 56 shows comparison of estimated short run coefficients for agriculture, forestry, and fishing value added. Colored bars denote significant coefficients and orange line shows long run coefficient according to pooled mean group estimator. The highest impact of agriculture on food security was found in Austria, Spain, United Kingdom, France, and Czechia. High value of coefficient was found also in Switzerland, but it was insignificant. In these countries agriculture plays an important role in ensuring food security.

This could be reason, why bad performance in food production led to surprisingly poor food security result in France. On the other hand, countries like Sweden, Portugal and Norway have their food security based on other sources than agriculture, forestry, and fishing. There was identified also countries with small, but significant influence of agriculture on food security, such as Serbia and Albania. Significant negative influence in some countries suggests a negative relationship between food security and agriculture value added.

For example, in Sweden and Portugal improved food security despite decrease of agriculture, forestry and fishing value added, on the other hand, food security position of Malta and Norway worsen despite increase in this variable.

In general, it can be concluded important role of agriculture in ensuring food security. In the long run it was the most influential variable according to results of pooled mean group model. Its significance is smaller in countries with specific conditions. It is interesting that variables like land, or arable land expressed in various indicators turned to be insignificant in pre analysis of this study. In contrast with significance of agriculture, forestry and fishing value added it seems, that rather than extensity of agriculture become important intensity of agriculture and efficient using of resources.

Slightly smaller long run impact on food security situation was estimated in case of trade (expressed as % of GDP). There are two ways it can impact food security situation. With import of food related goods, it can improve food security situation. On the other hand, with excessive export can be food security situation deteriorated. The long run impact of trade on food security was positive. Country specific short run results were heterogenous. Similarly, to agriculture, forestry and fishing value added, also in case of trade was its effect in long run higher than in short run in most of analyzed countries.

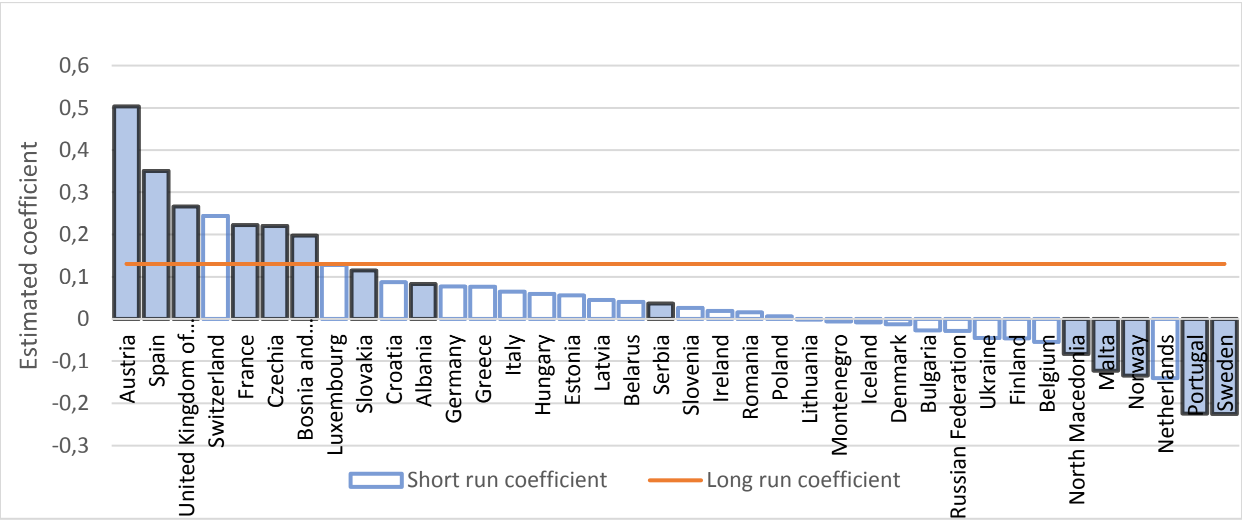

Fig. 56 Agricultural, fishing and forestry value added long run and short run coefficient values
Source: Author´s work

Estimated short run coefficient for impact of trade on food security are shown in figure 57. Significant positive short run impact of trade was recorded only in case of Italy and Slovenia. In both countries was not significant agriculture fishing and forestry value added. Their food security is based on trade, and food security risk will be associated more with factors influencing trade than agricultural related conditions.

Countries with significant negative values of short run influence of trade can be divided into two groups. For example, France and United Kingdom, which worsened their food security positions despite of slightly increase of share of trade on GDP over analyzed period. Second group are countries like Sweden, Latvia, Ireland, Iceland, and Hungary, which improved their

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food security position in Europe despite slightly decreasing share of trade in GDP. Therefore, for both groups with significant negative short run coefficients trade is crucial in the short run to ensure their food security and for the majority of analyzed countries.

However, unexpected change in trade can significantly decrease food security in Spain, Italy, and Slovenia. Also, the significance of this variable in short run equations suggests that for many European countries trade is a more important food security factor in long run, as it was insignificant in most of the short run equations.

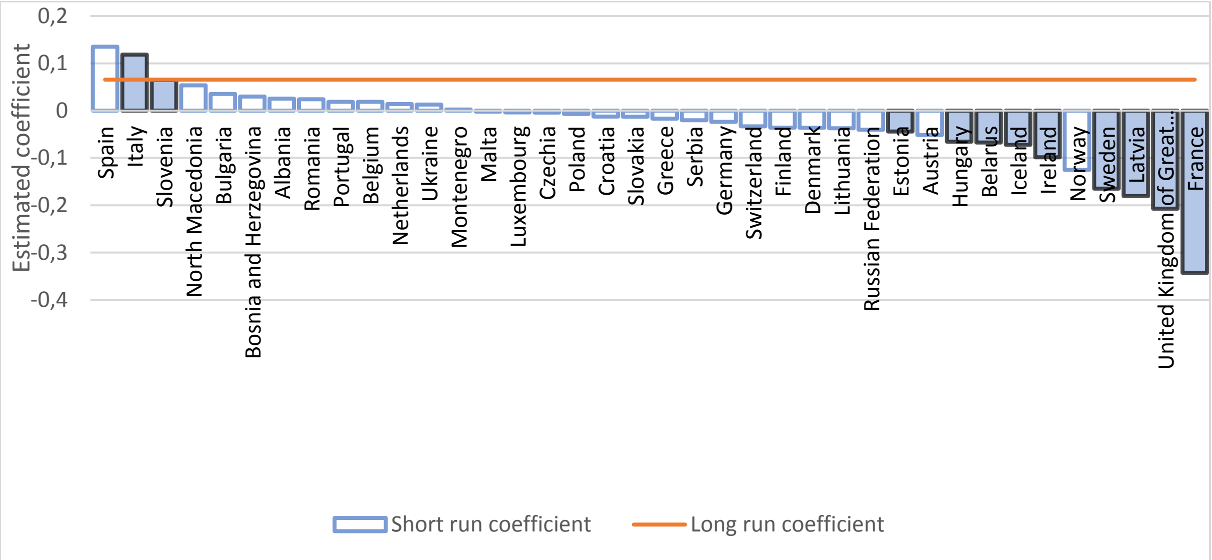

Fig. 57 Short run and long run coefficient for trade
Source: Author´s work

Another factor considered in the analysis performed was gross capital formation. This was the only variable related to food security level as an absolute cumulative indicator. It is interesting that when this variable was expressed as % of GDP or per capita, its effect in the long run was insignificant. It was also insignificant in the estimated fixed effects model.

The absolute value of an indicator includes not only information about investments in the country but also about its size. Even with standardized value of variable, consequence of its cumulative absolute value was some very high short run coefficient. Influence of Gross capital formation is shown in figure 58, extreme values of estimated short run coefficients are out of scale in the figure. Full colored columns denote significant short run coefficient. A long run coefficient with a value of 0.021 gives gross capital formation fourth place between considered food security factors.

It can be considered a significant short run impact of Gross capital formation on food security. It is interesting, that in contrast with previously analyzed two factors is short run effect in most of countries higher than long run. Especially food security in countries with large significant values of short run coefficients will depend on Gross capital formation.

On the other hand, between countries with negative values of short run coefficients can be again found countries which improved their food security position despite decrease of gross capital formation, such as Belgium or Portugal. On the other hand, in Slovenia or Malta food security situation got worse even with increase of Gross capital formation.

Therefore, food security in these countries is probably influenced more significantly by other factors. It can be concluded that sudden change of Gross capital formation would worsen food security situation in European countries mostly in short run, but long run effect would be smaller than in case of agriculture value added or change in trade conditions.

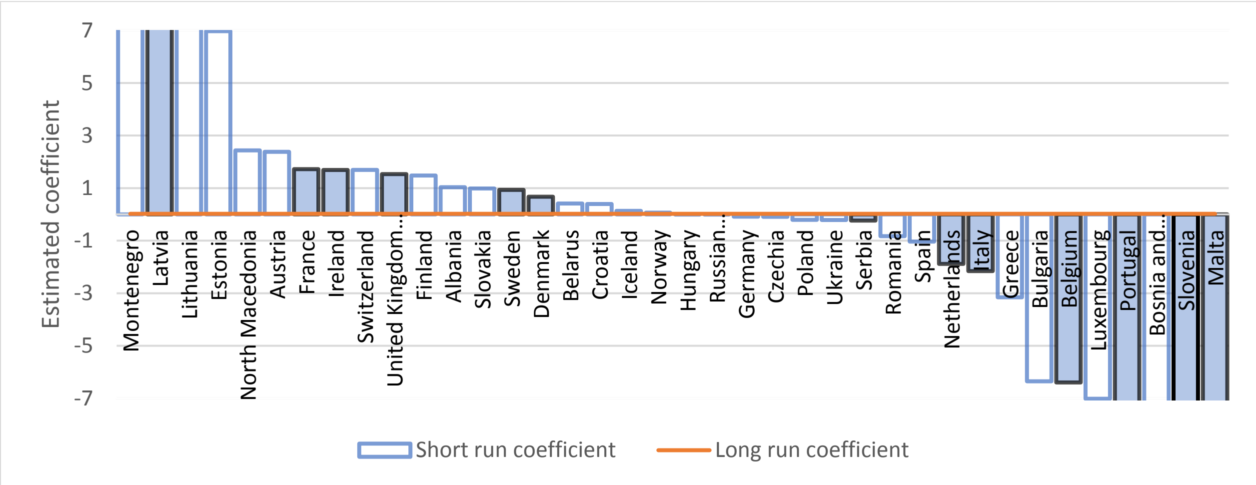

Fig. 58 Short run and long run coefficients for Gross capital formation
Source: Author´s work

Long run and short run effect of urbanization on food security shows figure 59. Similarly, to Gross capital formation, also in case of urbanization (expressed as % of urban population) was effect in long run much smaller than short run effect. But compared to influence of other considered factors, the effect of urbanization was evaluated in long run as the second important factor after agriculture fishing and forestry value added. It can be assumed that a high degree of urbanization could negatively affect food security situation. On the other hand, in some regions it means also a high concentration of human resources and capital.

Another interesting fact is that urbanization was significant in a substantial share of analyzed countries, compared to previously analyzed factors. Especially in Greece, United Kingdom, North Macedonia, and Serbia is urbanization important factor influencing food security. Much more interesting are countries in right part of figure 59, such as France, Bulgaria, and Italy, where was found significant negative influence of urbanization on food security in short run. Food security in these countries got worse despite the increased level of urbanization. It could mean that food security in these countries is related stronger to other factors. Another reason could be that the increased level of urbanization in these countries was not related to economic and income growth.

It should be noted that the short run effect in this case means the relationship between the first differences of variables in the case of yearly data. Compared to other analyzed factors, in this case it is not a large probability that there could be sudden large change in urbanization with instant significant impact on food security. Change in urbanization is usually slower and it can have two direct effects on food security.

In one case, it can be increased urbanization with growing cities area at the expense of agricultural land and production which would decrease availability of food, in other case it can be increased urbanization with increasing density of population in cities as the result of economic development related to change in economic structures, which may lead to increased income of population and improve accessibility and utilization of food.

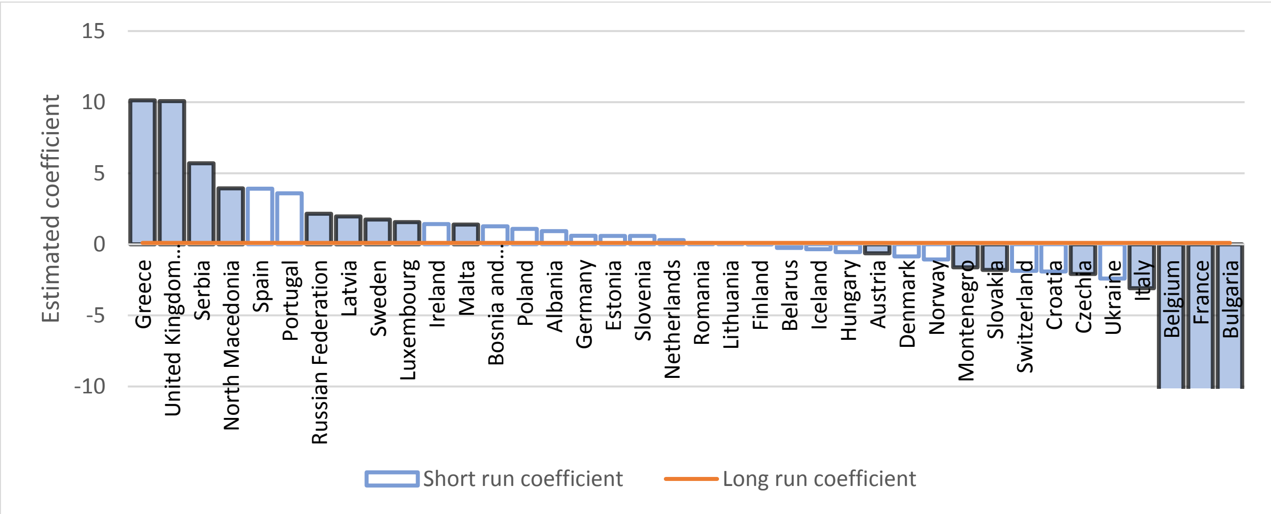

Fig. 59 Short run and long run effect of urbanization
Source: Author´s work

The last factor influencing the food security situation in European countries was accessibility of the Internet measured as % of population using the Internet. This variable was used as the measure of accessibility of information, which is also important to achieve food security. The long run impact of this variable was the smallest among considered factors, but this variable had significant positive coefficient in both long run pooled mean group equation and fixed effects model.

Availability of information therefore significantly improves the food security situation in a country. In short run was effect of internet access the most important in Serbia, Belgium, Estonia, Malta, and Sweden (figure 60). All these countries except Malta significantly improved their food security position among European countries. On the other hand, between countries where internet access had significant negative value of short run coefficient only Ireland improved its food security position.

It means, that food security performance in most of these countries decreased despite improvement in the accessibility of Internet. Results suggest that the short run impact of information availability can be more important than trade, especially in small countries, but its importance relative to other factors decreases in the long run.

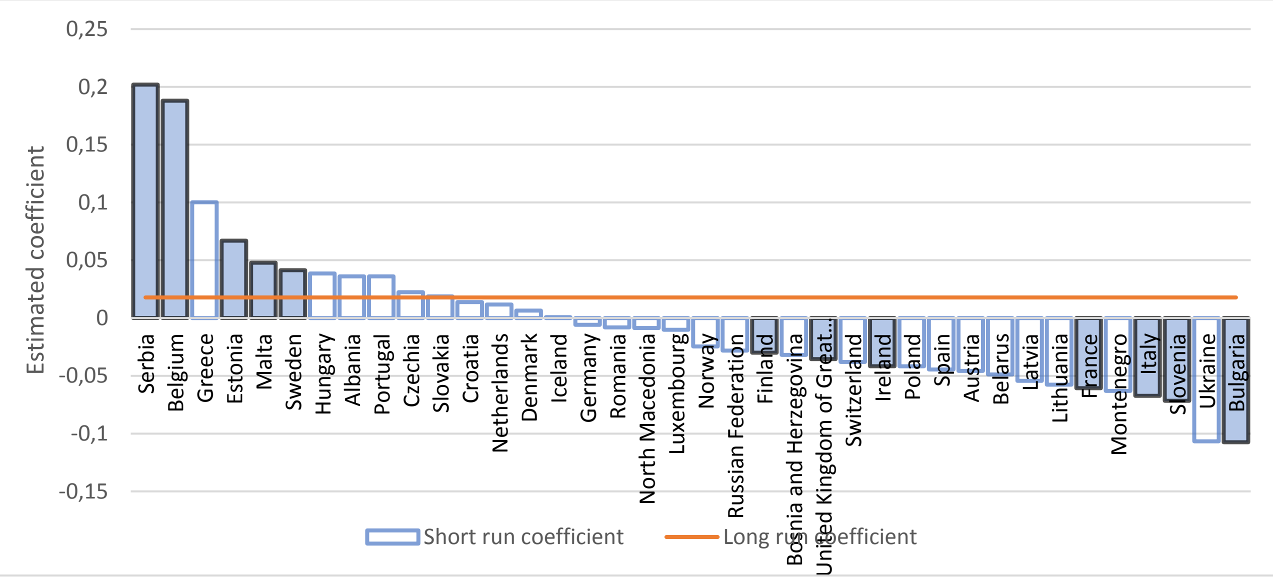

Fig. 60 Estimated short run effect of internet availability
Source: Author´s work

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5. The Last Chapter: Discussion and Some Conclusion Remarks about Food Security in Europe

Results of presented study agrees with Bjorch and Kjaernes (2016) which concluded alarming lack of knowledge about European food insecurity. Cooper et al. (2020) in their text mining study concluded, that most of the studies in the field of food security were focused on economic policy and global issues, which highlights added value of analysis in presented study. Methodology applied in this study to produce composite indicator was based on DEA analysis, which considered four basic pillars of food security as defined by FAO. In contrast with the view of Clapp et al. (2022) who suggested extension of food security to definition to six dimensions, results presented in this study and its comparison with GFSI showed that current four dimensions are sufficient.

Producing even more complex indicators with six dimensions could cause smaller weight of availability and quality of food in such measure. The presented comparison with GFSI indicator was inspired by study by Chen et al. (2019) who applied methodology to create composite index suggested by Kao (2010). The objective of his work was reassessment of GFSI based on DEA analysis which was applied at world level and included the same countries, pillars, and variables as GFSI. Our analysis applied the same DEA approach, but with pillars and variables according to FAO definition only for European countries. Both works concluded that there were not recorded significant differences between ranking according to constructed indicators and GFSI.

However, our work emphasized some significant differences in long term evaluation of some countries. The results and conclusions presented are in accordance with recommendations by Chen et al. (2019) which highlights food availability dimension. A similar assessment of GFSI was published also by Izraelov and Silber (2019). They also concluded that GFSI gives reasonable ranking of countries. But both Chen et al. (2019) and Izraelov and Silber (2019) reviewed GFSI performance at world level. Our study focused on its performance in specific conditions of European countries. Results confirmed conclusion presented by Thomas (2017) that complex nature of GFSI evaluate rather food security environment than its real level. On the other hand, results do not agree with Poudel (2021) who explored the disparity between global food security indicators and concluded large variability between them. But his work also emphasizes the importance of objective indicators with desired properties which could be used to measure food security at any level. Our conclusions agree with results of most research publications (e.g. Nardo et al., Saisana et al. 2005), that composite indicator should be based on objective weighting scheme.

The result of the conducted analysis confirmed the important role of agriculture in achieving food security. It is in accordance with the findings of Fan and Brzeska (2016) and Poudel and Gopinath (2021). There are more ways to express agriculture. Some authors used arable land, land productivity or added value of agriculture, fishing, and forestry. Arable land was not significant in conducted pre analysis, so it was not included in study´s results. This is in contrast with Poudel and Gopinath (2021) who found its influence significant, on the other side results confirmed their conclusion about significance of agricultural value added.

This variable was used also in analysis performed by Matkovski et al. (2020) and confirmed its significance, but concluded negative impact on food security which is in contrast with presented study.

According to expectations was confirmed significant influence of trade openness on food security. This supported the conclusion of Feleke et al. 2005, Dorosh et al. 2009, Pyakuryal et al. 2010, Dithmer and Abdulay (2017) and Poudel and Gopinath (2021). In case of urbanization was also confirmed significant positive effect on food security, which is in contrast with conclusions by Farrukh (2022) made for Pakistan. But it supports findings by Poudel and Gopinath (2021) and Li et al. (2023). about the significant effect of urbanization which is different for low income and high-income countries. The significance of gross capital formation and internet access also supports findings by Poudel and Gopinath (2021) which evaluates access to information as another significant source for achieving food security.

Food security in Europe may seem to be a less important issue compared with the rest of the world, especially poor and developing countries on other continents. In case of assessment of global food security may Europe look homogenous with developed food secure countries. The truth is that measuring European food security has some specifics which need to be considered. Europe has also its own problems in the field of food security which may be addressed and solved only with the use of suitable indicators. In the case of using GFSI for evaluating food security in Europe together with other world regions may not be identified any significant differences.

The solution is to investigate food security in Europe separately to identify problematic regions. Another fact which should be considered is that weights in GFSI are not derived on an objective basis, but according to expert opinions. An appropriate method to produce composite indicator with objective weights could be DEA, which would be applied only to European countries. Alternative methods could be indexing with objective weights based on different variability or correlation between chosen food security indicators, or principal components analysis. For analysis with large set of input indicators could be alternative also to use hierarchical approach or factor analysis. In the case of DEA would be European countries benchmarked only to the best performing countries which will set efficiency frontier for the comparison with others. This would allow us to identify weak European regions and compare them at the level corresponding to developed countries.

Another important task in this kind of analysis is proper selection of input indicators. Analysis presented in this study used 12 food security variables available for European countries selected according to pillars and definitions applied by FAO. On the other hand, GFSI is based on a wide range of indicators. This makes him a complex measure focused primarily on food security, but also including sustainability, economic and social development. Variables directly connected with availability, accessibility and quality of food are just part of indicator with smaller weights. Based on such an index can be country where people suffer poor food security conditions evaluated better in case if achieved better sustainability, environmental or legislative conditions.

Still, it is necessary to respect the multivariate nature of food security topic because its evaluation based only on one indicator, such as prevalence of undernourishment, can give biased information about the real situation in country. The optimal solution would be to use composite indicator with objective weights based on multiple input variables.

These variables should be directly related to food. Variables included in the analysis in the presented study can be used as an example of this approach. Selection of variables to produce composite food security indicator specifically focused to monitor situation in European countries could be subject to further discussion. Another discrepancy between DEA and GFSI indicator was in development of European food security in past years, when GFSI concluded its improvement over whole period, but DEA detected its decrease in years 2014-2016. This is given by the different nature and properties of both indicators, but it was also influenced by escalation of conflict in Ukraine in 2014.

An important role also plays in the availability of suitable data. The disadvantage of GFSI applied in the analysis of food security in Europe is that the data was available only for 26 countries but also included year 2022. Conducted DEA analysis which used data available at FAOstat included 38 countries, but data was available only until year 2020. The solution could be to use data available in European databases, with objective selection of variables respecting multivariate food security nature and its pillars. European food security should be monitored, especially in smaller countries which are not included in the Global food security index to identify the most vulnerable regions. Monitoring food security at aggregated level has also disadvantages. Vulnerable regions could be identified better if it were monitored at regional or household level.

Current studies published in the field of food security focus on developing countries in Asia and Africa. Most of these studies focused on measuring food security with available indicators, or analysis of its factors. Only a small number of studies are focused on the problem of its measuring. The major asset of the presented study is demonstration of specifics of measurement of food security in European countries and identification of main disadvantages of GFSI when applied to Europe. On the other hand, the limitation of the presented study was the availability of data only until 2020. Results thus does not show full influence of COVID pandemic and last escalation of conflict in Ukraine. Analysis showed that food security problems can be identified in the Eastern part and South-Eastern part of Europe. Both GFSI and composite DEA indicator also showed deterioration of food security position between European countries in France and Slovakia in period 2012-2020. These results were recorded before events in the last years. It may be expected that this negatively influenced the food security situation in Europe and the most endangered regions would be countries which did not perform very well in our analysis. This could be also a suggestion for further research, which could be conducted with enough relevant data.

The presented study contributes to actual food security discussion in both theoretical and practical perspectives. It demonstrates the application of methods to evaluate food security and investigate its determinants which can be used in general, not only in European regions. Results suggests that also Europe has food security issues, and its level did not improve since 2014. Food security in Europe was in last years affected by many fluctuations caused by covid

19 pandemic and military conflict in Ukraine. The most endangered region is in the Eastern and South-eastern part of Europe, but volatility of food supply was negatively influenced also in countries of central Europe. Performed analysis was limited by availability of relevant data, but in recent years could be expected further decline in food security indicators.

Conducted analysis showed that added value of agriculture, fishing and forestry and trade openness significantly influenced food security in long run. Important role plays especially intensity of agriculture and its technological development. It has an essential role especially in countries with good natural conditions. Food security in countries with smaller food productivity depends on trade and its influence was significant, especially in the long run. But the short run of trade was also significant, especially in countries with direct access to the sea.

Another considered factors are gross capital formation, urbanization and internet access seems to be important especially in the short run. Gross capital formation is a measure of economic development and influence of a country, and it has an essential role in ensuring food security in the short run, especially in less developed European countries. Discussion about urbanization evaluates its positive and negative aspects. In less developed countries it can bring positive externalities in higher income and resources concentration, but it can have also negative externalities in the form of price growth and environmental pollution. The analysis showed, that along with traditional sources of food security should be considered also effect of information access, which will increase even more in near future and has important role to ensure food security in short run. Significant limitation of this study was yearly data only for 20 years, which decrease flexibility of using more variables and lagged values in short run equation of pooled mean group models.

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Appendix 1: Countries Food Security Ranking according to DEA indicator

Country/year after 2000	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Albania	38	38	38	38	38	38	38	38	38	38	38	38	38	38	38	38	38	38	38	38	36
Austria	9	9	11	15	12	9	5	4	3	4	4	1	1	1	3	4	3	4	3	5	5
Belarus	24	24	27	26	31	29	32	29	28	28	27	35	33	35	31	34	36	35	37	35	34
Belgium	2	2	2	2	2	2	3	3	6	3	3	4	4	3	2	2	5	6	6	4	3
Bosnia and Herzegovina	37	37	36	35	35	35	36	36	35	35	33	33	34	31	36	33	32	33	31	31	31
Bulgaria	25	25	26	25	26	27	28	31	30	30	29	28	27	19	25	29	29	27	27	28	30
Croatia	32	32	30	31	30	32	29	28	26	26	28	29	30	30	29	28	24	32	33	33	32
Czechia	17	17	16	16	16	19	14	9	12	12	12	11	11	11	10	17	15	14	16	17	21
Denmark	7	7	10	10	9	12	12	11	13	14	13	13	14	14	14	9	9	9	11	12	14
Estonia	23	23	21	22	20	17	18	19	20	22	22	26	24	25	22	13	23	19	24	20	20
Finland	13	13	13	11	13	11	8	8	11	10	11	12	12	12	15	16	13	12	9	11	12
France	5	5	5	9	10	13	16	17	15	11	14	15	16	17	16	15	18	20	25	22	25
Germany	6	6	6	5	4	4	4	5	5	5	5	5	5	5	5	6	7	7	7	7	6
Greece	20	20	17	17	17	21	22	23	23	21	19	24	17	22	24	25	28	29	28	27	24
Hungary	21	21	19	20	21	20	20	24	21	20	23	25	25	23	20	19	16	15	13	16	11
Iceland	19	19	18	18	18	16	15	14	16	16	20	22	20	18	18	12	12	11	10	8	8
Ireland	11	11	12	14	15	18	19	18	19	19	17	14	15	15	13	10	6	3	4	2	4
Italy	3	3	4	4	5	5	6	7	7	6	7	6	6	9	11	18	17	21	19	10	13
Latvia	35	35	33	34	34	33	33	34	36	36	36	34	31	34	32	27	30	28	29	29	27
Lithuania	28	28	31	29	27	26	25	27	31	31	30	31	29	29	28	26	26	25	22	23	22
Luxembourg	1	1	1	1	1	1	1	1	1	1	1	3	3	2	1	1	1	1	1	1	1
Malta	8	8	7	6	7	6	7	6	4	7	6	8	8	7	7	11	10	10	12	18	19
Montenegro	34	34	35	36	36	36	34	33	32	33	34	27	28	28	34	32	27	30	32	34	35
Netherlands	12	12	9	7	8	7	11	12	10	8	8	7	9	6	6	5	4	5	5	6	7
North Macedonia	36	36	37	37	37	37	37	37	37	37	37	37	37	37	37	35	34	34	34	37	37
Norway	15	15	14	13	11	10	10	13	9	9	9	9	7	8	9	8	11	13	15	14	10
Poland	22	22	22	23	22	23	23	20	18	17	15	19	18	21	19	22	21	16	18	19	17
Portugal	26	26	23	21	23	22	21	22	22	24	24	23	22	26	27	21	25	18	20	15	18
Romania	31	31	28	28	28	28	24	25	25	23	21	21	26	24	23	31	31	26	26	21	26
Russian Federation	29	29	29	30	29	30	30	30	29	29	32	32	32	32	30	30	33	31	30	30	29
Serbia	27	27	32	33	33	34	35	35	34	32	31	30	35	33	33	36	35	36	35	32	33
Slovakia	18	18	20	19	19	15	17	16	8	15	18	20	19	20	17	23	20	23	21	25	28
Slovenia	30	30	25	27	24	24	26	21	24	25	25	18	21	27	26	24	22	24	23	26	23
Spain	14	14	24	24	25	25	27	26	27	27	26	17	23	13	21	20	14	22	14	24	16
Sweden	16	16	8	8	6	8	9	10	14	13	10	10	10	10	8	7	8	8	8	9	9
Switzerland	4	4	3	3	3	3	2	2	2	2	2	2	2	4	4	3	2	2	2	3	2
Ukraine	33	33	34	32	32	31	31	32	33	34	35	36	36	36	35	37	37	37	36	36	38
United Kingdom	10	10	15	12	14	14	13	15	17	18	16	16	13	16	12	14	19	17	17	13	15

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