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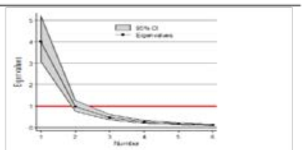
The use of the Global Food Security Index to inform the situation in food insecure countries

Thomas A.-C., D'Hombres B., Casubolo C., Kayitakire F., Saisana M.

2017

	Eigenvalue	Cumulative (variance)
Component1	4,00	0,67
Component2	0,98	0,83
Component3	0,47	0,91
Component4	0,26	0,95
Component5	0,17	0,98
Component6	0,11	1



	Correlation coefficients with the	
Indicators	Component 1	Component 2
Food consumption as a share of household expenditure	**0.44**	-0.00
Proportion of population under global poverty line	**0.44**	-0.07
Gross domestic product per capita (US$ PPP)	**0.42**	0.04
Agricultural import tariffs	0.10	**0.99**
Presence of food safety net programmes	**0.46**	-0.05
Access to financing for farmers	**0.47**	-0.13

Joint Research Centre

EUR 28885 EN

Contact information
Name: Anne-Claire THOMAS
Email: anneclaire.thomas@gmail.com

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Authors

THOMAS A-C, D'HOMBRES B., CASUBOLO C., SAISANA M, KAYITAKIRE F.

Abstract

This report is meant to document the use of the Global Food Security Index (GFSI) to inform the food security situation in countries of interest for DEVCO. Since the GFSI is a composite indicator, a clear understanding of its modelling choices is needed to insure a well-informed use of the indicator.

The reports is structures as follows. In the introduction of the report, we briefly remind the usual flow of composite indicators and derive the specific implications for measuring countries food security. The second section presents the conceptual framework behind the GFSI and the 2016 results. The assessment of the indicator follows. First, the conceptual framework is examined and the scope of the GFSI is defined. Second, the robustness of the GFSI country ranking is tested against the presence of outliers and missing values, and, against a change of the weighting scheme and aggregation method.

In its 2016 release, the GFSI score was computed for 113 countries. Among the 62 DEVCO priority countries, 37 countries received a GFSI score. The classification is globally consistent with other food security ranking. Yet, several country ranks are different from what is obtained with other food security indicators. The indicators included in the GFSI are indeed covering only a portion of the food security determinants. Moreover, the age of the data varies across countries and indicators. For example, countries hit by the 2015-2016 El Nino phenomenon rank better than expected because the impact of El Nino was not recorded in the indicator used for computing the score.

The review of conceptual framework indicates that the GFSI has to be interpreted as a food security environment rating. It focuses on the food security determinants rather than on the food security outcomes. It includes some of the usual food security determinants such as food supply, food share in total expenditure, poverty or nutritional policies and enlarges to less direct determinants like access to financial services, corruption, political stability and so on. It thus only partially overlap with existing food security indicators.

Indicators included in the GFSI are measured at the national level and not at the household level. Inequality indicators are not included. The GFSI is thus measuring the average situation in the countries rather than focusing on food insecure households.

The GFSI exhibits good statistical properties. The GFSI is statistically coherent and robust to changes in the weight and aggregation methods. The data coverage is good and the effect of outliers on the final score is not important. The indicators are on average

strongly correlated with their respective dimension and the principal component analysis suggests that the three dimensions composing the GFSI are indeed apprehending one single phenomenon. The uncertainty analysis also shows that although a few country ranks in the GFSI are sensitive to the methodological choices, the published GFSI ranking can be considered, for the vast majority of countries, robust to variations in the weighting scheme and the aggregation method.

Yet we note that the information contents of two indicators and two variables are lost at the dimension and overall index levels. In addition, the comparison of the weighting scheme with the statistical importance of each indicator suggests that there are differences between these two measures of importance. While this might have been done intentionally by the developers of the GFSI, this could be clarified.

It is thus recommended to use the GFSI in conjunction with other indicator of food insecurity namely those measuring the outcomes of food security in terms of food consumption and the nutritional status of the population.

1 Introduction

Tracking progress towards global food security is critical for designing and evaluating policies and programs. Nonetheless, finding appropriate indicators is challenging. It has been discussed widely that the concept of food security is multidimensional, dynamic and even context specific. The complexity of the concept, compounded by the challenge of collecting data led to a veritable proliferation of indicators in the last two decades (Hoddinott 1999; CFS 2011).

The Global Food Security Index (GFSI) is a **composite indicator** aiming at monitoring progress towards food security at country level. It was designed by the Economist Intelligence Unit and sponsored by DuPont. It is produced annually since 2012 and covers more than 100 countries. The conceptual framework of the GFSI is based on three dimensions of food security - namely affordability, availability and quality and safety. It uses a total of 28 indicators grouped in 3 domains: affordability (6 indicators), availability (11 indicators), and quality and safety (11 indicators). The index focuses on contributing factors to food security rather than on outcomes such as food consumption or the nutritional status of the population. Data sources include the Economist Intelligence Unit database as well as World Bank, FAO, WFP, and the World Trade Organization indicators. The individual indicators included in the GFSI and their weight in the final score have been decided by an expert panel coming from the academic, non-profit, and public sectors. In this report, we will examine the soundness of the framework chosen and the statistical validity of the weight and aggregation method used.

The choice of a composite indicator has the advantage to summarize a big amount of information in one unique score. It is a very appealing approach when monitoring countries food security progress because it simplifies dramatically trends analyses and comparisons between countries. However, if the composite is poorly constructed, interpreted or understood, it can lead to misleading conclusions and policy decisions. The pros and cons of composite indicators are well summarized in Table 1 copied from the OECD-JRC Handbook on Constructing Composite Indicators (OECD-JRC, 2008).

Table 1 Pros and Cons of Composite Indicators.

Pros and Cons of Composite indicators	
Pros	Cons
• Can summarize complex, multi-dimensional realities with a view to supporting decision makers • Are easier to interpret than a battery of many separate indicators • Can assess progress of countries over time • Reduce the visible size of a set of indicators without dropping the underlying information base • Make it possible to include more information within the existing size limit • Place issues of country performance and progress at the centre of the policy arena • Facilitate communication with general public (i.e citizens, media, etc) and promote accountability • Help to construct/underpin narratives for lay and literate audiences • Enable users to compare complex dimension	• May send misleading policy message if poorly constructed or misinterpreted • May invite simplistic policy conclusions • May be misused e.g. support a desired policy if the construction process is not transparent and/or lacks sound statistical or conceptual principles • The selection of indicators and weights could be subject of political dispute • May disguise serious failings in some dimensions and increase the difficulty of identifying proper remedial action if the construction process is not transparent • May lead to inappropriate policies if dimensions that are difficult to measure are ignored

Source: (OECD-JRC, 2008)

The “Pros” and “Cons” are both exacerbated in the field of food security because it is a very complex concept that is not well defined in terms of measurement. This renders the construction of a composite indicator of food security both appealing and very daring[1]. The final index is necessarily partial and subject to dispute. It is then crucial to understand how the individual indicators included in the model have been selected, how the weight have been chosen, and more generally how the design of the indicators affects the results obtained.

This report aims at enlightening what aspects of food security the GFSI is measuring. It tries to assess its fitness for purpose for measuring food insecurity in food insecurity prone countries. The goal is to understand the advantages and risks of using this index to inform decisions in selection and prioritization of countries (and at a less extent intervention areas) for fund allocation by the European Commission (DG DEVCO). To that

[1] For example, the FAO preferred monitoring a set of individual indicators rather than computing a composite indicator (http://www.fao.org/economic/ess/ess-fs/ess-fadata/en/#.WeCx4tOCxaQ)

end, the theoretical soundness of the framework used for the construction of the GFSI is reviewed. A statistical assessment is conducted. It first evaluate the impact of missing data and outliers. Second, it compares the actual statistical importance of each indicator to its assigned weight. Third, it assesses the robustness of the weights schemes and the aggregation method. Finally, the countries ranking obtained with the GFSI is compared with the one obtained with the IFPRI Global Hunger Index (GHI) and the FAO Prevalence of Undernourishment (PoU).

2 Conceptual Framework of the GFSI

2.1 Pillars, Aggregation and Weights

The Global Food Security Index (GFSI) is produced annually since 2012 by the Economist Intelligence Unit and covers more than 100 countries. The conceptual framework of the GFSI, based on three dimensions of food security, namely **affordability**, **availability** and **quality and safety.** It is is summarized in Table 2.

The three dimensions are populated by 19 indicators formed by **28 individual indicators**. The indicators were selected on the basis of EIU expert analysis and consultation with a panel of food-security specialists. As mentioned in Table 2, the GFSI includes

- ✓ **Quantitative** indicators from national and international statistical organizations. Where there were missing values in quantitative or survey data, the EIU has used estimates.
- ✓ **Qualitative** indicators either created by the EIU, based on information from development banks and government websites, or drawn from a range of surveys and data sources and adjusted by the EIU

Nine out of the 28 indicators are calculated by qualitative scoring by EIU analysts. Qualitative scoring requires the subjective judgement of the team of experts who designed. The qualitative scorings are summarized in Table 3.

The main data sources used in the GFSI are the EIU, the World Bank Group, the International Monetary Fund (IMF), the UN Food and Agriculture Organisation (FAO), the UN Development Programme (UNDP), the World Health Organisation (WHO), the World Trade Organisation (WTO), the World Food Programme (WFP), Agricultural Science and Technology Indicators (ASTI) and national statistical offices.

Indicator scores are normalized (min-max rescaling) and are scaled from 0 to 100, with 100 corresponding to the most favorable situation. The scores at the dimension level correspond to the weighted mean of underlying indicators. The overall GFSI score is a weighted average of the dimension scores. The default weights (see Table 2) are averages of the weightings suggested by the members of an expert panel. To assess how the weighting scheme is affecting the final ranking of countries, an uncertainty analysis is conducted in section 3.2.5.

Table 2 Conceptual framework of the GFSI – year 2016

Weight (%)	Dimension	Weight (%)	Indicators and sub-indicators*	Source
40	Affordability	22.22	**Food Consumption as a share of household expenditure**	National accounts
		20.20	**Proportion of population under global poverty line**	WB-WDI
		22.22	**GDP per capita at PPP**	EIU
		10.10	**Agricultural Import tariffs**	WTO
		14.14	**Presence of food safety-net programmes**	Qualitative scoring by EIU
		11.11	**Access to financing for farmers**	Qualitative scoring by EIU
44	Availability	*23.42*	**Sufficiency of supply**	EIU scoring
			Average food supply (73.33%)	FAO
			Dependence on chronic food aid (26.67%)	WFP
		8.11	**Public expenditure on agricultural research& development**	EIU estimates
		12.61	**Agriculture infrastructure**	EIU scoring
			Existence of adequate crop storage facilities (22.2%)	Qualitative scoring by EIU
			Road infrastructure (40.74%)	EIU Risk briefing
			Port infrastructure (37.04%)	EIU Risk briefing
		13.51	**Volatility of agricultural production**	FAO
		9.91	**Political stability risk**	EIU Risk briefing
		9.91	**Corruption**	EIU Risk briefing
		9.91	**Urban absorption capacity**	WB, WDI
		12.61	**Food loss**	FAO
16	Quality and Safety	20.34	**Diet diversification**	FAO
		13.56	**Nutritional standards**	EIU scoring
			National dietary guidelines (34.62%)	Qualitative scoring by EIU
			National nutrition plan or strategy (30.77%)	Qualitative scoring by EIU
			Nutrition monitoring and surveillance (34.62%)	Qualitative scoring by EIU
		25.42	**Micronutrient availability**	EIU scoring
			Dietary availability of vitamin A (33.33%)	FAO
			Dietary availability of animal iron (33.33%)	FAO
			Dietary availability of vegetal iron (33.33%)	FAO
		23.73	**Protein quality**	EIU
		16.95	**Food safety**	EIU scoring
			Agency to ensure the safety and health of food (32.14%)	Qualitative scoring by EIU
			Percentage of population with access to potable water (42.86%)	WB
			Presence of formal grocery sector (25%)	Qualitative scoring by EIU

**weights of sub- indicators are in parenthesis, Source: EIU Global Food Security Index – 2016*

Table 3 Indicators obtained from qualitative scoring by the EIU

Indicator	Scoring rule
Presence of food safety-net programmes	measured on a 0-4 scale based on the prevalence and depth of food safety-net programmes: 0 = No evidence of food safety-net programmes or very minimal presence of ineffective programmes run by NGOs or multilaterals only. 1 = Minimal presence of food safety-net programmes run by NGOs and multilaterals only or very rudimentary, ineffective government-run programmes. 2 = Moderate prevalence and depth of food safety-net programmes run by government, multilaterals or NGOs. 3 = National coverage, with very broad, but not deep, coverage of food safety-net programmes. 4 = National government-run provision of food safety-net programmes. Depth indicates the quantity of funds available to recipients; breadth indicates the range of services available.
Access to financing for farmers	Measured on a 0-4 scale based on the depth and range of financing for farmers: 0 = Virtually no access to government or multilateral financing programmes (typically, but not necessarily, a developing economy). 1 = Limited multilateral or government financing programmes (typically, but not necessarily, a developing economy). 2 = Some multilateral or government financing (typically, but not necessarily, an emerging-market economy). 3 = Broad, but not deep, financing (typically, but not necessarily, a developed economy) OR well-developed multilateral financing programmes (typically, but not necessarily, an emerging-market economy). 4 = Access to deep financing (typically, but not necessarily, an advanced economy). Depth indicates the quantity of funds available; range covers credit and insurance.
Dependence on chronic food aid	Measured on a 0-2 scale: 0 = Received chronic food aid on an increasing basis over the past five years. 1 = Received chronic food aid on a decreasing basis over the past five years. 2 = Receives little or no food aid or received food aid only on an emergency basis.
Public expenditure on agricultural research and development (R&D)	Measured as a percentage of agricultural GDP and is scored on a nine-point scale: 1 = 0-0.5% 2 = 0.51-1.0% 3 = 1.01-1.5% 4 = 1.51-2.0% 5 = 2.01-2.5% 6 = 2.51-3.0% 7 = 3.01-3.5% 8 = 3.51-4.0% 9 = 4.01-4.5%
National dietary guidelines	A binary indicator that measures whether the government has published guidelines for a balanced and nutritious diet: 0 = No 1 = Yes
National nutrition plan or strategy	A binary indicator that measures whether the government has a current, published national strategy to improve nutrition: 0 = No 1 = Yes *A country receives credit if the national strategy was current as of February 2016. For example, a national strategy covering 2010-20 would receive credit; a strategy covering 2010-15 would not receive credit. Credit may also be assigned if there is clear evidence that an expired strategy is currently being re-implemented or updated.
Nutrition monitoring and surveillance	A binary indicator that measures whether the government monitors the nutritional status of the general population. Examples of monitoring and surveillance include the collection of data on undernourishment, nutrition-related deficiencies, etc. 0 = No 1 = Yes
Agency to ensure the safety and health of food	Binary indicator that measures the existence of a regulatory or administrative agency to ensure the safety and health of food: 0 = No 1 = Yes
Presence of formal grocery sector	measured on a 0-2 scale: 0 = Minimal presence 1 = Moderate presence 2 = Widespread presence

2.2 Main results for the 2015 GFSI[2]

In the June 2016 release of the GFSI country ranking, the GFSI score was computed for 113 countries. Among the 62 DEVCO priority countries, 37 countries received a GFSI score, as listed in Table 4.

Table 4: List of DEVCO priority countries that received or did not received a GFSI score

Country that did not received a GFSI score in 2016: 25/62 -40%				
Afghanistan	Fiji	Namibia	CAR	Suriname
Bhutan	Gambia	North Korea	Sao Tomé	Swaziland
Cuba	Guinea Bissau	North Sudan*	Solomon Islands	Timor
Djibouti	Liberia	OPT	Somalia	Vanuatu
Eritrea	Mauritania	PNG	South Sudan*	Zimbabwe
Country that did received a GFSI score in 2016 : 37/62-60%				
Angola	Chad	Honduras	Nepal	Sri Lanka
Bangladesh	Colombia	Kenya	Nicaragua	Tanzania
Benin	Cote d'Ivoire	Laos	Niger	Uganda
Bolivia	Dem Rep Congo	Madagascar	Nigeria	Yemen
Burkina Faso	Ethiopia	Malawi	Pakistan	Zambia
Burundi	Ghana	Mali	Rwanda	
Cambodia	Guatemala	Mozambique	Senegal	
Cameroon	Haiti	Myanmar	Sierra Leone	

*: The GFSI gives a score for Sudan. It is not mentioned if Sudan means the former Sudan (North and South) or only North Sudan.

The country ranking and the GFSI scores are summarized in Table 5. The bottom 5 countries are Congo (Dem. Rep.), Haiti, Mozambique, Niger, Chad, Sierra Leone and Burundi. The country ranking obtained with the GFSI will be compared with the one obtained with the PoU and the GHI in section 4.

It may be worth noting that the GFSI is similar to a prevalence of food insecurity and not to the number of food insecure in absolute terms. For example, at the last place in the 2016 GFSI ranking (113/113), we find Burundi that has around 4 000 000 food insecure who represent 37% of the population in 2016, according to JRC, 2016, compared to a country like Ethiopia that rank much better (98/113) and that has a much larger number of food insecure, around 10 000 000 who represent 10 % of the population in 2016 according to JRC, 2016.

[2] These are the latest results at the time of the writing of the report. They were published in June 2016.

Table 5 2016 GFSI overall rankings table

Weighted total of all category scores (0-100 where 100=most favourable)

Rank	Country	GFSI score	Rank	Country	GFSI score	Rank	Country	GFSI score
1	United States	86.6	39	Mexico	68.1	77	Honduras	48.2
2	Ireland	84.3	40	Slovakia	67.7	78	Ghana	47.8
3	Singapore	83.9	41	Brazil	67.6	78	Pakistan	47.8
4	Australia	82.6	42	China	65.5	80	Myanmar	46.5
4	Netherlands	82.6	42	Romania	65.5	81	Uganda	44.2
6	France	82.5	44	Panama	64.4	82	Nepal	42.9
6	Germany	82.5	45	Turkey	63.6	83	Kenya	42.7
8	Canada	81.9	46	Belarus	63.1	84	Cote d'Ivoire	42.3
8	United Kingdom	81.9	47	South Africa	62.9	85	Cameroon	41.6
10	Sweden	81.3	48	Russia	62.3	86	Senegal	41.0
11	New Zealand	81.1	49	Colombia	61.0	87	Rwanda	40.7
12	Norway	81.0	50	Bulgaria	60.6	88	Benin	40.2
13	Switzerland	80.9	51	Thailand	59.5	89	Cambodia	39.8
14	Denmark	80.0	52	Serbia	59.4	90	Nigeria	39.4
14	Portugal	80.0	53	Tunisia	57.9	91	Mali	39.3
16	Austria	79.3	54	Botswana	57.8	92	Tajikistan	38.6
17	Finland	78.9	55	Peru	57.7	93	Togo	37.9
17	Israel	78.9	56	Ecuador	57.5	94	Tanzania	36.9
19	Spain	77.7	57	Azerbaijan	57.1	95	Bangladesh	36.8
20	Qatar	77.5	57	Egypt	57.1	96	Syria	36.3
21	Belgium	77.4	57	Vietnam	57.1	97	Guinea	35.0
22	Italy	75.9	60	Jordan	56.9	98	Ethiopia	34.7
22	Japan	75.9	60	Venezuela	56.9	98	Sudan	34.7
24	Chile	74.4	62	Morocco	55.5	100	Yemen	34.0
25	Czech Republic	73.9	63	Ukraine	55.2	101	Angola	33.7
26	Oman	73.6	64	Dominican Republic	55.1	102	Zambia	33.3
27	Kuwait	73.5	65	Sri Lanka	54.8	103	Laos	32.7
28	South Korea	73.3	66	Algeria	54.3	104	Madagascar	31.6
29	Poland	72.4	67	Paraguay	54.2	105	Malawi	31.4
30	United Arab Emirates	71.8	68	Kazakhstan	53.7	106	Burkina Faso	31.0
31	Greece	71.5	69	El Salvador	53.3	107	Congo (Dem. Rep.)	30.5
32	Saudi Arabia	71.1	70	Bolivia	51.6	108	Haiti	29.4
33	Bahrain	70.1	71	Indonesia	50.6	108	Mozambique	29.4
34	Hungary	69.3	72	Uzbekistan	49.8	110	Niger	29.0
35	Malaysia	69.0	73	Guatemala	49.6	111	Chad	28.6
36	Uruguay	68.4	74	Philippines	49.5	112	Sierra Leone	26.1
37	Argentina	68.3	75	India	49.4	113	Burundi	24.0
37	Costa Rica	68.3	75	Nicaragua	49.4			

The GFSI ranking does not capture the impact of El Nino on the food security. For example, in the 2016 GFSI ranking, South Africa, El Salvador and Guatemala ranks quite improved compared to the despite the important food security crisis linked to the consequences of El Nino. Similarly, Ethiopia improved its GFSI score in 2016 despite the large food crisis that hit the country following 2016 drought and floods. This supports what was already mentioned in section 2 that the GFSI does not capture the recent changes in the food security situation.

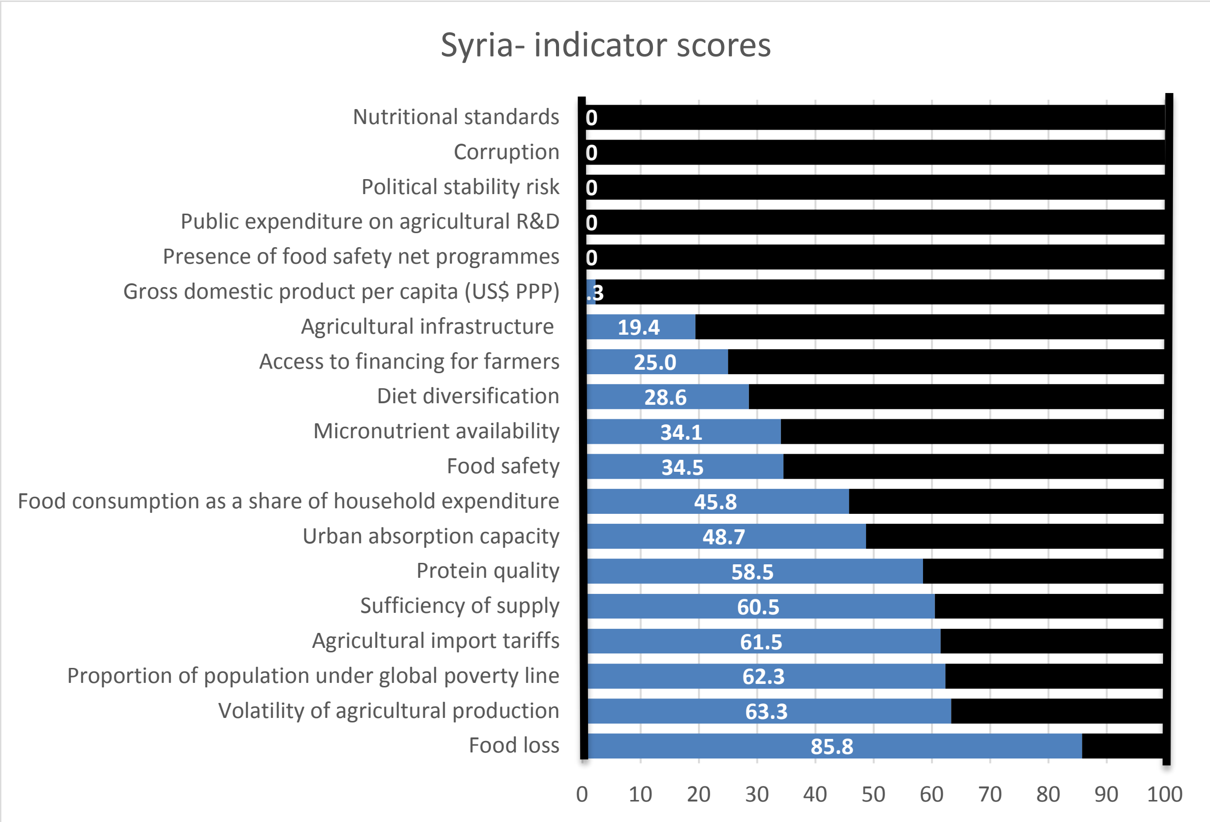
Below, several cases are examined more thoroughly to illustrate how the GFSI scores are obtained.

Syria ranks quite low (96/113) because of the consequence of the conflict. All indicators related to public policies 'Presence of food safety net programmes', 'Public expenditure on agricultural R&D', 'Political stability risk', 'Corruption' and 'Nutritional standards' are set to the worse score (zero on a 0 to 100 scale). This explains the ranking of Syria at the 96th rank over 113 even if sufficiency of supply, volatility of agricultural production , poverty rate and protein quality are quite good (see Figure 1).

Zambia ranks in the lower end of the ranking (102/113). This may be surprising since Zambia witnessed a rapid economic growth recently. In the GFSI, the low ranking comes from the country having a zero score for indicator of public expenditure (worse-off country) and a low score for GDP, protein and micronutrient availability, diet diversification and poverty rate. This is consistent with the results obtained from the IFPRI Global Hunger Index which indicate a very poor nutritional situation in Zambia. The FAO indicators 'Prevalence of undernourishment' and the 'Dietary supply adequacy' are also quite bad in 2015[3].

Chad has the third worse ranking. It is behind Niger. Chad scores zero (worse country) for corruption and political stability, nutritional standard, safety nets, public expenditures on agricultural R&D, and almost zero for the GDP. Niger has also a zero score for these indicators except for corruption where it reaches a 25% score. Niger has a much better sufficiency of supply than Chad, that explains (partly) why Niger scores better than Chad.

[3] The data quality for the computation of the PoU have been discussed. The nutrition figures on the opposite seems to be right and malnutrition seems highly prevalent in Zambia (see for example, http://www.renapri.org/wp-content/uploads/2017/01/IAPRI_TP5.pdf)



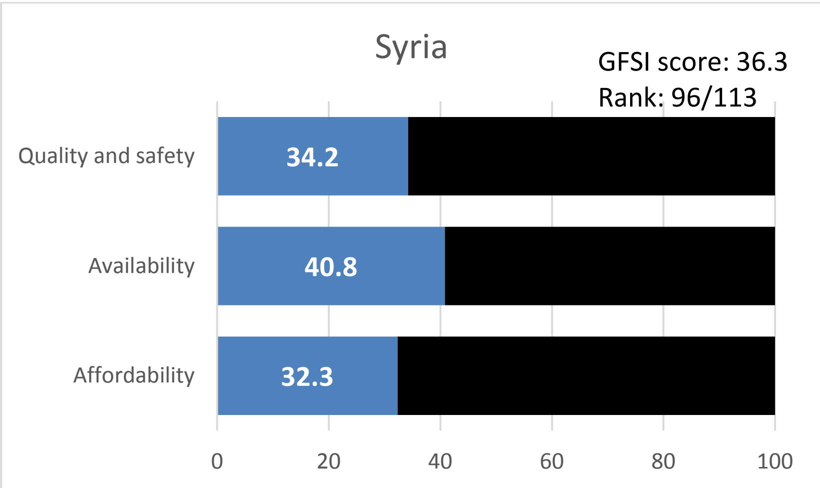
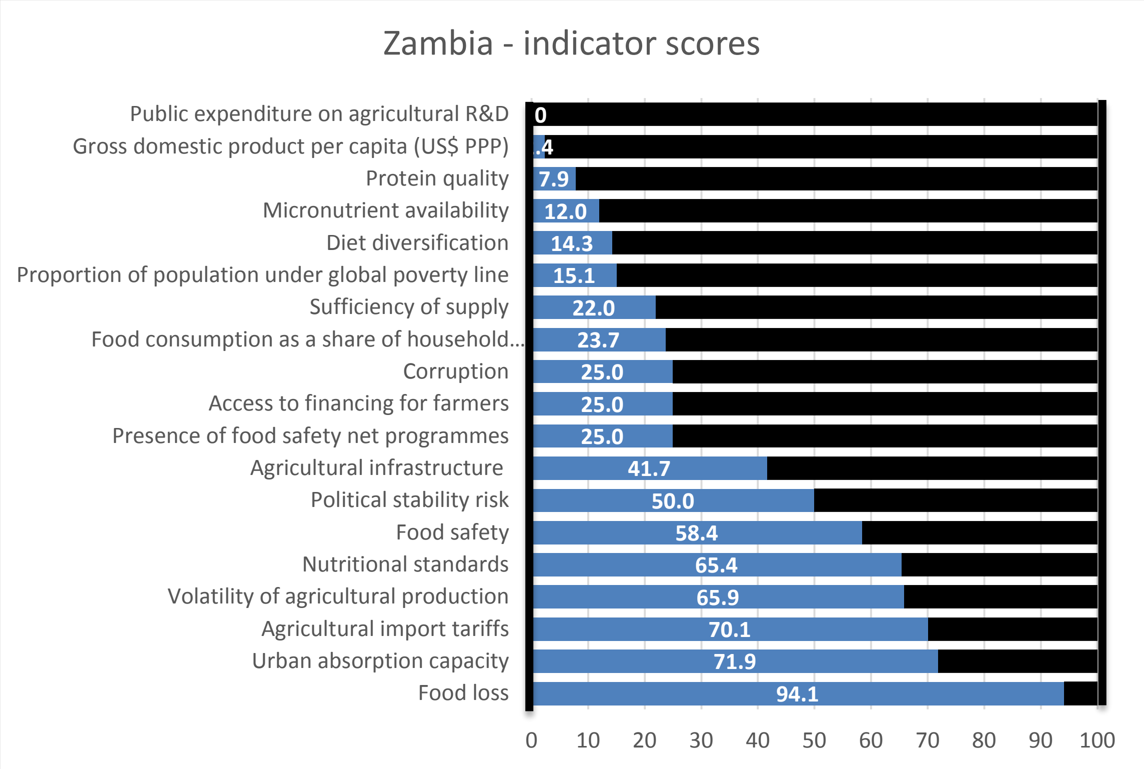


Figure 1 Syria indicator and dimension scores (0 to 100 scale)

0 means that the country is performing worse for the given indicator. 100 means that the country is performing best .These 0 to 100 score are the one used to compute the dimension score in association with the chosen weight, and the GFSI score.



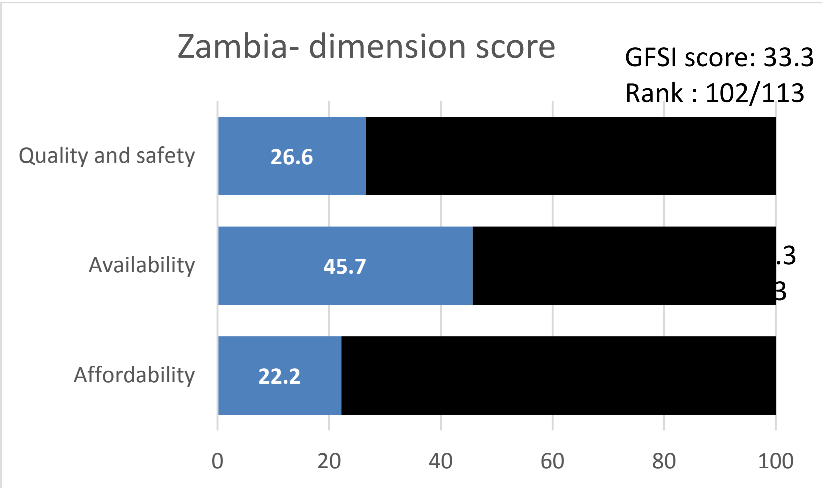
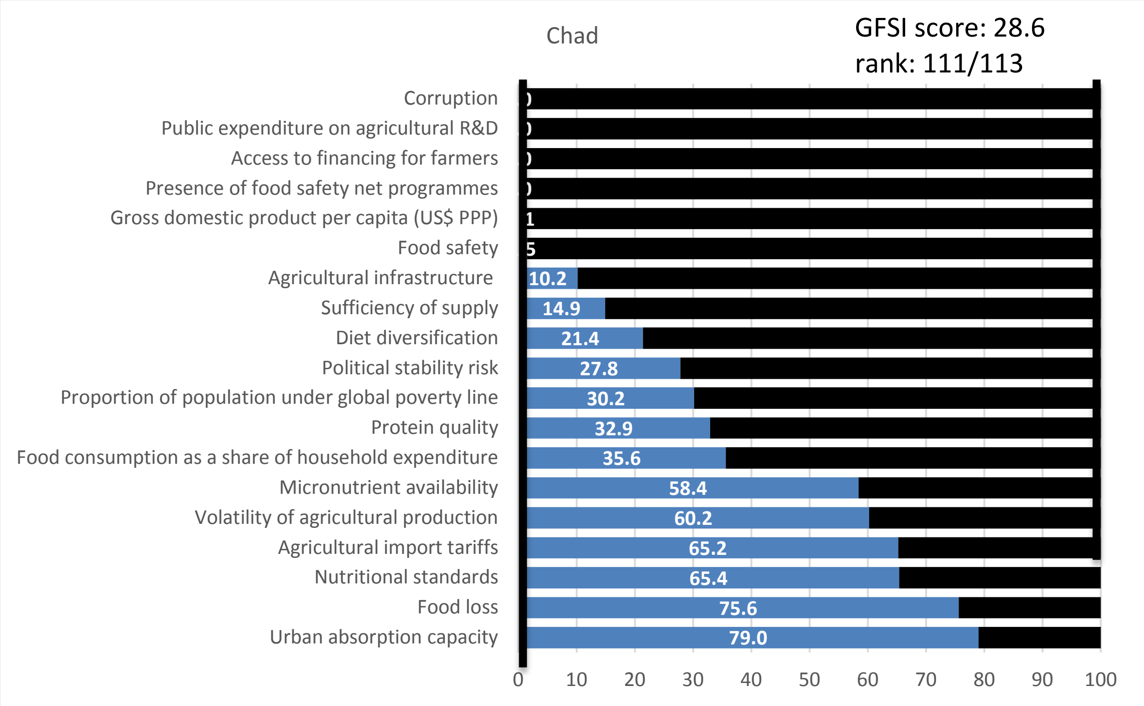
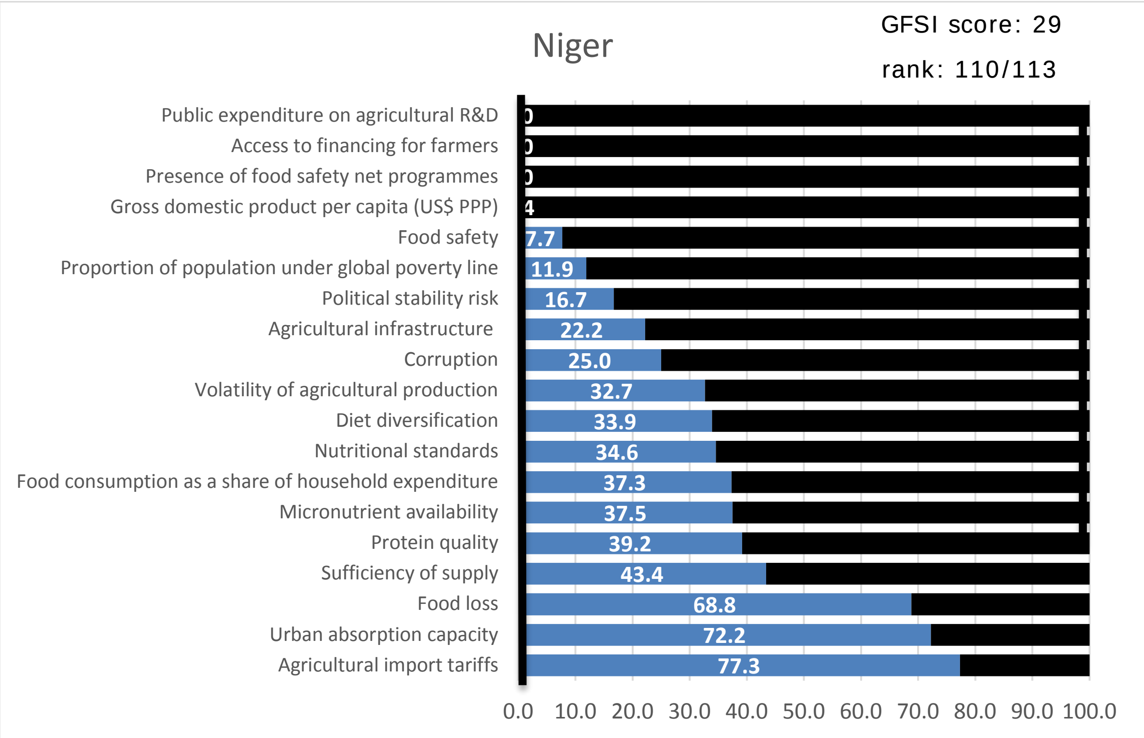


Figure 2 Zambia indicator and dimension scores (0 to 100 scale)

0 means that the country is performing worse for this,100 means that the country is performing best .These 0 to 100 score are the one used to compute the dimension final score in the GFSI calculation


Chad
GFSI score: 28.6
rank: 111/113
Corruption
Public expenditure on agricultural R&D
Access to financing for farmers
Presence of food safety net programmes
Gross domestic product per capita (US$ PPP)
Food safety
Agricultural infrastructure
Sufficiency of supply
Diet diversification
Political stability risk
Proportion of population under global poverty line
Protein quality
Food consumption as a share of household expenditure
Micronutrient availability
Volatility of agricultural production
Agricultural import tariffs
Nutritional standards
Food loss
Urban absorption capacity
10.2
14.9
21.4
27.8
30.2
32.9
35.6
58.4
60.2
65.2
65.4
75.6
79.0
0
10
20
30
40
50
60
70
80
90
100


Niger
GFSI score: 29
rank: 110/113
Public expenditure on agricultural R&D
Access to financing for farmers
Presence of food safety net programmes
Gross domestic product per capita (US$ PPP)
Food safety
Proportion of population under global poverty line
Political stability risk
Agricultural infrastructure
Corruption
Volatility of agricultural production
Diet diversification
Nutritional standards
Food consumption as a share of household expenditure
Micronutrient availability
Protein quality
Sufficiency of supply
Food loss
Urban absorption capacity
Agricultural import tariffs
7.7
11.9
16.7
22.2
25.0
32.7
33.9
34.6
37.3
37.5
39.2
43.4
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72.2
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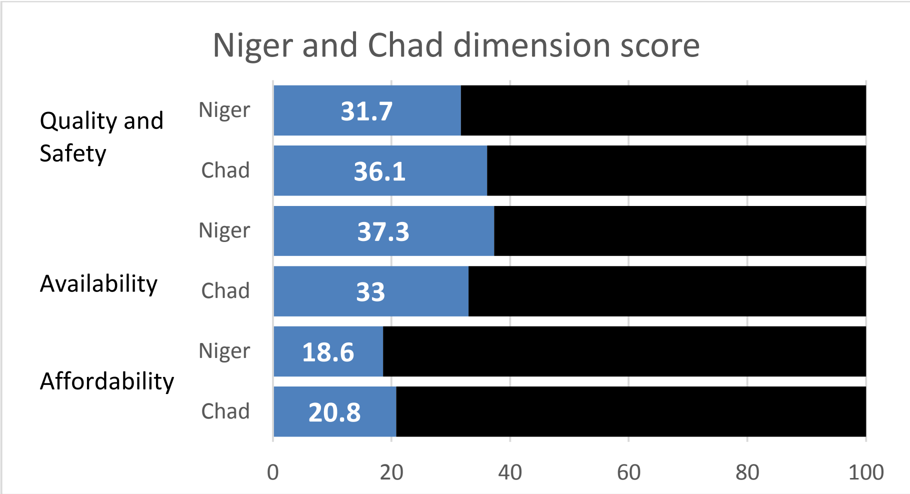


Figure 3 Chad indicator and dimension scores (0 to 100 scale)

0 means that the country is performing worse for this,100 means that the country is performing best .These 0 to 100 score are the one used to compute the dimension final score in the GFSI calculation

3 Assessment of the GFSI

3.1 Conceptual Framework

3.1.1 Conceptual choices and scope of the GFSI

Food security is defined as a situation where "all people, at all times, have physical and economic access to sufficient safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life." (1996 World Food Summit). This definition has been used to identity food security as a four-dimensional object (FAO, 2009). The four dimensions are: availability, access, utilization and stability. A hierarchy exists between the dimensions in terms of geographic scale and logic relationships. Availability is understood as the availability of food at the national or regional level. Access corresponds to the household level and is describing if the household have the physical and financial means to access food. Utilization corresponds to the individual level and to what extent an individual is making a good use of nutrients in the food consumed. It includes good care and feeding practices, food preparation, diversity of the diet, intra-household distribution of food, and biological utilization. In terms of logic relationships, availability is necessary but not sufficient for ensuring access, access is necessary but not sufficient to ensure utilization. Availability, access and utilization at all times are necessary to ensure stability and food security.

GFSI uses a different conceptualization. It understands food security as a tridimensional object. The three dimensions are **affordability, availability and quality and safety**. Affordability is described as "the capacity of country's people to pay for food, and the costs, that they may face both when the food supply is stable and at time of food related shocks". Availability is "the capacity of the country to produce and distribute food, including risks of food shortages". Quality and safety refers to "the nutritional quality of average diets and the food safety environment of each country".

Table 6 Standard and GFSI conceptualization of food insecurity

Standard Conceptualization of Food Security	GFSI Conceptualization of Food Security
Availability	Affordability and capacity to cope with shocks
Access	Availability and Risk of Food Shortages
Utilization	Quality and Food Safety
Stability	

From the conceptual point of view, having stability inside each dimension rather than separate seems reasonable. However, it is not straightforward to match the GFSI dimension to the 'usual' ones. Affordability contains part of the access dimension (the financial access) and part of the stability dimension, plus other information. Availability contains information on food supply and food aid that are also recorded in the 'FAO availability' concept, as well as, information usually recorded in the access dimension (such as infrastructure which describes the physical access) and in the stability dimension (such as volatility of agricultural production, political stability and food loss). It also embeds other information such as the research budget, the corruption level and the urban absorption capacity. Finally, the Quality and safety dimension includes a lot of information on nutrition policies that are not usually recorded in the utilization dimension, even if they are contributing factors. The theoretical model thus **only partially overlaps with the standard FAO conceptualization** of food security.

An important feature of the GFSI is that it focuses on the national level. The GFSI is **country-centered** whereas FAO conceptual framework is people-centered. The index is also not aimed at giving information about the food security status of vulnerable households neither on inequalities. Information on inequalities or specific groups of people such as the poor or the food insecure, for example, are not included in the index. All the indicators included are national averages. The GFSI is intended to measure food security worldwide. It is not focusing on food security prone countries. It tries to embed the food security issues of rich countries and middle-income countries. In that sense, it is different from the Global Hunger Index (GHI) or the results from the Integrated food security classification analysis (IPC) that focus on food security prone countries.

Moreover, it is focusing on the average (also called structural or chronic) level of food security over a certain period. It is generally not describing the acute situation, especially in case of recent food security changes. The main reason is that the data covers a time window of approximately ten years. This is usual and almost unavoidable when computing a composite index with global coverage. The index is thus representative of the situation of the country only to the extent that the data (still) depict the current situation. More specifically, if the situation is stable in a country (regarding the indicators measured), the score will well represent the current situation. In a country where the situation is changing quickly, the score will not represent the current situation. A direct implication of that is also that the index cannot be used to monitor the food security condition in real time. It is reacting with some delay. A fortiori, it means that it does not give information on the acute situation during a crisis for deciding on humanitarian aid allocation.

The GFSI is thus designed to monitor trends in food security in a country. Alternative indicators with similar purposes[4] include:

— the indicators chosen to monitor the goal 2.1 and 2.2 of the Sustainable Development Goals (SDG): The Prevalence of Undernourishment (PoU), the Food Insecurity Experience Scale (FIES) both calculated by the FAO, the prevalence of Stunting (low height-for-age) in children under 5 years of age, the prevalence of overweight children under 5 years of age.
— the FAO set of indicators food security that can be found at http://www.fao.org/economic/ess/ess-fs/ess-fadata/en/#.V_N-gZPhCfc
— the Global Hunger Index (GHI) by IFPRI
— the IPC Chronic product[5].

Last but not least, the GFSI contains only contributing factors to food insecurity. It does not contain outcomes such as food consumption or nutritional status of the population like the Global Hunger Index for example. This may be a valid choice. An index based on contributing factors is useful when informing how to improve the food security environment of a country. Looking at individual indicator or dimensions by “deconstructing” the final score helps to identify where the country is performing or is rather lagging behind. When interpreting the GFSI, it should be remembered that it is measuring the conditions able to lead to food security but not the results in terms of food consumption or nutritional status of the population. The final score tends to measure the **conditions for food security, or an enabling environment for food security instead of actual food security level**.

3.1.2 Selection of indicators

Regarding the selection of indicators (see Table 2), the choice has been driven by both data availability at global level and expert judgment about which indicators to be included. Subjective (but well informed) interpretation of data is common when evaluating food insecurity in food insecurity prone countries. This is linked to the

[4] Others indicators have the purpose to inform the severity of food insecurity and/or the number of food insecure in almost real time. This is for example the product of the IPC acute analysis or the WFP indicators such as the Food Consumption Score or the Coping Strategy Index.

[5] This product is more ambitious and wants to give population estimates in different severity of food insecurity. Moreover, it wants to work at the second order administrative level.

complexity of factors contributing to food security and the importance of context in interpreting these factors. It is thus important to apprehend correctly the scope of an indicator before using it.

The GFSI contains usual food security determinants such as supply, losses, poverty, share of food in expenditures but it also extends to governance and policy areas that have a less direct relationship to food security measures even if they are recognized as contributing factors. Because of that, both the relationship to the dimension and the placement in one dimension rather than another can be discussed. For example, the availability dimension contains political risk, corruption, urban absorption capacity and agricultural infrastructure. They could also be well related to affordability of food. Similarly agricultural import tariff and access to finance for farmers could also be conceptually linked with availability rather than with affordability. In fact, the statistical analysis confirms that the three dimensions (availability, affordability and quality) are strongly inter-related and not independent.

Regarding individual dimension, 'affordability' is defined as "the capacity of country's people to pay for food, and the costs, that they may face both when the food supply is stable and at time of food-related shocks". It includes six indicators (Table 2). Average income and poverty prevalence fully make sense in this dimension given the definition of the dimension. The agricultural import tariffs indicator may make sense for developed countries but it is more questionable in food insecure countries. It may bring information on food price levels, but only very partially, or on trade openness[6] depending on the context. Additionally, the population[7] average of 'Food Consumption as a share of household expenditure' and the ability of the population only very partially capture the ability of the food insecure to cope with shocks.

The availability dimension is built on 11 indicators (Table 2). Sufficiency of supply, trend of food aid over the past five years, and food losses do not call discussion for inclusion in that dimension. Including public expenditure on agricultural R&D may be questionable in food insecure countries. A limited budget can lead to divert expense from R&D to food security intervention. The volatility of agricultural production over the most recent 20 years period capture the risks of food shortages. Political instability and corruption surely play a role in determining food insecurity but are quite indirect determinants.

The Quality and safety dimension includes several indicators (protein quality, micronutrient availability, diet diversification) that are describing the production side

[6] The link between trade openness and food security is not straightforward. Both the existence of a link and the polarity of the link between tariffs may be questioned in food security prone countries.

[7] The average on the poorest quintiles of the population is generally preferred when assessing food insecurity. Here, the GFSI focuses on the average situation rather than the poorest quintile of poverty distribution.

rather than the actual consumption of individuals or households. Following the FAO conceptualization of food security, these indicators would rather be included in the availability dimension, unless we assume that food consumption reflects very well the domestic food production. This dimension also includes indicators that measure nutrition governance and the food safety environment. The Quality and Safety dimension is thus quite different from the utilization dimension in the standard FAO model of food insecurity. The latter focuses on nutritional outcomes at the individual level, whereas the former focuses on contributing factors to food safety and diet quality at the national level.

3.2 Statistical assessment

The statistical assessment of the GFSI presented below is based on the normalized scores of the 2016 GFSI version.[8]

3.2.1 Estimated data and outlier detection

In this section, we examine whether the indicators include missing values and/or contain extreme values.

Assessing the quality of the data, in particular the percentage of imputed data, is an important component of the statistical evaluation of any composite indicator. Missing data can indeed hinder the development of robust composite indicators (OECD/JRC Handbook on Constructing Composite Indicators, 2008).

The data coverage of the GFSI is very good with more than 60% of the indicators containing no estimated values at all for the year 2016. In addition, for 25% of the indicators, the percentage of imputed values is less than 5%. Similar findings are reported at the country level. For more than 46% of countries (52 out of 113 countries), the 28 indicators are fully covered. One or two have been imputed for more than 50% of countries.

Imputed values are mainly concentrated on two indicators, i.e. *Proportion of population under global poverty line* (dimension affordability) and *Public expenditure on agricultural R&D* (dimension availability). For both indicators, the share of estimated values amounts to around 30%. Two countries – *Bahrain* and *Qatar* stand a bit apart with the values of the indicators having been imputed in 28% and 25% of cases in the two respective countries.[9]

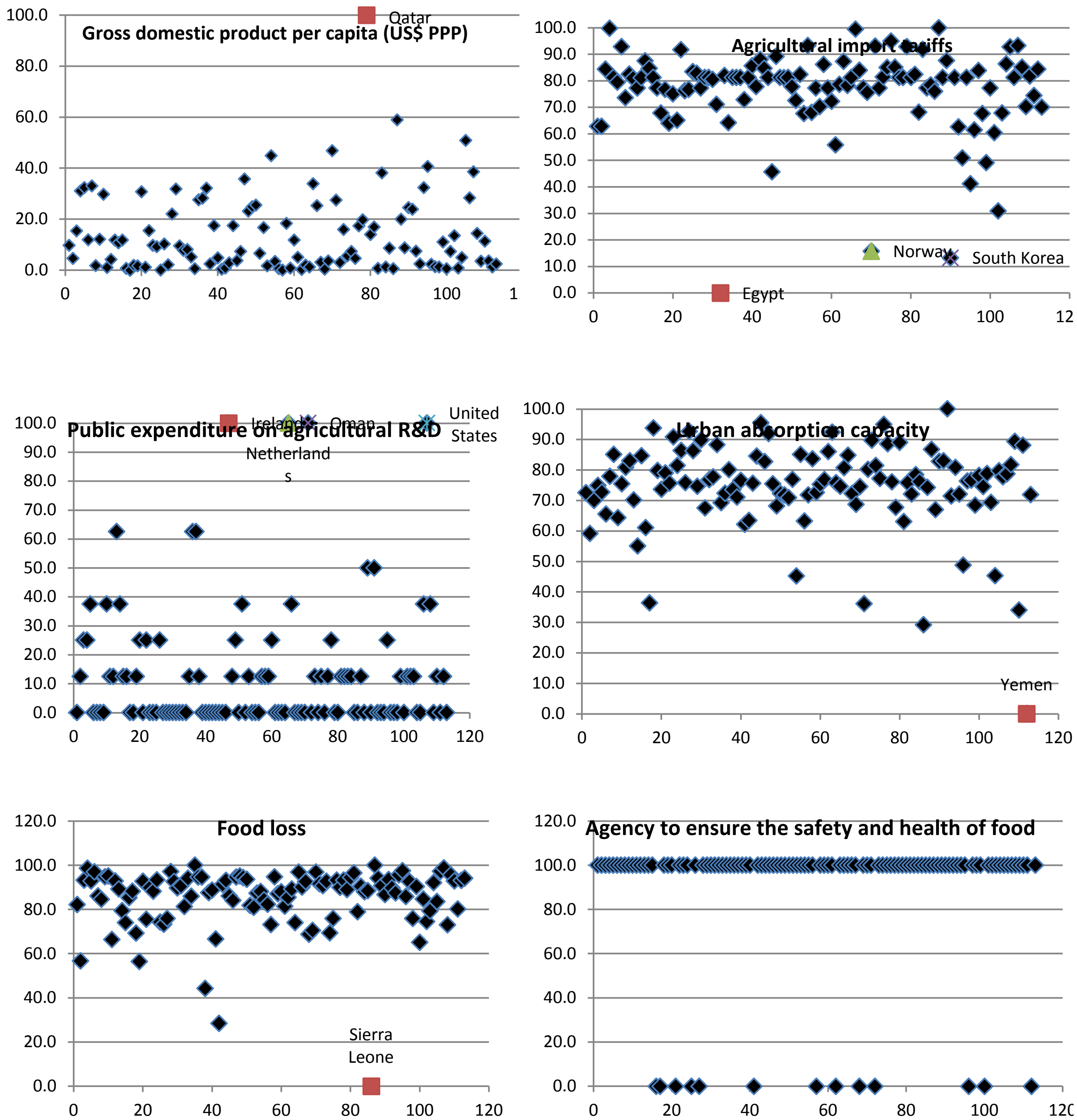
[8] However, we also checked if similar conclusions are reached while relying on data collected for the entire period available, i.e. 2012-2016. The results could be discussed for the complete audit of the GFSI.
[9] Estimated values for Oman and Singapore amounts to 14%.

We then examine if some indicators and variables contain observations with unusually large or small values, i.e. extreme values called outliers. These outliers might be the results of value incorrectly recorded or simply infrequent data values. Outliers are problematic in the context of composite indicators because they may become unintended benchmarks and bias the correlation structure. In order to identify potential outliers, we study the shape of the distribution of each of the indicators and compute the kurtosis and the skewness. Indicators with the absolute values of the skewness and kurtosis respectively greater than 2 and 3.5 are considered problematic and should be carefully examined. Table 7 shows that there are six such indicators. In Figure 4 we plot these indicators so as to identify countries for which extreme values are observed. In this case, outliers are infrequent values rather than wrong values.

Table 7 Outlier detection- Indicators with an absolute value of skewness greater than 2 and an absolute value of kurtosis greater than 3.5

Dimensions	Indicators/Variables	Absolute values of Skewness/Kurtosis
Affordability	Gross domestic product per capita (US$ PPP)	2.16/7.65
	Agricultural import tariffs	2.36/7.68
Availability	Public expenditure on agricultural R&D	2.44/6.30
	Urban absorption capacity	2.04/7.05
	Food loss	3.03/13.67
Quality and Safety	Agency to ensure the safety and health of food	2.44/4.05

Figure 4 Outliers detection – countries with extreme values



To correct for the possible effect of extreme values on the aggregated scores, we have winsorized the problematic indicators. This implies that the highest/smallest value of the indicator is replaced by its next highest/smallest value and the procedure is repeated until the skewness and kurtosis values are respectively above 2 and above 3.5. This classical method employed to correct for the effect of extreme values works well for continuous variables but not for discrete ones. Hence the winsorization has been done for all 6 indicators but the one measuring Agency to ensure the safety and health of food

(Quality and safety dimension). We then compared the ranking of the countries obtained with the GFSI and the winsorized version of the GFSI. As shown in Table 8 Difference of country ranking before and after the winsorization, most of the countries only shift by one or two positions. The countries for which we observe a shift by more than four positions the outliers identified in Figure 2.

Table 8 Difference of country ranking before and after the winsorization

Rank difference	Percentage	Countries
0	60.18%	
+/-1	30.09%	
+/-2	3.53%	
+/-3	2.65%	
Shift by more than 4 positions		Qatar (-6), Netherlands (-6), Egypt (+5)South Korea (+4)

The comparison of the rankings of countries without and with winsorization suggests that the effect of the outliers on the final score is not important.

3.2.2 Correlation analysis

We analyze below the correlation structure of the GFSI. Correlation analysis is an important component of any statistical assessment as it allows identifying if there are silent indicators, negative and significant correlations and up to which level the indicators/variables maintain their information content.

Table 9 Spearman' rank correlation coefficients between the indicators, the three dimensions and the overall GFSI. The Spearman's rank correlation has the advantage to be insensitive to outliers (contrary to the Pearson correlation coefficient). Most of the bivariate correlations between the indicators and their corresponding dimension range between 0.3 and 0.9. Yet, some indicators and sub-indicators exhibit low or very low correlations with the corresponding pillar and the overall GFSI score. This is the case of the following indicators *Volatility of agricultural production* and *Urban absorption capacity* (dimension Availability), and of two variables, namely *National nutrition pla*n or *strategy and Dietary availability of vegetal iron* belonging to the third dimension Quality and Safety. Note that while these two variables are relatively influential at the indicator level, their information content is lost at the dimension and overall GFSI index levels. Moreover, the correlation coefficients of these four indicators with all the others indicators included in the GFSI are very low and insignificantly different from zero. This might suggest that the inclusion of these indicators in the framework is cosmetic.

The bivariate correlations reported in Table 9 Spearman' rank correlation coefficients between the indicators, the three dimensions and the overall GFSI also show that most of the indicators are strongly correlated with the dimension to which the indicators belong to as well as with the two other dimensions. This suggests that most of the variables could be placed under the different pillars. We normally expect the indicators to be more strongly correlated with their corresponding dimension than with the other dimensions composing the overall index. This is indeed, on average, the case in the context of the GFSI.

Table 9 Spearman' rank correlation coefficients between the indicators, the three dimensions and the overall GFSI

	Indicators *and sub.indicators*	Dimension Affordablity	Dimension Availability	Dimension Quality and Safety	Overall GFSI
Affordability	**Food consumption as a share of household expenditure**	0.90	0.85	0.82	0.90
	Proportion of population under global poverty line	**0.95**	0.83	0.89	**0.92**
	Gross domestic product per capita (US$ PPP)	**0.96**	0.88	0.90	**0.95**
	Agricultural import tariffs	0.45	***0.29***	0.35	0.38
	Presence of food safety net programmes	**0.91**	0.86	0.86	**0.91**
	Access to financing for farmers	**0.92**	0.87	0.88	**0.92**
Availability	**Sufficiency of supply**	0.85	0.85	0.87	0.88
	Average food supply	0.80	0.81	0.84	0.83
	Dependency on chronic food aid	0.81	0.77	0.78	0.81
	Public expenditure on agricultural R&D	0.43	0.52	0.47	0.49
	Agricultural infrastructure	0.85	0.89	0.81	0.89
	Existence of adequate crop storage facilities	0.38	0.44	0.36	0.42
	Road infrastructure	0.82	0.84	0.79	0.85
	Port infrastructure	0.76	0.81	0.73	0.80
	Volatility of agricultural production	***-0.05***	***0.13***	***-0.01***	***0.03***
	Political stability risk	0.62	0.74	0.64	0.69
	Corruption	0.71	0.83	0.70	0.78
	Urban absorption capacity	***0.02***	***0.10***	***-0.01***	***0.05***
	Food loss	0.62	0.61	0.61	0.64
Quality and Safety	**Diet diversification**	0.83	0.75	0.87	0.83
	Nutritional standards	0.54	0.65	0.65	0.62
	National dietary guidelines	0.52	0.60	0.60	0.58
	National nutrition plan or strategy	***0.08***	***0.18***	***0.18***	***0.14***
	Nutrition monitoring and surveillance	***0.20***	***0.28***	***0.24***	***0.25***
	Micronutrient availability	0.74	0.71	0.84	0.77
	Dietary availability of vitamin A	0.72	0.64	0.77	0.72
	Dietary availability of animal iron	0.86	0.80	0.89	0.87
	Dietary availability of vegetal iron	***-0.18***	***-0.10***	***-0.06***	***-0.13***
	Protein quality	0.82	0.81	**0.91**	0.86
	Food safety	**0.90**	0.87	**0.92**	**0.92**
	Agency to ensure the safety and health of food	0.45	0.47	0.50	0.48
	Percentage of population with access to potable water	0.90	0.86	0.89	**0.91**
	Presence of formal grocery sector	0.80	0.75	0.81	0.81

3.2.3 Principal Component Analysis

Principal component analysis (PCA) is a method of extracting relevant information from a high data dimensional space. In the context of the assessment of the GFSI PCA is useful to identifying patterns of association across indicators. More specifically this will allow us to examine whether the indicators grouped under each of the three pillars are all positively associated with the given dimension and are well balanced. Intuitively, for each pillar, the first principal component corresponds to the weighted arithmetic average of the underlying indicators with the weight assigned to each indicator being set in a way to maximize the proportion of the variance explained by this first principal component. The second principal component accounts for the maximum of the remaining variance and so on. The last principal component contains all the remaining variance not accounted in the previous components.

The result of the principal component analysis at the level of the three dimensions is reported in the Table 10 below. The Kaiser's rule recommends retaining only components with eigenvalues greater than one. In our context, this implies that the **three dimensions are properly capturing one underlying phenomena**. The first component explains 86% of the total variance of the three dimensions and is equally correlated with each of them. The index seems to measure the conditions for food security. The statistical analysis confirms the conceptual analysis. The three dimensions in the GFSI framework, availability, affordability and quality and safety are strongly inter-related despite that the design gives the impression of independent dimensions.

	Eigenvalue	**Cumulative (variance)**
Component1	2,59	0,86
Component2	0,26	0,91
Component3	0,15	1

	Correlation coefficients with the Components 1
Affordability	**0.58**
Availability	**0.56**
Quality and Safety	**0.58**

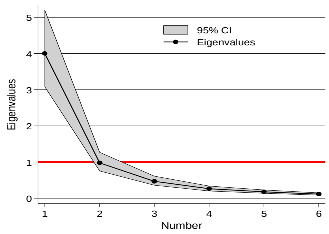
Table 10 Statistical coherence of the GFSI

3.2.3.1 Dimension Affordability

The results of the principal component analysis for the Affordability dimension are displayed in Table 11. The principal component analysis reveals that the dimension is composed of two statistical dimensions that capture together 83% of the variance. Table 11 shows that the first component is mainly described by five out of the six indicators equally. Only the indicator *Agricultural import tariffs* do not correlate much with the first component while the second component is entirely made of this stand-alone indicator *Agricultural import tariffs*. Should this indicator be excluded from this pillar, the Cronbach's alpha would increase from. 0.88 to 0.92. The cronbach's alpha is a measure of correlations for all pairs of indicators, which assesses the reliability of the indicators composing the dimension. When the cronbach's alpha is above 0.7, the indicators are considered to reliably measure the underlying dimension.

Table 11 Statistical coherence of the Affordability Dimension

	Eigenvalue	Cumulative (variance)
Component1	4,00	0,67
Component2	0,98	0,83
Component3	0,47	0,91
Component4	0,26	0,95
Component5	0,17	0,98
Component6	0,11	1



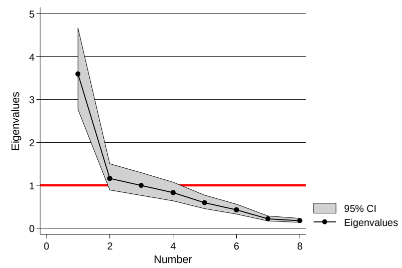
Indicators	Correlation coefficients with the Component 1	Component 2
Food consumption as a share of household expenditure	**0.44**	-0.00
Proportion of population under global poverty line	**0.44**	-0.07
Gross domestic product per capita (US$ PPP)	**0.42**	0.04
Agricultural import tariffs	0.10	**0.99**
Presence of food safety net programmes	**0.46**	-0.05
Access to financing for farmers	**0.47**	-0.13

3.2.3.2 Dimension Availability

The Availability dimension is composed of two dimensions, with the first one explaining 45% of the variance while the second one accounts for 15 % of the variance. The first component is described by six of the eight indicators, namely *Sufficiency of supply*, *Public expenditure on agricultural R&D*, *Agricultural Infrastructure*, *Political stability risk*, *Corruption* and *Food loss*. However, Food loss and Public expenditure on agricultural R&D are only moderately correlated with the component, with a correlation coefficient equal to approximatively 0.30 in both cases. The second dimension is largely based on the *Urban absorption capacity indicator* and *Volatility of agricultural production*. The Availability dimension has a cronbach's alpha equal to 0.78, which implies that the indicators belonging to this dimension are reliable to measure the underlying phenomena. Note that the value of the cronabach's alpha would rise to 0.86 if the two indicators less correlated with the first component were removed from the dimension.

Table 12 Statistical coherence of the Availability Dimension

	Eigenvalue	Cumulative (variance)
Component1	3,59	0,45
Component2	1,16	0,59
Component3	1,00	0,72
Component4	0,83	0,82
Component5	0,60	0,90
Component6	0,43	0,95
Component7	0,22	0,98
Component8	0,18	1,00



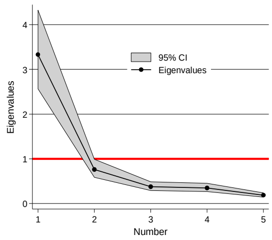
Indicators	Correlation coefficients with the Component 1	Component 2
Sufficiency of supply	**0,42**	-0,18
Public expenditure on agricultural R&D	**0,32**	-0,37
Agricultural Infrastructure	**0,47**	-0,03
Volatility of agricultural production	0,01	0,37
Political stability risk	**0,43**	0,18
Corruption	**0,47**	-0,03
Urban absorption capacity	0,11	**0,79**
Food loss	**0,29**	0,19

3.2.3.3 Quality and Safety Dimension

As shown in Table 13, the Quality & Safety dimension is composed of one dimension, which alone explains 66% of the variance. This component appears to be relatively well correlated with each of the five indicators and the value of the cronbach's alpha is well above the 0.7 threshold (0.86).

Table 13 Statistical coherence of the Availability Dimension.

	Eigenvalue	Cumulative (variance)
Component1	3,33	0,67
Component2	0,76	0,82
Component3	0,38	0,89
Component4	0,35	0,96
Component5	0,18	1,00



Indicators	Correlation coefficients with Component 1
Diet Diversification	**0,47**
Nutritional Standards	**0,33**
Micronutrient availability	**0,47**
Protein Quality	**0,49**
Food Safety	**0,46**

3.2.4 Weights versus importance of the indicators

We now compare the importance of the indicators with the weight assigned to them by the developers of the GFSI. The ratio of nominal weights inform on the relative importance of two indicators under scrutiny (Paruolo et al., 2013). This importance given to each indicator can then be compared with statistical measures of the importance of variables based on the squared of the Pearson's correlation coefficients. Comparisons of the nominal weights to the statistical importance of the dimensions are reported in Figure 5.

The bars represent the statistical importance of each dimension while the dots correspond to the weights assigned to each of the three dimensions. The associated figures are displayed in Table 14. Column 1 displays the weight while column 2 reports the squared person correlation (equivalent to the R-squared) associated with each dimension. The squared Pearson correlation coefficients measure the percentage of the variance of the overall GFSI score explained by each dimension.

While the designers of the GFSI have assigned more than twice the weight to each of the first two dimensions (Affordability and Availability) than to the third dimension, the statistical importance of the three dimensions is roughly the same.

Figure 5 Weight scheme versus Statistical Importance of each dimension

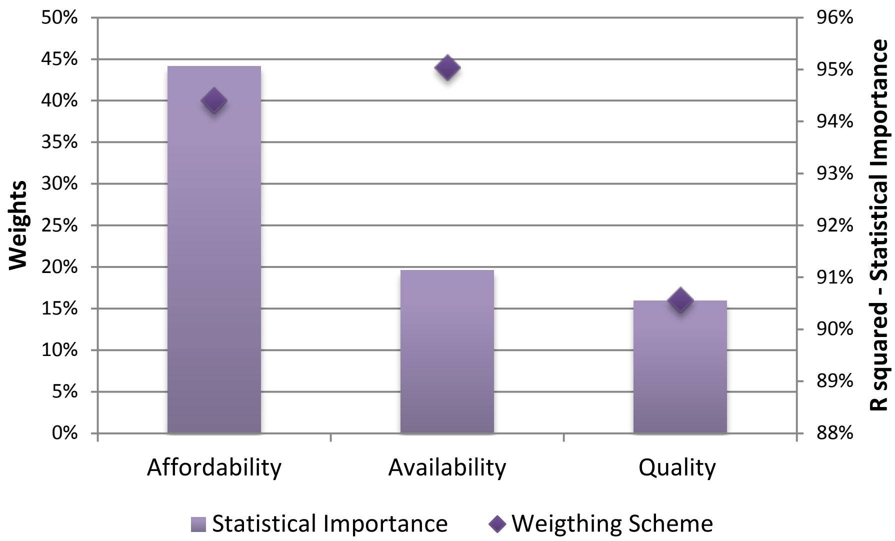


Table 14 Weight scheme versus Statistical Importance of each dimension

	Overall GFSI score	
	Weight	**Squared Pearson Corr**
Affordability	40%	95%
Availability	44%	91%
Quality	16%	91%

Tables 15-17 report the corresponding results at the dimension level. The corresponding figures are reported in Appendix.

At the affordability dimension level, we note that while the weights assigned to *Agricultural import tariffs* and *Access to financing farming* were roughly the same, statistically speaking the second indicator is far more important than the first one. Overall, the last two indicators reported in Table 15 count more than the first two indicators, contrary to what it was "assumed" looking just at the weighting scheme.

Table 15 Weight scheme versus Statistical Importance within the Affordability dimension

	Weight	Squared Pearson Corr
Food consumption as a share of household expenditure	22.22%	76%
Proportion of population under global poverty line	20.20%	82%
Gross domestic product per capita (US$ PPP)	22.22%	66%
Agricultural import tariffs	10.10%	5%
Presence of food safety net programmes	14.14%	84%
Access to financing for farmers	11.11%	86%

Table 15 underlines that, at the Availability dimension level, two indicators, namely Volatility of agricultural production and Urban Absorption capacity have almost no impact on the score attributed to this dimension. Additionally, the weight assigned to the last three indicators reported in Table 16 also stands in sharp contrast with the statistical importance of these indicators.

Table 16 Weight scheme versus Statistical Importance within the Availability dimension

	Weight	Squared Pearson Corr
Sufficiency of supply	23.42%	69%
Public expenditure on agricultural R&D	8.11%	31%
Agricultural Infrastructure	12.61%	78%
Volatility of agricultural production	13.51%	5%
Political stability risk	9.91%	57%
Corruption	9.91%	69%
Urban absorption capacity	9.91%	5%
Food loss	12.61%	29%

Finally, results displayed in Table 17 show that the weight assigned to each indicator within the Safety and Quality dimension are in line with the statistical importance of each indicator.

Table 17 Weight scheme versus Statistical Importance within the Safety and Quality dimension

	Weight	Squared

		Pearson Corr
Diet Diversification	20.34%	74%
Nutritional Standards	13.56%	35%
Micronutrient availability	25.42%	72%
Protein Quality	23.73%	82%
Food Safety	16.95%	70%

Overall, the results reported above suggest that the statistical importance of the indicators is not related to the weight assigned to them. While this might have been done intentionally by the developers of the GFSI, this should be certainly clarified.

3.2.5 Impact of Modelling Assumptions on the GFSI index results

Country ranks depend in large part on modelling choices, ranging from the selection of indicators and imputation of missing values, to the normalization, weight and aggregation methods employed to combine the indicators into a single index. The purpose of the uncertainty analysis below is to complement the country ranks with some confidence intervals and see if some countries positions are particularly sensitive to the modelling choices.

In what follows we examine the robustness of the GFSI to two modelling assumptions, namely, the choice of the **weighting scheme** and the **aggregation function** at the dimension level. Note that other uncertain parameters entering into the calculation of the GFSI could have been taken into account in particular the normalization scheme or the imputation method for the missing data. However, previous uncertainty analyses show that these two assumptions (aggregation method and weighing scheme) are those having the strongest impact on composite indicators-based rankings.

For the robustness assessment of the GFSI, we have carried out Monte Carlo simulations as follows. First 1,000 different weighting schemes were generated, each one corresponding to a different set of weights applied to the three dimensions of the GFSI, i.e., *Affordability*, *Availability* and *Quality and Safety*. The weights were randomly sampled from a uniform distribution centered at the weight value adopted for the GFSI (respectively 40%, 44% and 16% for the dimensions Affordability, *Availability* and *Quality and Safety).* A perturbation of the weights ± 25% around these reference values was adopted. For each simulation, weights are rescaled so that they always sum up to 1. Second, we have relaxed the assumption of perfect substitutability between the three dimensions induced by the use of a weighted arithmetic mean as aggregation method.

This aggregation method has been challenged in the literature because of its fully compensatory nature, i.e. a comparative high advantage in one dimension can be compensated by comparative disadvantage in another dimension (Munda, 2008). For the robustness assessment, we thus considered an alternative aggregation method - the geometric average - which is only partially compensatory.[10]

Two models were then tested based on the combination of the aggregation method (arithmetic *versus* geometric average) and the 1000 simulated weighing schemes. The GFSI score was thus simulated 2,000 times. Table 18 summarizes the uncertainties considered for the robustness assessment of the GFSI.

Table 18 Uncertainty analysis: weighing and aggregation methods

Uncertainty in aggregation method at the dimension level		
Reference: weighted arithmetic mean	Alternative: Weighted geometric mean	
Uncertainty in the weights at the dimension level		
Dimension/Sub-index	*Reference value for the weight*	*Distribution assigned for robustness analysis*
Affordability	*0.40*	*U[0.30, 0.50]*
Availability	*0.44*	*U[0.33, 0.55]*
Quality & Safety	*0.16*	*U[0.12, 0.20]*

The main results of the robustness analysis are shown in Figure 6. Countries are ordered from best to worst according to their reference rank (black line), the dot being the median rank. Error bars represent, for each country, the 90% interval across all simulations. The same information, reported in Table 19, allows to more closely examine the impact of the two modelling choices – aggregations method and weighing scheme - on each country rank.

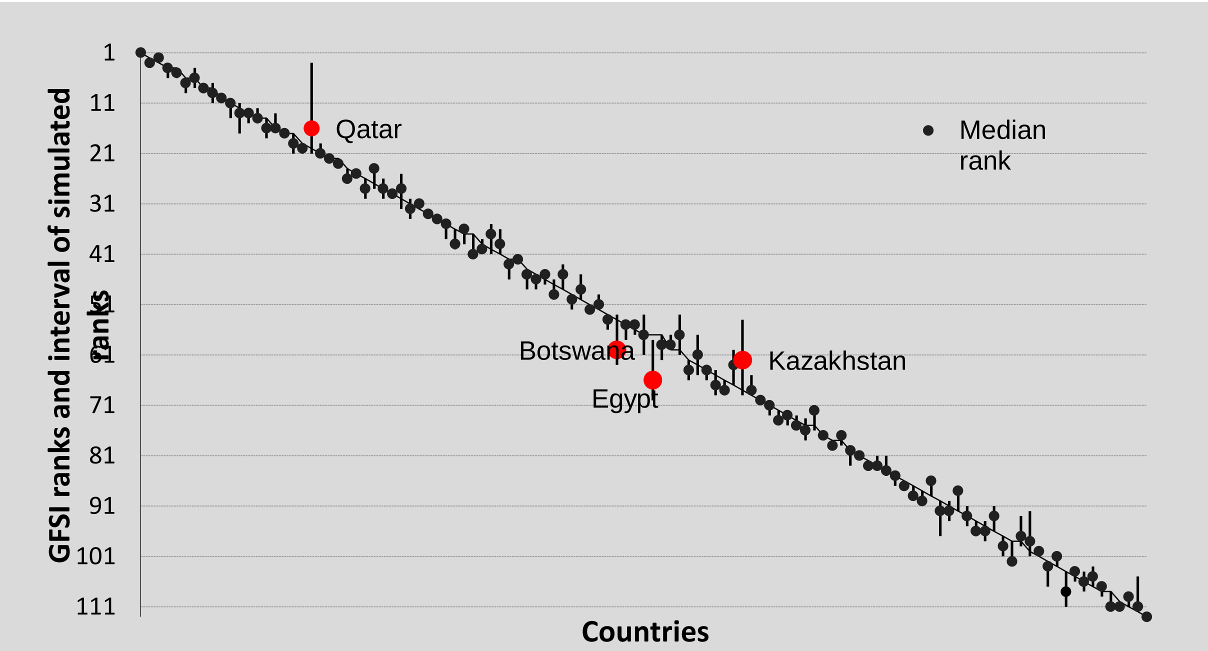
The uncertainty analysis suggests that the country ranks are robust to changes in the methodological choices with the median rank being very closed (less than ± 4 positions differences) to the GFSI reference rank for 92% of countries. Similarly, the

[10] Note that we have not changed the aggregation method and the weighing scheme *within* each dimension.

simulated confidence intervals are narrow for most of the countries (less than ±5 positions for more than 75% of the countries) and all GFSI ranks lay within the simulated 95% confidence intervals.

However, we note that for a small number of countries, the ranks are sensitive with variations in the weighting scheme and aggregation function. This is particularly the case for *Qatar*, *Botswana*, *Egypt* and *Kazakhstan*. For these four countries, the difference between the median rank and the GFSI reference rank amounts to 10 or more positions. Those large swings are due to performance variations across the three dimensions. *Quatar* ranks first in Affordability dimension and 43th in Quality and Safety dimension. Similarly, Kazakhstan ranks 45th in the Affordability dimension and 97th in the Quality and Safety one. More generally, if we compute the coefficient of variation across the three dimensions for each country, it is apparent that the top performer countries tend to perform well across the three dimensions (low coefficient of variation) while the low performer countries, on contrary, show uneven performance across the dimensions.

Figure 6 Robustness analysis GFSI rank vs. median rank, 90% confidence intervals)



Overall, although a few country ranks in the GFSI are sensitive to the methodological choices, the published GFSI ranking can be considered, for the vast majority of countries, robust to variations in the weighting scheme and the aggregation method.

Table 19 Country ranks and 90 % intervals for the GFSI

Countries	GFSI rank	Median rank	95%CI	Countries	GFSI rank	Median rank	95%CI
United States	1	1	[1, 1]	Egypt	57	66	[58, 70]
Ireland	2	3	[2, 4]	Vietnam	57	59	[57, 62]
Singapore	3	2	[2, 3]	Jordan	60	59	[57, 60]
Australia	4	4	[4, 6]	Venezuela	60	57	[53, 61]
Netherlands	4	5	[5, 6]	Morocco	62	64	[62, 66]
France	6	7	[6, 9]	Ukraine	63	61	[57, 65]
Germany	6	6	[4, 8]	Dominican Republic	64	64	[63, 66]
Canada	8	8	[8, 9]	Sri Lanka	65	67	[64, 69]
United Kingdom	8	9	[7, 11]	Algeria	66	68	[66, 69]
Sweden	10	10	[9, 11]	Paraguay	67	63	[60, 67]
New Zealand	11	11	[11, 14]	Kazakhstan	68	62	[54, 69]
Norway	12	13	[11, 17]	El Salvador	69	68	[65, 69]
Switzerland	13	13	[12, 15]	Bolivia	70	70	[69, 70]
Denmark	14	14	[12, 15]	Indonesia	71	71	[71, 73]
Portugal	14	16	[14, 18]	Uzbekistan	72	74	[72, 75]
Austria	16	16	[13, 16]	Guatemala	73	73	[72, 75]
Finland	17	17	[16, 18]	Philippines	74	75	[73, 75]
Israel	17	19	[17, 21]	India	75	76	[74, 78]
Spain	19	20	[19, 21]	Nicaragua	75	72	[71, 76]
Qatar	20	16	[3, 21]	Honduras	77	77	[76, 78]
Belgium	21	21	[19, 21]	Ghana	78	79	[78, 79]
Italy	22	22	[22, 23]	Pakistan	78	77	[76, 79]
Japan	22	23	[22, 23]	Myanmar	80	80	[80, 83]
Chile	24	26	[24, 27]	Uganda	81	81	[80, 81]
Czech Republic	25	25	[25, 26]	Nepal	82	83	[82, 84]
Oman	26	28	[26, 30]	Kenya	83	83	[81, 83]
Kuwait	27	24	[24, 28]	Cote d'Ivoire	84	84	[81, 85]
South Korea	28	28	[26, 30]	Cameroon	85	85	[84, 87]
Poland	29	29	[28, 30]	Senegal	86	87	[86, 88]
United Arab Emirates	30	28	[25, 32]	Rwanda	87	89	[87, 89]
Greece	31	32	[30, 34]	Benin	88	90	[88, 90]
Saudi Arabia	32	31	[31, 32]	Cambodia	89	86	[85, 89]
Bahrain	33	33	[32, 34]	Nigeria	90	92	[90, 97]
Hungary	34	34	[33, 35]	Mali	91	92	[90, 94]
Malaysia	35	35	[34, 38]	Tajikistan	92	88	[87, 92]
Uruguay	36	39	[36, 40]	Togo	93	93	[91, 95]
Argentina	37	36	[35, 39]	Tanzania	94	96	[94, 97]
Costa Rica	37	41	[37, 41]	Bangladesh	95	96	[94, 98]
Mexico	39	40	[38, 40]	Syria	96	93	[91, 96]
Slovakia	40	37	[35, 41]	Guinea	97	99	[97, 101]
Brazil	41	39	[36, 41]	Ethiopia	98	102	[98, 102]
China	42	43	[42, 46]	Sudan	98	97	[93, 99]
Romania	42	42	[42, 43]	Yemen	100	98	[92, 101]

Panama	44	45	[44, 48]	Angola	101	100	[99, 101]
Turkey	45	46	[45, 48]	Zambia	102	103	[102, 107]
Belarus	46	45	[44, 47]	Laos	103	101	[100, 103]
South Africa	47	49	[46, 50]	Madagascar	104	108	[104, 111]
Russia	48	45	[43, 48]	Malawi	105	104	[104, 106]
Colombia	49	50	[49, 52]	Burkina Faso	106	106	[104, 108]
Bulgaria	50	48	[45, 50]	Congo (Dem. Rep.)	107	105	[103, 107]
Thailand	51	52	[51, 52]	Haiti	108	107	[106, 109]
Serbia	52	51	[49, 52]	Mozambique	108	111	[108, 112]
Tunisia	53	54	[53, 56]	Niger	110	111	[110, 112]
Botswana	54	60	[53, 63]	Chad	111	109	[108, 111]
Peru	55	55	[54, 58]	Sierra Leone	112	111	[105, 112]
Ecuador	56	55	[54, 57]	Burundi	113	113	[113, 113]
Azerbaijan	57	57	[53, 61]				

4 Comparison of the GFSI with other indicators

4.1 Comparison with the IFPRI Global Hunger Index

In this section, we compare the ranking of countries obtained with the GFSI with the one derived from the Global Hunger Index (GHI). The GHI is designed to measure and monitor hunger globally and by country and region. This index, produced annually by the International Food Policy Research Institute (IFPRI), is based on four indicators, (i) the percentage of the population that is undernourished, (ii) the percentage of children under five years old who suffer from wasting (low weight for height), (iii) the percentage of children under five years old who suffer from stunting (low height for age), and (iv) the percentage of children who die before the age of five (child mortality).

The indicators on undernourishment and mortality are assigned a weight of one-third while the other two indicators on malnutrition weight one-sixth each. Additional information on the GHI can be found at http://ghi.ifpri.org/results/.

We rely on the 2015 GHI version and limit the analysis to the set of countries for which an overall score has been computed for both indices. The sample is composed of 78 countries.

Table 20 Countries common to the GFSI and GHI rankings

Algeria	Angola	Argentina	Azerbaijan	Bangladesh	Belarus	Benin	Bolivia	Botswana
Brazil	Bulgaria	Burkina Faso	Cambodia	Cameroon	Chad	Chile	China	Colombia
Costa Rica	Cote d'Ivoire	Dominican Republic	Ecuador	Egypt	El Salvador	Ethiopia	Ghana	Guatemala
Guinea	Haiti	Honduras	India	Indonesia	Jordan	Kazakhstan	Kenya	Kuwait
Laos	Madagascar	Malawi	Malaysia	Mali	Mexico	Morocco	Mozambique	Myanmar
Nepal	Nicaragua	Niger	Nigeria	Pakistan	Panama	Paraguay	Peru	Philippines
Romania	Russia	Rwanda	Saudi Arabia	Senegal	Serbia	Sierra Leone	Slovakia	South Africa
Sri Lanka	Tajikistan	Tanzania	Thailand	Togo	Tunisia	Turkey	Uganda	Ukraine
Uruguay	Uzbekistan	Venezuela	Vietnam	Yemen	Zambia			

The rank correlation between the two indices is very high with the spearman rank correlation coefficient being equal to 0.90. Figure 7 clearly shows that the two rankings are highly correlated to each other.

We then examine how the two rankings differ for each country. Results reported in Table 21 show the following:

- The rankings based on the two indices differ by 2 positions or less for 19 countries (i.e. 24.3% of countries),
- There are substantial differences in the rankings for 50% of the countries. In particular, for 35% of countries, the rank difference with the two indices is equal to 10 or more,
- The median rank difference amounts to 7,
- 17 countries ranking in the bottom 25% “less food secured” are common to both rankings while five countries are ranked in the bottom 25% in one ranking only.

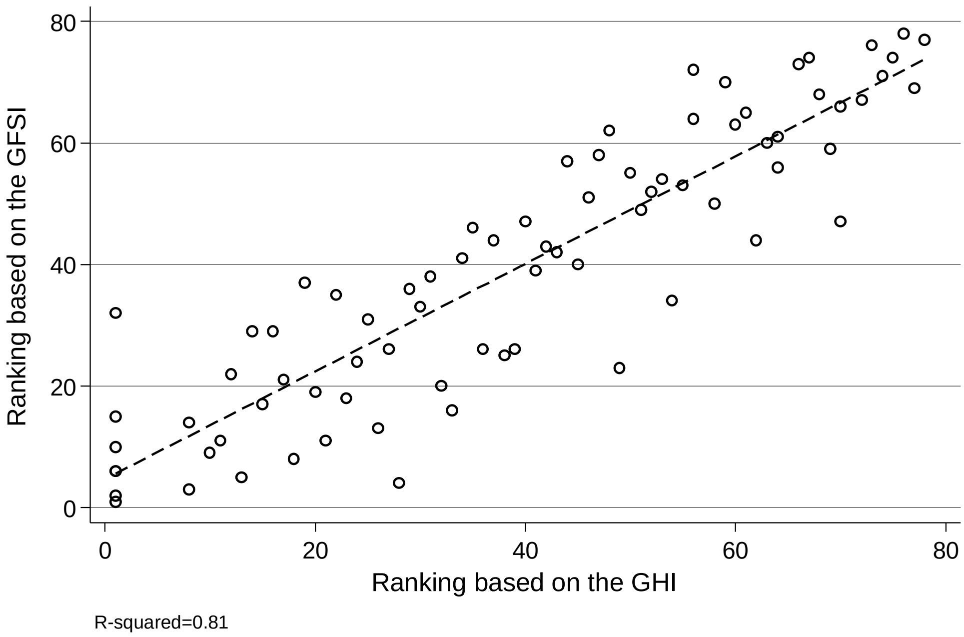


Figure 7 GFSI ranking against GHI ranking

Table 21 Country Ranking – GFSI ranking versus GHI ranking

Rank difference	Number of Countries (%)	Rank difference	
Between 0 and 2 positions	19 (24.3%)	0	Angola, Chile, Kenya, Peru, Romania
		-1/+1	Azerbaijan Bulgaria Cameroon Chad Guatemala Haiti Kuwait Philippines Slovakia
		-2/+2	Bolivia Ivory Coast Myanmar Russia Sierra Leone
Between 3 and 6 positions	19 (24,3%)	-3/+3	Dominican Republic Madagascar Mali Niger Tajikistan Tanzania
		-4/+4	Ethiopia Guinea Serbia
		-5/+5	Argentina Colombia Costa Rica Indonesia Nepal Saudi Arabia Senegal Yemen
		-6/+6	Morocco Turkey
Between 7 and 9 positions	13 (16.6%)	-7/+7	Burkina Faso El Salvador Ghana Mozambique Nicaragua Paraguay Uzbekistan
		-8/+8	Bangladesh Rwanda Uganda Uruguay Zambia
		-9/+9	Brazil
10 positions or more	27 (34.6%)	-10/+10 positions or more	Algeria Belarus Benin Botswana Cambodia China Ecuador Egypt Honduras India Jordan Kazakhstan Laos Malawi Malaysia Mexico Nigeria Pakistan Panama South Africa Sri Lanka Thailand Togo Tunisia Ukraine Venezuela Vietnam

Countries ranked in the 25% less "food/hunger secured" with the GHI and the GFSI
Common countries
Angola Burkina Faso Chad Ethiopia Guinea Haiti Laos Madagascar Mali Mozambique Niger Nigeria Sierra Leone Tajikistan Tanzania Yemen Zambia
Countries in one of the two rankings
India Bangladesh Malawi Pakistan Rwanda Togo

In order to understand better the differences between these two rankings we also look at the correlation rank between the GFSI indicators and the GHI. Results reported in appendix in Tables 24-26 are twofold. First, the indicators composing the GFSI are on average strongly correlated with the GHI. Second, the indicators that were very weakly associated with the overall GFSI index are also unrelated to the GHI. This is the case of two indicators belonging to the Availability dimension, i.e, *volatility of agricultural production* and *urban absorption capacity*.

4.2 Comparison with the Prevalence of Undernourishment (PoU)

In this section, we compare the ranking of countries obtained with the GFSI with the one derived from the Prevalence of Undernourishment (PoU). The prevalence of undernourishment, or proportion of population below the minimum level of dietary energy consumption, was a Millennium Development Goal indicator (MDG 1.9) and is a Sustainable Development Goal Indicator. It is published annually by the FAO in the State of Food Insecurity (SOFI) report. The PoU is estimated, by computing the *value of the cumulative distribution of the food consumption evaluated at the minimum dietary energy requirement*.

For the comparison, we rely on the 2015 PoU and limit the analysis to the set of countries for which an overall score has been computed for both the GFSI and the PoU. The sample composed of 73 countries is reported in Table 22.

Table 22 Countries common to the GFSI and PoU rankings

Algeria	Angola	Argentina	Azerbaijan	Bangladesh	Benin	Bolivia	Botswana	Brazil
Burkina Faso	Cambodia	Cameroon	Chad	Chile	China	Colombia	Costa Rica	Cote d'Ivoire
Dominican Republic	Ecuador	Egypt	El Salvador	Ethiopia	Ghana	Guatemala	Guinea	Haiti
Honduras	India	Indonesia	Jordan	Kazakhstan	Kenya	Kuwait	Laos	Madagascar
Malawi	Malaysia	Mali	Mexico	Morocco	Mozambique	Myanmar	Nepal	Nicaragua
Niger	Nigeria	Oman	Pakistan	Panama	Paraguay	Peru	Philippines	Rwanda
Saudi Arabia	Senegal	Sierra Leone	South Africa	Sri Lanka	Tajikistan	Tanzania	Thailand	Togo
Tunisia	Turkey	Uganda	United Arab Emirates	Uruguay	Uzbekistan	Venezuela	Vietnam	Yemen
Zambia								

The spearman rank correlation is equal to 0.73. Figure 8 shows that the GFSI ranking is less correlated with the PoU ranking than with the GHI one. Thirteen countries placed in the bottom 25% of the GFSI and PoU rankings are common while almost the same number of countries (12) ranks in the bottom 25% in only one of the two rankings (see Table 23). The correlation rank between the GFSI indicators and the PoU is reported in Tables 27-29. As for the GHI, we find that two indicators belonging to the Availability dimension, i.e., *volatility of agricultural production* and *urban absorption capacity* are not correlated with the PoU index. Furthermore, two additional indicators, i.e. *Political stability risk* and *Agricultural Import tariffs* (belonging respectively to the GFSI availability and affordability dimensions) appear to be not related to the PoU index.

The comparison of the country ranks obtained with the two rankings cannot be replicated for the PoU because of ties related issues, the PoU having for instance 24 countries with the index value equal to 5.

The comparisons of the GFSI with other indicators show that the GFSI is relatively strongly correlated with the GHI. In comparison, the PoU and the GFSI differ much more substantially. Two indicators belonging to the GFSI i.e, *volatility of agricultural production and urban absorption capacity,* appear to be uncorrelated with GFSI index himself but also with the GHI and PoU indices.[11]

[11] While not reported in the document, note that the rank correlation between the PoU and the GHI is higher than the rank correlation between the PoU and the GFSI. Around 17 out of the 25 countries ranking in the bottom 25% are common to both rankings. 99 countries are common to both rankings.

Figure 8 GFSI ranking against PoU ranking

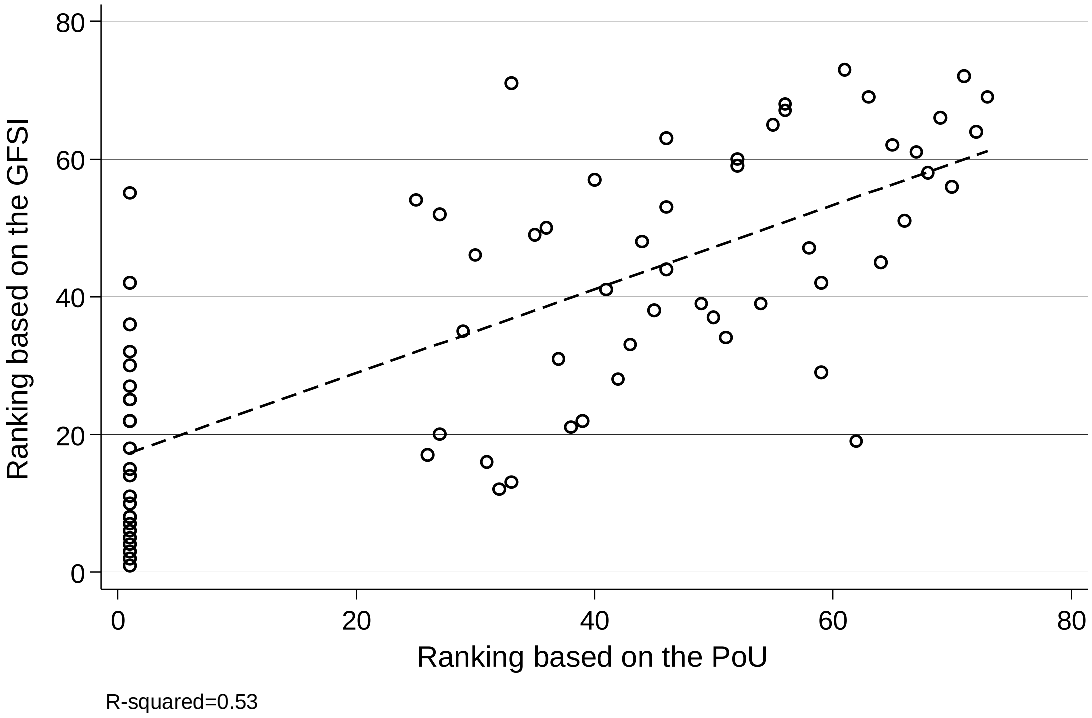


Table 23 Countries ranked in the 25% less "food secured" with the GFSI and PoU rankings

Common countries
Burkina Faso Chad Ethiopia Haiti Laos Madagascar Malawi Mozambique Sierra Leone Tajikistan Tanzania Yemen Zambia
Countries in one of the two rankings
Angola Bangladesh Botswana Kenya Guinea Mali Pakistan Rwanda Niger Sri Lanka Uganda Togo

5 Conclusions

Like any measurement, the GFSI has its specific characteristics and limitations.

The GFSI is that it is **based on contributing factors** rather than outcomes of food security. It does describe the food security conditions. However, it does not measure the outcomes of food security, namely food consumption or malnutrition figures. It tends to measure the conditions for food security, or an **enabling environment for food security instead of actual food security level**. In addition, given constraints linked to data availability (timeliness, frequency) and the choice of indicators included, the indicator is meant to measure structural levels food insecurity. It tends to integrate the changes in the food security situation of a country with some delays, depending on how recent the data are.

The GFSI does not capture the entire spectrum of food security. It reflects specific aspects chosen by the team of experts that designed the index. The index namely focuses on the GDP as well as poverty and on the agricultural production side. The GFSI extends to governance and policy areas that are usually not directly included in food security indicators. It is thus complementary to other food security measures but it is not a substitute.

The GFSI, like any other composite indicator, does not allow to draw any causal inference between the dimensions of the indicators (affordability, availability, quality and safety), or the individual indicators included, and food security. Any change in an individual indicator included in the composite will mechanically change the final score, proportionally to the weight of the indicator in the final score. This will happen even if the individual indicator has nothing to do with food security. Any causal relationship between an individual indicator and food security should be tested outside of the composite indicator construction process by a regression analysis between the individual indicator and valid measure of food security, ideally an “output variables” like food consumption.

The statistical assessment of the GFSI shows that the index exhibits good statistical properties.

Data coverage is very good. The percentage of imputed values is low both at the country and indicator levels. Six out of the twenty-eight indicators contain outliers. The comparison of the rankings of countries without and with winsorization suggests that the effect of the outliers on the final score is not important.

The indicators are on average strongly correlated with their respective dimension. Yet we note that the information contents of two indicators and two variables are lost at the dimension and overall index levels. The principal component analysis reveals that the three dimensions composing the GFSI are indeed apprehending one single phenomenon.

The comparison of the weighting scheme with the statistical importance of each indicator suggests that there are differences between these two measures of importance. While this might have been done intentionally by the developers of the GFSI, this could be clarified.

The uncertainty analysis has shown that although a few country ranks in the GFSI are sensitive to the methodological choices, the published GFSI ranking can be considered, for the vast majority of countries, robust to variations in the weighting scheme and the aggregation method. Overall the statistical analysis suggests that the index is statistically coherent and robust to changes in the weight and aggregation methods.

The GFSI and the GHI are strongly correlated to each other. Seventeen out of twenty countries ranking in the bottom 25% of the two rankings are common. In comparison, the correlation between the GFSI and the PoU is lower.

We thus recommends to use the GFSI in conjunction with other indicator of food insecurity namely those measuring the outcomes of food security in terms of food consumption and the nutritional status of the population to have a good assessment of the actual food security and nutrition situation in food insecure countries.

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List of abbreviations and definitions

EIU	Economist Intelligence Unit
WB	World Bank
WDI	World Development Index
WTO	World Trade Index

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Annexes: Statistical assessment – complementary figures

Figure 9 Weight scheme versus Statistical Importance within the Affordability dimension

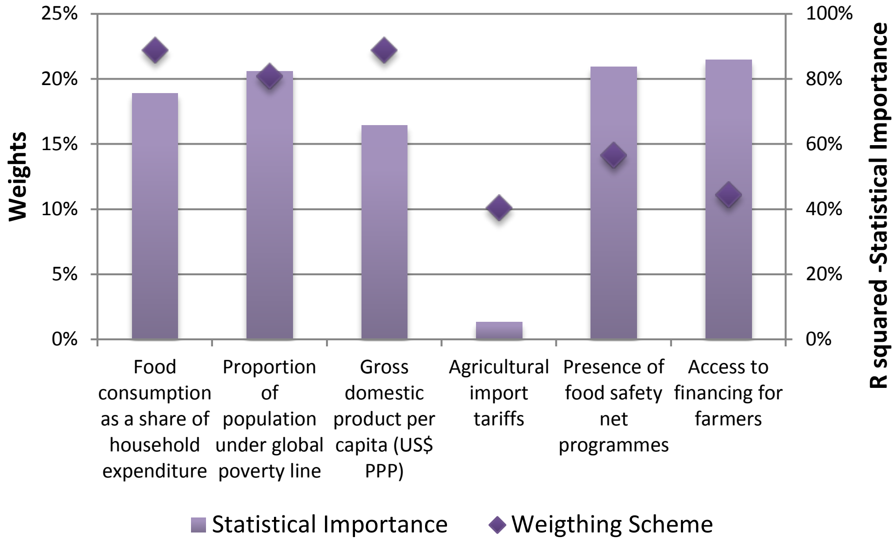


Figure 10 Weight scheme versus Statistical Importance within the Availability dimension

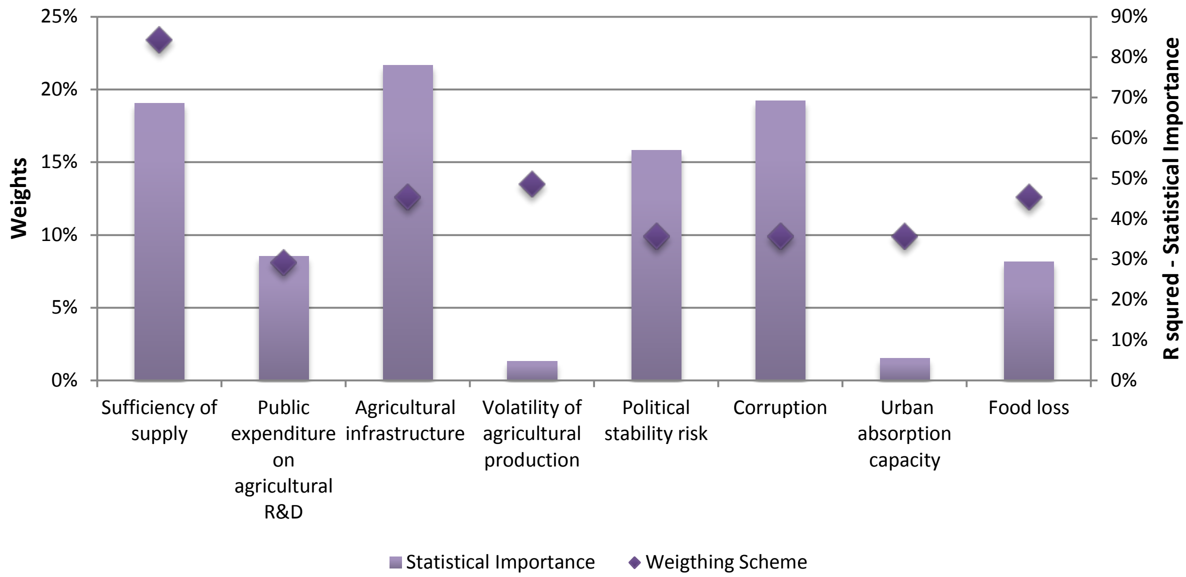


Figure 11 Weight scheme versus Statistical Importance within the Safety and Quality dimension

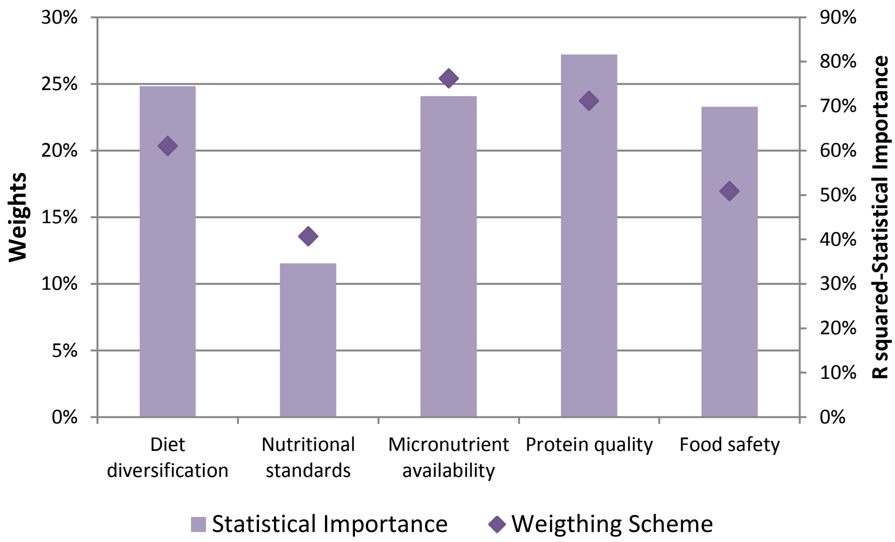


Table 24 Spearman Rank correlation between GFSI Affordability related indicators and GHI scores

GFSI Indicators	GHI	GFSI
Food consumption as a share of household expenditure	0.63	0.90
Proportion of population under global poverty line	0.88	0.92
Gross domestic product per capita (US$ PPP)	0.83	0.95
Agricultural import tariffs	0.34	0.38
Presence of food safety net programmes	0.87	0.91
Access to financing for farmers	0.77	0.92

Table 25 Spearman Rank correlation between GFSI Availability related indicators and GHI scores

GFSI Indicators	GHI	GFSI
Sufficiency of supply	0.85	0.88
Public expenditure on agricultural R&D	0.30	0.49
Agricultural Infrastructure	0.65	0.89
Volatility of agricultural production	**-0.02**	**0.03**
Political stability risk	0.20	0.69
Corruption	0.34	0.78
Urban absorption capacity	**-0.03**	**0.05**
Food loss	0.32	0.64

Table 26 Spearman Rank correlation between GFSI Quality and Safety related indicators and GHI scores

GFSI Indicators	GHI	GFSI
Diet Diversification	0.72	0.83
Nutritional Standards	0.28	0.62
Micronutrient availability	0.57	0.77
Protein Quality	0.76	0.86
Food Safety	0.89	0.92

Table 27 Spearman Rank correlation between GFSI Affordability related indicators and PoU scores

GFSI Indicators	PoU	GFSI
Food consumption as a share of household expenditure	0.42	0.90
Proportion of population under global poverty line	0.66	0.92
Gross domestic product per capita (US$ PPP)	0.68	0.95
Agricultural import tariffs	**0.17**	0.38
Presence of food safety net programmes	0.75	0.91
Access to financing for farmers	0.62	0.92

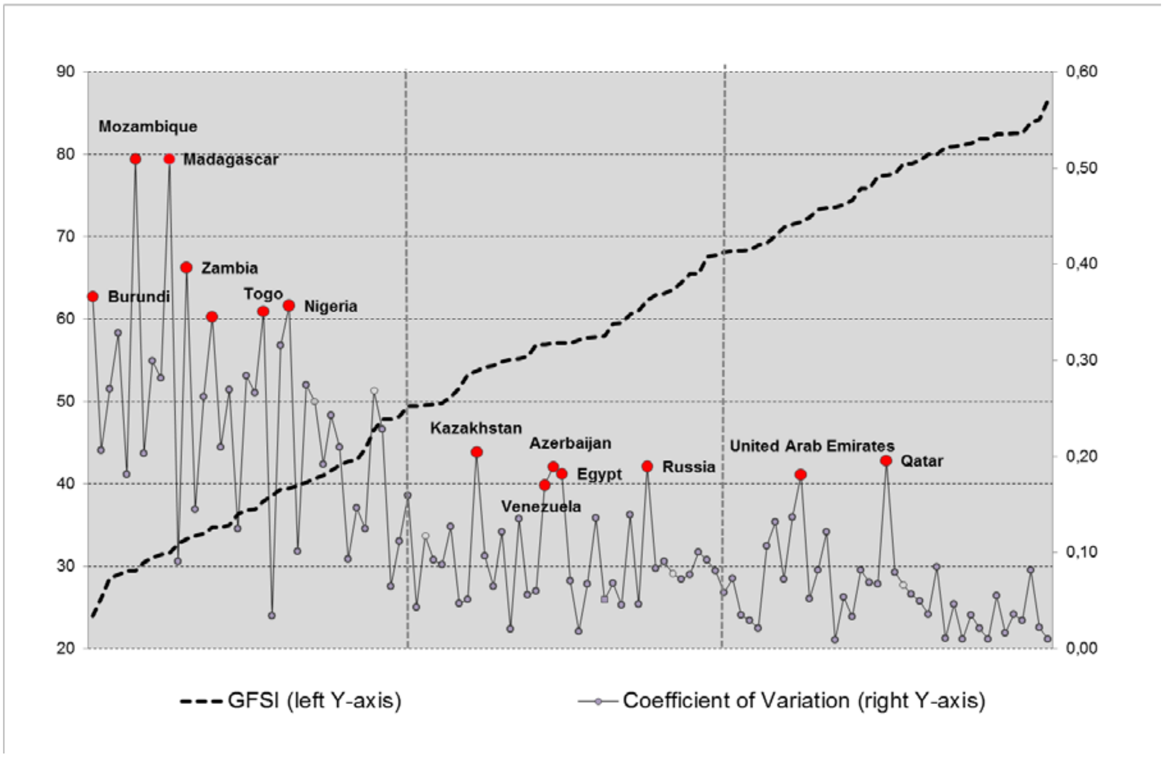
Table 28 Spearman Rank correlation between GFSI Availability related indicators and PoU scores

GFSI Indicators	PoU	GFSI
Sufficiency of supply	0.85	0.88
Public expenditure on agricultural R&D	0.36	0.49
Agricultural Infrastructure	0.57	0.89
Volatility of agricultural production	**0.10**	**0.03**
Political stability risk	**0.11**	0.69
Corruption	0.39	0.78
Urban absorption capacity	**-0.13**	0.05
Food loss	0.67	0.64

Table 29 Spearman Rank correlation between GFSI Quality and Safety related indicators and PoU scores

GFSI Indicators	PoU	GFSI
Diet Diversification	0.42	0.83
Nutritional Standards	0.23	0.62
Micronutrient availability	0.57	0.77
Protein Quality	0.77	0.86
Food Safety	0.72	0.92

Figure 12 Dimension scores – coefficients of variation across dimensions



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