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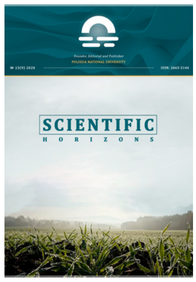

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Concept and Measurement of the Food System Sustainability: A Bibliometric Research

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Abstract. In view of climate change and population growth, making food system sustainable is a global concern. A lot of policies regulate this issue, but recent data show that global (and national) food systems are still far from the sustainability. Improvement of existing policies in the field of food system regulation requires a clear understanding of the food system sustainability concept itself: specification of its traits, attributes, measurement indicators, and goals. These issues are reflected in a lot of research papers, but none of these articles summarise the major trends, content, and features of the food system sustainability concept's evolution. This study for the first time summarises history and contents of research in the field of concept and measurement of food system sustainability through bibliometric analysis of Scopus indexed papers for 1991-2022. The growth of scientific interest in this area, led by researchers from the USA, Italy, and France, was found to be wave-like with peaks following the global food crises appearance patterns. The results of this study show that modern perception of the concept (since 2018) is complicated and intertwined in the notions of systems and system thinking, sustainability, and life cycle assessment, contrasting to the previous views (1991-2018) focused on food production system and food security. In general, a little attention is given to social and economic aspects of food system sustainability, in contrast to environmental, food, and agri-food issues. The elaboration of one-size-fits-all policy and solutions favouring food systems sustainability is suggested to be unlikely due to the complexity of the concept's perception. Governance of food system sustainability should go in line with concrete institutional, economic, social, and natural environments that need to be comprehensively studied in a future. Studies from developing countries are of special interest in this context

Keywords: sustainable food, concept evolution, assessment, bibliometrix, biblioshiny

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INTRODUCTION

Food security and global food system sustainability are the main challenges of modern development on the background of climate change, natural disasters, and pandemic crisis (Pachapur *et al.*, 2020). Although the FAO defined a sustainable food system in 2018 as "a food system that delivers food security and nutrition for all in such a way that the economic, social, and environmental bases to generate food security and nutrition for future generations are not compromised" (FAO, 2018), society still lacks the clear vision of ways, steps, and tools to guarantee the food systems sustainability locally and globally (Loboguerrero *et al.*, 2020; Towards a sustainable food system, 2020; von Braun *et al.*, 2021; Mishenin *et al.*, 2021). Food security and global food system sustainability are the main challenges of modern development on the background of climate change, natural disasters, and pandemic crisis (Pachapur *et al.,* 2020). Although the FAO defined a sustainable food system in 2018 as "a food system that delivers food security and nutrition for all in such a way that the economic, social, and environmental bases to generate food security and nutrition for future generations are not compromised" (FAO, 2018), society still lacks the clear vision of ways, steps, and tools to guarantee the food systems sustainability locally and globally (Loboguerrero *et al.*, 2020; Towards a sustainable food system, 2020; von Braun *et al.,* 2021; Mishenin *et al.,* 2021). According to FAO and World Bank estimates, about 11% of people globally are undernourished, which renders the achievement of "zero hunger" sustainable development target until 2030 impossible (FAO, 2019; World Bank, 2020). Despite the sufficiency of resources available to feed up to 10 billion people, current hunger problem exists precisely because of unfair resources' allocation (World Bank, 2020). Food system vulnerability also deepens due to climate changes affecting agricultural productivity and income of rural people. Extension of farmlands (especially in developing countries) – to meet the challenges of productivity decrease and additional food demand caused by population growth – jeopardises functioning of ecosystems and exacerbates the climate problem (Koblianska *et al.*, 2021). In another vein, developed and rapidly developing countries also adversely affect the global food system sustainability due to change in diet and consumer behaviour following unhealthy and unsustainable patterns (increase of meat consumption, eating out, excessive food consumption, and food wasting). For instance, about 38% of energy consumed by global food chain is lost with food wastes (FAO, 2017; Klymchuk *et al.*, 2020). Meeting the food system sustainability challenge is eminently complicated for developing countries exporting food. Ukraine is a good case here to illustrate the adverse effects of prominent agriculture development. Despite the large amount of food exports feeding the world, Ukrainians (rural habitants above all) lack basic food in the diet: meat and dairy products, fish, vegetables, and fruits (Mishenin *et al.*, 2021). Number of people suffering from hunger and undernourishment amounts up to 1.1 million (FSIN, 2020). Additionally, an environmental price of food produced in Ukraine, measured via environmental footprint, increases year by year (Koblianska *et al.,* 2021; Sineviciene *et al.,* 2021). The latter is true for other agriculture-dependent regions in the world: land-use change and forestry sectors, in contrast to developed world pathway, cause a considerable increase of carbon dioxide emissions in these countries (WRI, 2021). All this and expected resource scarcity (until 2050) will significantly intensify competition, destructive land use practices, and conflicts, endangering welfare of the most vulnerable, agriculture-dependent people around the world. In view of this, the food system sustainability transition is rather a matter of humanity survival than debatable issue. However, society needs a constructive, multi-stakeholder, interdisciplinary discussion on technological, social, cultural, economic, political, international aspects of future food system development path.

The current vision of further food systems development embraces transformations towards the sustainability driven by science and innovations. In this context, not only technological but also social, political, and institutional innovations ruled by values, perceptions, and conceptions of the food system sustainability come to the fore (Koblianska *et al.,* 2020; von Braun *et al.,* 2021). The value underlying the concept of food system sustainability also influences means of measurement and so, implementation actions that need to be harmonised (Schader *et al.,* 2014; Alrøe *et al.,* 2017; Leźnicki, 2021). This requires documenting knowledge and experience from different disciplines and intellectual traditions to reflect the challenges and critical threats to the sustainability of food system and to define a suitable framework for research, policy, and actions (von Braun *et al.,* 2021; El Bilali *et al.,* 2021). In view of this, a study of the complete set of interpretations of food system sustainability as a concept and its evolution is an effective way to shed light on the opportunities, strengths, and weaknesses of ensuring the systemic and coordinated actions towards the food system sustainability on innovative basis. *The purpose of this article* is to cover the evolution of the food system sustainability concept and explore insights via bibliometric research to support further fruitful scholar and policy discussions in this field.

LITERATURE REVIEW

The food system sustainability concept is quite broad and covers various phenomena. To illustrate the complexity and multifaceted nature of the concept, one should point out, for instance, the range of topics covered by the special issue "Towards more sustainable food systems" of the International Journal of Environmental Research and Public Health: 1) food security at the local level; 2) manifestation and potential impact of food production environment transformations; 3) food consumption environmental impacts and specific measures to deal with; 4) ways to support expedient food supply system transformations

(Kusch-Brandt, 2020). Despite the growing number of issues covered and studies on the food system sustainability, the society is still far from the desired changes (Loboguerrero *et al.,* 2020) and scholars point the need to explore the variety of values, perceptions, and approaches related to food systems sustainability aiming to ensure coordinated and cooperative actions towards further food system transformations (Alrøe *et al.,* 2017; Loboguerrero *et al.,* 2020; Kusch-Brandt, 2020). Within this framework, the bibliometric studies, providing insights on research field development and trends, are of growing interest.

Recent studies explore scientific efforts and results concerning the issues of sustainable consumption (Maria Claudia *et al.*, 2019; Nornajihah *et al.,* 2021), sustainable agri-food systems (El Bilali *et al.,* 2021) and their modelling (Monasterolo *et al.,* 2016), halal food system sustainability (Rejeb *et al.,* 2021), sustainability of urban food systems (Zhong *et al.,* 2021) and concrete food supply chain (Both *et al.,* 2021), etc.

Results of bibliometric analysis of Scopus indexed publications on sustainable consumption for 1974-2019 (2352 documents) made by N.H. Nornajihah et al. (2021) evidence the USA dominance in the number of articles published, the University of Göttingen (Germany) leadership in scientific productivity, and the most relevance of the Sustainability Switzerland as a publishing source in this field. Authors also identify four clusters of sustainable consumption psychosocial factors: social norms, attitude, environmental concern, and perceived value (Nornajihah *et al.,* 2021). Studying the food consumption sustainability, Maria Claudia et al., (2019) found consumer and consumption patterns to be the thematic core of the Web of Science covered sample of publications for 1975-2018 with abstracts including "sustainable food consumption" (103 publications) (Maria Claudia *et al.,* 2019).

Agri-food systems are the closest to sustainability issues strand of food systems. Utilising the data from the Web of Science (1289 documents), H. El Bilali et al. (2021) analysed studies on the sustainability of agri-food systems and their relationships to environmental, economic, social, and political aspects of sustainable development in early January 2020. Authors noted a growing scientific interest concerning the sustainability of agri-food systems as confirmed by an exponential increase in the number of publications. Scholars from developed countries are found to be the most productive and relevant in this field. Research results testify a lack of emphasis on the social, economic, and political aspects of sustainable agri-food systems development, while environmental aspects are well explored (El Bilali *et al.,* 2021).

Modelling of agricultural and agri-food systems functioning constitutes an essential aspect of the food systems sustainability concept and studies. Monasterolo et al. (2016), applying citation and co-citations analysis, bibliographic coupling, and other classic bibliometric techniques, explored records from ISI Web of Science for 1970 to 2016 on Agricultural Modelling and Agricultural Complex Systems Modelling topics and found the growing trend to use a comprehensive system approach to the analysis of agri-food systems in the framework of classical modelling techniques. Results of research show the need to account for the complexity of agricultural systems when developing the conceptual and methodological innovations aimed at changing global food policy towards sustainable development and inclusive agri-food systems (Monasterolo *et al.,* 2016).

A. Rejeb et al. (2021), exploring the halal food systems sustainability studies (74 journal articles), also noted the growing interest in this topic for the last two decades, but, in contrast to (El Bilali *et al.*, 2021), found the primary focus on economic and social aspects of halal food systems sustainability with a little attention paid to environmental issues (Rejeb *et al.,* 2021).

Within the corpus of urban food systems sustainability research covered by the Web of Science Core Collection (5,360 publications), Q. Zhong et al. (2021) found the dominance of environmental issues. Scholars noticed the growing scientific interest in this research field fuelled by urbanisation, social, and environmental changes, but a lack of studies concerning the urban food system resilience, trade-offs between resilience and sustainability, and comparative research. Issues of food security, food consumption, and food waste form the core of the urban food system sustainability research area (Zhong *et al.,* 2021).

As A.V.R. Both et al. (2021) mention, sustainability concern becomes a growing trend in organisations involved in food value chains (in particular, rice value chain) since 2016, driving research in this field (Both *et al.,* 2021).

One should point out that within the food system sustainability research field, studies on cellular agriculture (Nyika *et al.,* 2021), human rights and social justice (Oktaviani *et al.,* 2021), food security and climate change (Sweileh, 2020) are also of growing interest.

The abovementioned bibliometric studies explore various aspects of the complex issue of food system sustainability. However, there is a lack of a comprehensive research concerning the concept and measurement of food system sustainability. This study aims to fill this knowledge gap and, through bibliometric analysis, to elaborate on the contributors, evolution, modern visions, and growing trends in studies focused on conceptualisation and measurement of sustainability of food system.

MATERIALS AND METHODS

This study utilises the Scopus collection to form the sample of scientific records for bibliometric analysis. The Scopus provides a comprehensive database of publications analysing citations over a longer period compared to the ISI Web of Science Core Collection (Aria *et al.,* 2020; Nornajihah *et al.,* 2021). The search query was the following: TITLE (sustainab* W/3 *food* W/3 system*)) AND (KEY (concept* OR theor* OR design* OR method* OR metric* OR assess* OR indicator OR measur* OR index*

OR frame* OR content); only articles, conference papers, reviews, and book chapters included; only English-language; all available years. The list of search results contained 107 documents as of October 19, 2021. The initial screen and analysis of records were made to eliminate the possible duplicated and inconsistent records: 1 document was excluded due to duplication, 9 documents – due to mismatching the request (not relevant content), 11 documents – due to absence of abstracts (2) and authors' keywords (9). The final sample amounts to 86 documents obtained from 52 sources for 1991-2022.

Bibliometric and network analysis is an effective way to illustrate general trends in the research field allowing to identify key schools of thoughts, academic interrelationships, research productivity through performance analysis, co-word analysis, bibliographic coupling, and factorial analysis. The analysis of networks reveals the social, intellectual, and conceptual structures of the studied field. Intellectual structures are exposed through bibliographic coupling that is an alternative to co-citation criterion for evaluating relationships. Coupling allows visualising links between publications revealing the common ideas. Conceptual structures are explored through the mapping of research space using co-word networks and factorial analysis. This allows to interpret the knowledge base embodied in the analysed collection and to explore the diverse topics within the research field (Aria *et al.,* 2020). The analysis was performed with the use of R {bibliometrix} package and Biblioshiny App (R Core Team, 2014; Aria & Cuccurullo, 2017). Bibliometrix package is a tool to quantify the scientometric and bibliometric indicators, to analyse knowledge structures (intellectual, social, conceptual) utilising R programming language. In this research {bibliometrix} was applied through RStudio that is user-friendly integrated development environment (IDE) for data science (RStudio Team, 2020). The Bibliometrix package allows to run a Biblioshiny App – an easy-to-use web-based extension to perform a science mapping analysis comprising nice graphics (for example, to visualise indicators of different levels via three fields plot) (Aria & Cuccurullo, 2017).

RESULTS AND DISCUSSION

Food system sustainability research: Evolution and geographical patterns

Table 1 summarises the main data about the bibliographic collection, which mainly comprise journal articles (77%). The number of authors studying the food system sustainability concept and measurement amounts to 391 persons; the average number of documents per author is 0.22. Multi-authored publications predominate with an average size of research group of about five persons. However, the share of single-authored publications is also significant and amounts to 9%, that is every 11th publication in this collection is single-authored. The average time from publication to citation of the article is a little more than 4 years.

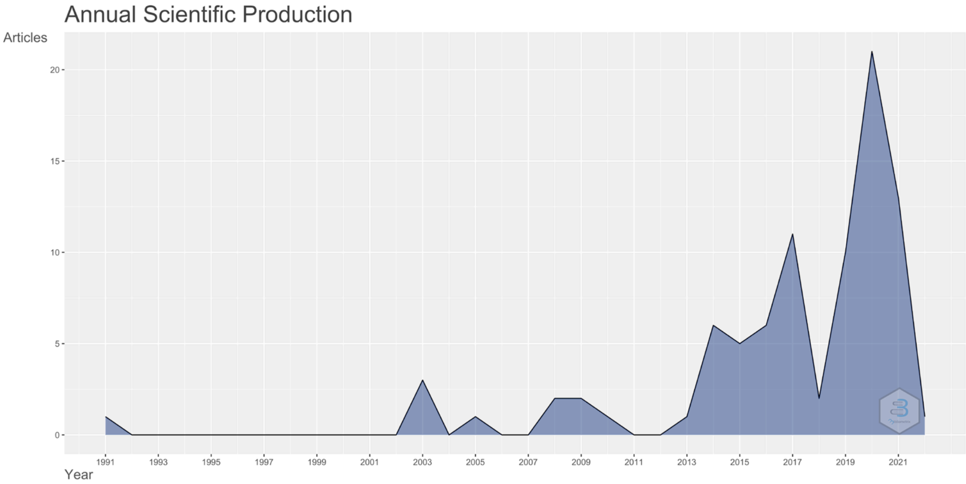
Table 1*. Descriptive statistics for bibliographic collection*

Description	Results
MAIN INFORMATION ABOUT DATA	
Timespan	1991-2022
Sources (Journals, Books, etc)	52
Documents	86
Average years from publication	4.2
Average citations per documents	16.12
Average citations per year per document	2.626
References	7021
DOCUMENT TYPES	
Article	66
Book chapter	2
Conference paper	11
Review	7
DOCUMENT CONTENTS	
Keywords plus (ID)	620
Author's keywords (DE)	398
AUTHORS	
Authors	391
Author appearances	414
Authors of single-authored documents	7
Authors of multi-authored documents	384
AUTHORS COLLABORATION	
Single-authored documents	8
Documents per Author	0.22
Authors per Document	4.55
Co-Authors per Documents	4.81
Collaboration Index	4.92

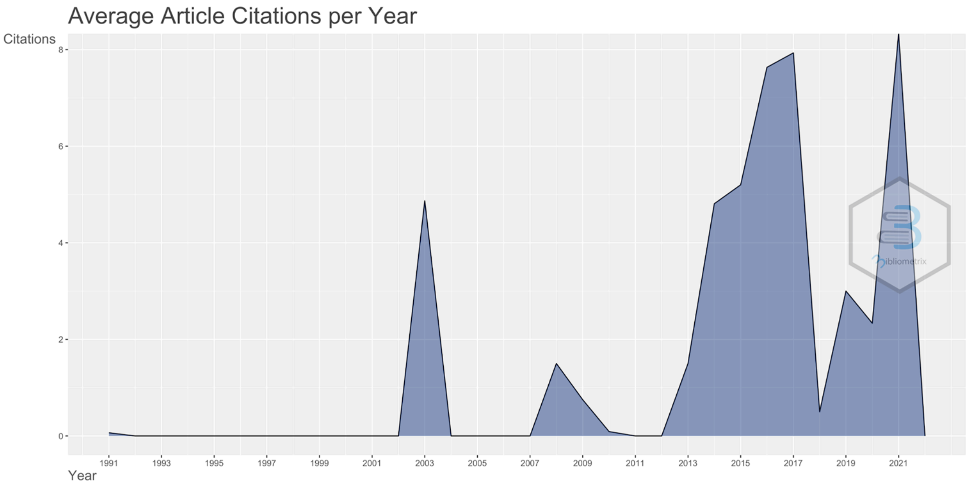
Source*: authors' development via Bibliometrix*

Analysing the quantitative parameters of research field development, one should note the wave-like growing number of publications and citations (Fig. 1).

Figure 1 illustrates periods of scientific interest increase and some spikes: 2003, 2008-2009, 2013-2017 (with peaks in 2014, 2017), 2020. A decline in number of research is followed by an increase in 2019 and a peak in 2020. Change of an average number of citations per year also comprises severe peaks: 2003 (an average annual number of citations amounts to 4.87 and to 87.67 per article), 2008 (1.5 and 19.5, respectively), 2017 (7.93 and 31.73), 2019 (3.0 and 6.0) and 2021 (with the average number of citations per article of 0.23).



a) annual scientific production



b) average article citations per year

***Figure 1**. Historical development of research field*
***Source**: authors' development via Biblioshiny app (R Core Team, 2014; Aria & Cuccurullo, 2017; RStudio Team, 2020)*

In 1991 only one article was published and no publications on food system sustainability concept and measurement were covered by Scopus over the decade to follow. 2003 was marked by the food crisis in central and eastern Africa caused by the drought. Moreover, the decline of wheat production in the USA and respective depletion of food stock destined to aids led to the prices increase. As a result, the FAO reported about 39 countries "facing severe food shortages" that year (Reliefweb, 2003). This could be the reason for an increase of scientific interest and publications on food systems sustainability concept and measurement. This is true also for 2008 crisis with the largest world food prices surge for the last 30 years. Issues of food availability, security, and abilities to overcome the crisis were put at the forefront of food policies at different scales (Hultman, 2008), pushing the research activity. Then, due to food price fluctuations (2011-2012) and a critical decline in global food stocks in 2012 (below 1974 level) expectations of the possible onset of the food crisis in 2013 (Vidal, 2012) were reasonable. This could be judged as a factor leading to an increase of scientific publications in the analysed field.

In 2015-2016, the United Nations Organisation approved the Agenda 2030 putting the sustainability of food system at the centre of 17 sustainable development goals. In December 2016, Barilla released the food sustainability index (Barilla Center for Food..., 2021) allowing to quantify and to illustrate the scale of the problem. In 2018, the FAO formulated an official definition of sustainable food system. Those events could serve core drivers of significant increase in the number of publications concerning the concept and metrics of food system sustainability since 2015.

The bibliographic collection analysed comprises publications made by authors from 45 countries in total (Fig. 2). Scientists from the United States, Italy, and France make the greatest contribution to the scholarly elaboration of the concept and metrics of food system sustainability (frequencies amount to 40, 36, 27 documents authored, respectively). The Netherlands (18), Canada (16), UK (15), Australia (14), Germany (12), China (9), Brazil, New Zealand, and Spain (7 for every) are a little less productive.

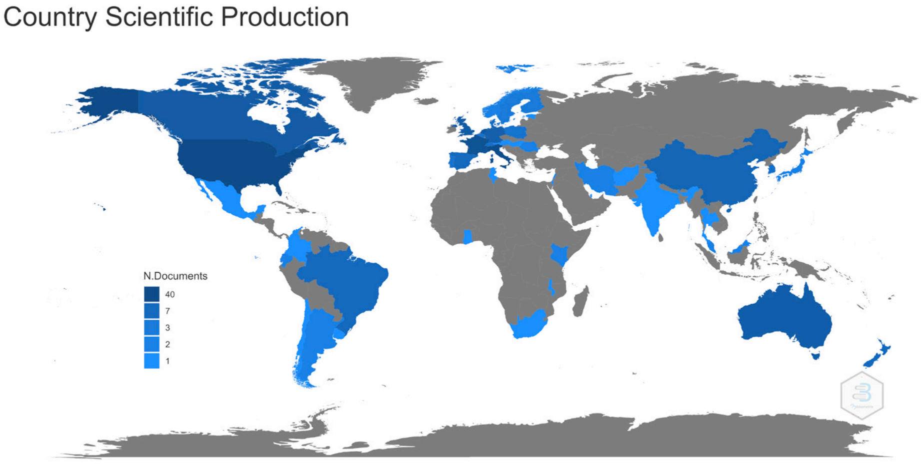


***Figure 2**. Country scientific production for 1991-2022*
***Source**: authors' development via Biblioshiny app (R Core Team, 2014; Aria & Cuccurullo, 2017; RStudio Team, 2020)*

The United States, Italy, and France also represent the most three cited countries, which is logical; Switzerland is the fourth in the ranking of cited countries (Fig. 3), although it ranks only 15th in terms of productivity with only five articles in the collection.

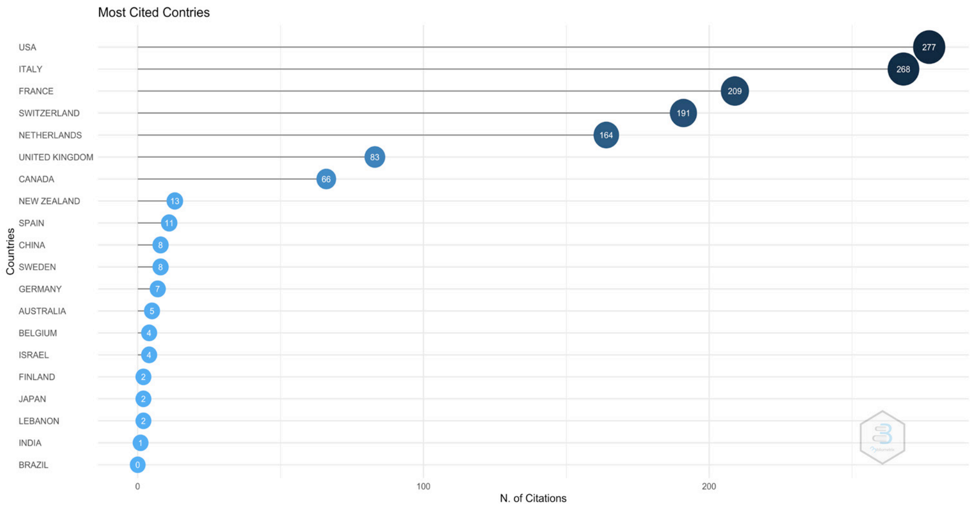


***Figure 3**. Most cited countries*
***Source**: authors' development via Biblioshiny app (R Core Team, 2014; Aria & Cuccurullo, 2017; RStudio Team, 2020)*

With respect to the corresponding author, the USA, Italy, and France also are leading countries by number of papers published (12, 11, 7, respectively). The UK and the Netherlands (6 documents each) follow those countries and complete the top five countries in the field of food system sustainability and metrics research.

Among the countries with a high productivity, the UK, Switzerland, Italy, the Netherlands, and France are the most engaged in international scientific cooperation, according to the collaboration index (0.833, 0.667, 0.545, 0.5, 0.286, respectively). Although the collaboration indices for publications made by corresponding authors from Sweden, India, and New Zealand are the highest and amount to one each, the number of articles authored by researchers from these countries is small (2, 1, 1, respectively).

To illustrate the scientific relationships between countries, the countries collaboration network was built using Louvain clustering and an association strengths normalisation approach (Fig. 4).

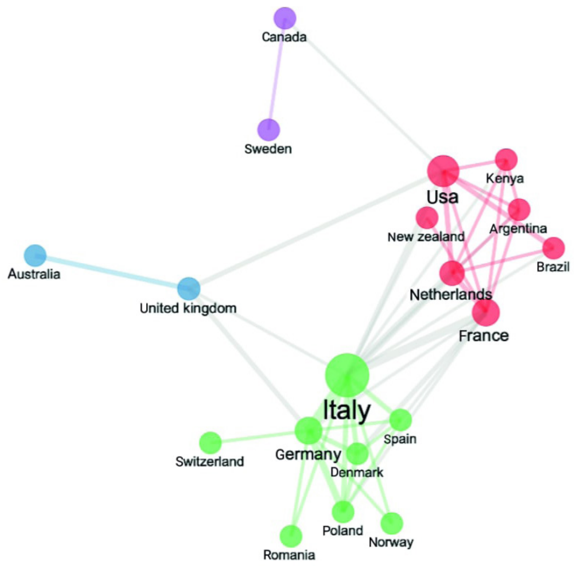


***Figure 4**. Countries collaboration network*
***Source**: authors' development via Bibliometrix (R Core Team, 2014; Aria & Cuccurullo, 2017; RStudio Team, 2020)*

Figure 4 illustrates the existence of four clusters of international cooperation in the field of conceptualisation and measurement of food system sustainability research. There are two dominant clusters: 1) European, which is led by Italy and unites mainly researchers from European countries (and Spain); 2) American, led by the USA and France, connecting scientists from Argentina, Brazil, Kenya, the Netherlands, and New Zealand.

The most relevant organisations (by number of publications), according to the corresponding author's affiliation are the following: University Paris-Saclay (8), University of Sydney and Wageningen University and Research (5 articles each), Acadia University, UN Food and Agriculture Organisation, University of California, and University of Copenhagen (4 articles each), Asia University, Cornell University, University of Manchester, Montpellier University, University of Minnesota, University of Naples Parthenope, Wageningen University (3 articles each). Thematic avenues of research (top 20) by countries and organisations are given in Figure 5.

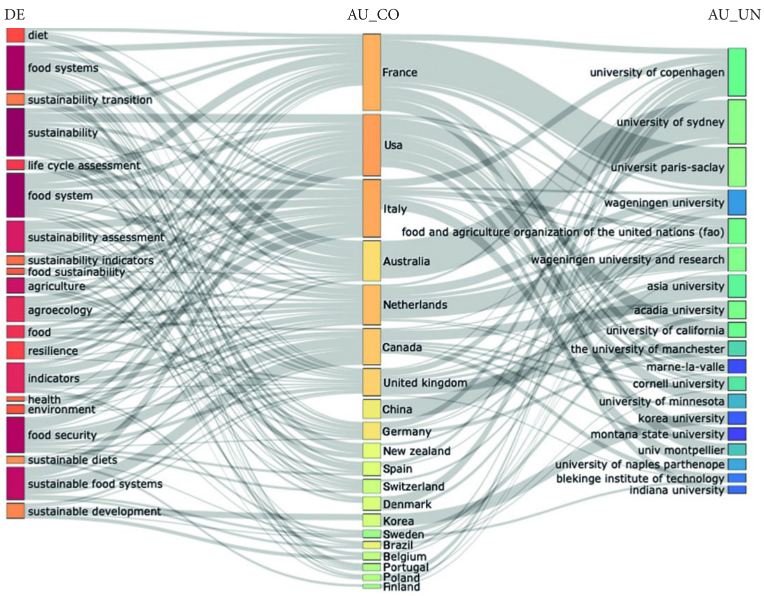


***Figure 5**. Three fields plot: Author's Keywords-Countries-Affiliations*
***Source**: authors' development via Biblioshiny app (R Core Team, 2014; Aria & Cuccurullo, 2017; RStudio Team, 2020)*

The Sustainability (Switzerland) journal (16 documents), the Journal of cleaner production (5 papers), the Frontiers in Sustainable Food Systems journal, the Journal of Hunger and environmental nutrition (4 articles each), the Agricultural Systems journal, and the Nutrients journal (4 papers each) are the most relevant sources for publications covered by the sample. This goes in line with previous research (Sweileh, 2020) concerning the leading role of Sustainability (Switzerland) as the platform to present research on food system sustainability issues.

Main concepts and trends in food system sustainability research

The most productive authors by number of documents fractionalised are ranked in Figure 6.

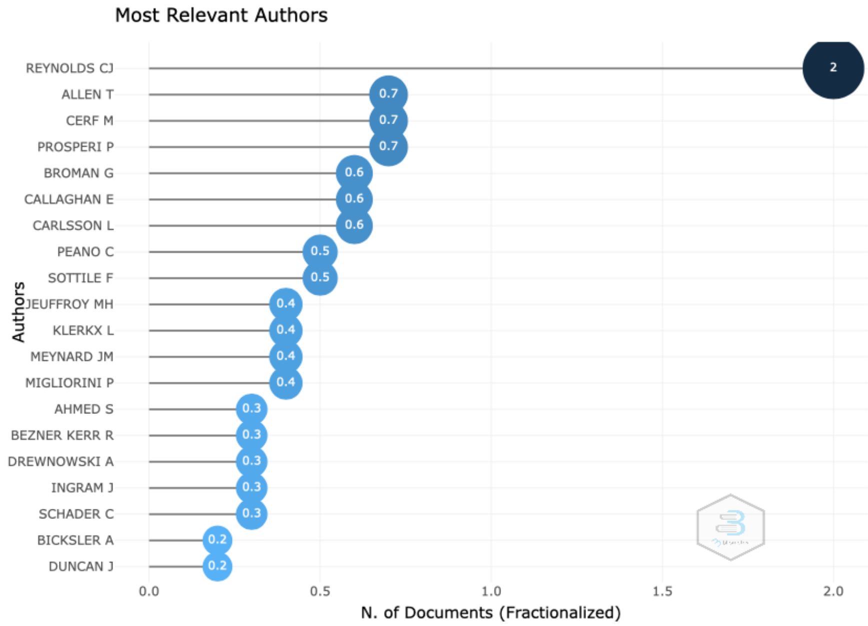


Figure 6. *Most relevant authors*
Source: *authors' development via Biblioshiny app (R Core Team, 2014; Aria & Cuccurullo, 2017; RStudio Team, 2020)*

The major of these scientists has launched research on food system sustainability conceptualisation and measurement in 2016-2017 and continue to explore this topic (Fig. 7).

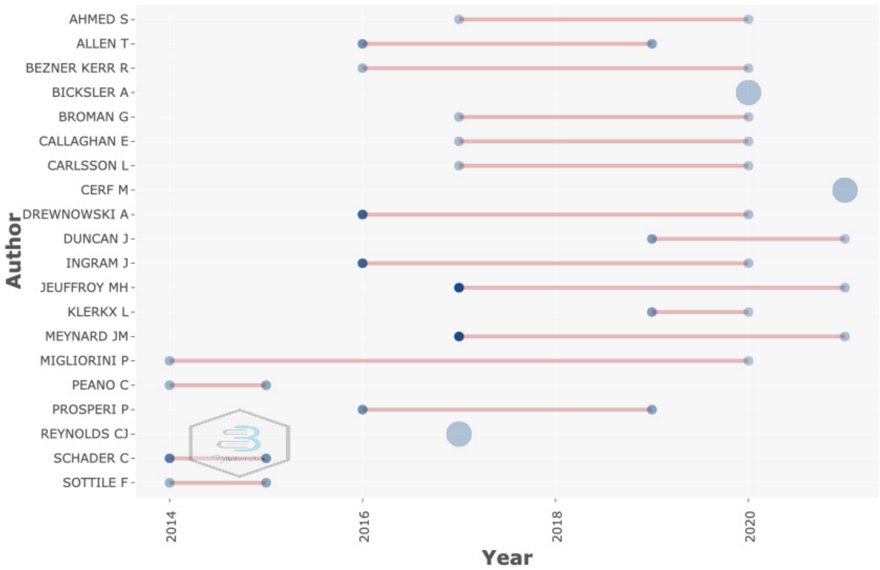


Figure 7. *Top-authors' production over the time*
Source: *authors' development via Biblioshiny app (R Core Team, 2014; Aria & Cuccurullo, 2017; RStudio Team, 2020)*

T. Allen & P. Prosperi (2016) started to explore the concept and metrics of food system sustainability in 2016 with the study of sustainable food system (SFS) modelling (Allen & Prosperi, 2016), and then develop indicators to measure SFS applying the Delphi approach (Allen *et al.,* 2019). Carlsson, Callaghan, and Broman (2017) began with the research on planning and evaluating of community development favourable for SFS (Carlsson *et al.,* 2017), and further pursue a study of the community impact on the SFS development with respect to the food habits and culture formation (Carlsson *et al.,* 2020). Starting with an innovations' design supporting the agri-food systems sustainable transformations (Meynard *et al.,* 2017), Meynard, Jeufroy, and Cerf focus on research organisation promoting innovations' development and implementation for sustainability of agri-food systems (Brun *et al.,* 2021). Drewnowski and Ingram (2016) investigated indicators to measure the SFS in respect of nutrition security (Gustafson, 2016) and develop healthy diets conducive to the food system sustainability (Drewnowski *et al.,* 2020). Ahmed (2017, 2020) focuses on the educational aspect of movement towards the SFS: practice-oriented student's learning (Ahmed *et al.,* 2017) and joint development of adaptive knowledge outcomes to make education contributory to the SFS transformation (Ebel *et al.,* 2020).

Recent papers (2019-2021) focus on agri-environmental measures ensuring the SFS development (Mottet *et al.,* 2020; Barrios *et al.,* 2020), diversity of food systems and their characteristics in terms of sustainability (Gaitán-Cremaschi *et al.,* 2019), food system resilience concerning crises (Bisoffi *et al.,* 2021), food system and agricultural policies changes in the context of digitisation (Lajoie-O'Malley *et al.,* 2020).

Word cloud (Fig. 8) shows the most frequent author's keywords (Fig. 8b): "food system", "food security", "indicators", "agriculture". Measured by the logarithmic occurrence (Fig. 8a), keywords like "agriculture", "indicators", "agroecology", "resilience", and "food" constitute the corpus of terms with the growing use.

a) log word occurrence measure

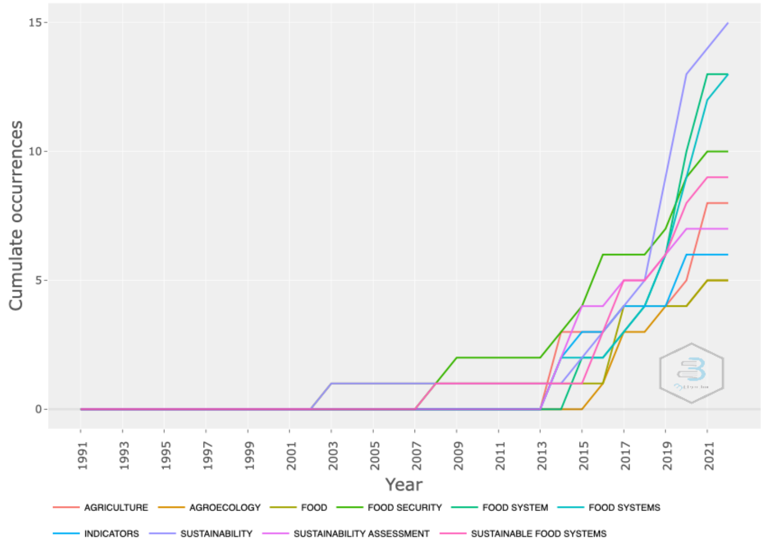
b) frequency word occurrence measure

Figure 8. *Word cloud of author's keywords*

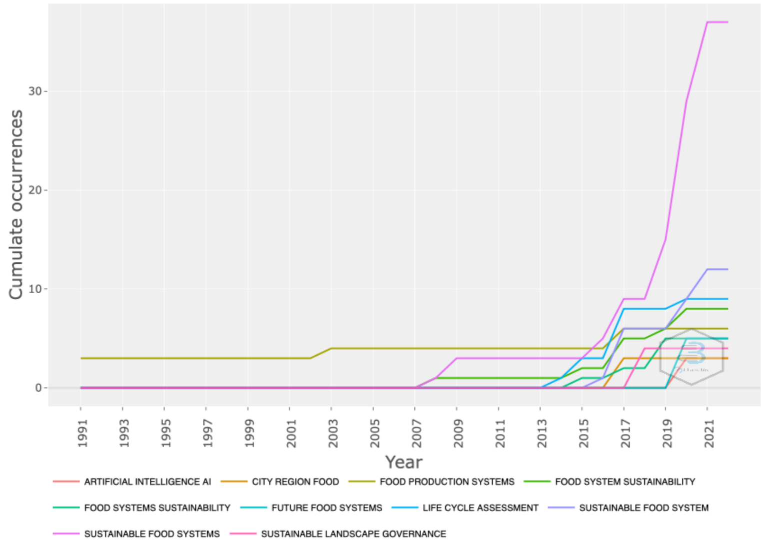
Source*: authors' development via Biblioshiny app (R Core Team, 2014; Aria & Cuccurullo, 2017; RStudio Team, 2020)*

Word growth analysis allows to identify growing and new trends in the research field. Cumulate occurrence of author's keywords (Fig. 9a) shows changes in scientific elaboration of SFS concept and measurement for 2002-2021: the term "sustainability" was leading in 2002-2008 period, then the "food security" concern became dominant since 2008 until 2018, when the "sustainability" came to the fore again. Current SFS conception embraces a lot of views with the predominance of "sustainability" and "food system (systems)" context leading to the failure of "food security" significance. Keywords "agriculture" and "agroecology" complete a semantic variety of phrases constituting the SFS concept (other than terms used in the search query).

Cumulate occurrence of abstract trigrams (Fig. 9b) provides more comprehensive insights of research contents. The phrase "food production systems" dominated in the analysed area over 25 years since 1991. In 2016 the trigram "sustainable food systems" received higher rates and is demonstrating an exponential growth of occurrence since that. According to abstract trigrams, modern view of the SFS concept and measurement is embodied mainly in "sustainable food system (systems)", "life cycle assessment", "food system sustainability", followed by the growing trends like "future food systems", "sustainable landscape governance", "city region food", and "artificial intelligence".



a) authors' keywords (top 10)



b) abstracts trigrams (top 10)

***Figure 9**. Word growth measured by cumulative occurrence*
***Source**: authors' development via Biblioshiny app (R Core Team, 2014; Aria & Cuccurullo, 2017; RStudio Team, 2020)*

To show common visions and variety of approaches to the SFS concept and measurement, documents were coupled by references and clustered (Fig. 10). The following threshold values and settings were used in the analysis: number of documents – 250; minimum cluster frequency – 5; impact measurement – a global citation ranking; cluster title – three author keywords. Cluster entitled "sustainability, agri-food products, agri-food systems" is the most relevant in terms of global citations (impact value of 5.03), while cluster "sustainability, food security, agriculture" is the least (1.61). Despite the common keyword used (sustainability), identified clusters disclose different views on the concept and measurement of the food system sustainability, putting emphasis on food security and food system (green-coloured cluster), food security and agriculture (blue-coloured), agri-food products and systems (purple-coloured). Cluster with keywords "food system, food systems, sustainable food systems" embraces documents with the most frequent references, while documents in the cluster with the highest impact reference the least frequent sources.

Words co-occurrence network graph shows the insights of SFS concept and measurement studies (Fig. 11). Build by abstracts unigrams with Louvain clustering, association strength normalisation, and Fruchterman and Reinghold shaping approach, Figure 11 illustrates four contextual clusters with the dominance of block combining issues of systematicity, sustainability, food, environmental aspects, approach, and frameworks. Another, slightly less relevant cluster embraces terms like development, research, policy, change, challenges, and agriculture. The word "production" is largely accompanied by analysis, consumption, and current state. Sustainability assessment studies comprises indicators, data, levels, results, and knowledge. Changes in the research subject are well illustrated with the thematic evolution map (Fig. 12).

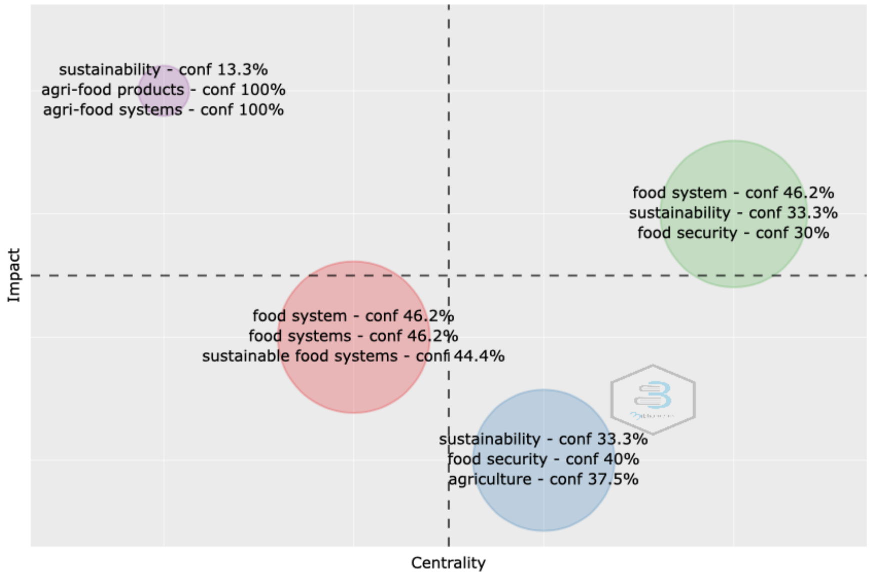


***Figure 10**. Clusters of documents coupled by references*
***Source**: authors' development via Biblioshiny app (R Core Team, 2014; Aria & Cuccurullo, 2017; RStudio Team, 2020)*

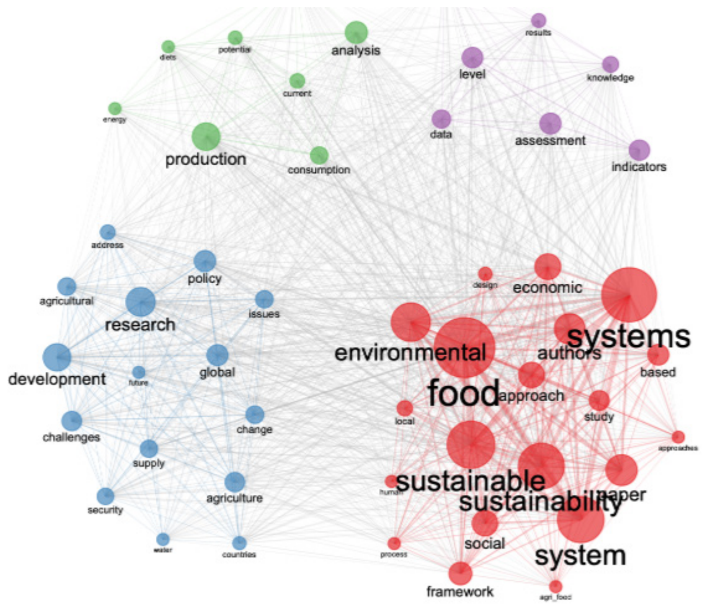


***Figure 11**. Abstracts' unigrams co-occurrence network*
***Source**: authors' development via Biblioshiny app (R Core Team, 2014; Aria & Cuccurullo, 2017; RStudio Team, 2020)*

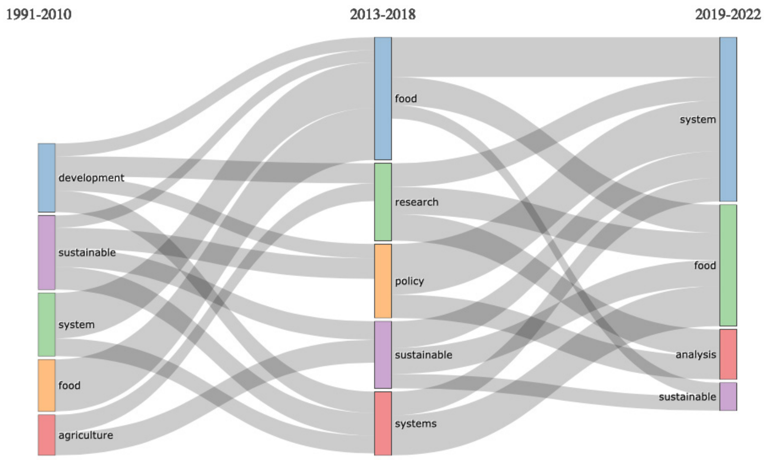


***Figure 12**. Thematic evolution map by abstracts' unigrams*
***Source**: authors' development via Biblioshiny app (R Core Team, 2014; Aria & Cuccurullo, 2017; RStudio Team, 2020)*

Previously identified periods of scientific interest growth (Fig. 1) were used to set up historical stages of research field (the SFS concept and measurement) development. The following settings were applied: the inclusion index weighted by word co-occurrence with the threshold value of minimum 0.1, the minimal number of words – 250, and minimum cluster frequency of 20. Applying abstract unigrams approach allows revealing the broader context compared to keywords. The results obtained show the dominance of system and food concerns in recent studies (2019-2022), while studies of 1991-2010 were focused on development, sustainable, system, food, and agriculture issues. Period of 2013-2018 is characterised by the balancing of research, policy, sustainable, system aspects with a slight dominance of food issue.

Concept map gives a measure of relatedness among single notions within the research field – the closer the terms are on the concept map, the more similar they are in use. Conceptual map of abstracts' bigrams was constructed by multiple correspondence analysis (MCA) approach with the following threshold values: number of terms – 50; number of documents – 5 (Fig. 13). Upon doing that, two clusters of scientific thoughts were specified: 1) cluster dominated by issues of sustainability assessment (the growing trend) centred around food supply, agri-food systems, supply chains, food security, climate change; 2) cluster comprising research focused on environmental impacts, food consumption, sustainable diets, and life cycle assessment. Commenting on the relatedness of the concepts covered, one should emphasise the relations between "local level" and "nutrition security"; "sustainability" and "system thinking"; "future research", "climate change" and "agri-food systems"; "agricultural production" and "environmental sustainability".

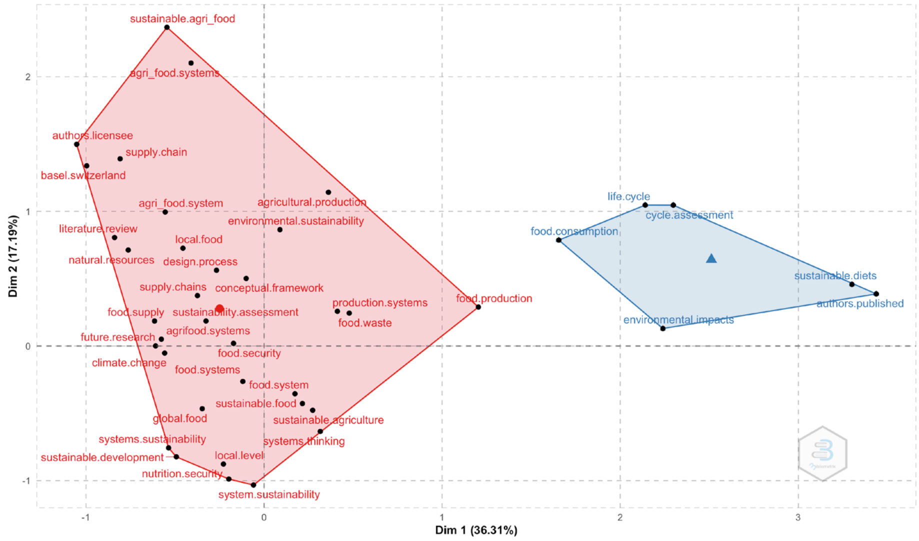


***Figure 13**. Conceptual structure map: MCA approach by abstracts' bigrams*

***Source**: authors' development via Biblioshiny app (R Core Team, 2014; Aria & Cuccurullo, 2017; RStudio Team, 2020)*

Finally, to show research contents it is desirable to analyse the most globally cited documents (Table 2). The most cited papers focus on the complexity of food systems that causes difficulties in conducting sustainability assessments by means of life cycle assessment (LCA) (Heller & Keoleian, 2003; Notarnicola *et al.*, 2017), explore the research priorities in assessment of food system sustainability (Soussana, 2014), investigate organisational issues promoting the innovation-based food system sustainable development (Berti & Mulligan, 2016; Meynard *et al.*, 2017).

***Table 2**. Top 10 global cited documents (by total citations per year)*

Paper	Total Citations (TC)	TC per Year
Notarnicola, B., Sala, S., Anton, A., McLaren, S.J., Saouter, E., & Sonesson, U. (2017). The role of life cycle assessment in supporting sustainable agri-food systems: A review of the challenges. *Journal of Cleaner Production*, 140, 399-409. doi: 10.1016/j.jclepro.2016.06.071	197	39.4
Meynard, J.-M., Jeuffroy, M.-H., Le Bail, M., Lefèvre, A., Magrini, M.-B., & Michon, C. (2017). Designing coupled innovations for the sustainability transition of agrifood systems. *Agricultural Systems*, 157, 330-339. doi: 10.1016/j.agsy.2016.08.002	92	18.4
Schader, C., Muller, A., El-Hage Scialabba, N., Hecht, J., Isensee, A., Erb, K.-H., Smith, P., Makkar, H.P.S., Klocke, P., Leiber, F., Schwegler, P., Stolze, M., & Niggli, U. (2015). Impacts of feeding less food-competing feedstuffs to livestock on global food system sustainability. *Journal of the Royal Society Interface*, 12(113). doi: 10.1098/rsif.2015.0891	104	14.86

Table 2, Continued

Paper	Total Citations (TC)	TC per Year
Gustafson, D., Gutman, A., Leet, W., Drewnowski, A., Fanzo, J., & Ingram, J. (2016). Seven food system metrics of sustainable nutrition security. *Sustainability*, 8(3). doi: 10.3390/su8030196	88	14.67
Berti, G., & Mulligan, C. (2016). Competitiveness of small farms and innovative food supply chains: The role of food hubs in creating sustainable regional and local food systems. *Sustainability*, 8(7). doi: 10.3390/su8070616	74	12.33
Schader, C., Grenz, J., Meier, M. S., & Stolze, M. (2014). Scope and precision of sustainability assessment approaches to food systems. *Ecology and Society*, 19(3). doi: 10.5751/ES-06866-190342	87	10.86
Di Vaio, A., Boccia, F., Landriani, L., & Palladino, R. (2020). Artificial intelligence in the agri-food system: Rethinking sustainable business models in the COVID-19 scenario. *Sustainability*, 12(12). doi: 10.3390/SU12124851	16	8
Heller, M. C., & Keoleian, G. A. (2003). Assessing the sustainability of the US food system: A life cycle perspective. *Agricultural Systems*, 76(3), 1007-1041. doi: 10.1016/S0308-521X(02)00027-6	149	7.84
Allen, T., & Prosperi, P. (2016). Modeling Sustainable Food Systems. *Environmental Management*, 57(5), 956-975. doi: 10.1007/s00267-016-0664-8	46	7.67
Soussana, J.-F. (2014). Research priorities for sustainable agri-food systems and life cycle assessment. *Journal of Cleaner Production*, 73, 19-23. doi: 10.1016/j.jclepro.2014.02.061	52	6.5

***Source**: authors' development via Bibliometrix (R Core Team, 2014; Aria & Cuccurullo, 2017; RStudio Team, 2020)*

Scholars point out and discuss the main problems, caused by food systems complexity, concerning the LCA sustainability assessment: the right choice of a unit of analysis; difficulties to incorporate and assess the alternative and multifunctional value of biological resources and ecosystems; measuring and modelling of emissions; the need to assess consumer behaviour within the LCA (Notarnicola *et al.,* 2017). M.C. Heller & G.A. Keoleian (2003) suggest developing indicators to measure environmental, economic, and social impacts along the whole food production value chain, note the need to change consumer behaviour to ensure the sustainability of food systems (Heller & Keoleian, 2003). J.-F. Soussana (2014) proposes to improve the LCA methodology through inclusion of natural capital and public health concerns to assess the food system sustainability (Soussana, 2014). C. Schader et al. (2014) and D. Gustafson et al. (2016) investigate other approaches to measure the food system sustainability including that measuring the nutritional adequacy and safety (Gustafson *et al.,* 2016). However, LCA-focused studies predominant in the field of SFS measurement research.

Specification of the main SFS attributes, a search for trade-offs, overcoming suboptimality in decision-making concerning the composition and functioning of the SFS (Allen & Prosperi, 2016); an introduction of innovations to support sustainable transformation of food system based on a system thinking and network development (Meynard *et al.,* 2017); organisational changes supporting better introduction of new technologies for the sustainability of food systems (Berti & Mulligan, 2016), in particular, digitisation (Di Vaio *et al.,* 2020) – these are the main issues covered by the most cited papers.

CONCLUSIONS

Results of the study show that research on the concept and measurement of food system sustainability has a long history starting in 1991, when the first paper was published (indexed by Scopus). Since then, a scientific interest to this topic has been growing wave-like, with peaks following the global food crises existence pattern and admission of the problem by the global institutions like FAO. Despite the wave-like course, there is a tenfold increase in the number of publications for 2013-2020. The United States, Italy, and France are leading countries in this research area by the number of published and cited documents. Among them, Italy dominates in international collaboration: the number of publications engaging authors from different countries even exceeds the number of domestic authored publications. There are distinguished two main geographical clusters of scientific collaboration: European, led by Italy, and American, guided by the USA and France. The top three relevant organisations consist of University Paris-Saclay (France), University of Sydney (the USA), and Wageningen University and Research (the Netherlands). Sustainability (Switzerland) was found to be the most relevant source for publishing research on the concept and measurement of food system sustainability.

Although the most frequent authors' keywords include "food system", "food security", "agriculture", terms "indicators", "agroecology", "food", "resilience" are of growing use. Modern perception of the SFS concept and measurement (since 2018) is intertwined in the notions of systems and system thinking, sustainability, and life cycle assessment. The comprehensive vision of sustainable food system seemingly goes behind the food production and embraces the system-wide perspective. The results of factorial analysis (conceptual structure map) confirm this thesis to a certain extent: studies focused on food supply, agri-food systems, supply chains, food security, climate change are dominant and close to the growing trend of sustainability assessment. Conceptual mapping discloses a variety of visions and understandings that are relevant to the SFS and allows suggesting the complex and multifaceted nature of the concept. However, food, environmental aspects, agriculture, agri-food systems, and life cycle assessment are still the main terms constituting the core of research on the concept and measurement of SFS with a little attention given to social and economic aspects of food system sustainability.

Due to the complexity of the SFS connotation, the elaboration of one-size-fits-all policy and solutions are unlikely. In view of this, further research on the concept, measurement, and governance of food system sustainability should go in line with concrete institutional, economic, social, and natural environment. Studies from developing countries are of special interest in this case.

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Концепція та вимірювання сталості продовольчої системи: бібліометричне дослідження

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Анотація. В умовах змін клімату та зростання населення, забезпечення сталості продовольчої системи є глобальною проблемою. Багато політик регулюють це питання, але останні дані показують, що глобальна (і національні) продовольчі системи ще далекі від сталого стану. Удосконалення існуючої політики у сфері регулювання продовольчої системи вимагає чіткого розуміння самої концепції сталого розвитку продовольчої системи: уточнення її ознак, атрибутів, показників для оцінки та цілей. Ці питання відображені у багатьох наукових роботах, але жодна з наявних не підсумовує основні тенденції, зміст та особливості еволюції концепції сталого розвитку продовольчої системи. У цьому дослідженні вперше узагальнено історію та зміст досліджень щодо концепції та вимірювання сталості продовольчої системи шляхом бібліометричного аналізу робіт у Scopus за 1991–2022 роки. Встановлено хвилеподібне зростання наукового інтересу до цієї теми, де лідерами є дослідники із США, Італії та Франції, з піками, що збігаються із часом виникнення глобальних продовольчих криз. Результати цього дослідження показують, що сучасне сприйняття концепції (з 2018 р.) є складним і відображено у тісно пов'язаних поняттях системності та системного мислення, стійкості та оцінки життєвого циклу, на відміну від попередніх поглядів (1991–2018 рр.), що концентрувались на системі виробництва продовольства та продовольчій безпеці. Загалом, мало уваги приділяється соціальним та економічним аспектам сталості продовольчої системи, на відміну від екологічних, продовольчих та агропродовольчих питань. Підкреслено, що розробка універсальної політики та рішень, що сприяють стійкості харчових систем, є малоймовірною через складність сприйняття концепції. Управління сталим розвитком продовольчої системи має відповідати конкретним інституційним, економічним, соціальним і природним умовам, які потребують всебічного вивчення в майбутньому. Особливий інтерес у цьому контексті представляють дослідження умов країн, що розвиваються

Ключові слова: стале продовольство, еволюція концепції, оцінка, bibliometrix, biblioshiny