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Mapping the contribution of agroecological transitions to the sustainability of food systems

Conceptual framework and available scientific knowledge

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Abstract

By mapping the potential interactions between two conceptual frameworks of agroecology (HLPE 2019) and food systems (David-Benz et al. 2022), and by analyzing the scientific literature focusing on the agroecology/food system interface, a wide variety of links has been identified between 13 agroecological principles and four sustainability dimensions of food systems. They illustrate the multidisciplinary of these subjects and the potential contribution of the agroecological transition towards more sustainable food systems. The sustainability dimension “food security, nutrition and health” on the one hand, and the agroecological principles of biodiversity, co-creation of knowledge and social values on the other hand, appear to be the most addressed aspects of the interface. On the contrary, other agroecological principles and sustainability dimensions of food systems need further research. These include among others the equity within food systems and the principles of land and resources governance, input reduction, recycling and economic diversification. The farm/agricultural system scale is the most covered segment of food value chains, while mid-stream segments would benefit from being further explored, just like multi-scale/multi-dimensional/multi-actors research is needed to allow deeper understanding of systems and trade-offs. The key findings of this report are expected to usefully assist and guide further researches relevant to the agroecological transition towards the sustainability of food systems.

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1 Introduction

Though the notion of agroecology has evolved independently for several decades in different parts of the world, and a precise definition of agroecology and of agroecological systems remains challenging, there are three definitions or frameworks on which scientists and practitioners seem to agree: the definition of agroecology as (multidisciplinary) science, set of practices and social movement (Wezel et al. 2009; Méndez et al. 2013), the 10 elements of agroecology as an analytical framework to support the design of differentiated paths for agriculture and food systems transformation (Barrios et al., 2020), the 13 HLPE principles constructed from the literature on agroecology as manifest as a science, a set of practices and a social movement (Wezel et al., 2020; HLPE 2019).

Such definitions and frameworks highlight the multiple dimensions of the concept, which relates to agricultural production, ecological principles, social impacts, economic performance, food sovereignty, right to food, social justice, governance, addressing thus the whole food system and beyond.

Moreover, as noted in (HLPE 2019), agroecology can provide possible transition pathways towards more sustainable farming and food systems. On the one hand, the agroecological approach tends to optimize environmental interactions, to favour the use of natural processes, to limit input imports, to promote resource recycling and use efficiency. On the other hand, it considers the globality of the socio-ecological system around production, in particular improving social relationships between local actors, farmers' empowerment to conduct changes and to negotiate favourable conditions to develop their activity. In addition, agroecology promotes the use of local knowledge and participatory approaches to improve scientific and technical knowledge through experience (HLPE 2019; Barrios et al. 2020).

The concept of a food system emerged in 1990 and is defined by (Malassis 1994) as a way by which people organize themselves in space and time to produce, obtain and consume their food. This definition has evolved and has become more complex with the industrialization and globalization of production and distribution systems (Bidaud et al. 2017; Dury et al. 2019). A systemic approach became necessary to account for this complexity at multiple scales (Prosperi et al. 2016; Dury et al. 2019; Béné et al. 2019; David-Benz et al. 2022). Current definitions aim to integrate all supply chains in the system, considering their actors, activities, and functional role in the flow of food.

Today, despite a global surplus, agricultural production is not sufficient in several regions of the world to sustainably support food and nutrition security (FAO 2019). In 2015, Sustainable Development Goals (SDGs) were adopted by UN Member States. In particular the SDG2 "Zero hunger" aims to eradicate hunger and malnutrition by 2030 through access to safe, nutritious, and adequate food for all (UN 2016). Moreover, as recognised at the UN Food Systems Summit 2021, food systems are on one hand substantially contributing to global greenhouse gas (GHG) emissions, to erosion of biodiversity, environmental pollution, degradation of land and water resources, on the other hand are increasingly impacted by climate change. With a large proportion of the population working in agriculture or in other segments of the food supply chains, food systems are also likely to contribute to different social and economic SDGs, linked to poverty and equity.

Moving to sustainable food systems has been recognized as an essential solution to these existing challenges. In addition, recent reports from several intergovernmental research groups maintain that a transformation of our food systems is needed to meet these international goals (IPBES 2018; IPCC 2019; UNCCD 2017). In this context, the development of sustainable agriculture has become a priority to meet the commitments of the 2030 Agenda. The FAO then recognized that agroecology could play a significant role in the transformation needed to meet the SDGs and address global environmental, food, and societal challenges (Barrios et al. 2020). In the frame of the UN Food Systems Summit 2021 the need to boost nature-based solutions, and among these agroecology, is one of the five key actions track for moving towards sustainable food systems.

In parallel to policy developments and global agreements, since the early 2000s more and more research programs on agroecology have been conducted around the world. As a result, literature on agroecology is growing in numbers, gathering papers of various nature (e.g. field experiences, methodologies, conceptual frameworks, scenario exercises, reviews etc.). These cumulated experiences fed a global reflection to define better the different principles of change linked to agroecological transitions. Such bulk of literature represents thus the current global state of knowledge on agroecology, that, when organised in a systematic way can illustrate how agroecology may contribute to improving sustainability in food systems.

To do so, the aim of this work is to develop a conceptual framework of the interactions between agroecological transitions and food systems through a literature review, and to highlight both the well- and under-studied interactions between both concepts. The general objective is to revisit current knowledge on the contribution of

agroecology to the sustainability of food systems. It is expected to usefully assist and guide further researches relevant to the agroecological transition toward the sustainability of food systems.

Chapter 2 focuses on the conceptual frameworks used to represent the potential links between agroecology and food systems. In relation to the identified reference framework, Chapter 3 presents the methodology used to identify and analyse the scientific literature on the agroecology-food system interface. In Chapter 4, the potential links identified by a panel of experts and the critical analysis of the specific literature targeting simultaneously agroecology and the food system are computed in order to describe more in depth identified links as well as remaining knowledge gaps.

The Knowledge Centre for Global Food and Nutrition Security⁽¹⁾, part of the EU Commission's platform for evidence-based policymaking, has coordinated the present study.

¹ https://knowledge4policy.ec.europa.eu/global-food-nutrition-security/about_en

2 Identification and description of links at the agroecology - food system interface

2.1 Conceptual frameworks

The procedure adopted to create a conceptual framework, suited to the identification of the interactions between agroecology and food systems, is based on the identification of existing reference frameworks for both the two concepts. The choice of setting as reference existing frameworks rather than creating a new ad-hoc one is especially linked to the need to explore existing scientific literature. Linking keywords and concepts already present in literature to such an overarching framework, besides easing the process, grounds the results into the present common understanding of agroecology and the food system.

2.1.1 Food System

Existing food system frameworks have been considered (HLPE 2017; TEEB 2018; UNEP 2019, David-Benz et al. 2022). Given the need to identify the framework allowing an optimal match with agroecology principles, David-Benz et al. (2022) was selected. Compared to the other three frameworks, in fact, it is considering, in addition to food security and nutrition, socioeconomic and environmental sustainability impacts, also territorial balance and food system equitable management as fourth sustainability outcome of the food system. Agroecology transitions take place at the territorial scale and foster rural-urban linkages in a sustainable and equitable way, and taking the territorial dimension into consideration is key.

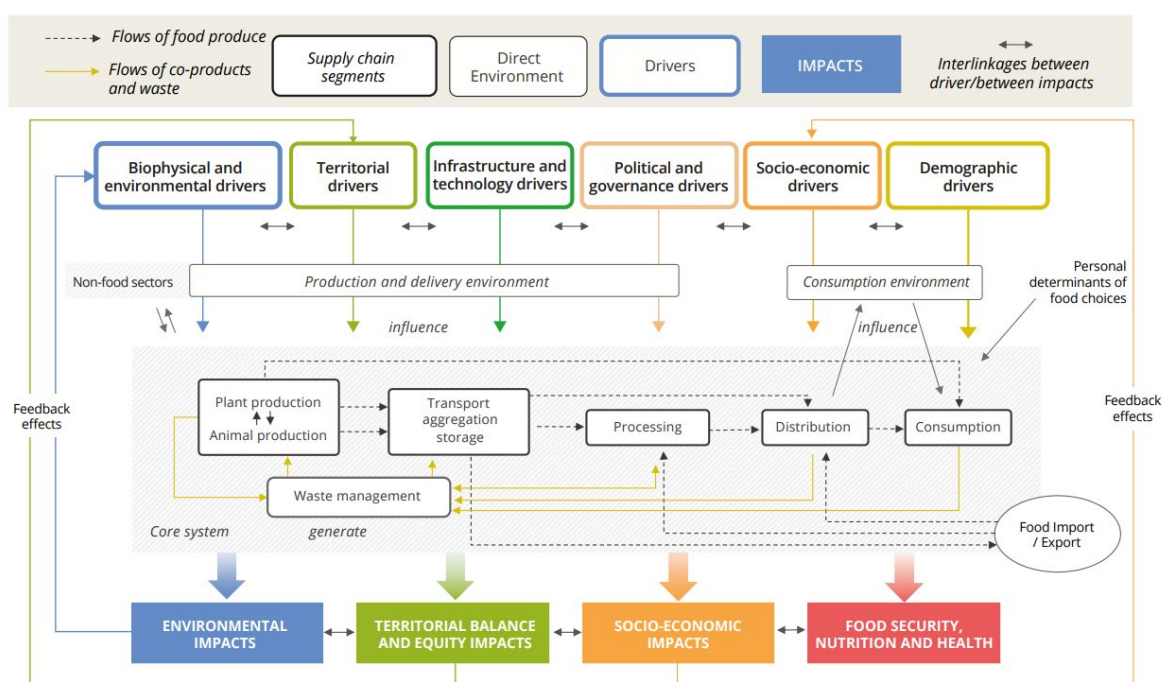
David-Benz et al. 2022 describe food systems as encompassing *“the range of actors and their activities involved in food supply chain functions, including their direct environment and the drivers that influence them, as well as their long-term impacts on the main sustainability dimensions, which in turn affect the other elements via feedback loops”*. The four identified dimensions are therefore embedded into a wider frame (Figure 1) including:

- (i) food supply chain actors and activities (production, storage, processing, distribution, consumption and waste management);
- (ii) drivers (biophysical and environmental drivers; demographic drivers; socioeconomic drivers; political drivers; territorial drivers (stability, balance); and infrastructure and technological drivers)
- (iii) direct environments, are those in which actors operate, and that influence the way food systems function as well as the production practices applied by different actors and their relative performance ;
- (iv) direct consumption environments, representing the interface between food distribution actors and activities and consumers (availability of food in terms of proximity/physical accessibility of sales points; diversity; affordability; promotion/advertising/information; labelling; product safety and quality);
- (v) the four dimensions of sustainability impacts mentioned above:
 - Food security, nutrition and health: provide sufficient, healthy and balanced food, in order to meet the needs and preferences of all people in a stable manner and to contribute to their health.
 - Socioeconomics: provide decent livelihoods and employment for all actors in the food system, including smallholders, women and youth, and contribute to inclusive economic growth through the food sector (from production to distribution) and an improved food trade balance
 - Territorial balance: contribute to an equitable distribution of power and resources among food system actors and to a balanced territorial development, in order to promote stability and equity
 - Environment: manage, preserve/ regenerate ecosystems, biodiversity and natural resources, and limit their effects on climate change.

2.1.2 Agroecology

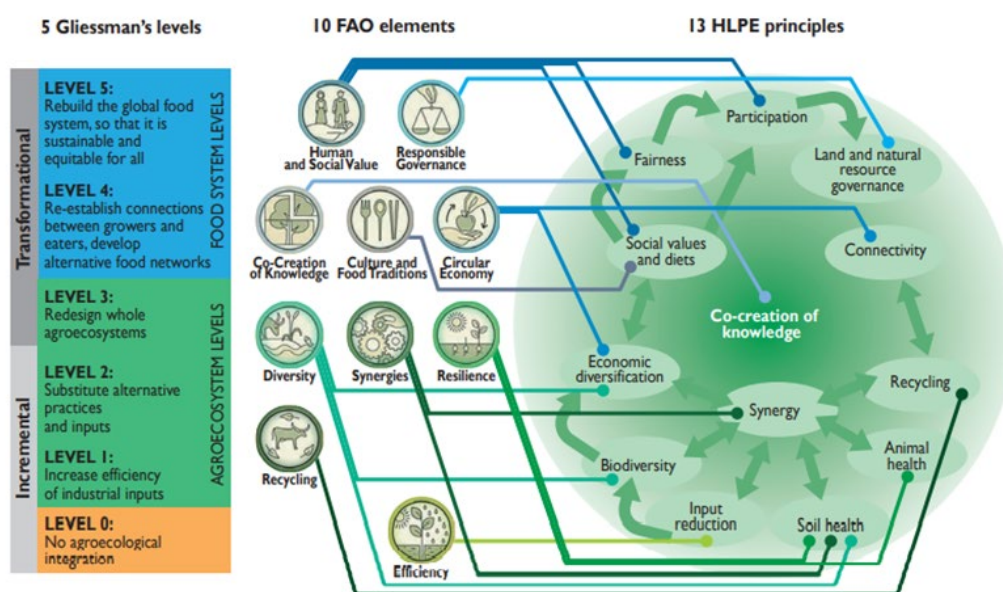
The conceptual frame for agroecology that was identified as suitable for the present study is HLPE 2019. It describes agroecology through 13 principles, addressing agricultural and ecological management of agrifood systems as well as taking into account socio-economic, cultural and political aspects presented in Table 1. These principles can be grouped in three categories (resource efficiency, resilience, and social equity/responsibility). Other two relevant frameworks are Gliessman (2016), which theorizes the levels of agroecological transitions, and Barrios et al. 2020 which describes the 10 elements of agroecology identified by FAO as analytic tool to plan, manage and evaluate agroecological transitions (FAO, 2018). Figure 2 shows how principles and elements are linked to the agroecological transition.

Figure 1. Food system conceptual framework.



Source: David-Benz et al. 2022.

Figure 2. Levels of agroecology transitions and agroecology principles.



Source: Wezel, 2020.

2.2 Identification of potential links between agroecology and the food system

In order to identify potential links between agroecology and the food system, a set of scientific articles was screened, and a panel of researchers in both agroecology and food system fields was identified and interviewed. Based on expertise of the interviewed scientists, potential interactions between agroecology and the food system were identified, and the possible nature of these connections were described. These links are theoretical and not exhaustive but illustrate the current vision on potential interactions. The results of this first part of the study are presented in Chapter 4 per each agroecology principle (Table 1).

In Chapter 4 results are illustrated through a graphic representation of the links per each of the 13 agroecology principles in relation to the schematisation of the food system. Direct links are represented with a continuous line, indirect links with a dashed line; each link connects to a corresponding sub-element of the food system. A corresponding table provides a more detailed description of the links identified by the experts.

Table 1. Definitions of agroecology principles (source: HLPE, 2019).

Principle	Definition
Improve resource efficiency	
Recycling	Preferentially use local renewable resources and close as far as possible resource cycles of nutrients and biomass
Input reduction	Reduce or eliminate dependency on purchased inputs and increase self-sufficiency
Strengthen resilience	
Soil health	Secure and enhance soil health and functioning for improved plant growth, particularly by managing organic matter and enhancing soil biological activity
Animal health	Ensure animal health and welfare
Biodiversity	Maintain and enhance diversity of species, functional diversity and genetic resources and thereby maintain overall agroecosystem biodiversity in time and space at field, farm and landscape scales
Synergy	Enhance positive ecological interaction, synergy, integration and complementarity among the elements of agroecosystems (animals, crops, trees, soil and water)
Economic diversification	Diversify on-farm incomes by ensuring that small-scale farmers have greater financial independence and value addition opportunities while enabling them to respond to demand from consumers
Secure social equity/responsibility	
Co-creation of knowledge	Enhance co-creation and horizontal sharing of knowledge including local and scientific innovation, especially through farmer-to-farmer exchange.
Social value and diets	Build food systems based on the culture, identity, tradition, social and gender equity of local communities that provide healthy, diversified, seasonally and culturally appropriate diets.
Fairness	Support dignified and robust livelihoods for all actors engaged in food systems, especially small-scale food producers, based on fair trade, fair employment and fair treatment of intellectual property rights.
Connectivity	Ensure proximity and confidence between producers and consumers through promotion of fair and short distribution networks and by re-embedding food systems into local economies.
Land and natural resource governance	Strengthen institutional arrangements to improve, including the recognition and support of family farmers, smallholders and peasant food producers as sustainable managers of natural and genetic resources.
Participation	Encourage social organization and greater participation in decision-making by food producers and consumers to support decentralized governance and local adaptive management of agricultural and food systems.

3 Systematic search of agroecology and food system-related literature

In this chapter the process to identify relevant literature describing how agroecology can improve food systems sustainability is described. To carry out this study, a corpus of articles addressing agroecology and food systems simultaneously was identified and screened. The protocol for selecting scientific papers and analysing them is presented in this chapter.

3.1 Methods

3.1.1 Literature selection method

Peer-reviewed articles related to food system and agroecology were sought in the online library "Web of Science" (WoS). The first step consisted in building a search equation based on the terms "agroecology" and "food systems". Then, to select relevant articles, the topic was divided into sub-topics and search equations were developed for each sub-topic to cover all categories of contribution of agroecology to food system's sustainability.

3.1.2 Search string

The search string, defined around agroecology and food system concepts, was the following:

TS = ("food system\$" or "agrifood system\$") AND TS = ("agroecolog*" or "agro ecolog*")

In the rest of this report, we call the *main corpus* this first corpus extracted from this initial search string.

3.1.3 Subtopic search equations

3.1.3.1 Splitting the main topic into subtopics

The main topic was split into sub-topics by maintaining the same scheme used in Chapter 2. Based on the conceptual frameworks of agroecology (AE) developed by HLPE 2019, and of food systems (FS) developed by David-Benz et al. (2022), each concept was split into items, or subtopics, as follows.

For the AE part, the agroecological principles of HLPE (HLPE 2019) were used. Considering that 'soil health' and 'animal health' have been addressed in the same item, 12 *AE search equations* were designed. For the FS part, the conceptual framework the four dimensions of FS sustainability (Food Security, Nutrition, and health (FSN); Environment; Socioeconomic; and Territorial balance and equity) were identified as reference, thus, 4 *FS search equations* were built.

3.1.3.2 Identification of keywords

In this step relevant keywords (in English) were identified for each item, to build the 16 sub-topic search equations. To do this, three strategies were applied:

- keywords from the definition of each AE principle and FS category were identified, based on the vocabulary used in some of the articles in this field already identified.
- Other terms were selected from search equations proposed by DIST, CIRAD's scientific and technical information department.
- Subsequently, synonyms associated with these first keywords from the FAO Agrovoc dictionary were identified.

This set of keywords was tested during the design of the search equations process (Appendix 1). Plurals, derivatives, and other syntactic variations of these words were tested and, if necessary, included (e.g., considering plurals with the acronym "\$", prefix or suffix with the acronym "*", etc.).

3.1.3.3 Search equations design and validation

Subsequently, a search equation was built per-item with specific but sufficiently common keywords to have a wide variety of documents returned. By combining pairs of the per-item search equations within the initial *search repository*, a list of documents appropriate to each of the search sub-topic was expected to be returned, illustrating very specific links across the categories of the AE/FS interface. By proceeding this way, a large proportion of off-topic documents was removed, while retaining articles relevant to the search frame, i.e., related to the concept of AE and FS.

These search equations were tested in WoS and readjusted to obtain a sufficient and representative corpus of articles for each item:

- a simple search equation with the name of the item was constructed and tested in the repository (i.e., combined with the search equation "*search repository*" by the conjunction "AND").
- the keywords were added one by one to the search equation to test their relevance in the repository building on two tests: (i) a comparative quantitative test consisting in comparing the number of outputs between different search equations on the same item. Keywords providing additional information were kept and others were eliminated; (ii) a quantitative test carried out on the articles eliminated when a search equation was modified (e.g., suppression of a keyword, modification of the formulation). The keywords that led to a bias (e.g., high polysemy) were identified and eliminated. The others were used to build search equations appropriate to the boundaries of each sub-topic.

As initially explained the search was carried out on Web of Science All Databases. The search was run without any temporal limit, the oldest articles present in the databases having been published in the 1950s.

The process for design and validation of search equations is summarized in Figure 3 below, search equations are listed in Table 2 and Table 3.

Figure 3. Search equation design methodology

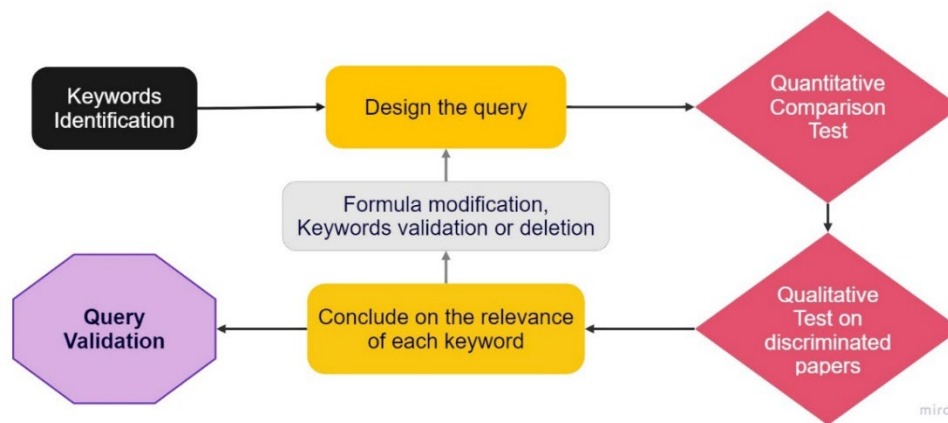


Table 2. AE search equations

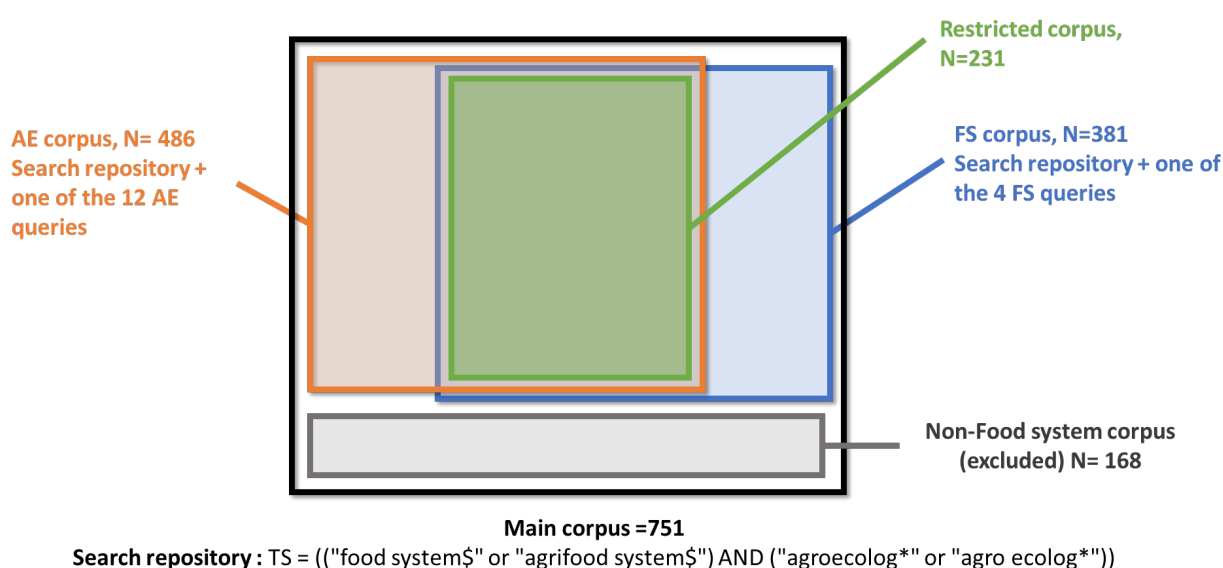
AE Principle	Selected search equations
Input reduction	TS = ("Input\$ reduct*" or "input\$ dependen*" or "low input")
Recycling	TS = ("Recycl*" OR "reus*")
Synergy	TS = (Synerg* OR "Ecological interaction\$" or Integrat* or complementarity)
Biodiversity	TS = ("Biodiversity" OR "biological diversity")
Soil and animal health	TS = ("Soil health" or "Animal health" or "Soil ecosystem*" or "Animal welfare")
Economic diversification	TS = ("Economic diversification" or "Livelihood diversification" or "income\$ diversification")
Social value and diet	TS = (("Social value\$" or "culture\$" or "identity" or "equity") AND ("Food tradition\$" or "diet\$"))
Cocreation of knowledge	TS= ("Co creation" or "codesign" or "co design" or "knowledge shar*" or "communit* of practice" or "social learning" or "collaborative learning" or ("local knowledge" and "scientific knowledge") or "representation or perception")
Connectivity	TS = ("Connectivity" or "proximity" or "circular*")
Participation	TS = ("Participat*" or "decision making" or "social organi?ation" or "producer\$ organi?ation" or "cooperative")
Fairness	TS = ("Fair*" or "Equit*")
Land and natural resources governance	TS = ("land governance" or "land management" or "land use planning" or "natural resource\$ management")
TS means that the keywords are searched among the topics of the articles in the databases. This considers the title, keywords and abstract.	

Table 3. FS search equations

FS sustainability dimensions	Selected search equations
Food Security and Nutrition (FSN)	TS = ("food *security" or "food safety" or "**nutrition")
Socio-economy	TS = ("inclusive development" or "employment" or "economic sustainability" or "socioeconomic sustainability")
Environment	TS = ("environmental sustainability" or "climate change" or "natural resources preservation")
Territorial balance and equity	TS = ("territorial balance" or "territorial develop*" or "territorial equity" or "equitable value chain\$" or ("equit*" AND "value chain\$"))
TS means that the keywords are searched among the topics of the articles in the databases. This considers the title, keywords and abstract.	

3.1.3.4 Data extraction

The 16 search equations (4 FS and 12 AE search equations) were designed independently and allow extracting 16 literature corpuses. *AE corpus* and *FS corpus* are the set of repository articles found at the output of AE search equations and FS search equations, respectively. By intersecting the 12 *AE corpuses* to the 4 *FS corpuses*, 48 (12x4) sets of articles were obtained, each of them referring to one type of AE/FS interface. This was done using a spreadsheet software, directly from the corpuses obtained in the outputs of AE and FS search equations. This leads to a *restricted corpus*, i.e., all the articles in the *search repository* also found in the output of at least one AE search equation and one FS search equation. Figure 4 summarises how literature corpuses are nested and the number of returned or selected documents in the different phases of literature search.

Figure 4. Schematisation of literature corpuses retrieved in the screening process

3.1.4 Method used for the quantitative analysis

First, a bibliometric study was designed, to quantify the importance in the literature of each of the 48 categories of the AE/FS interface, i.e., each of the 48 combinations of two items from different concepts, and to identify the current knowledge gaps which are reflected in the quantity of articles in the output of each search equation. The quantitative analysis was performed on a spreadsheets program. The main corpus and the 16 relative (12 AE and 4 FS) corpuses were imported into the same folder. For each article in the main corpus, their occurrence in each of the relative corpuses was marked. This way a double entry table was drawn, with all AE and FS items as entries. By program processing, search equations were combined and the number of articles related to each of the 48 search equations was obtained.

In addition, articles that did not appear in at least two corpora out of the 16 AE and FS corpora were identified and eliminated, in order to obtain a so-called *restricted corpus* for the qualitative analysis. Then, histograms were drawn, showing the distribution of articles in the *restricted corpus* according to sub-topics. Finally the percentage of articles eliminated from the repository was calculated.

These preliminary results allowed to point out anomalies, in terms of unexpected results, which could in some cases indicate the low relevance of a search equation. This analysis was thus useful for readjusting the corpus by improving the search equations, particularly by adding previously unidentified keywords.

3.1.5 Method used for the qualitative analysis

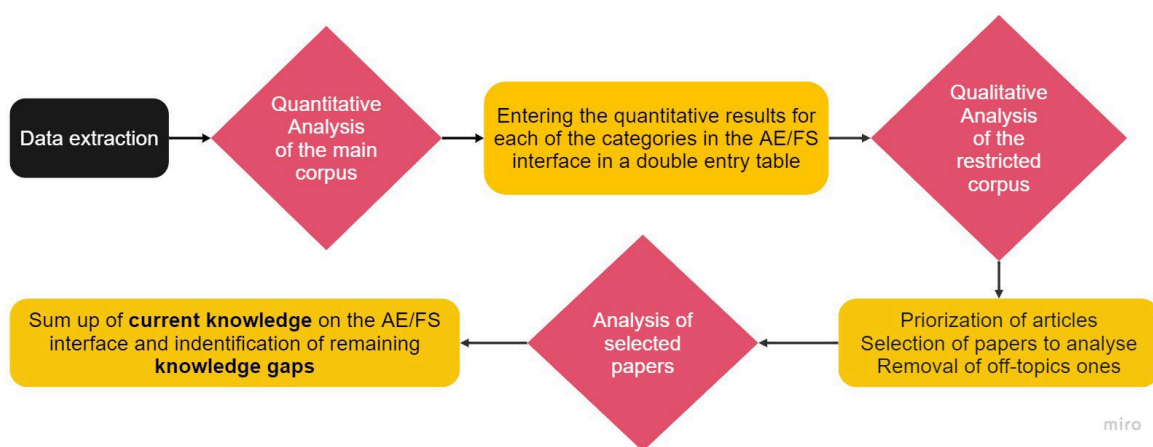
The bibliometric study was coupled with a qualitative analysis of the bibliography. The restricted corpus was explored to assess how the AE/FS interface is addressed in the literature, and in particular how the AE principles might contribute to FS sustainability. Since the search equations yield to a large number of articles, it was necessary to identify those whose reading was a priority. The abstract of each article was screened, with the aim of choosing the most relevant ones. First, duplicates, articles with no PDF, data sheets (n=16) as well as off-topic papers (n=45) were excluded. Then, the criteria to prioritize the articles were: a) highly cited, b) at the interface between FS and AE (based on abstract), c) recent papers and d) reviews. At least three articles from each search equation (i.e., each category of the AE/FS interface) were analysed. This choice was made to obtain a global view of the contribution of AE to FS and to identify knowledge gaps between categories. A final set of 29 papers were identified as most fitting the purpose of this review, and analysed. Hereafter they are discussed in relation to relevant *ad hoc* documents and to the hypothetical relationships formulated in Chapter 2 of this report.

An analytical grid was built indicating the information to be extracted from the articles. In addition to the modes of interaction between AE principles and FS sustainability, the following information was extracted from each article (**Error! Reference source not found.**):

- The date of publication
- The entry concept of the article (AE, SA, or the interface of the two)
- The type of paper (conceptual, methodological, empirical)
- The type of analysis (quantitative, qualitative, or both)
- The AE principles and FS dimensions addressed in the paper
- The geographical area on which the paper focuses
- The scales (e.g., plot, farm, value chain, territory) and value chain links addressed (e.g., production, processing, consumption)
- The types of agriculture studied (smallholders, family farming, agro-industrial, etc.) or farming sector
- For some papers: whether a trade-off analysis was carried out in the case where several AE principles were addressed

The identified literature corpora were then analysed quantitatively and qualitatively as shown in Figure 5.

Figure 5. Literature analysis method



4 Results

4.1 Peer-reviewed literature on agroecology and food system

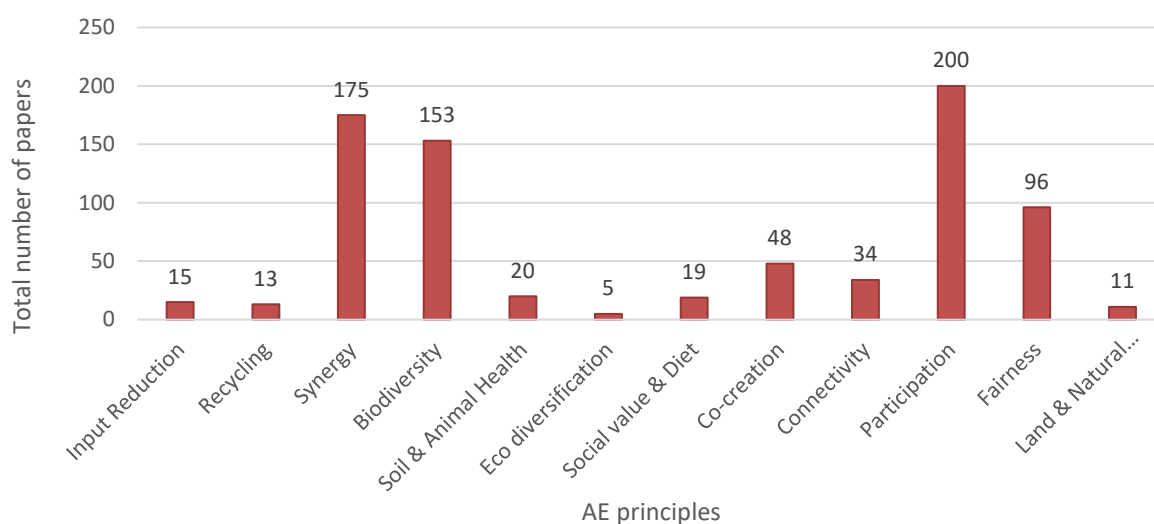
The *main corpus*, i.e., related to the search repository related to agroecology and food systems concepts, resulted composed by 751 articles.

4.1.1 Literature in relation to agroecology principles

The *AE corpus* included 486 articles, which represented 64% of the *main corpus*. Within the AE corpus, the results obtained for each AE principle were uneven. The number of articles ranged from 5 to 200 depending on the AE search equation (Figure 6).

Thus, it became clear that some principles are more studied than others, in relation to FS. The search equations related to the items Participation, Synergy and Biodiversity covered 60% of the outputs of the AE search equations. On the contrary, the search equation associated with the principle Economic diversification returned only 5 papers.

Figure 6. Distribution of AE-related articles, per AE principle

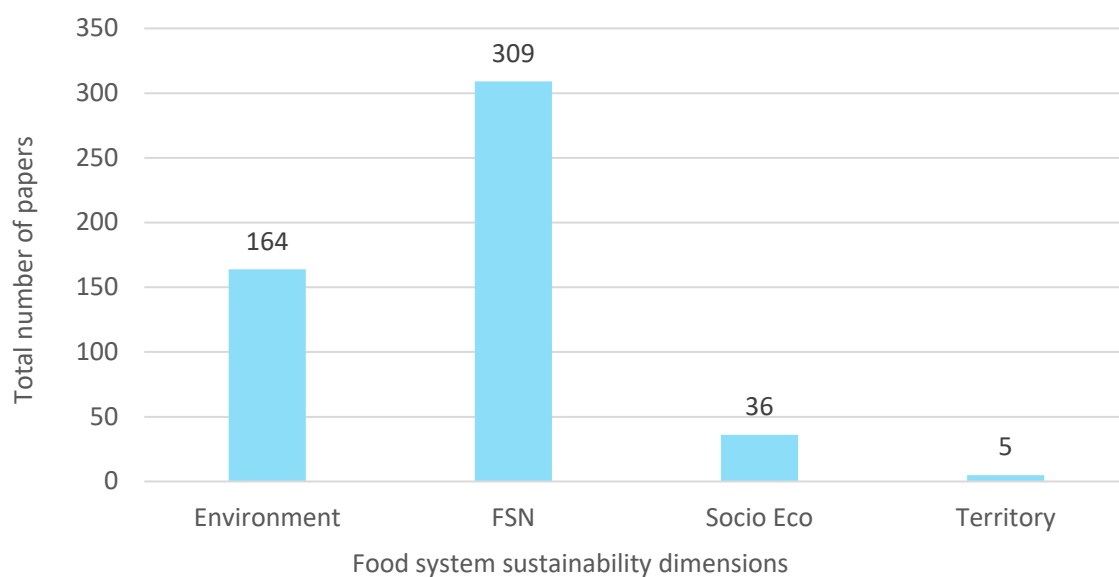


4.1.2 Literature in relation to food system

With 381 articles, the *FS corpus* covered 51%² of the *main corpus*. Within the FS corpus, high disparities were found between the different FS items, from 5 to 309 articles depending on the FS search equation (Figure 7). The categories Environment and Food security, nutrition and health (FSN) covered 92% of all the outputs of the FS search equations. On the contrary, the search equation associated with the Territorial balance and equity dimension of FS sustainability yielded to only 5 articles.

² Some papers were identified in both the AE corpus and the FS corpus, for this reason the share equals to 51% and not to 36% as may be expected

Figure 7. Distribution of FS-related articles, according to FS sustainability dimensions



4.1.3 Results on agroecology/food system interface categories

The *restricted corpus* was composed of 231 articles, which covered 31% of the *main corpus*. Table 4. Number of papers of the restricted corpus, disaggregated by AE principles and FS sustainability dimensions presents the results from each search equation, obtained from the intersection of two search equations in the repository. Again, we noticed a wide disparity in the results, and we spotted both the well-documented categories and the knowledge gaps in the main corpus. The most documented links were those from the most recurrent items in the *main corpus* (combining Environment, FSN, Biodiversity, Participation, Synergies).

Table 4. Number of papers of the *restricted corpus*, disaggregated by AE principles and FS sustainability dimensions

		Environment	FSN and health	Socio-economics	Territorial balance and equity
Improve resource efficiency	Input Reduction	4	7	1	0
	Recycling	2	4	1	0
Strengthen resilience	Synergy	52	89	6	1
	Biodiversity	59	79	9	1
	Soil & Animal Health	9	12	1	0
Secure social equity and responsibility	Co-creation	5	9	1	0
	Connectivity	10	9	1	1
	Eco diversification	4	4	0	0
	Fairness	24	41	5	2
	Land & Natural Resource Governance	2	4	1	0
	Participation	36	67	11	1
	Social value & Diet	10	15	2	1

Reading note: For instance, 79 papers came out of both the equation "FSN and health" ("food *security" or "food safety" or "*nutrition") and the equation "Biodiversity" ("Biodiversity" OR "biological diversity").

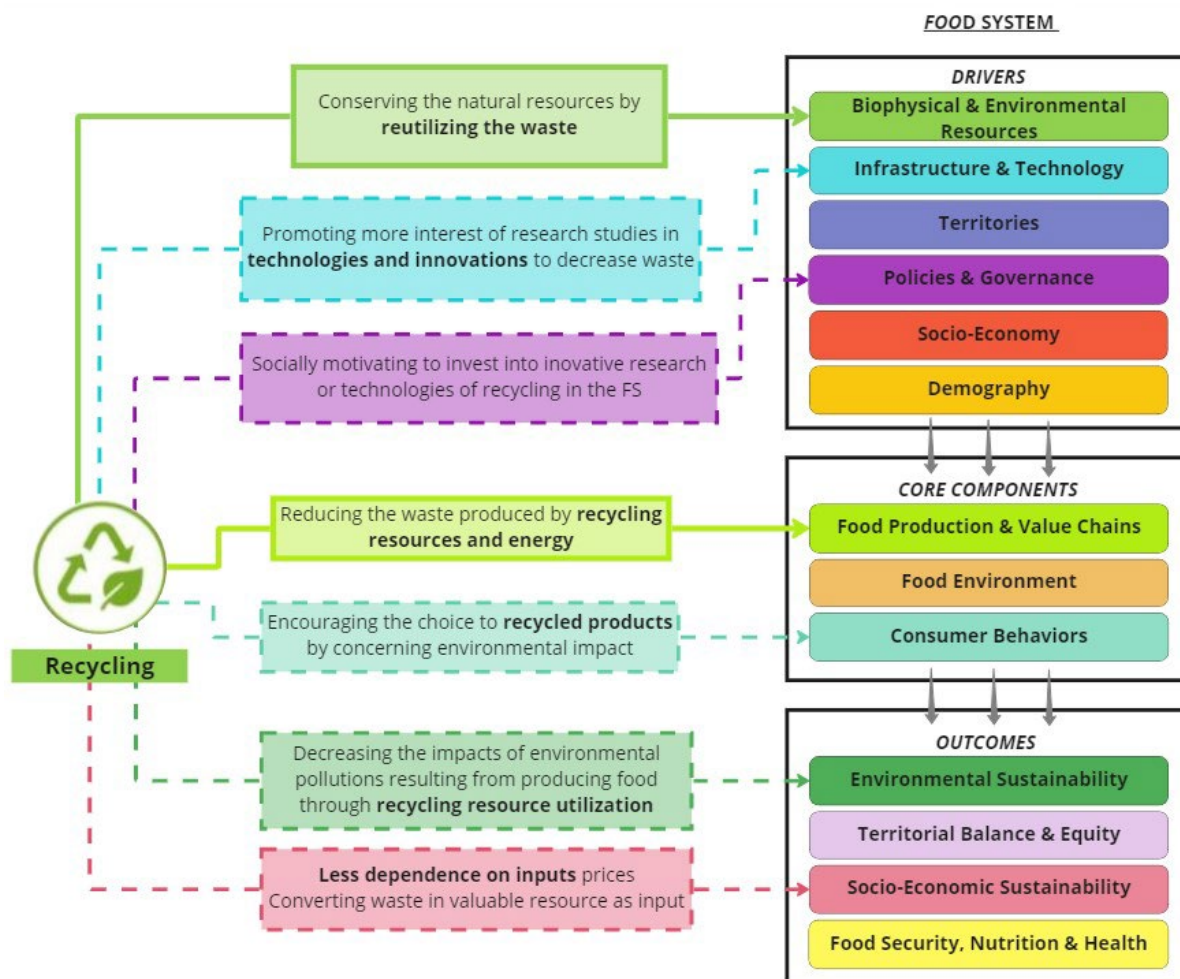
4.2 Knowledge synthesis

Hereafter results on the interlinkages agroecology/food system are presented per agroecology principle following a common scheme: the graph derived from expert consultation and the corresponding description of identified links as described in Chapter 1 are presented, together with a knowledge synthesis derived from the

analysis of the literature presented in Chapter 2. Presenting results from the two approaches allows identifying knowledge gaps (e.g. comparing what is important according to expert knowledge with what is targeted by scientific research). It is noteworthy that many papers discuss several agroecological principles simultaneously and therefore are recurrently cited.

4.2.1 Recycling

Potential links identified by expert knowledge



Links description according to expert knowledge

FOOD SYSTEM		
DRIVERS	CORE COMPONENTS	OUTCOMES
<p>Technology, Innovation, and Infrastructure: Promoting more interest of research studies in technologies and innovations to decrease waste and on waste transformation, with high efficiency and effectiveness to rapidly accelerate the advancement of waste management.</p> <p>Biophysical and Environmental resources: Due to the recycling to produce circularly and sustainably, the natural resources would be preserved which would ensure the viability of production systems in the future.</p> <p>Policies and Governance: The importance of recycling is gaining visibility in society. That may motivate governmental or private sectors to invest even more budgets into the innovative research or technologies for enhancing recycling in the different components of the food systems.</p>	<p>Production and value chains: Recycling of resources or energy into the production (or processing) process dramatically helps to make the food production (or processing) cycle more efficient in term of input use. Consequently, the system is more independent from the fluctuating price of external inputs.</p> <p>Consumer behavior: Encouraging consumers to shift to recycled products by raising awareness on environmental impacts, which have significant effects on the quality of our daily life.</p>	<p>Environmental sustainability: Reutilizing the waste and co-products at each stage of food production is expected to reduce the pressure on non-renewable resources. Therefore, the heavy exploitation and extraction of natural resources would be dramatically decreased, and negative consequences of environmental impacts will also significantly reduce until reaching the eco-equilibrium.</p> <p>Decreasing the impacts of environmental pollution resulting from producing food through recycling resource utilization.</p> <p>Socio-Economic sustainability: Less dependence on input prices and favourable impact on outputs prices (less consumption) and converting waste to be valuable resource functioning as the inputs back for food systems (e.g. biomass to energy).</p>

Findings from literature

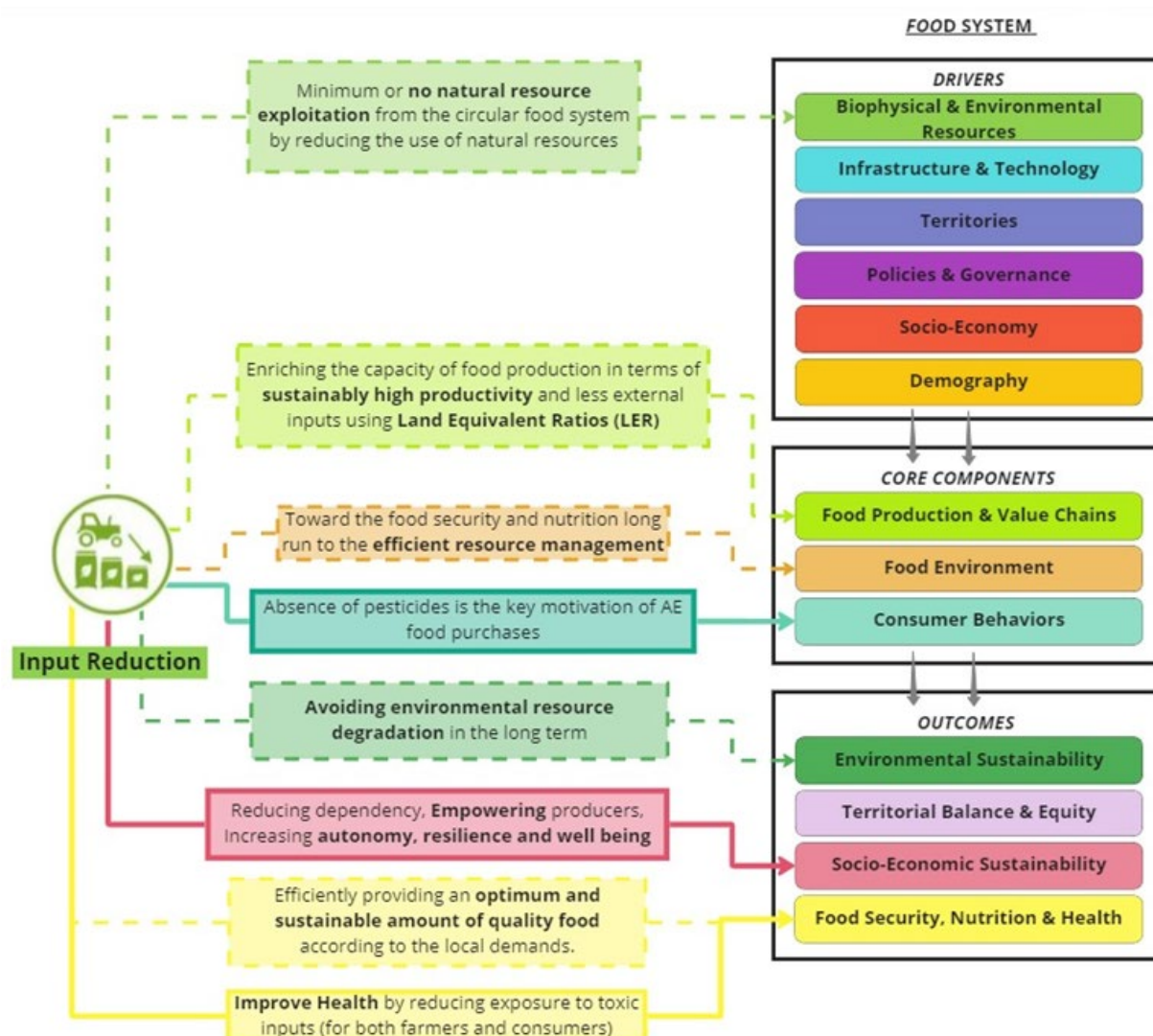
Recycling is central in circular agriculture and food systems, which encompass not only the farm scale and the production process but also the flows of matter and energy at territorial and regional scales, as well as between sectors of the food system. E.g., food waste or processing by-products as biochar recycled back onto agricultural soils to support plant production, fed to animals, or used for biogas production (Woolf et al. 2010; de Boer and van Ittersum 2018). Thus this principle is sometimes addressed in papers that recognize that recycling can positively contribute to agroecosystem's sustainability (Blesh et al. 2019) or in papers that connect the principle of recycling to the circular economy that might be developed in food systems (Zarba et al. 2021).

When true-costs are accounted for, recycling can more likely lead to agricultural production with lower economic and environmental costs (FAO 2014) and improved systems efficiency (Rufino et al. 2007). Re-designing food systems based on the principles of circular economy can also contribute to facing the global food loss and waste challenge by enhancing recycling, making food value chains shorter, and more resource-use efficient (Ghisellini et al. 2016; FAO 2019).

Therefore, potential links between “Recycling” at different stages of food value chains and the sustainability of food systems should be further explored. There is a need of research about the environmental and socioeconomic benefits – at different scales from plots, farms, and territories to countries – that might result from recycling. Indeed, on the one hand, recycling may reduce dependence on inputs and production costs and, on the other hand, it may decrease environmental pollution and the pressure on (already depleted) natural resources through valuing waste in all the segments of the food system, and not only through nutrient recycling in agroecosystems.

4.2.2 Input reduction

Potential links identified by expert knowledge



Links description according to expert knowledge

FOOD SYSTEM		
DRIVERS	CORE COMPONENTS	OUTCOMES
<p>Biophysical and Environmental resources: A more equilibrated environment with more efficient ecosystems services will make the global production process less dependent of external inputs to reach acceptable objectives of production. Both production and processing systems will need then to make a more efficient and sustainable use of natural resources (land, biomass, water).</p>	<p>Food production and value chains: Enriching the capacity of food production along with the food systems, in terms of sustainable high productivity of the land and less external inputs using complementarity and synergies between cultivated species. In addition, agroecology should stably increase the production of food due to the efficient use of natural resources and inputs even reduced. Pluri-specificity at field level and plurality of activities at farm level are complementary since they prevent the surplus and shortage of production without mobilizing too much external inputs.</p> <p>Absence of pesticides is a key motivation of agroecological products purchases.</p>	<p>Environmental sustainability: Reducing use of inputs can decrease negative externalities of the production process (e.g. less direct impact on chemicals on biodiversity, land or water quality). Inputs reduction (energy or other products) into the processing or transportation components may also decrease global environmental impact of the whole food system. Reducing inputs in processing and distribution – (e.g. packaging, transport energy...) means fewer wastes and then fewer environmental impacts.</p> <p>Socio-Economic sustainability: Reducing dependency on external resources empowers producers by increasing their autonomy and resilience to natural or economic shocks. Globally we may expect that if investment costs for inputs are reduced, farmers general income may increase if productivity is maintained though other agroecological principles. On the contrary, agroecology attractiveness may be jeopardized if too much labour is necessary. agroecology may also reduce costs dedicated to non-necessary inputs if applied to other elements of the food system such as packaging or wastes management.</p> <p>Food Security, Nutrition and Health: Reducing input use may despite all contribute to efficiently provide an adequate and sustainable amount of food according to the local demands. In quantity we may expect to have enough and diversified products with lower prices if productivity and economic efficiency is maintained. In quality agroecology may provide better products because of less chemical inputs use and more nutrients equilibrium. Food and nutrition security may be achieved in the long run through the efficient resource management whilst conserving the ecological functionality and balance that agroecology may improve. agroecology may contribute in reducing human health problems though less pesticides.</p>

Findings from literature

Reducing input means re-designing agricultural and food systems, with synergies in mind, which inherently aim to increase resource-use efficiency. Agroecological transitions should promote food systems with the necessary biological, socio-economic and institutional diversity and alignment in time and space to support greater efficiency. In such sense, reducing input may contribute to answering to related challenges, such as so-called ecological or sustainable intensification of agriculture in a context of climate change (Tittone 2014).

The principle of “input reduction” is explored in literature although not as main subject, in fact only few papers in the *restricted corpus* explore the reduction of inputs explicitly in relation to the sustainability of food systems. While it has been empirically shown that the absence of pesticides is one of the key determinants of the purchases of agroecological foods (April-Lalonde et al., 2020), or that reducing inputs combined with diversification of the systems should contribute to increased net incomes over time (Altieri et al. 2012; Gliessman 2015; Van der Ploeg et al. 2019), only one paper was found in the output of “Input Reduction” search equation. Although not providing empirical evidence, (Cheng et al. 2022) argue that reducing the use of input and improving social cohesion and participation in urban food systems may trigger environmental and socioeconomic benefits where, according to the authors, agroecological transformation is expected to be more easily implemented. It has been also argued in (Teeb 2018) that the economic benefits of reducing the use of input while improving participation and social cohesion would be clearer with true-cost accounting, taking thus into consideration externalities or ecological costs of the production process, even if returns to labor may not necessarily increase in the short term (Ajayi et al. 2009).

Bezner Kerr et al. (2022) reviewed 240 articles about the theoretical knowledge and the empirical evidence of agroecological linkages with social well-being, livelihood, meaningful work, gender and other forms of social inequity. Three types of relationships between input reduction and the sustainability of food systems were explored:

- (i) between the lower use of toxic inputs and health,
- (ii) between the lower use of external inputs and the freedom of farmers and their increased control over the means of production,
- (iii) between the lower use of inputs, the increased workloads and the additional work burden that disproportionally falls on women.

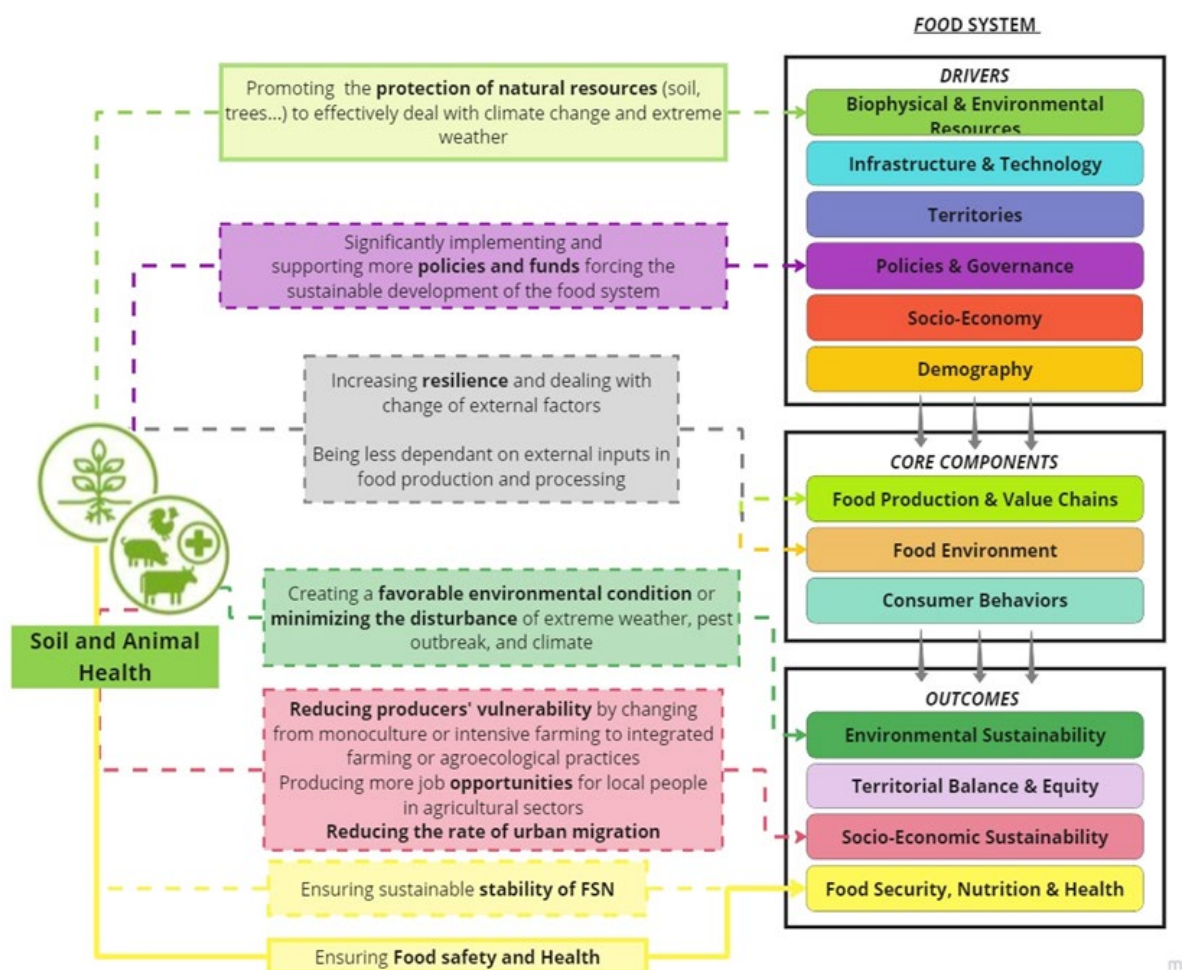
Bezner Kerr et al. (2022) conclude however that there is very little literature demonstrating the (positive/negative) impacts of input reduction on:

- (i) the socioeconomic dimensions: reduced dependence on inputs, greater financial autonomy, increased self-provisioning for farmers
- (ii) the nutrition and health dimension: significantly improved health and well-being gains through reduced exposure to toxic inputs for farmers.

It is worth noting that the potential contribution of reduced input use on increased equity between food systems actors is overlooked. The papers identified are few and mostly general, and there is a lack of knowledge on the environmental and economic benefits of input reduction and its associated waste reduction in AE/FS research.

4.2.3 Soil health / Animal health

Potential links identified by expert knowledge



Links description according to expert knowledge

FOOD SYSTEM		
DRIVERS	CORE COMPONENTS	OUTCOMES
<p>Policies and Governance: Policies more favorable to equitable access to land and other resources will encourage sustainable management of soils and animals.</p> <p>Biophysical and Environmental resources: promoting the protection of natural resources (soil, trees...) to effectively deal with climate change and extreme weather</p>	<p>Food production and value chains: Healthy soil and livestock can reduce sensibility to the external factors variability (e.g. Rapid Climate Change). Both soil and livestock systems are then less dependent on the external inputs for food production. Soil and animal health contribute strongly, by improving ecosystems services, to the production system resilience and efficiency.</p> <p>Through resilient soil and livestock, producers and herders reduce their vulnerability by changing from monoculture or intensive farming to integrated farming or agroecological practices.</p> <p>Through animal health, herders maintain the viability of their livelihoods.</p>	<p>Food Security and Nutrition: Soil health allows to produce food crops with more equilibrated contains in nutrients. Animal health give access to safe, rich in proteins, products. Ensuring healthy Food Security and Nutrition to the rural families allows them to stay on and to cover by their production part of the local food demand. Guaranteeing soil and animal health contribute in ensuring food safety (no toxic elements, antibiotics...)</p> <p>Environmental Sustainability: Soil health enhances a favourable environmental condition or minimizes the disturbance of extreme weather, pest outbreak, and climate changes because of the ecological functionalities, complementarity of diversity, and natural resource conservation. Thus, it provides a significant impact on resilience of the system, on biophysical and environmental variability along time as one of the drivers in the food system. By guaranteeing animal health through sustainable raising practices, may reduce the use of antibiotics and the related pollution and resistance to antibiotics generated from it.</p> <p>Territorial balance and equity: Based on the resilient soil fertility and livestock resources, the local stakeholders are more likely to effectively deal with climate change and extreme weather. A resilient local food system based on agroecology should then produce more job opportunities for local people; therefore, there are fewer people taking risks to migrate abroad or to the urban areas seeking work opportunities. This may provide a balanced territorial development across regions and across countries. All this could contribute to reduce the abandonment of farms due to migrations and maintain food availability locally, which in turn contributes to local food security.</p>

Findings from literature

Soil health and animal health may directly and positively be improved by agroecology. Agroecological practices aim to work with the biological complexity of soil ecology promoting a diverse community of interacting organisms to allow the ecosystem to self-regulate when facing pest and disease outbreaks (Tscharrntke et al. 2005; Midega et al. 2018; Landis et al. 2000).

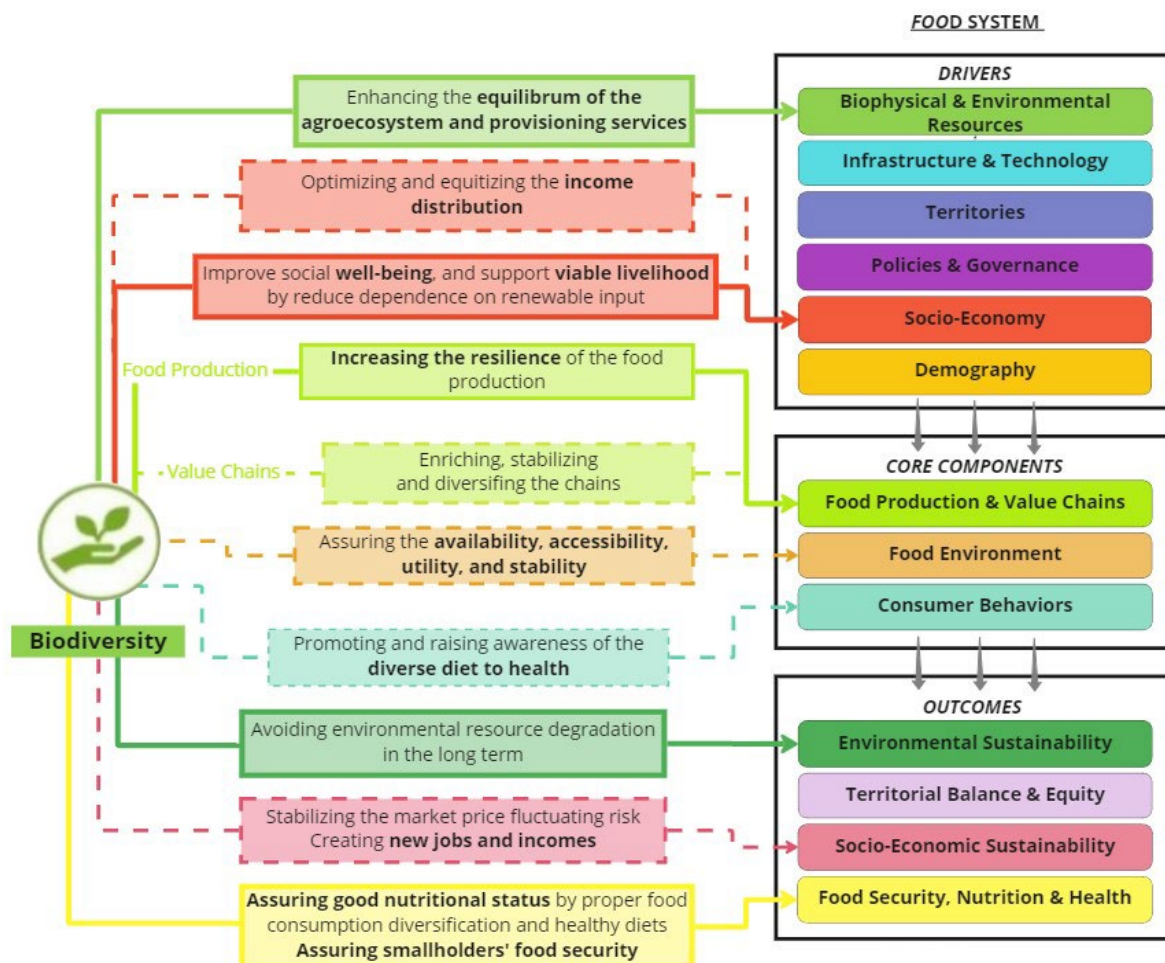
Among the selected papers, soil health is sometimes provided as an example of benefits of agroecological practices or indirectly discussed through soil nutrients and fauna, whereas animal health is almost never mentioned as a consequence of agroecological practices. For instance, soil health is covered by Blesh and Wittman (2015) that empirically demonstrate that an alternative land governance system and agroecological practices in the Brazilian Cerrado region (supported by "landless rural workers movement") enhanced soil fertility, soil nutrient status, particularly phosphorus content.

On the contrary, though several examples exist connecting animal diseases or animal production and food safety (mad cow disease, other) no analysis was present in the *restricted corpus*. For instance, Johnston (2000) explores links between animal health and food safety, but not through the agroecology/food system lens.

There is a considerable knowledge gap on how improving soil health and animal health through agroecology can ensure food security, nutrition and health, minimize environmental disturbances and influence socioeconomic resilience, for instance concerning job opportunities and migration to cities

4.2.4 Biodiversity

Potential links identified by expert knowledge



Links description according to expert knowledge

	FOOD SYSTEM	
DRIVERS	CORE COMPONENTS	OUTCOMES
<p>Biophysical and environmental resources: A good equilibrium of agroecosystem is favourable to (agro)biodiversity. As a result, natural resources can be wisely utilised, and systems can be easily adapted to climate change.</p> <p>Socio-economy: An important and diversified demand of food should stimulate "biodiversification" of the systems.</p> <p>Territories: Proactive territorial governance to preserve natural resources and habitats at a landscape level may favour biodiversity (i.e. insects) and natural self-regulation.</p>	<p>Food production and value chains: Biodiversity could stably increase the productivity of food production with less external inputs due directly to diversity of products and indirectly to the enhancement of ecosystem services improving the production capacity of systems. The production of optimal and diversified amounts of food may contribute in stabilizing markets, reducing shortage or surplus, preventing the fluctuating price impacts, and offering a variety of products. Thus, diversification also offers opportunities for new value chains to be developed.</p> <p>Food Environment: Assuring the availability, accessibility, utility, and stability of various local food commodities.</p> <p>Consumer behaviours: Promoting and raising the awareness of the health benefits of the diversified diets, with nutrient dense food items, to meet the requirement of healthy life, in order to promote the diversification of products in agroecological systems (demand effect).</p>	<p>Food security, nutrition and health: good nutritional status can be assured by proper food consumption based on diversification and healthy diets.</p> <p>Socio-Economic sustainability: Biodiversity can be a strategy for farmers to manage risk (production, market price fluctuations, maintaining stability of incomes). Diversity and quality of products may encourage the apparition of some smaller food retails closer from consumers, opening new jobs opportunities. Plus, biodiversity also promotes the valorization of traditional and local products. Optimizing and equitizing the income distribution among the stakeholders through the economic diversification from various commodities and preventing for all of them the risk linked to a frequently fluctuated trading market.</p> <p>Environmental sustainability: Avoiding environmental resource degradation and increasing ecosystem services in the long term by increasing biodiversity and less chemical utilization for pest and disease management.</p> <p>Territorial balance and equity: All this could contribute to reduced migrations and abandonment of plots due to migrations; food availability is maintained.</p>

Findings from literature

Several studies have highlighted the positive contribution of crop diversity to the quality of ecosystem services and to level and stability of agricultural yields (Li et al. 2011; Gaudin et al. 2015; Bowles et al. 2020), to farm income (D'Annolfo et al. 2017; Van der Ploeg et al. 2019), and to agricultural employment at the country scale (Garibaldi and Pérez-Méndez 2019).

However, the contribution of the agroecology biodiversity principle to food security, nutrition and health remains the most explored linkage.

Ten selected papers here collected show this link and most of them report about positive correlations between a diversified production and:

- (i) self-sufficiency throughout the year (Bahadur et al. 2016; Fernandez and Mendez 2019; Sampson et al. 2021),
- (ii) dietary diversity (Schipanski et al. 2016; Blesh et al. 2019; Bezner Kerr et al. 2022),
- (iii) nutrient adequacy (i.e. meeting key nutrient needs) and dietary moderation (i.e. avoiding dangerous excesses) (Deaconu et al. 2021),
- (iv) child nutrition (Bezner Kerr et al. 2022)
- (v) resilience to extreme events (Marrero et al. 2022).

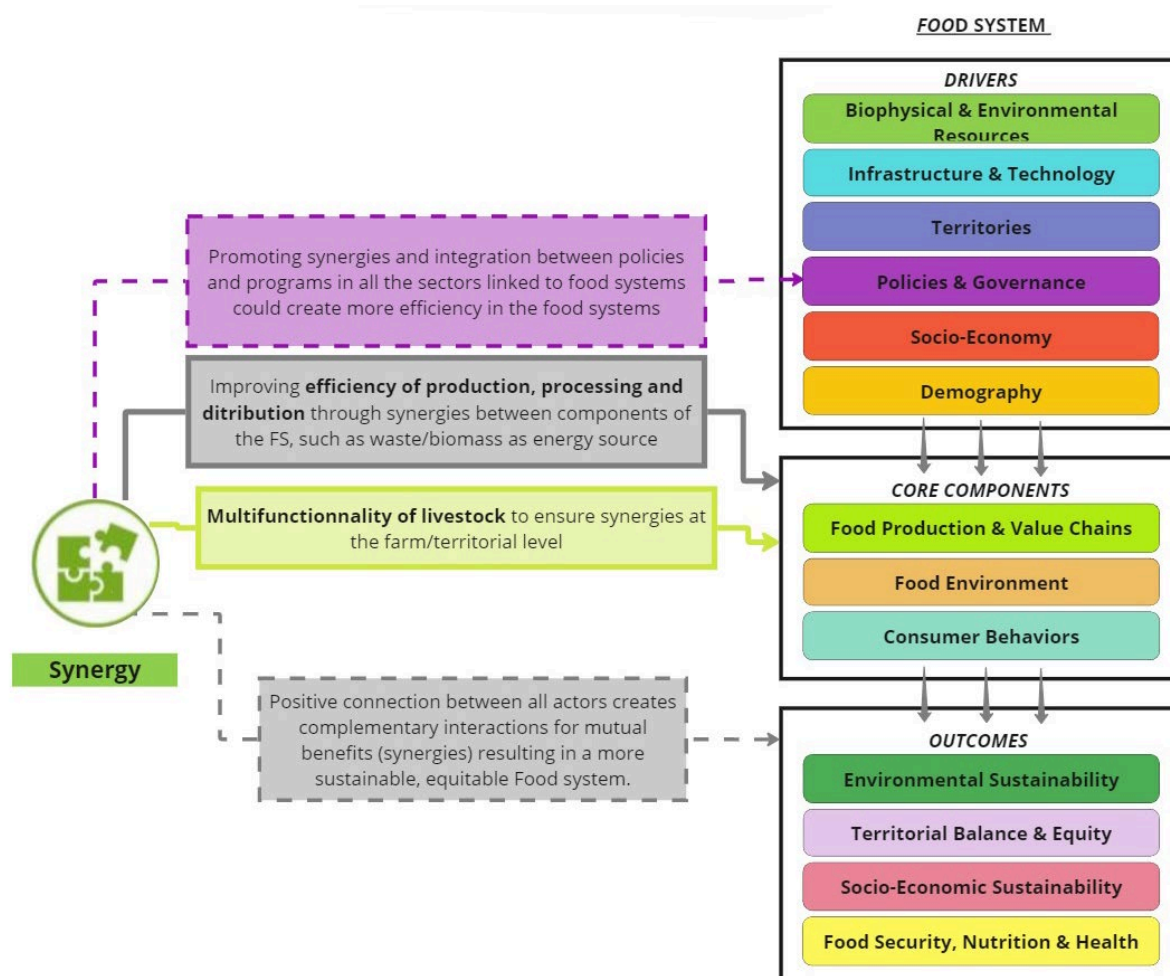
Agrobiodiversity is also closely linked to genetic resources, link explored in two retained papers. Kliem and Sievers-Glotzbach (2022) revealed on the one hand that the establishment of commons organization in seed production could potentially play a central role in food system sustainability, as they counter the ongoing commodification of seeds and plant genetic resources, reclaim global seed sovereignty and enhance the re-democratization of seed systems. On the other hand, Bullock et al. (2017) highlight the role of a diverse crop rotation and varietal mixture in yields resilience and of diversity at a taxonomic level in enhancing resilience to climatic perturbations. Some of the papers are also looking at the link to environmental ((Blesh et al. 2019, Bullock et al. 2017, Fernandez & Mendez 2019, Schipanski et al. 2016, Kliem & Sievers-Glotzbach 2022) or socioeconomic (Bezner Kerr et al. 2022, Schipanski et al. 2016, Blesh & Wittman, 2015) dimensions of food system sustainability. Agrobiodiversity is explored in relation to social-ecological synergies and global change pressures and viewed as a way of increasing ecosystem resilience and mitigating vulnerability to climate, resource availability and access, and market variabilities (Schipanski et al. 2016; Blesh et al. 2019), especially when associated to land tenure reform (Blesh and Wittman 2015).

Although this principle is quite well covered, some knowledge gaps were identified. Two papers point out the lack of empirical data about agroecosystem processes in diversified farms: there are only few evidences that biodiversity enhances agroecosystem resilience in both farm and landscape scale (Bullock et al. 2017); Blesh et al. (2019) highlight the lack of data in agroecosystems where ecological processes are managed, and thus the lack of connection between practices and outcomes.

On this second point it has to be noted that there is no lack of literature about the link between practices and outcomes in general terms (e.g. not directly linked to increasing food system sustainability), see for example (Ponisio et al. 2015; Smith et al. 2020). Moreover, linkages between management of (agro)biodiversity and socioeconomic and equity impacts of food systems are not well covered in the studies, such as farmers' incomes, workloads or gender equity, although some papers suggest that an increase in the diversity of activities, products, or services can help to evade risks generated by uncertain markets or policy environments (Ellis 2000; Reilly and Willenbockel 2010). Finally, another gap concerns the types of food system actors and activities considered: biodiversity is only addressed through a production/farming lens while there is no evidence on the implications of greater agrobiodiversity for the other segments of food value chains (processing, trade, consumption).

4.2.5 Synergy

Potential links identified by expert knowledge



Links description according to expert knowledge

FOOD SYSTEM		
DRIVERS	CORE COMPONENTS	OUTCOMES
<p>Enhancing synergies and coherence among (actionable) drivers of food systems could help achieving sustainability.</p> <p>Policies and Governance: Promoting synergies and integration between policies and programs in all the sectors linked to food systems (energy, health, agriculture, trade...) could improve the efficiency of the later.</p>	<p>The synergies between all the components of the agroecosystem (soil, crops, trees, animals etc.), at different scales, will improve the efficiency of food production, and its global efficiency for achieving food and nutrition security.</p> <p>The principle of synergy between components can also be applied to the global Food System. The latter could take advantage for example of the complementarity of the products in terms of distribution over time or in the transformation process. Livestock-Farming integration is also a way to promote synergies within the food systems. Multifunctionality of livestock (traction, organic manure, meat and milk production) is an important characteristic for ensuring the effectiveness of the interaction.</p> <p>Wastes in some products transformation (non-productive biomass) may be used as energy sources for transformation of other products. They may also be used for mulching soil, to create new habitat for fauna, for fertilizing fields, increasing opportunities of synergy between food systems components.</p>	<p>Positive interactions between elements of the agroecological systems may results in higher and more diversified production. Positive connection between all actors creates complementary interactions for mutual benefits (synergies) resulting in a more sustainable, equitable Food system.</p>

Findings from literature

Increasing synergies through re-designing agricultural and food systems, embraces the need to strategically use biological diversity (Barrios et al. 2020; Midega et al. 2018; Rosenstock et al. 2019), and market linkages (Schipanski et al. 2016; Vermeulen et al. 2012) to harness multiple concurrent benefits from components interactions.

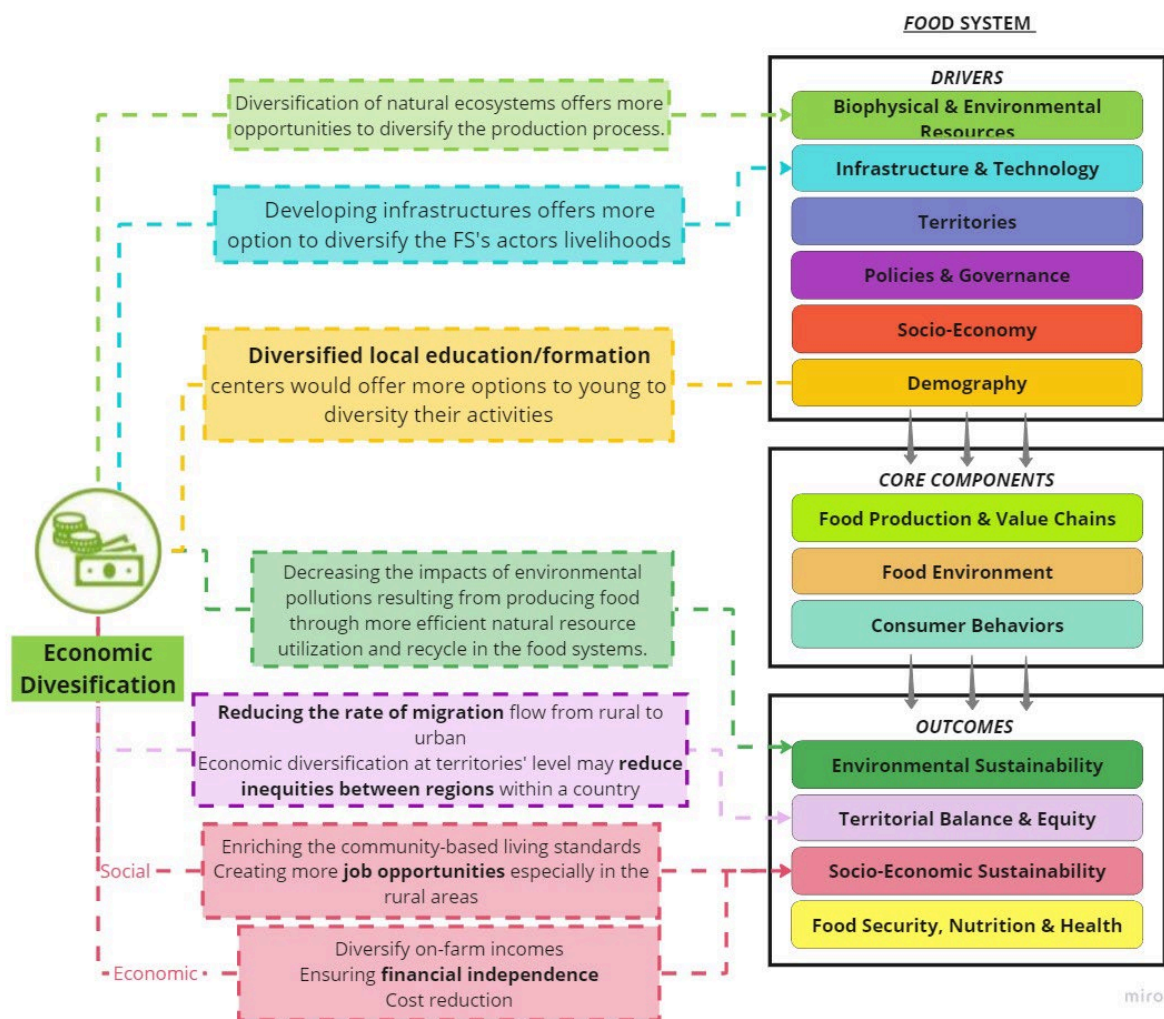
Among the reviewed papers, six particularly addressed the agroecological principle 'synergy'. As an ecological concept of interactions between elements, synergy is often addressed through ecological key functions such as biodiversity and soil health.

Synergies between crop and livestock systems are particularly important at farm and territorial levels, and are linked to both environmental and socioeconomic food systems sustainability (Garrett et al. 2017; Fernandez and Mendez 2019). Synergies are also considered for plant-microbe interactions in the root zone which is relevant to both agroecosystem sustainability and nutritional crops quality (Blesh et al. 2019) and in relation to agroforestry agrobiodiversity which is expected to enhance ecosystem services and contribute to resilience and food security (Bullock et al. 2017; Fernandez and Mendez 2019). Only one paper focused on a broader scale assessing contrasted food systems (agro-industrial, smallholders farming and agroecological systems) and revealing that agroecology and local food systems have high sustainability and high environmental performances thanks to biodiversity and synergetic crop-livestock integrations which provide ecosystems services (Jacobi et al. 2020).

There are still knowledge gaps regarding the quantified consequences of such interactions on the global performances of the system. For example, in the case of integrated crop-livestock systems, there is a knowledge gap about diversification, nutrient and GHG emissions, and sediment loads compared to continuous and high intensity crops or livestock systems. Moreover, tradeoffs between different ecosystem services in integrated crop-livestock systems are rarely analyzed. There is a lack of consideration of agroforestry and animal welfare in the food systems.

4.2.6 Economic diversification

Potential links identified by expert knowledge



Links description according to expert knowledge

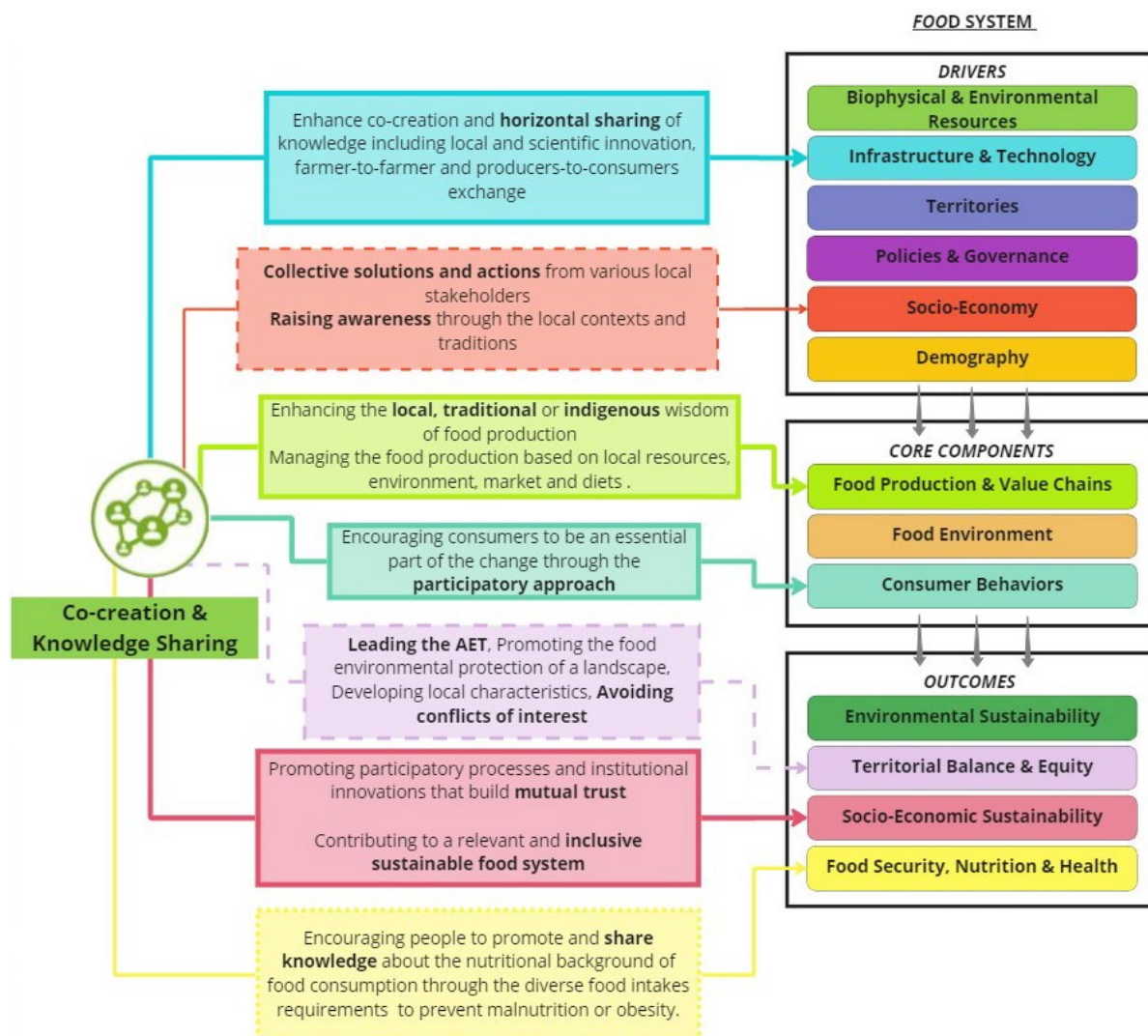
FOOD SYSTEM		
DRIVERS	CORE COMPONENTS	OUTCOMES
<p>Biophysical and environmental resources: Diversified natural ecosystems offer more options to diversify the production process.</p> <p>Infrastructure and technology. Developing infrastructures offers more option to diversify the FS actors' livelihoods, for instance through processing or trade</p> <p>Socio-economy: performant and diversified local education/formation centers would offer more options to young people to diversify their activities.</p>	<p>Food production and value chains: Economic diversification may apply at each food chain actor with diversification through on-, off- or non-farm activities for the farmers and in or out of the food processing, distribution activities for other actors of the food system.</p> <p>It may apply too at each component of the food systems by diversifying products involved by the same production, transformation or distribution actors.</p>	<p>Socio-Economic sustainability: Economic diversification may enrich the community-based living standards and the accessibility to the basic living requirement through the individual income.</p> <p>It may create more job opportunities especially in the rural areas and may reduce the rate of migration flow from rural to urban.</p> <p>Diversification may improve on-farm incomes by multiplying a diversity of activities; ensuring that small-scale farmers have greater financial independence and value addition opportunities while enabling them to respond to demand from consumers.</p> <p>Diversification may reduce cost by improving synergies between activities (interaction between diversity and synergy principles); giving social inclusion under agroecological food systems.</p> <p>Environmental sustainability: Diversification may increase the efficiency of natural resources utilization through making better use of the waste of the diverse products and reusing usable materials issue from their transformation (interaction between diversity, recycling and efficiency principles).</p> <p>Territorial balance and equity: Economic diversification at actors and territories' levels may reduce the inequities between subnational regions within a country</p>

Findings from literature

Agroecological transitions through economic diversification should enhance socio-economic resilience with less dependence to external inputs and therefore greater resilience to price volatility and financial independence (Wezel et al. 2020). Economic diversification may be linked to crop diversification (Bacon et al. 2014) but also to off/non-farm diversification. Through diversification and integration, producers reduce their vulnerability should a single crop, single livestock specie, and other commodities and activities fail because of diseases or other external shocks (Freed et al. 2020). By diversifying their activities, agroecological farms may secure their livelihoods and improve food security (Freed et al. 2020) and it is a common adaptation strategy developed by households to navigate seasonal hunger (Bacon et al. 2014). Agroecological farms and value chains should contribute to a dynamic rural local economy with more farmers and local jobs, producing a wider range of products and services and keeping more money circulating within regional economies. This might be reducing carbon footprint and other off-site environmental impacts on communities. However, there is a huge gap in the literature regarding the concrete contribution of economic diversification to food system sustainability.

4.2.7 Co-creation and knowledge sharing

Potential links identified by expert knowledge



Links description according to expert knowledge

FOOD SYSTEM		
DRIVERS	CORE COMPONENTS	OUTCOMES
<p>Infrastructure and technology: Co-creation and horizontal sharing of knowledge is favored by local scientific innovation, farmer-to-farmer, and producers-to-consumers exchanges.</p> <p>Socio-economy: Solidarity and awareness regarding local contexts and tradition help to integrate local knowledge and build collective solutions.</p>	<p>Food production and value chains: Co-creation & knowledge sharing enhance the local, traditional, or indigenous knowhow on food production and preparation. Combining local knowledges with external/scientific information may effectively and properly improve the food production process combining more efficiently the local resources, environment, market, and diets.</p> <p>Consumers behaviour: Encouraging consumers to be an essential part of the change towards sustainable food systems through sharing their knowledge, demands, and concerns as food consumption plays an important role in shifting food system policy's and production's incentives.</p>	<p>Socio-Economic sustainability: co-creation and knowledge sharing approach may build mutual trust contributing to more relevancy for local people and inclusiveness. It helps to recognized and safeguard indigenous knowledge and skills. Individual and collective self-esteem and confidence may be reinforced.</p> <p>Territorial balance and equity: This principle could improve equity between food systems actors by recognizing and considering their own knowledge, interests and constraints. The combination of individual and collective actions of co-creation of knowledge is expected to build on local characteristics of the agricultural food system (terroir) and therefore be more likely to promote the environmental protection of a landscape while maintaining its capacity of food production. In these cases, all stakeholders integrate the landscape scale into their decisions and actions and try to avoid conflicts of interest. This may go along with more equitable territorial food systems where actors share their respective knowledge.</p>

Findings from literature

Agroecology can encourage multi stakeholders' engagement and may facilitate the blending of knowledge from different sources, including traditional and indigenous knowledge, on agricultural biodiversity and management experience for specific contexts, practical knowledge of producers, traders' knowledge related to markets, and global scientific knowledge and practices (Méndez et al. 2013; Bendito and Barrios 2016; Nobre and Tavares 2017). Hence, fostering co-creation processes builds relevance, credibility, and legitimacy to the agroecological transition. Such processes are also crucial to the crafting of knowledge that is useful for sustainable development (Warner 2007; Barrios et al. 2012; Lemos et al. 2018; Cash et al. 2003; Clark et al. 2016). A better integration of local knowledge may enhance the sustainable management of the agroecosystem, since humans are an integral part of ecosystems, while culture and environment exhibit a strong influence on each other (Tomich et al. 2011; Ratner et al. 2013).

Eight of the selected articles explored more specifically how knowledge co-creation and sharing interact with dimensions of food systems sustainability, especially socio-economic and food security, nutrition and health (Rahman et al. 2021, Ahmed and Stepp 2016, Bullock et al. 2017, Wittman et al. 2020, April-Lalonde et al. 2020, Kliem and Sievers-Glotzbach 2022, Jacobi et al. 2020, Sampson et al. 2021). The papers argue that the importance of this principle for the engagement of stakeholders to transit towards a sustainable food systems, is increasingly recognized.

In the socioeconomic sustainability dimension, the role of co-creation and knowledge sharing (for instance between scientists and local communities) is highlighted in relation to:

- young interest in agriculture and farmers' access to innovation (Rahman et al. 2021),
- farmers' adaptation capacity to consumer decision-making and agroecosystems variations (Ahmed and Stepp 2016),
- abilities to deal with issues and shocks through self-organizing (Bullock et al. 2017),
- new innovations such as an open-access digital tools aiming to assess the sustainability impacts of AE systems (Wittman et al. 2020),
- learning opportunities through farmers-to-consumers discussions engaged in agroecology markets (April-Lalonde et al. 2020),
- farmers' independence regarding access to seeds and inputs when co-creation and knowledge sharing is applied through Seed Commons initiatives (Kliem and Sievers-Glotzbach 2022).

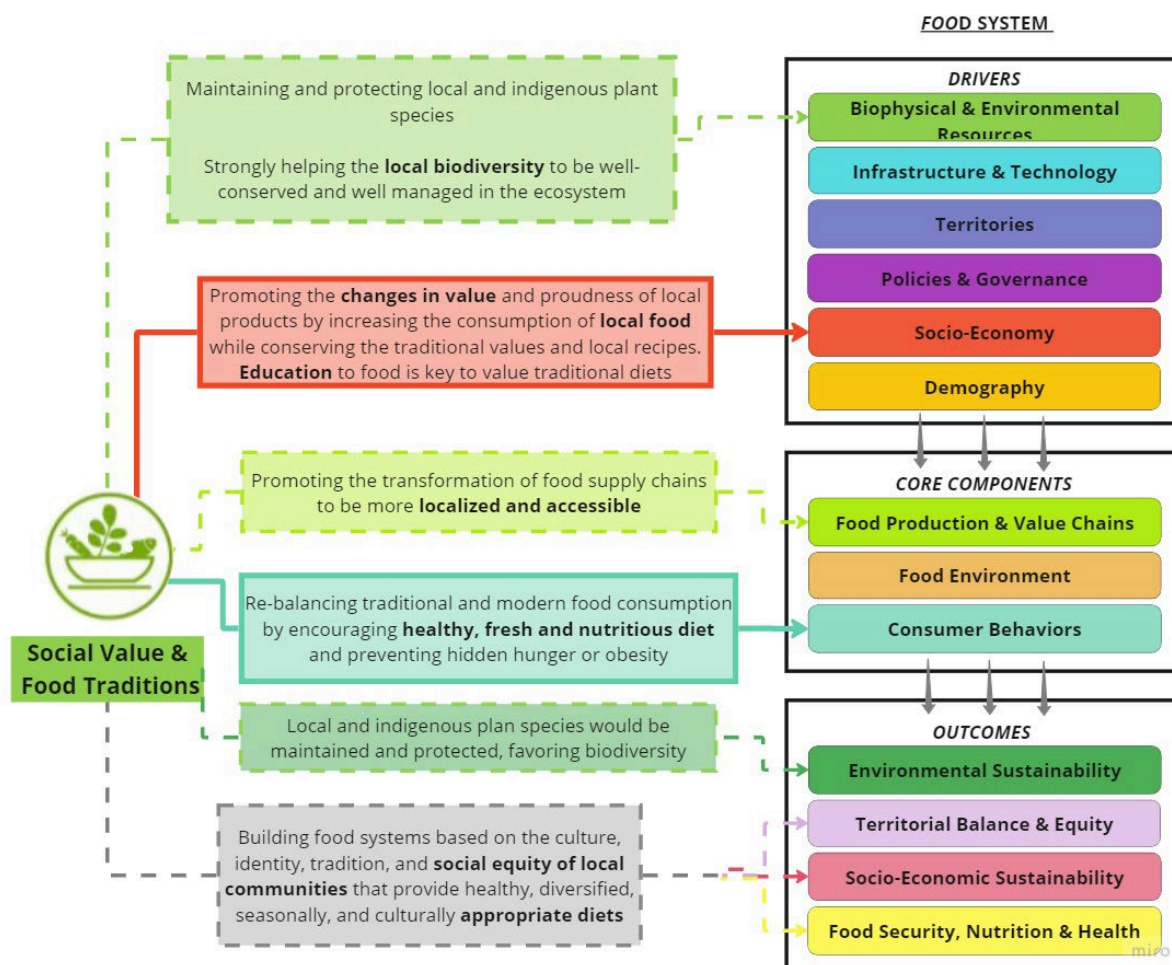
The food security, nutrition and health benefits of co-creation/knowledge sharing in agroecology is highlighted through the food sovereignty approach, where agroecological systems co-designed with farmers are more likely to fit local and traditional diets and to be associated with greater nutritional diversity for the farmers (Sampson et al. 2021).

Finally, the environmental sustainability of the food system may be favored by co-creation and knowledge sharing in the case of breeding programs based on Seed Commons, leading to improved plant robustness not reliant on chemical inputs, and easy to adapt to changing environmental conditions through natural enhancements of varieties (breeding of open-pollinated, naturally reproducible varieties via crossing and selection methods) (Kliem and Sievers-Glotzbach 2022). Such seed production systems based on Seed Commons also positively contributes to increasing equity between food systems actors, in particular between seed, service providers and farmers.

Except in the case reported by (Kliem and Sievers-Glotzbach 2022) mentioned above, information on how co-creation and knowledge sharing interact with environmental and territorial dimensions of food system sustainability was not found. Moreover, two other main knowledge gaps were identified on this principle. First, there is a lack of focus on traditional knowledge sharing and on its potential impacts on agricultural management and food system sustainability. Then, it is not clear how co-creation and knowledge sharing can influence stakeholders' actions at a landscape scale and avoid conflicts of interest.

4.2.8 Social value and diets

Potential links identified by expert knowledge



Links description according to expert knowledge

FOOD SYSTEM		
DRIVERS	CORE COMPONENTS	OUTCOMES
<p>Socio-economy: Agroecology in cultural dietary movements promotes proudness of local products while conserving the traditional ways of local recipes and maintaining local value. Education is key to promote a healthy diet, to valorize local diet and dishes and to preserve social values.</p>	<p>Food production and value chain: The cultural dimension of traditional food could promote the transformation of food supply chains to be more localized and accessible because the traditional food specifically uses local ingredients while keeping the cultural identity and sense of local place through territories and food systems.</p> <p>Consumers behaviour: Applying this principle, consumers should tend to have more connection with the local value of their cultural food habits because agroecology plays a pivotal role in re-balancing traditional and modern food consumption, by encouraging the themes of a healthy, fresh and nutritious diet and preventing hidden hunger or obesity.</p>	<p>Environmental sustainability: As a result of cultural dietary conservation, local and indigenous plant species would be permanently maintained and protected by local producers. It also strongly helps the local biodiversity to be well-conserved and well-managed in the agroecosystem.</p> <p>Food security, nutrition and health: As a result of cultural dietary conservation, food systems recognize the culture, identity, tradition, and social equity of local communities that provide healthy, diversified, seasonally, and culturally appropriate diets. This should help maintaining traditional skills in artisanal food processing or conservation.</p>

Findings from literature

Agriculture and food should be considered as core components of human heritage. Culture and food traditions, developed as a result of long-term human and environmental interactions, have played a central role in society and in shaping human behavior, underpinning agroecological transitions (Gosnell et al. 2019). As a result of the co-creation and sharing of knowledge processes, including all the actors involved in the food system, it should play a pivotal role in supporting the internalization of human and social values, culture and food traditions, as key food nutrition and security features.

Among the papers prioritized for this review, seven explored how the principle of social values/food tradition of agroecology is linked to the sustainability of food systems. Only Rahman et al. (2021) clearly focus on this linkage on the agroecology/food system interface, by discussing the role of food tradition and heritage to connect food production with consumption and people with their homeland.

Most of these papers consider effects on food nutrition and security, health and socioeconomic sustainability of food systems, while the effect on equity, territorial balance and environmental sustainability of food systems are less studied. The papers discuss to what extent building food systems on social and cultural values is important:

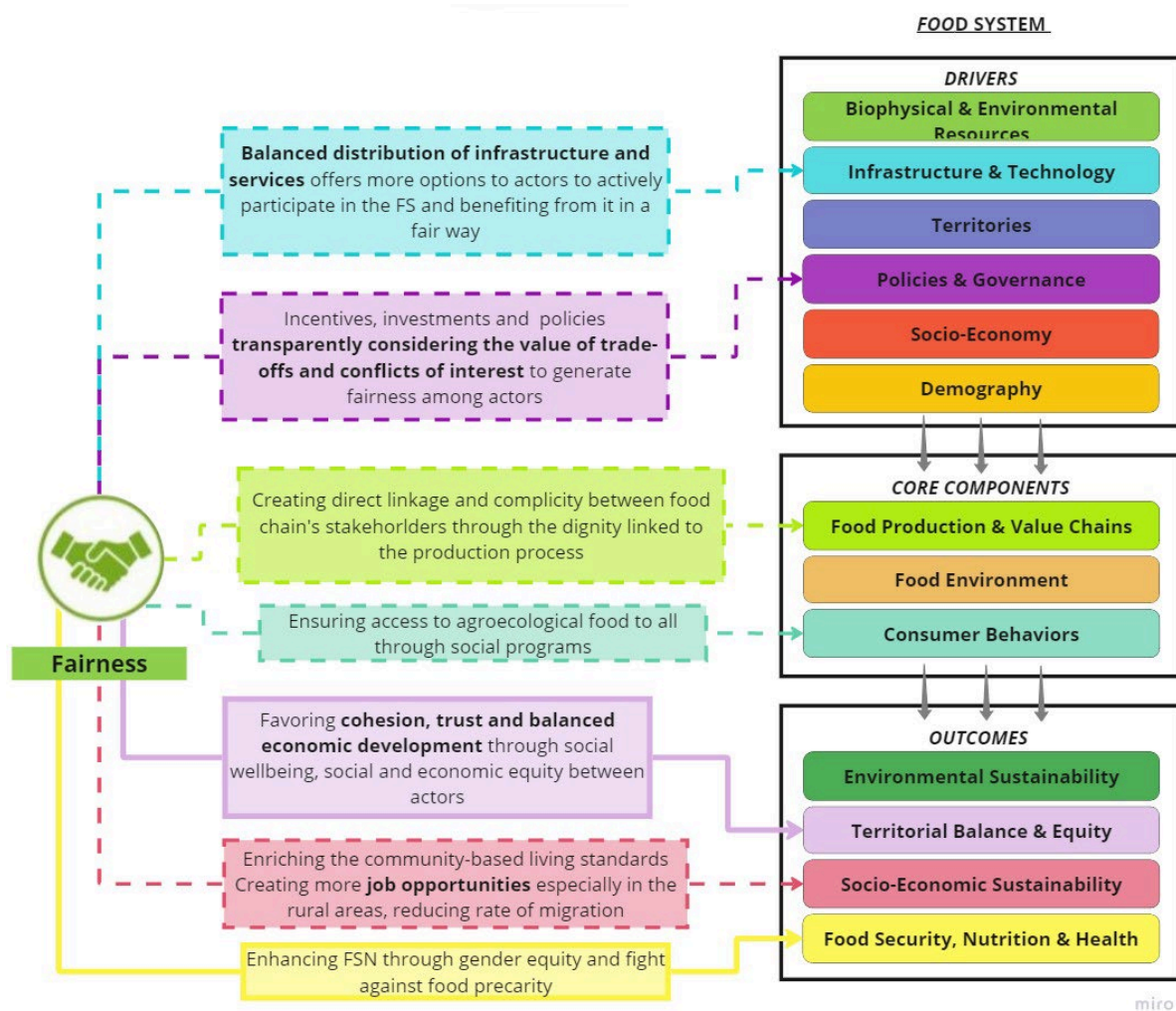
- (i) At the consumers level to develop healthy diets (April-Lalonde et al. 2020) and stronger dietary moderation (i.e. avoiding dangerous excesses) Deaconu et al. (2021) as well as promoting environmental impact reduction and farmer's conditions improvement (April-Lalonde et al. 2020).
- (ii) At farmers and food value chains actors level to give impulse to environmentally-sustainable practices in an ecological and economic long-term view (Jacobi et al., 2020), for instance in face of climate change (Ahmed and Stepp 2016), or by raising insects which are considered as a sustainable source of proteins, matching local food traditions (Borgerson et al. 2021).

Despite strong evidence that social value and food traditions contribute to enhance the sustainability of food systems, a lot still needs to be considered in agroecology research. Rahman et al. (2021) flag that only little work has been done to demonstrate how culture and food traditions intersect with agroecology, referring to a paper that was not identified through the applied search equations because not directly linked to food systems (Morgan and Trubek 2020).

With reference to the potential links identified by the expert panel, some knowledge gaps remain on how social values and diets promote more localised and accessible food systems, and on how that can contribute to maintain local biodiversity and indigenous plant species. Moreover, April-Lalonde et al. (2020) point out that it would be interesting to further research consumers' response to food insecurity, and its impact on consumption of agroecological products.

4.2.9 Fairness

Potential links identified by expert knowledge



Links description according to expert knowledge

FOOD SYSTEM		
DRIVERS	CORE COMPONENTS	OUTCOMES
<p>Policies and Governance: Incentives, effective policies or green investment in the food system transparently considering the value of trade-offs and conflict interests may generate fairness among all actors involved.</p> <p>Infrastructure and technology: Balanced distribution of infrastructure and services across a country offers more options for actors from various subnational areas to actively participate in the food systems and gain benefits from it.</p>	<p>Food production and value chain: introducing dignity into the production process means a direct linkage and complicity between producers and other stakeholders of the food chain. Fairness should apply for all stakeholders of the food system for them to access to decent livelihoods and should improve mutual confidence between them.</p> <p>Consumers behaviour: Given that a share of the population struggle in accessing to food in quantity and quality because of poverty, the fairness agroecological principle applies to consumers level, by ensuring access to agroecological food to all, through social programs for instance.</p>	<p>Socio-economic sustainability: As a result, the agroecology fairness principle attributes and enriches the community-based living standards with more jobs opportunities and decent livelihoods for people in the countryside or rural areas.</p> <p>Territorial balance and equity: improvement in livelihoods for all actors in rural areas may contribute to reduce the rate of migration to urban areas. Fairness in value chains trigger social and economic equity between local actors and may reinforce equity between urban/rural areas. This might favour cohesion, trust and a balanced economic development in a country or a territory.</p> <p>Food security, nutrition and health: Fairness in food systems may reduce food precariousness and improve food security and nutrition of the poorest consumers. Gender equity both in production and processing/trade may contribute to improved FSN</p>

Findings from literature

Agroecology fairness principle is expected to support dignified and robust livelihoods for all actors engaged in food systems, especially small-scale farmers, based on fair trade, fair employment, and fair treatment of intellectual property rights. For instance, shorter food circuits and local markets may be a lever to improve fairness, promote economic development, and strengthen the resilience of the rural fabric. These food circuits have been shown to increase and sustain incomes of food producers while encouraging fair prices for consumers (Schipanski et al. 2016; Feliciano 2019).

In the present review, five articles shed more light on the role of fairness for food system sustainability. April-Lalonde et al. (2020) address fairness between farmers and consumers in direct purchasing channels, while recognising farmers' difficulties and risks.

The other papers mostly focus on fairness between different groups of people within the farming segment:

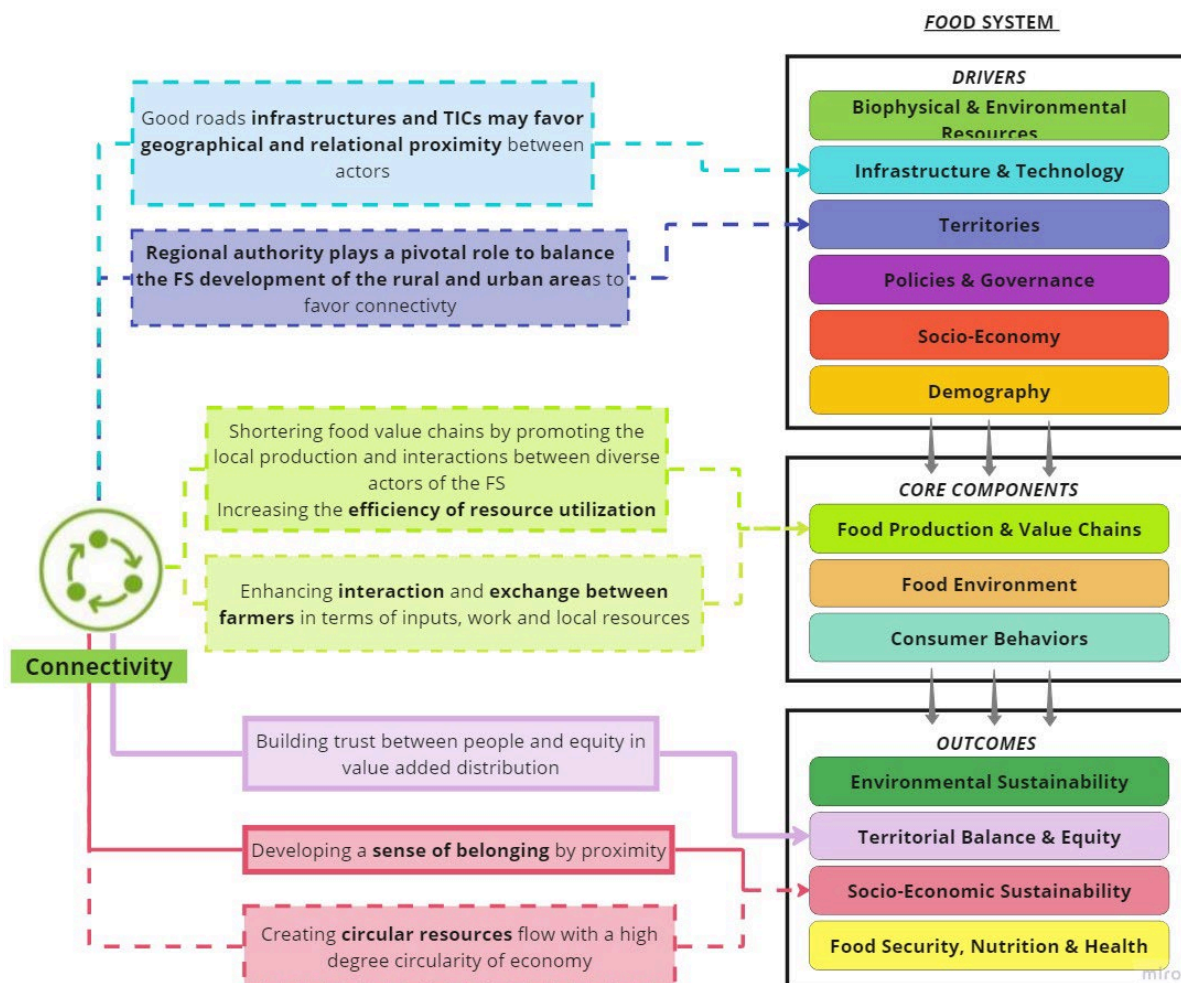
- (i) Gender equity: work that should be equitably shared between women and men in agroecological farming systems (Bezner Kerr et al. 2022), as well as the importance of increasing social justice and gender equity to increase food accessibility and women empowerment (Schipanski et al. 2016). Along these lines Schipanski et al. (2016) gather evidence that improving woman access to land, resources and education has multiple and cascading benefits on food security and human health. Sampson et al. (2021) conclude in their review that 12 studies out of 15 demonstrate the positive impacts of gender equity and women's empowerment on food security, nutrition and health across many geographic and economic contexts.
- (ii) Racial equity: racial equity within farmers is starting to be explored in the Americas (Bezner Kerr et al. 2022).
- (iii) More broadly: equitable access to resources, both for production and transformation. The general question is if agroecological food systems would better preserve soil and ecosystems while producing healthy nourishing food (Vaarst et al. 2018).

However, there are clear knowledge gaps concerning equity in the food system at both micro, meso and macro scales. Kremen et al. (2012) and Schipanski et al. (2016) highlight that ethnicity, socioeconomic, and gender equity are often neglected in studies about alternative food systems or addressed into a broad social justice category without recognizing the diverse groups, which is also reported in Sampson et al. (2021). For instance, Kremen et al. (2012) point out the importance of this knowledge gap, noting that there is evidence that farmers belonging to racial groups in the US (such as black, latino or asian farmers) are more likely than others to embrace sustainable agricultural practices if they are adequately supported. At meso scale, despite some work on direct or short chains, there is a knowledge gap on how fairness could guide the governance in longer food chains.

At macro scale, the fairness of policies that support agroecology transition or transition towards more sustainable food systems are not discussed. Similarly, to what extent the agroecology transition may allow a balanced territorial development while reducing territorial inequalities and internal migration, remains a research gap.

4.2.10 Connectivity

Potential links identified by expert knowledge



Links description according to expert knowledge

FOOD SYSTEM		
DRIVERS	CORE COMPONENTS	OUTCOMES
<p>Territories: Regional authority plays a pivotal role to balance the food system development of the rural and urban areas by creating a short circuit or territorial food system.</p> <p>Infrastructure and technology: good roads infrastructures and TICs may favor geographical and relational proximity between actors which in turn would help to promote connectivity in the food systems</p>	<p>Food production and value chain : Enhancing interaction and exchange between farmers in terms of inputs, work and local resources may improve their collective efficiency</p> <p>Enhancing direct relations between the diverse actors of the food system, particularly between producers and consumers, would result in complementary interactions for mutual benefits.</p>	<p>Socio-economic sustainability :</p> <p>Multiplying interactions between actors of the food system, in particular between producers and consumers may result in a sense of belonging, relational proximity, and connection to nature for consumers</p> <p>Connecting local resources into the production process with a high degree circularity of economy instead of the linear pattern using a lot of inputs from outside, could generate jobs and environmental benefits.</p> <p>Promoting local food value chains by valuing the close production and shorter value chains by increasing the efficiency of processes and resource utilization.</p> <p>Territorial balance and equity: Good connectivity between food chains actors (in particular between producers and consumers) helps building trust among people and equity in the added value repartition.</p>

Findings from literature

The connectivity principle applied to the agroecosystem ensures as a first point a better interaction between the ecological elements of the ecosystem, a better complementarity between farm sub-systems and enhances as a consequence efficiency and sustainability of the production process (FAO 2019). Applied to the food system, it may also ensure proximity and confidence between producers and consumers through promotion of fair and short distribution networks, and by re-embedding food systems into local economies (Ghisellini et al. 2016; FAO 2019).

In the review considered nine papers address particularly the food system as a whole and the effects of connectivity through marketplaces, cooperatives and other form of social interaction. These papers mostly discuss the socioeconomic benefits of improved connectivity in food systems:

- greater social interactions between consumers and producers, and within communities to ensure the sustainability of the food system and preservation of farming in the communities (Rahman et al. 2021; Bezner Kerr et al. 2022);
- social relationships, knowledge sharing and investigation of trade-offs and synergies between sustainability dimensions of agroecology systems thanks to participatory guarantee systems and an associated app (Wittman et al. 2020);
- reasonably priced markets thanks to proximity and absence of intermediaries (April-Lalonde et al. 2020) which also allows value redistribution along the chains and renewed trust between producers and consumers (Kremen et al., 2012);
- mitigation of vulnerability to price variability, through connectivity to cooperatives and global fair trade network with the example of coffee (Bacon et al. 2014).

On the contrary, food systems with large geographic distances between production and consumption points, i.e., non-local food systems, are shown to be prone to disruption from either environmental or socio-economic shocks (Jacobi et al. 2020).

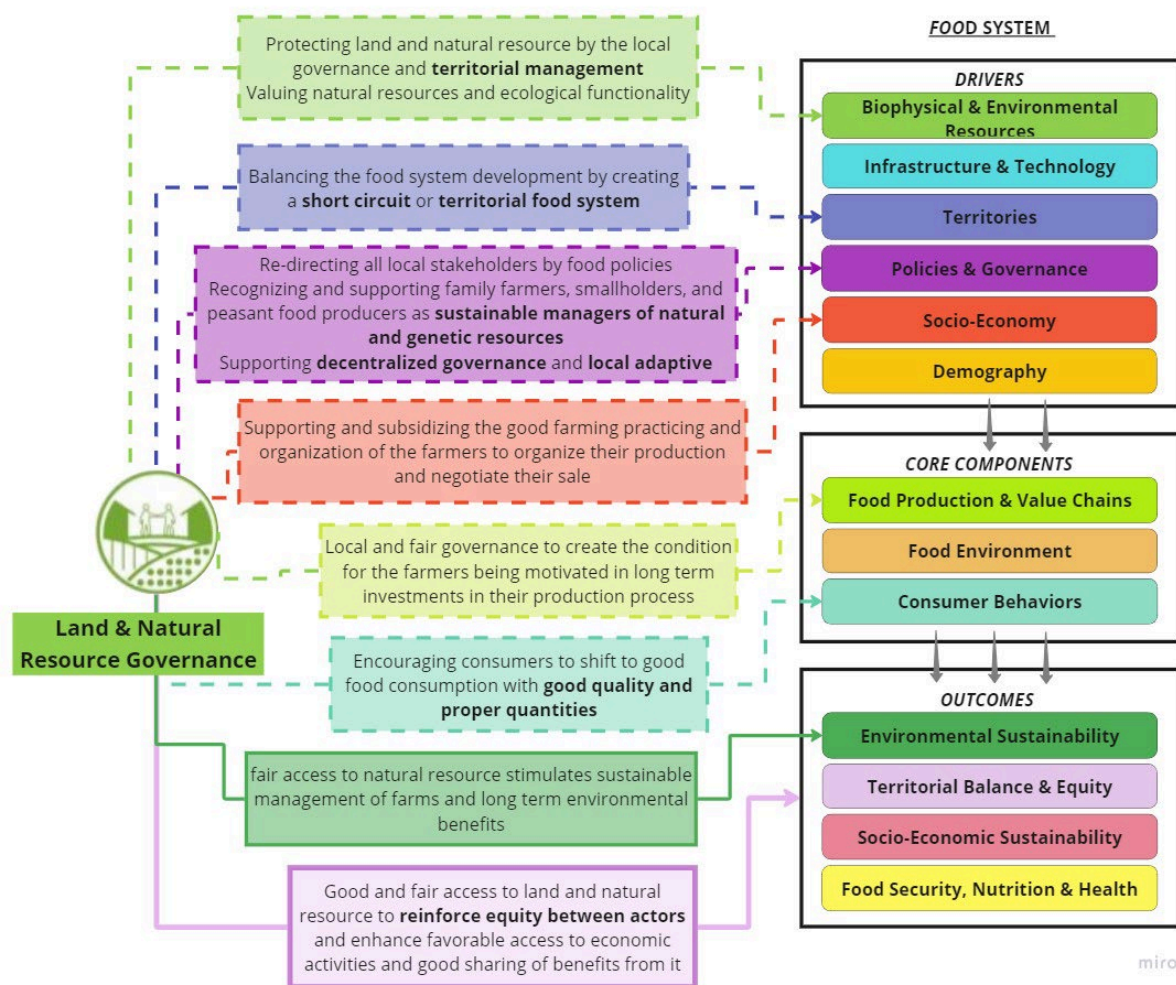
Positive correlations between connectivity in food systems and food nutrition and security are also reported in the literature. The crucial role is reported

- (i) of agricultural cooperatives which can build strategies to improve storage and provide food access during lean months faster than production-based approaches (Bacon et al. 2014),
- (ii) of collective reinvigoration of local agriculture after disasters that may promote food nutrition and security, preserve cultural traditions, and can be a foundation for sociopolitical autonomy, with the example of Puerto Rico (Marrero et al. 2022),
- (iii) of local markets promoted by food sovereignty approaches, that are associated to positive impacts on farmers food security and nutrition (Sampson et al. 2021).

None of the retained papers refers to connectivity among the ecosystem elements and relative impacts on food production, which is relevant due to their indirect effect on food systems sustainability. Moreover, while connectivity between farmers and consumers is explored (short or direct value chains), little is known concerning farmer-to-farmer exchanges, for instance in terms of input, work and resources, or longer value chains (with mid-stream actors). Indeed, the pros and cons of various ways to market agroecological products remains an open question, specifically in terms of number of intermediates and how to guarantee the quality of the products. This question would benefit from being further explored in contrasted contexts and for various types of products. Finally, reviewed papers do not explain how connectivity leads to circular value chains and how circularity might influence economic, environmental, and social sustainability of food systems.

4.2.11 Land and natural resources governance

Potential links identified by expert knowledge



Links description according to expert knowledge

FOOD SYSTEM		
DRIVERS	CORE COMPONENTS	OUTCOMES
<p>Socio-economy: Some political and economic drivers might ease a good natural resources and land governance.</p> <p>Strengthening institutional arrangements to improve, including the recognition and support of family farmers, smallholders, and peasant food producers as sustainable managers of natural and genetic resources.</p> <p>Social organization and greater participation in decision-making by food producers and consumers may be able to support decentralized governance and local adaptive management of agricultural and food systems.</p> <p>Policies and Governance: Food policies supporting and subsidizing the good farming practices and organic farming may incentivize farmers to correctly manage natural resources</p> <p>Biophysical and environmental resources: Land and natural resources will be protected by the local governance and territorial management, respecting the local people living within those areas, with social responsibility.</p> <p>Valuing natural resources and ecological functionality, change the way local actors establish trade-off between production activities and the potential negative impacts of these activities on natural resources.</p>	<p>Food production and value chain: a good local governance guaranteeing a fair and stable access to local resources, should create the condition for the farmers being motivated in long term investments in their production process. Soil fertility and water quality as examples could be maintained through more complex management. Applied to the rest of the value chain this principle also allows local processors and transporters to access to these resources in a negotiated and stable process.</p> <p>Consumers behaviour: Through food policies, consumers are encouraged to shift to good food consumption with good quality and proper quantities according to the dietary recommendation for health and nutrition, but also to food consumption respecting environment and good governance of resources, as shown by the rapid development of sustainability labels.</p>	<p>Environmental sustainability: A good local governance of land and resources may enhance a better distribution among the diverse actors of the food system. Better stability in the access to such resources should stimulate their sustainable management generating long-term environmental benefits. agroecologicalpractices thus often fostered such process.</p> <p>Territorial balance and equity: good and fair access to land and natural resources obviously reinforce equity between local actors of the food system. Better repartition of these production factors enhances favorable access to economic activities and good sharing of benefits from economic activities.</p>

Findings from literature

Strengthening responsible governance of local resources should be a crucial ambition of agroecological transitions, in order to create an enabling environment that simultaneously promotes social, economic, and environmental sustainability. Agroecological transitions towards sustainable agriculture and food systems demand the development of effective and innovative policies, institutions, governance mechanisms, and markets that enable and support transformative change (Caron et al. 2018). For instance, equitable access to land and natural resources (FAO 2012) is both key to social justice and a strong incentive for long-term investments necessary to protect soil, biodiversity, and ecosystem services (Ratner et al. 2013; Anderson et al. 2019). Responsible governance mechanisms at different scales, compatible with a sustainable production/transformation process, can support specific markets and the branding of agroecological products (Wezel et al. 2009; IPES-Food 2019). This is a way of rewarding agricultural management that enhances regenerative production through the protection and enhancement of biodiversity and ecosystem services (van Noordwijk et al. 2012).

Nevertheless, land, natural and genetic resource governance are rarely discussed in reviewed papers resulting from the search equations. Of these, three papers are presented hereafter, addressing this issue and covering several dimensions of sustainable food systems and more particularly land governance in Brazil and Canada with a specific focus on indigenous peoples (Blesh and Wittman 2015; Wittman and James 2022).

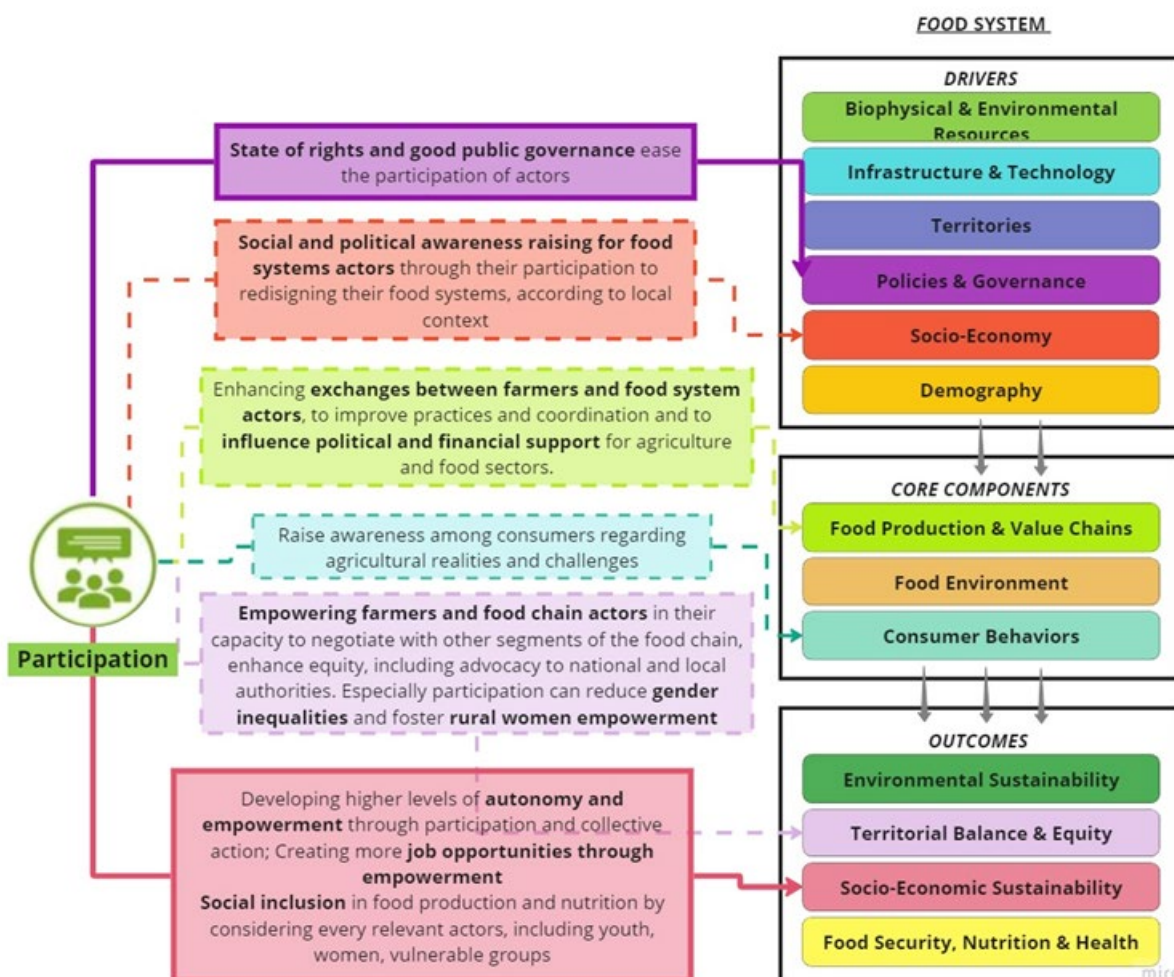
The papers demonstrate that “land dispossession” has damaged food security of local communities by reducing access to spaces used for hunting, fishing, gathering, cultivating. On the contrary, according to the authors some forms of “agroecological relations to land” may enhance food sovereignty. Social movements have the potential to (re)shape landscapes and to achieve food systems sustainability, such as equity and justice, self-determination, food security and nutrition and ecological health (Wittman and James 2022). Previously in Brazil, an empirical study carried out by Blesh and Wittman (2015) assessed how land reform settlements of the Cerrado region, already strongly committed with agroecology and food sovereignty, contributed to food system resilience in local communities through positive contributions of the various agroecological principles, particularly the “land governance” one.

Making the case of genetic resources, the paper from Kliem and Sievers-Glotzbach (2022) while demonstrating the positive contribution of self-organized breeding systems based on participation and co-creation principles of agroecology, also points out the importance of resources governance, confirming the role it can play in advancing towards more sustainable food systems.

Main knowledge gaps remain on how recognising and supporting smallholders and peasant food producers as sustainable managers of natural resources, and contribute to improving both environmental and socioeconomic sustainability of food systems. Even if some papers try to study the land/natural resources governance – agroecology – food system nexus, further research is still needed to better understand how this agroecology principle may encourage social organisations, farmers autonomy, sustainable farming practices and play a role in sustainable food systems. In particular the role of decentralized governance of land, natural resources and how it links to food systems in general constitute a gap of knowledge.

4.2.12 Participation

Potential links identified by expert knowledge



Links description according to expert knowledge

FOOD SYSTEM		
DRIVERS	CORE COMPONENTS	OUTCOMES
<p>Policies and Governance: The strong participation of all stakeholders to the redesign of the food system to be adapted to their local context raises social and political awareness on the importance of food systems patterns. It is thus essential that all stakeholders, especially local authority, significantly supports and enhances local food systems. State of rights and good public governance would ease the active participation of all food system actors, defending their rights and interests.</p>	<p>A strong participation and collective organization of all the actors of the food system will favor better practices and coordination between actors. It will also be necessary to influence political and financial support to agricultural and food sectors and make them more favorable to AE production practices and to more sustainable organization of the value chains.</p> <p>Consumers behaviour: participation of consumers in the redesign of food systems may bring new perspectives and increase awareness on agricultural and food patterns and challenges.</p>	<p>Socio-economic sustainability:empowering food chain actors in their capacity in negotiating with other segments of the food chain and actors of the food systems, including advocacy to national and local authorities. In particular, favoring participation may reduce gender inequalities and empower rural women in family farming agriculture to develop higher levels of autonomy and creating more job opportunities since women make up half of the rural population. Moreover, the agroecological approach mainly aims to enhance social inclusion in food production and nutrition by considering every relevant component or actor including young farmers or young members of the households, women, and so on.</p>

Findings from literature

Participation is usually a strong opportunity of learning and capacity building (learning by doing) and, as a first step, farmers can improve their production by managing more efficiently their agroecological systems. By building autonomy and adaptive capacities to manage agricultural and food systems and making claims in an organized manner, agroecology can strengthen the capacity of people and communities to overcome poverty, hunger, and malnutrition and inequity through the participatory approach (Altieri and Toledo 2011; Lemos et al. 2018). As a bottom-up, grassroots paradigm for sustainable rural development, agroecology can empower people to become agents of change (Holt-Giménez 2002; Tomich et al. 2011). As a result of the participation of social organization and actors involved in the food system, participation should play a pivotal role in promoting human and social values, culture and food traditions, as key features to be considered in increasing food system sustainability.

Few of the articles returned by the search equations directly study participation, meaning the principle of encouraging social organizations and increased participation of food producers and consumers in decision making in order to promote decentralized governance and local adaptive management of agricultural and food systems. Five papers explore, among other issues, the links between participation and food system sustainability (Bezner Kerr et al. 2022, Kliem and Sievers-Glotzbach, 2022, Wittman et al. 2020, Blesh and Wittman 2015, Deaconu et al., 2021).

Participation is mostly explored in relation to the socioeconomic sustainability of food systems in the long term, highlighting that participation and labor sharing have a meaningful role in smallholder farming communities (Bezner Kerr et al. 2022). This is the case when farmers acknowledge joining in participatory guarantee systems and in the monitoring of their activity to favor adaptive management of their farming and food systems (Wittman et al. 2020). Locally adapted management of farming systems by farmers is also encouraged by polycentric organization structure and decentralized projects with their own decision-making competences and processes, as shown by Kliem and Sievers-Glotzbach (2022) for breeding programs based on Commons. This leads to a more balanced territorial development and autonomy of these territories regarding external inputs and competencies.

Beyond farming communities, other actors may play a significant role participating in food systems governance, social organizations and movements such as the "land-less rural workers movement" and regional NGOs in Brazil. Their involvement has the potential to advance socioecological resilience in rural communities and more sustainable food systems based on commitment to agroecology and stable and farmer-friendly market channels (Blesh and Wittman 2015).

The participation in social organization plays a role for food security and nutrition as well, as demonstrated by Deaconu et al. (2021) in Ecuador, where stronger nutrient adequacy for agroecological farmers is likely promoted by the social and human capital developed within their networks.

However, little is known about the benefits of the participation to the territorial dimension of food systems sustainability, and especially on empowerment of farmers and women, job opportunities, and social inclusion. In addition, contribution of this principle to environmental and food security and nutrition dimensions were not addressed in reviewed papers, such as the conservation of natural resources based on social-networks, except in Kliem and Sievers-Glotzbach (2022) discussed further in 4.2.11 "Land and natural resources governance".

5 Discussion

Firstly, it is worth analysing the process of literature screening and choices made therein. The aim of the study was to analyse only articles specifically related to links (or interactions) between agroecology principles and dimensions of food system sustainability. It was therefore necessary to identify them within a large body of papers that may superficially refer to agroecology and the food system. Thus, the fact that the restricted corpus represented only one third of the main corpus was expected. The outliers' pool (very frequent and very scarce interactions) deserves to be discussed. Search equations that have led to many articles are those using very common keywords (e.g., nutrition, integration, participatory, etc.). Therefore a decrease in the number of articles actually associated with those topics was expected as the screening proceeded. Based on the abstract, 45 off-topics papers were excluded. At this stage the fact that for some interactions a higher number of articles was retrieved was expected. For instance, the resulting number of papers for the biodiversity principle was not surprising since the initial scope of agroecology was the implementation of ecological practices in agronomy, biodiversity being an indicator of ecological health. Therefore it can be assumed that the large proportion of papers linking biodiversity and the food system is related to a longer history of this environmental issue in agroecology. In the opposite case, where results are few, this may be due to the search equation being too specific or to a bias in the search repository. For example, considering the agroecology principle "Economic diversification" or the food system sustainability dimension "Territorial balance and equity", it can be assumed that research on these subjects is not so often linked to the concept of agroecology. Two other hypotheses can be put forward to explain the disparities of outputs between the different links on the agroecology/food systems interface. The first is that some sub-topics are easier to deal with, both methodologically and empirically. The second is that some links are more obvious and their role more visible (e.g., the case of links between biodiversity and food security and nutrition).

Moreover, it is worth noting that links between agroecology principles and food system dimensions are not always evident directly from the results of the search equations, but reading the abstracts and the text was necessary, to actually identify the links.

Overall, the search equations have proven to be relevant to discuss of the agroecology/food system interface and to allow for a fair identification and description of each of the categories of links studied.

Lastly, it is worth noting that the search was run on English keywords and on peer-reviewed literature. The study was carried out at the global scale, therefore further improvements could be provided by adding grey and non-English literature and explicitly considering cultural and spatial variations.

The quantitative analysis both identifies the main topics covered and provides information on remaining knowledge gaps. The bibliometric approach was complemented with a qualitative analysis of the bibliography to refine results and mitigate artifacts eventually generated by the choice of search equations. The analytical grid was used to extract useful information, to identify the predominant research questions, to highlight knowledge gaps for each of the interface categories. It was then possible to underline some trends within identified literature:

- Most of the papers were conceptual (and mostly reviews). They summarized a wide corpus of papers from different fields and offered consistent narratives on the connections between agroecology principles and food system sustainability but empirical studies that demonstrate these links on the basis of case studies (or on the basis of capitalization of several case studies), are scarcer.
- Articles identified are either focusing on the global scale, in particular in reviews, or on the local scale and are based on a specific context or case studies (regional or national). Only few empirical papers are comparing results extracted from diverse socio-environmental contexts in order to generalize conclusions and/or shed light on factors that lead to positive/negative outcomes.
- On the one hand many papers are focusing on the farm scale and smallholders in rural areas and only few studies go beyond, while it would be interesting to consider all stakeholders in those connected food systems, and especially youth, the mid-stream segments, the urban consumers and the members of food movements and governments (Blesh et al. 2019; Bezner Kerr et al. 2022). On the other hand, many papers on food security and nutrition are focusing on the demand of consumers, sometimes from the cities, rarely linking all the components of food systems.
- Notwithstanding production and consumption, other segments of the value chain (storage, process, trade, transport) are not, or very little discussed from an agroecological perspective.

- Although synergy and participation are not widely discussed, a relevant number of papers still refers to terms such as “integrated” implying multidisciplinary and multifunctionality, and “participatory” since this is the most common approach used in agroecology case studies.
- Some reviews also refer to synergies and participation, arguing that the pathway to achieve Sustainable Development Goals and resilience should be participatory, place-based, integrated, and should focus on maximizing synergies, reducing trade-offs by addressing these goals collectively at different scales (Bullock et al. 2017; Blesh et al. 2019).
- Agroecology principles are not often explicitly referred in papers, since agroecology (or comparable systems) is generally discussed as broad concept. Another case encountered in the review is the discussion of a principle without connecting directly to agroecology but referring to it from a scientific point of view or from the perspective of a social movement integrating it. To summarize, the agroecology principles are not precisely referred to when papers link agroecology with food security and nutrition, or the same principles are applied to sustainable food systems without referring to agroecology.

Considering food system sustainability dimensions, this study brings out remaining uncertainties highlighted by some reviews. Regarding the food security, nutrition and health dimension, health represents a gap in literature, even if nutrition-related diseases (such as obesity and malnutrition) are often mentioned as a critical issue that can be reduced by good practices along the food system. More specifically, the implication of mental health has been identified as an underexplored issue (Bezner Kerr et al. 2022).

With respect to the socioeconomic dimension, “true-cost accounting” including non-monetary benefits/costs (for instance immeasurable benefits/costs on marginalized groups), are lacking in the scientific literature (Saj et al. 2017; Bezner Kerr et al. 2022). Moreover, the way how agroecology can improve people livelihood through increased income, reduced input dependency, greater autonomy and self-provisioning still needs to be further explored (Bezner Kerr et al. 2022). The question of the quantity and quality of labour within food systems, more or less aligned with agroecological principles, is poorly documented.

Moreover, a knowledge gap is identified on how agroecology may help mitigating climate change effect on crops quality (e.g. nutrient composition) (Ahmed and Stepp 2016). Food security and nutrition and environmental dimensions are individually discussed in literature but further research is needed to better understand how both dimensions interact with each other and how climate change adaptation and food security goals could be addressed simultaneously (Saj et al. 2017). In addition, the compatibility of technological innovations such as mechanization within agroecological systems needs further analysis. With reference to different mechanization options, long-term consequences on soil health, on production and its stability, and on food security and nutrition are not sufficiently discussed.

The fourth dimension of sustainable food systems, territorial balance and equity among actors and territories, is far less explored in the literature compared to the others. Cases when this sustainability dimension is covered, are connected to the agroecology principles of “Fairness” and “Land and natural resources governance”.

Finally, even when several agroecology principles and food system sustainability dimensions are discussed in the same paper, trade-offs between them are rarely analyzed. However, some have been identified. For instance, there is evidence that without proper approaches to an equal division of work, gender inequalities can be reinforced because agroecology may be more labor-intensive than non-agroecological practices, that may also lead to negative impact on child nutrition when women are affected, and more generally on farmers health (Bezner Kerr et al. 2022). Another example are the trade-offs between production, food security and nutrition and climate change mitigation (Blesh et al. 2019).

6 Conclusions

By mapping the potential interactions between the two conceptual frameworks of agroecology (HLPE 2019) and food systems (David-Benz et al. 2022), and by analyzing the scientific literature focusing on the agroecology/food system interface, a very wide variety of links has been identified, illustrating the multidisciplinary of these subjects and the contribution of the agroecological transition towards more sustainable food systems.

Results of the study enable identifying a few key insights:

- 1.** Theoretically, many connections between the 13 agroecology principles and food systems have been identified, whether in terms of drivers, practices and strategies of the actors of food chains, or the impacts in the addressed sustainability dimensions (food security, nutrition and health; socioeconomics; territorial balance; environment).
- 2.** The number of scientific papers identified through the search equations confirms the importance of the topic and the growing interest of the academic world in the agroecology-food systems nexus.
- 3.** Notwithstanding the high number of papers identified through search strings, the number of scientific papers strictly focusing on specific interface agroecology/food system is still limited. Papers are mostly generalist and coming from specific research communities. The “food sovereignty” or “Alternative Food Networks” research communities seem to provide the more encompassing approaches. This calls for further multidisciplinary studies, benefiting from the expertise of both sides.
- 4.** Most studies highlight linkages and potential win-win contribution of agroecology in several food system sustainability dimensions, but empirical studies are still limited – except for the (agro)biodiversity-food security, nutrition and health linkage. More studies aiming at demonstrating the links, based on empirical data, are still needed, in contrasted contexts.
- 5.** On the food system side, food security, nutrition and health is the most covered dimension of food systems sustainability, with regard to the agroecology transition. This was quite expected since the food security and nutrition issue is well covered by literature (both from the agroecology sphere and the food system sphere), while the other sustainability outcomes of food systems (socio economic, environmental and even more equity/territorial balance) are more recent targets of research on food systems, and of agroecology research as well. In particular, the equity dimension of sustainable food systems, either territorial equity or equity between actors (e.g. gender equity, marginalized groups) is poorly explored, which is in line with the conclusions made by other authors.
- 6.** On the agroecology side, biodiversity, co-creation of knowledge and social values appear to be the most studied principles (with regard to food systems). However, while papers covering “biodiversity” are narrowly studying this principle, the ones covering “social values principle” take a wider perspective, with social values mostly viewed as a cross-cutting condition to enhance agroecological transition and transformation towards a more sustainable food system. Furthermore, in the literature reviewed, two principles clearly connect agroecology to food systems resilience –rather than sustainability—, which are biodiversity and synergies. The less studied principles are: economic diversification, land and resources governance, input reduction and recycling.
- 7.** The farm/agricultural system scale (in particular for smallholders) is still the most covered segments of food value chains. This is consequent to the fact that a key aspect of agroecology is the transformation of farming systems based on ecological principles, particularly adapted for small scale farmers. In addition, there are some researches at consumers’ level, highlighting the role of values in the purchases of agroecological products. However, research on mid-stream segments is lacking as well as how the numerous components of value chains (farming, process, storage, trade) are connecting to each other. Agroecological principles might imply more circular value chains, notably at a territorial level, which would benefit from being further explored.
- 8.** Cross-cutting studies remain a research front, such as cross-scale, cross-dimensions, or cross-value chain segments studies. Because of the complexity of both food system and agroecology concepts, research that is able to discuss the trade-off and co-benefits from agroecology transitions at various scales / dimensions of food system sustainability / segments of value chains is very scarce. In order to support policy makers and private actors to engage in agroecology transitions that are beneficial for the sustainability of the whole food system, multi-scales/multi-dimensional/multi-actors research is needed to allow deeper understanding of systems and trade-offs.

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List of abbreviations and definitions

AE	Agroecology
CIRAD	Centre de coopération internationale en recherche agronomique pour le développement
DIST	Délégation à l'information scientifique et technique
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
FS	Food System
FSN	Food Security and Nutrition
HLPE	High Level Panel of Experts
ICLS	Integrated Crop-Livestock Systems
IPBES	Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services
IPCC	Intergovernmental Panel on Climate Change
SDG	Sustainable Development Goal
TEEB	The Economics of Ecosystems and Biodiversity
UN	United Nations
UNCCD	United Nations Convention to Combat Desertification
WoS	Web of Science

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Annexes

Annex 1. Selected keywords for search string design

Related query	Selected Keywords
Search repository	Food system, Agrifood system, Agroecology, Agroecosystem
Input reduction	Input reduction, Input dependency, Chemical, Chemical reduction, Chemical dependency, Fertilizer, Fertilizer reduction, Fertilizer dependency, Low input
Recycling	Recycle, Reuse, Closing cycle, Cycle of nutrients, Cycles of biomass, Waste, Resource use efficiency, By product
Synergy	Synergy, Ecological interactions, Integration, Complementarity
Biodiversity	Biodiversity, Biological diversity, Genetic resources, Functional diversity, Activities diversification, Resilience
Soil and animal health	Soil health, Animal health, Soil ecosystem, Animal welfare
Economic diversification	Economic diversification, Livelihood diversification, Income diversification, On-farm income diversification, Off-farm income diversification, Non-farm income diversification
Social value and diet	Social values, Food tradition, Diet, Culture, Identity, Equity, Gender
Cocreation of knowledge	Co-creation, Co-design, Co-construction, Knowledge sharing, Horizontal sharing, Way of knowing, Community of practice, Social learning, Organization learning, Collaborative learning, Indigenous knowledge, Local knowledge, Scientific knowledge, Representation, Perception, Farmer to farmer, Farmer to consumption
Connectivity	Connectivity, Proximity, Circular, Food from somewhere
Participation	Participation, Decision Making, Social organization, Producer organization, Cooperative, Decentralized governance, Farmers organisation, Community involvement
Fairness	Fairness, Fair, Equity, Equitable, Dignified and robust livelihoods, Fair value chains, Treatment of intellectual property rights
Land and natural resources governance	Land governance, Natural resources access, Environmental equity, Land use planning, Land use management, Land management, Natural resources management, land use
Food Security and Nutrition (FSN)	Food security, nutrition, dietary diversity
Socio-economy	Inclusive development, employment, Socioeconomic development, Economic development, Socioeconomic sustainability, Economic sustainability
Environment	Environmental sustainability, Climate change, Natural resources preservation
Territorial balance and equity	Territorial balance, Territorial development, Territorial equity, Equitable value chain

Annex 2. Retained papers per agroecology principle and their interaction with the four dimensions of sustainable food systems

Input reduction

Article reference	FSN and health	Environment	Socioeconomic	Territorial balance/equity
(Bezner Kerr et al., 2022)	x		x	
(April-Lalonde et al., 2020)			x	
(Cheng et al., 2022b)			x	

The most general paper under this section is Cheng et al. (2022). Based on a review of the literature, the authors discuss the potential benefits and challenges faced by agroecological transformation for urban food systems. Although not providing empirical evidence, they argue that reducing the use of input and improving social cohesion and participation may trigger environmental and socioeconomic benefits for the food systems in urban areas, where AE transformation is expected to be more easily implemented.

Bezner Kerr et al. (2022) reviews 240 articles about the theoretical knowledge and the empirical evidence of agroecological linkages with social well-being, livelihood, meaningful work, gender and other forms of social inequity. Three types of relationships are explored between input reduction and the sustainability of food systems:

- (i) between the lower use of toxic inputs and health,
- (ii) between the lower use of external inputs and the freedom of farmers and their increased control over the means of production, between the lower use of inputs, the increased workloads and the additional work burden that disproportionately fall on women.

April-Lalonde and al. (2020) use cross sectional quantitative data and qualitative approach to analyse consumer behavior in alternative food purchases and shows that the absence of pesticides is one on the key determinants of the purchases of agroecological foods.

Recycling

Article reference	FSN and health	Environment	Socioeconomic	Territorial balance/equity
(Blesh et al., 2019)		x		
(Zarba et al., 2021)			x	
(Vaarst et al., 2018)		x		

Zarba et al. (2021) analyze the European planning instruments for circular economy and give examples in the potential benefits of recycling at different value chains segments in the Olive sector in Italy, but the link to agroecology is not clearly made.

Exploring the concept of Agroecological Food System, Vaarst et al. (2017) emphasises the importance of recycling and minimizing losses of biomass and natural resources in terms of food, water, and compost between the different levels of a food system, particularly by reorganizing rural-urban cycles.

Synergies

Article reference	FSN and Health	Environment	Socioeconomic	Territorial Balance/Equity
(Garrett et al., 2017)		x	x	
(Fernandez-Mena et al., 2020)		x	x	
(Jacobi et al., 2020)		x		
(Bullock et al., 2017)	x	x		
(Fernandez & Méndez, 2019)	x	x		
(Blesh et al., 2019)	x	x		

Synergies have been addressed by Garrett et al. (2017) in a review on Integrated Crop-Livestock Systems (ICLS) in Middle/High Income Countries regarding nutrient flows and crop performances, animal performance, and related socio-ecological outcomes. The authors explore two dimensions of FS sustainability.

- (i) Environment: there is evidence that ICLS provides multiple ecological benefits for agroecosystem enhancement, resilience to climate shock, and GHG mitigation. First, synergies between crop and livestock improve soil health by improving both micro and macro fauna. ICLS can also enhance nutrient flows by improve N and P accessibility and enhance their loss and soil organic carbon accumulation. Self-sufficiency and resilience to climate shock are increased in ICLS. Finally, ICLS have lower GHG emissions par unit of land (for crops) and food (for livestock) that continuous systems.
- (ii) Socioeconomics: ICLS often increase yields par unit of N or P input, but outcomes are dependent on biophysical or socioeconomic context (e.g., seasonally scarce, or poorly managed regions; grazing intensity). ICLS provides further benefits in income stability and resilience to all type of shocks including economic shock on market. Then, several non-monetary benefits are perceived by farmers.

Additionally, Fernandez-Mena et al. (2020), showed the importance of coupling crops and livestock for reaching self-sufficient circular systems. Scenarios that simulated best management practices at the farm scale and collective solutions for recycling (organic fertilization and anaerobic digestion) at territorial scale substantially improved the degree of circularity by tightening the local nitrogen (N) cycle without affecting food production.

More broadly, assessing contrasted food systems FS (agro-industrial, smallholders farming and agroecological systems), Jacobi and al. (2020) reveal evidence that AE and local FSs have high sustainability and high environmental performances thanks to biodiversity and synergetic livestock-crop integrations which provide ecosystems services.

Others benefits of synergy are addressed in literature, illustrating the benefits of positive interactions between vegetal species to enhance ecosystems services, several examples describe tree-soil interactions in agroforestry for example:

- (i) Bullock and al. (2017) review how resilience and food security are discussed in the literature regarding ecology. In this paper, authors support that bolstering the resilience of key functions such as soil condition by agroforestry, or pollination services by wild by diversity, will enhance resilience of production.
- (ii) Fernandez and Méndez (2019) study the benefits of agrobiodiversity in coffee plantation on stallholder's food security. It addresses potential benefits of interactions between trees and soil in diversified coffee crops on yield, health, and household's food security.

Moreover, in a review about the treatment of SDG 2 "Zero Hunger" in several disciplines, Blesh and al. (2019) identify papers addressing plant-microbe interactions in the root zone which is relevant to both agroecosystem sustainability and nutritional crops quality.

Biodiversity

Article reference	FSN and health	Environment	Socioeconomic	Territorial balance/equity
(Blesh et al., 2019)	x	x	x	
(Bullock et al., 2017)	x	x		
(Fernandez & Méndez, 2019)	x	x		
(Bezner Kerr et al., 2022)	x		x	
(Marrero et al., 2022)	x			
(Schipanski et al., 2016)	x	x	x	
(Bahadur et al., 2016)	x			
(Sampson et al., 2021)	x			
(Kliem & Sievers-Glotzbach, 2022)		x	x	x
(Deaconu et al., 2021)	x			
(Blesh & Wittman, 2015)	x		x	

The comprehensive review written by Blesh and al. (2019) considers ecology and agricultural sciences as one of the central perspectives to achieve Zero Hunger. Among the articles relationships between biodiversity and SDG2 are dressed through three dimensions of FS sustainability:

- (i) Ecological and nutritional benefits of functional diversity are highlighted, as well as ecological synergies such as linkages with soil fertility and quality, nutrient recycling, ecosystem resilience and climate change mitigation through sequestration and carbon storage.
- (ii) Biodiversity directly impacts on diet diversity and nutrition. The authors highlight strong evidence of association between crop species richness and diet diversification among farming households in low- and middle-income countries.
- (iii) Finally, regarding socio-ecological approaches, managing biodiversity can reduce dependence on non-renewable inputs and support viable livelihood in addition to environmental sustainability, FSN and human health.

In a critical analysis of key FS vulnerabilities and strategies that could enhance its resilience, Schipanski et al. (2016) provide other examples of initiatives linking social and ecological dimensions of FS sustainability by improving human health through production diversification and dietary diversity.

A review written by Bezner Kerr et al. (2022), also explores linkages between food production diversity and dietary diversity, and goes further ensuring that it can be beneficial for child nutrition, food security and well-being. It exposes considerable evidence of improved human health through increased dietary diversity and consumption of culturally significant foods linked to indigenous values. Therefore, AE can improve social wellbeing by keeping diversified and culturally meaningful foodways.

Sampson et al. (2021) conceptually explore the contribution of food sovereignty and food rights to food security and nutrition. Increasing autonomy over the production process through agroecological production practices is considered as one of the key action types that are implemented within the food sovereignty approach. The authors mention several papers that demonstrate that increasing diversification in farming systems, as part of

an AE production practice towards food sovereignty, is resulting in improved food security and nutrition for rural communities.

Based on household data (n = 1664) from Nepal, Bahadur KC et al. 2016 explores the relationships between crop diversity and food self-sufficiency for farming households. They conclude that FSN (measured by sufficiency) benefits from crop diversity. They also highlight that the contribution of agrobiodiversity to food security depends on local agroecological contexts: the poorest farmers in the poorest region with low access to market are more diversifying their cropping systems and benefiting to diversify and stabilize their diets. On the contrary, for farmers well connected to markets, diversifying cropping system would take resources away from main commercialized crops (vegetables in this case)

In Ecuador, Deaconu et al. (2021) use mixed methods (including survey data) to assess how farmers' participation in agroecological associations may impact their diets and health. They show that agroecological farmers outperform reference farming neighbours on both nutrient adequacy (i.e. meeting key nutrient needs) and dietary moderation (i.e. avoiding dangerous excesses). They demonstrate that stronger nutrient adequacy is likely related to agroecological farmers' higher production diversity as well as the social and human capital developed within their networks (See Participation).

Fernandez and Méndez (2019) provide empirical evidence of the benefits of agrobiodiversity in smallholders food security and ecological benefits, in a Mexican coffee-plantation case study. Two benefits of agrobiodiversity are addressed. Firstly, provisioning services as nutrient cycling and biological nitrogen fixation depend on biological diversity in farm. Secondly, agrobiodiversity was found to be strongly correlated with food and nutrition security through decrease of thin months at smallholder farm scale and at larger scale through landscape biodiversity.

In a recovery after disaster focus, Marrero and al. (2022) report smallholder farmers perception of agricultural resilience in a climate-vulnerable food system and identify linkages between agrobiodiversity and level of food access after a storm, while it provides resilience to disaster and considering that some products can be harvested in weeks.

Schipanski and al. (2016) support that enhancing social-ecological links and fostering adaptive capacity are essential to cope with short-term volatility and longer-term global change pressures. This paper presents several relevant evidence that biodiversification can increase ecosystem resilience, for instance by enhancing nutrient and organic matter cycles, or by increasing resilience to drought and to fertilizer dependency. It points out that crops diversification can mitigate vulnerability to climate, resource availability and market variabilities, whereas simplified production systems are dependent on only few crops. It also addresses that a shift to more perennial crops could benefit to improve ecosystem functions.

Based on qualitative study, Blesh and Wittman (2015) argue that a land reform in Brazil (supported by the "land less rural workers movement") enhance AE farming systems and some resilience outcomes, including both food sufficiency at farmers level and socioeconomic well-being. They show the necessity to combine several AE principles to enhance socioecological resilience, land tenure being one of the necessary but insufficient condition (See Land governance section).

Biodiversity is closely linked to the genetic resources, which has been explored in two retained papers. Kliem & Sievers-Glotzbach (2022) provides an empirical assessment, based on a document analysis of publications from breeding and seed-producing organizations in the German-speaking vegetable seed sector. They revealed the positive effects of commons structures in seed production on agroecological resilience and some outcomes of Sustainability / resilience of food systems (see section "Co-creation" and "Participation"). They also explore the Biodiversity principle of AE and show that these commons-based seed productions are based on breeding of open-pollinated, traditional, locally relevant varieties which favour higher genetic diversity in varieties and have a positive impact on environmental and socioeconomic sustainability/resilience of food systems. On the contrary, the authors show that "conventional breeding system" focus on monogenetic resistances and genetic uniformity which leads to a concentration on few crop species and very generalist high-yielding varieties.

Bullock and al. (2017) reviewed some papers providing empirical evidence that diverse crop rotations and varietal mixture can aid yield resilience with both genetic and species diversity. Moreover, this paper brings to light the role of diversity at a taxonomic level in resilience to climatic perturbations.

Social value and tradition

Article reference	FSN and health	Environment	Socioeconomic	Territorial balance/equity
(Rahman et al., 2021)	x		x	
(Jacobi et al., 2020)	x		x	
(Ahmed & Stepp, 2016)	x	x	x	x
(Borgerson et al., 2021)	x	x		
(Bezner Kerr et al., 2022)	x		x	
(April-Lalonde et al., 2020)			x	
(Deaconu et al., 2021)	x			

Rahman and al., 2021 studies linkages between AE and Heritage by developing the concept of social ecology of food. This paper argues that food traditions is a “glue” that makes the FS and knowledge work together. A direct link to food security is establish as culture and cultural practices could affect food production and consumption. Thus, food choices depend on tradition and traditionally eaten product contribute to connect people with their homeland.

In the assessment presented by Jacobi and al. (2020), an indigenous food system in Bolivia is studied. Authors found that its resilience comes from culturally appropriate food production and associated knowledge, as well as agrobiodiversity, reciprocity mechanisms and independence, identified as crucial factors in an ecological and economic long-term view.

An example of ecological and nutritional benefit of food tradition is given by Borgenson and al. (2021) through a case study of reintegration of a traditional eaten insect in diets. This intervention was beneficial for both environment and FSN. Insect can be raised within the broader agroecological continuum without requiring significant human or economic capital or biodiversity loss. Thus, this insect farming is considered as safer and more sustainable source of wildlife from forest and thus, can increase food security.

Ahmed and Stepp, (2016) review some literature on climate change effects on crop quality and agroecological management. It supports that producers’ response to climate shifts in their ecosystems depend on several human dimensions including some that refers to social values and participation such as cultural norms, social networks, collective management, and cultural memory that encompasses knowledge, beliefs, and values. Other dimensions are related to expertise, perceptions on variations in climate and in crop quality and access to resources. Consumers’ response is also addressed and mainly depend on sensory perceptions and market variables

April-Lalonde et al. (2020) describe characteristics and motivations of agroecological consumers (people purchasing AE products) and reveal that while direct food purchase is mainly driven by self-oriented motivations. AE consumption is also driven by altruistic reasons and social values. According to consumers, buying in AE market is not just a purchasing pattern but part of a responsible, healthy, and sustainable lifestyle. This lifestyle seems to be integrated in social values as most of families are ties to alternative food networks, by schools or consumer organizations for instance. Healthy dietary habits are also encouraged by increased opportunities for learning and sensory experience and through social support in AE marketplaces. Agroecological consumers are also more likely to eat frequently traditional foods, they have more environmental motivations than other consumers, and they recognize the importance of supporting AE practices and products that incorporate traditional knowledge. Thus, AE is perceived as culturally appropriate. Moreover, ACs have socio-political and socioecological motivations to build a FS that allows access to healthy food while preserving agri-food socio-ecosystems, as environmental impact reduction and farmer’s conditions improvement is part of purchasing lifestyle. Furthermore, authors report that in Ecuador, supporting AE networks is seen as a way to resist the conventional industrializes food system.

Also in Ecuador, Deaconu et al. (2021) show with quantitative methods that stronger dietary moderation (i.e. avoiding dangerous excesses) observed for agroecological farmers, compared to reference ones, is likely related to food traditions, their greater consumption of foods obtained through own-production and the social economy.

Co-creation and knowledge sharing

Article reference	FSN and health	Environment	Socioeconomic	Territorial balance/equity
(Rahman et al., 2021)			x	
(Ahmed & Stepp, 2016)			x	
(Bullock et al., 2017)			x	
(April-Lalonde et al., 2020)	x		x	
(Jacobi et al., 2020)	x			
(Wittman et al., 2020)			x	
(Kliem & Sievers-Glotzbach, 2022)		x	x	x
(Sampson et al., 2021)	x			

Rahman and al., (2021) highlight the importance of co-creation and knowledge sharing in the engagement of stakeholders to transit towards a sustainable FS. They add that farmers' access to innovation is considered to encourage knowledge exploration, to increase young farmers' interest in agricultural process, and to enable them to find suitable adaptative mechanism, for instance to mitigate impacts of climate change.

In the context of breeding, Kliem & Sievers-Glotzbach (2022) demonstrate how commons-based seed production systems positively contribute to the sustainability of food systems in various dimensions. First, the co-creation process studied aims at achieving plant robustness without chemical inputs and adaptability to changing environmental conditions through natural enhancements of varieties (breeding of open-pollinated, naturally reproducible varieties via crossing and selection methods). This is likely to positively contribute to the environmental sustainability of the FS. Second, with reproducing varieties, farmers' independence is more guaranteed with these common-based breeding programs, which contribute to social resilience of farming communities. Third, the authors show how seed production built on co-creation and knowledge sharing favour more equity between food systems actors, in particular between seed and services providers and farmers.

Ahmed and Stepp (2016) assume that farmers' responses in agricultural management to consumer decision-making, market and agroecosystems variations depend on their knowledge acquired through social network. In addition, Bullock et al. (2017) recognizes that knowledge transfer to and among farmers can contribute to enhancing social networks and allows them to self-organize to address resilience issues. Wittman et al. (2020) explore the potential of and challenges related to the digitalization of agroecological systems and provides an example of a farmer-scientist partnership that resulted in an open-access digital tool. The tool aims at monitoring AE practices and their impact on various dimensions of FS sustainability (including data on worker satisfaction and labour quality, profits and costs of production, the number of people fed (across nutritional dimensions), fertilizer and water use efficiency, soil health, market prices (relative to other local farmers in the network), biodiversity conservation), in the context of a participatory agroecological certification.

The link between co-creation/knowledge sharing and food systems sustainability also exists through the "food sovereignty" approach, as supported by the Sampson et al. 2021 review. They show that agroecological practices co-designed with farmers, based on traditional knowledge is likely to guarantee food systems sustainability, in particular food security and nutrition. The majority of studies they reviewed show that

diversified farming practices informed by local and traditional knowledge are associated with greater nutritional diversity for the farmers.

April-Lalonde and al. (2020) explore the importance of knowledge through: level of education of AE consumers and knowledge sharing about the origin and safety of products.

- (1) First, AE consumers are more likely to have higher education and to be highly knowledgeable about the nutrition label on processed foods (salt intakes control, daily consumption of fruit and vegetables, rare consumption of industrially process food), and they are more likely to be employed. It seems that the initial level of education facilitates the process of knowledge sharing. This knowledge-predisposition factor among AE consumers is even more important when we know that no links between AE purchase and gender or income level was found. Finally, this paper flags a difference of behaviour according to consumer's age. Indeed, young adults are less concerned about long-term impact on their health, and do not value social interactions at the time of purchase, but rather fast and independent shopping experiences.
- (2) On other hand, knowledge sharing is determinant in motivation and trust that have AE consumers in purchasing AE products. In this study, only AE consumers emphasized their trust in products allowed by the transparency on their origin and safety. Moreover, AE purchasing is linked to the farmers-to-consumers learning opportunities afforded in AE markets.

Finally, Jacobi and al. (2020) ensure that the transdisciplinary process of knowledge co-creation can enable stakeholders from different food systems to learn from each other how to increase food sustainability.

Connectivity

Article reference	FSN and health	Environment	Socioeconomic	Territorial balance/equity
(Bezner Kerr et al., 2022)			x	
(April-Lalonde et al., 2020)			x	
(Kremen et al., 2012)		x	x	x
(Jacobi et al., 2020)		x	x	
(Bacon et al., 2014)	x			
(Marrero et al., 2022)	x		x	
(Rahman et al., 2021)			x	
(Wittman et al., 2020)			x	
(Sampson et al., 2021)	x			

Bezner Keer and al. (2022) identify articles addressing connectivity in FS through local markets. It notices that fostering greater interactions between producers and consumers in local markets was documented, sometimes with the concept of agroecological territories.

April-Lalonde et al. (2020) bring to light socio-economic benefits of connectivity in the FS:

- (i) This is one motivation of consumers because proximity allows them to get to know producers. Thus, consumer can directly assess producers' degree of responsibility in the product and address them concerns and share knowledge with farmers.

- (ii) Direct markets are reasonably priced thanks to proximity and absence of intermediaries. This is important considering that saving money is a key factor in the choice of food shopping location. In the case of AE product, some consumers are willing to pay a little more for the quality of food.

Kremen and al. (2012) address alternative agri-food systems (such as organic or low-input farming which are related to AE practices) and benefits of the connectivity built between farmers and consumers. Authors describe several forms of relationships (such as direct marketing, fair trade certification and food justice movement) that help sustain ecosystem services and social infrastructures. Alternative food networks, often rooted in agroecological farming practices, seek to produce and distribute healthy, environmentally sustainable, and socially just food. Value is redistributed through the food chain, trust between farmers and consumers is rebuilt and new forms of governance emerge in these systems. This paper argues that farmers markets more equitably support small-scale producers and urban consumers, by bypassing industrialized FS through direct connection and knowledge exchange, even if it may provide equity only for small-scale growers and not for consumers. In addition, farmer's connection to small holder cooperatives and global fairtrade network help mitigate vulnerability to crashing coffee commodity prices.

Jacobi and al. (2020) argue that FS with large spatial distances between production and consumption points, i.e., non-local FS, are prone to disruption from either environmental or socio-economic shock. At contrary, two papers discuss multiple benefits of connectivity either during seasonal hunger (i) or after disaster (ii):

- (i) Bacon and al. (2014) explore multiple factors influencing smallholders' seasonal hunger. Concerning connectivity, this paper argue that agricultural cooperatives can built strategies to improve storage and provide food access during lean month quicker than production-based approaches and thus address food security.
- (ii) In the case of Puerto Rico, which suffers from extreme events, Marrero and al. (2022) present findings suggesting that connectivity, through reinvigoration of local agriculture, may promote FSN, preserve cultural traditions, and can be a foundation for socio-political autonomy.

Rahman and al., (2021) address connectivity through social relationship in the traditional "subak" system (in Bali), arguing it is crucial to ensure the sustainability of the system and to protect farming as the main livelihood in the community. Connectivity may also be facilitated by digital tools as promoted in Wittman et al. (2020). Participatory guarantee systems in Latin America use an app to monitor agroecological practices and their impacts in various dimensions at farmer's scale. This is expected to investigate trade-off among sustainability dimensions of FS.

Finally, while this is not the core of the paper, Sampson et al. (2021) discuss the role of Creating and Supporting Local and Regional Markets to Make Food Accessible, as part of the actions promoted by food sovereignty approaches. Their review included four studies reporting positive correlation between these outlets and farmers food security and nutrition.

Participation

Article reference	FSN and health	Environment	Socioeconomic	Territorial balance/equity
(Bezner Kerr et al., 2022)			x	
(Kliem & Sievers-Glotzbach, 2022)			x	x
(Wittman et al., 2020)			x	
(Deaconu et al., 2021)	x			
(Blesh & Wittman, 2015)			x	

(Bezner Kerr et al., 2022) demonstrates that labour sharing have a meaningful role in smallholder farming communities. In addition, the review underlines that the participation of marginalized groups and youth are key components of AE urban projects. In the same vein, the app aiming at monitoring AE practices presented by

Wittman et al. (2020), not only favour farmers' involvement in the creation of the app/indicators used but also in the data gathering and analysis which makes them active actors of monitoring which can favour adaptive management of their farming and food systems. The participation in social organization play a role for food security and nutrition as well. Deaconu et al. (2021) show that agroecological farmers outperform reference farming neighbours on both nutrient adequacy (i.e. meeting key nutrient needs) and dietary moderation (i.e. avoiding dangerous excesses) in Ecuador. They demonstrate that stronger nutrient adequacy is likely promoted by the social and human capital developed within their networks.

Beyond the benefits from co-creation and knowledge sharing reported in the commons-based breeding programs studied by Kliem & Sievers-Glotzbach (2022), the systems are based on "polycentric organization structure of breeding organizations" and decentralized breeding projects/monitoring with their own decision-making competences and processes. This type of decentralized governance encourages locally adapted management and increased participation of farmers within their communities. This leads to a more balanced territorial development and autonomy of these territories regarding external inputs and competencies.

In Brazil in addition to land reform, civic engagement by the "land less rural workers movement" and regional NGOs with government social welfare programs is an example of the participation principle promoted by AE transitions. The involvement in social organization and movements have the potential to advance socioecological resilience in rural communities and more sustainable food systems based on commitment to agroecology and stable and farmer-friendly market channels (Blesh and Wittman, 2015).

Fairness

Article reference	FSN and health	Environment	Socioeconomics	Territorial balance/equity
(Bezner Kerr et al., 2022)			x	x
(April-Lalonde et al., 2020)			x	x
(Schipanski et al., 2016)	x		x	x
(Sampson et al., 2021)	x			
(Vaarst et al., 2018)	x			

April-Lalonde et al. (2020) identify fairness as one of the several motivations of direct purchasing channels consumers. Local farmers' difficulties and risks are recognized and participants of direct purchasing channels want to be part of equitable exchanges by supporting fair markets.

Bezner Kerr et al. (2022) review articles supporting the idea that integrate knowledge sharing opportunities and give attention to gender dynamics can contribute to ensure that the AE work is equitably shared. According to the racial equity, the review identifies nascent literature linked to AE, largely coming from the Americas.

Vaarst et al. (2017) assert that equity is a cornerstone in agroecological food systems through equitable access to resources, both for production and transformation, and the better way to nurture the soil and the ecosystems while producing healthy nourishing food.

Schipanski and al. (2016) also insist on the need to address more social justice and gender equity to benefits for FSN-related and social outcomes and present a large body of work bringing to light the importance of increasing social justice and equity to increase food accessibility. This paper shows a focus on gender equity in the literature and gathers evidence that improving woman access to land, resources and education has multiple and cascading benefits on food security and human health. Moreover, woman participation in groups is addressed as it benefits empowerment and indirectly socioeconomic and nutritional outcomes, and thus contributes to promote more equitable FS at larger scale. This is in line with the paper written by Sampson et al. (2021) which review the contribution of food sovereignty and right to food approach to FSN. Indeed, they

conclude that 12 studies out of 15 report evidence of the positive impacts of gender equity and women's empowerment on FSN across many geographic and economic contexts.

Land and natural resources governance

Article reference	FSN and health	Environment	Socioeconomics	Territorial balance/equity
(Wittman & James, 2022)	x			x
(Kliem & Sievers-Glotzbach, 2022)		x	x	x
(Blesh & Wittman, 2015)	x		x	

Wittman and James (2022) study the linkages between land governance, AE farming systems and some sustainability outcomes of FS: FSN, territorial equity, and equity between peoples, with a specific focus on indigenous peoples. They highlight several ways in which land has been conceptually and materially contested across agrarian transitions, historically and into the present day, in Canada and Brazil. They demonstrate that “land dispossession (and resulting loss of place-specific ecological knowledge)” has damaged food security of local communities by reducing access to spaces used for hunting, fishing, gathering, cultivating. In addition, conventional land management have resulted in concentration of lands, resources and power in the hand of few people, at the expense of nature and indigenous peoples in both countries. On the contrary, some forms of “agroecological land relations” linked to food sovereignty social movements have the potential to (re)shape landscapes and to result in agroecological outcomes and FS sustainability, such as equity and justice, self-determination, food security and nutrition and ecological health.

Previously in Brazil, an empirical case study carried out by Blesh and Wittman (2015) focused on a land reform settlement supported by the “landless rural workers movement” in the Brazilian Cerrado. The land settlements of farmers are based on commitments to social equity and environmental conservation, and organized around principles of agroecology and food sovereignty. This study assesses the contribution of these land reform settlements to food system resilience in Brazilian communities, focusing on various indicators chosen by the communities, including food self-sufficiency, soil health, income, market access. As we reported before, the agroecological system analysed in this paper mobilized many principles of AE. To sum up, positive contributions of these various AE principles have been found on various FS’ sustainability dimensions, although “threshold of dignified lives” (as defined by farmers) are not yet achieved.

With the case of genetic resources, the paper from Kliem & Sievers-Glotzbach (2022) demonstrates the positive contribution of self-organized breeding systems based on participation and co-creation principles of AE, and that this is in fact also a matter of resources governance, confirming the role of the latter in advancing towards more sustainable food systems.

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