Organic farming as policy to address vulnerabilities of the prevailing European food system based on conventional agriculture?

(Abbreviated version)

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1 INTRODUCTION

Food is of key relevance to human health and survival. Europeans take their food and nutrition security (FNS) for granted and rely on a food system in which most of the food is produced by conventional farmers [1]. Over the last decades this system has achieved tremendous improvements in productivity [2]. As a result, nowadays more food is supplied than demanded at historically low prices. This allows European consumers to spend only a small percentage of their household disposable income on food [1], [3].

These FNS achievements in Europe are, however, far from ideal and looking ahead Europeans may not be as food secure as they perceive to be. The European consumers rely on a complex system, in which conventional farmers, driven by profit maximization, are continuously intensifying, specializing, standardizing, expanding their operations and becoming even more dependent on the application of off-farm sourced modern tools such as chemicals to manage fertility and pests, diesel-powered machines, biotechnology and proprietary seeds [2]. These processes and practices, in turn, feed back to the environment and to society with numerous unintended consequences, *inter alia,* soil degradation, nutrient runoff, greenhouse gas (GHG) emissions, biodiversity loss, pesticide-born health damage and socio-economic decline in rural communities. These consequences pose risks to FNS and well-being of future generations [4]. Moreover, much of the productivity advances and associated trends in the European food system were realized in times of relatively stable climate, when natural resources seemed to be infinite, and the human population was considerably smaller [5,6]. In the face of already observed changing climate, deteriorating natural resources, growing population as well as many other emerging challenges and uncertainties, there are growing concerns that the European food system is vulnerable and thus unable to withstand disturbances without undesirable outcomes [4], [6], [7]–[12].

In order to cope with the challenges and uncertainties, we need a new approach to agriculture in the food system [7], [8]. Such an approach must change both the farming practices as well as the socio-economic organization of food production to increase the food system's resilience and its ability to deliver sustainable and equitable FNS today and in the future [1,5,7–9]. One of the potential candidates is organic farming [5,7,9,13,14], which from all the alternate approaches is the only one that has been regulated and supported at EU level by a vast array of legal, financial and knowledge-based policy instruments for the last several decades [15]. Accordingly, the number of organic farms, the extent of organically farmed land, funding devoted to organic farming and the market size for organic foods have steadily increased across Europe [15–17].

Organic farming seems to be a promising approach as it is built on four systemic principles formulated by the International Federation of Organic Agriculture Movements (IFOAM): *health*, *ecology*, *fairness* and *care*. Organic farming thus aims to produce wholesome food in an environmentally-friendly way, as well as to contribute to economic sustainability and social justice [18]. In research and public debate, however, organic farming has a history of being contentious [19]. On the one hand, many studies provide evidence for organic farming's ability to balance the multiple sustainability goals [19] and build resilience to disturbances, especially at farm level [20–23]. On the other hand, critics consider organic farming as an inefficient approach to FNS, one that will become irrelevant in the future, because of too many shortcomings and poor solutions to agriculture problems [3], [19]–[21] as well as high price of organic food which inhibits access to food [24,25]. Furthermore, some argue that organic farming undergoes 'conventionalization' and is a mere 'substitution of inputs' rather than a 'system's redesign' guided by a holistic understanding of organic principles [26]. Consequently, organic farming may violate many of the ecologically, socially and economically progressive principles originally valued [18,27], further exacerbating the vulnerabilities the prevailing European food system [5].

In this paper we adopted a system dynamics approach to understand vulnerabilities of the conventional European food system's to various disturbances and to assess whether organic farming has potential to reduce the vulnerabilities and enhance the resilience of the European food system (Figure 1). Following we involved stakeholders to develop portfolio of policy interventions for making organic farming a significant contributor to resilient and sustainable FNS in Europe. Finally, we assessed these policies using Meadows *Leverage Points* framework (Figure 1) [28].

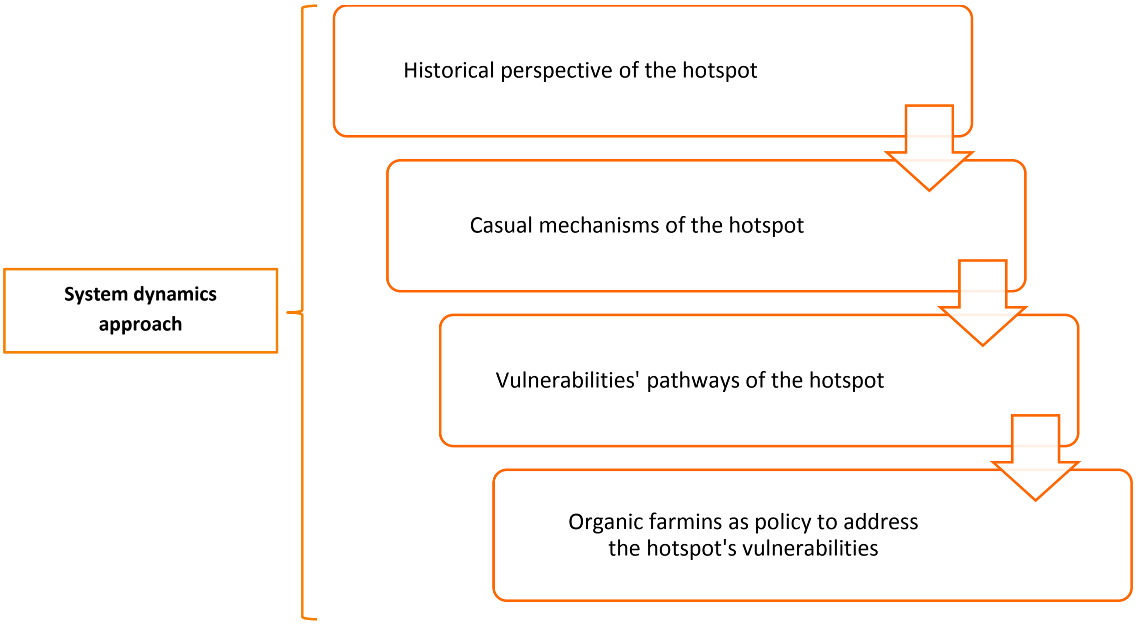

Figure 1 Structure and approach taken in the paper

2 BAU ANALYSIS

2.1 METHODOLOGY: SYSTEM DYNAMICS APPROACH

Food systems are coupled social-ecological systems (SES) formed by many internal factors and external drivers that are interconnected through feedback processes at various scales and levels and that determine FNS along with other environmental and socio-economic outcomes [29–31]. When exposed to various and unforeseen disturbances, the emergence of undesirable outcomes indicates that somewhere in the food system a critical capacity is failing and that the structure and processes driving the functioning of the system make it vulnerable [32]. We thus define *vulnerability as a system's inability to respond to disturbances without generating undesirable outcomes*. In vulnerable food systems, even small disturbances may cause detrimental changes from which it is difficult to recover [29]. *Resilience*, on the other hand, *is the capacity of a food system to withstand disturbances and continue providing the same or possibly even improved desirable outcomes* [31]. Vulnerability and resilience are dynamic and normative in the sense that the value judgement of what is desirable and what constitutes improvement or detriment over what period of time depends on the observer [33]. Hence, to assess whether a food system is resilient or vulnerable we have to define: (1) the boundaries of the system (vulnerability/resilience of what), (2) relevant disturbances (vulnerability/resilience to what) and (3) what constitutes desirable change over what time frame and to whom. We address these questions in our vulnerability/resilience assessment by adopting a system dynamics approach.

System dynamics is an approach designed to study and manage complex systems that change over time [34]. The central principle of this approach is that the endogenous structure and feedback processes of a system determine its dynamic behavior over time and how it responds to disturbances [13,35]. The system dynamics methodology provides structural thinking tools – stocks, flows, feedback loops and structural diagrams – to advance understanding of the interrelationships among factors in the system. The structural diagrams represent the structure and feedback processes underlying a dynamic problem. They provide important qualitative insights into the system's behavior [36] and facilitate the identification of leverage points for intervention in the system [35]. Based on structural diagrams computer simulation models can be created to experiment on how the system behaves under unanticipated disturbances or policy interventions [13,37]. Quantitative analysis of system behavior when exposed to disturbances is, however, beyond the scope of this paper.

In this paper we adapt the approach taken by Stave and Kopainsky [13]. They used system dynamics to promote qualitative structural insights on mechanisms and pathways of food supply vulnerability, arguing that "*any examination of food supply vulnerability to disturbances, or ability to withstand disturbances that could lead to food supply disruption, should start by examining the food system's components, causal connections, and feedback mechanisms and describing system interactions in terms of material and information flows that pass changes in one component on to other components*" [13]. The approach taken in this paper consists of three iterative steps inspired by the system dynamics modelling process as presented in Figure 2 [34,35].

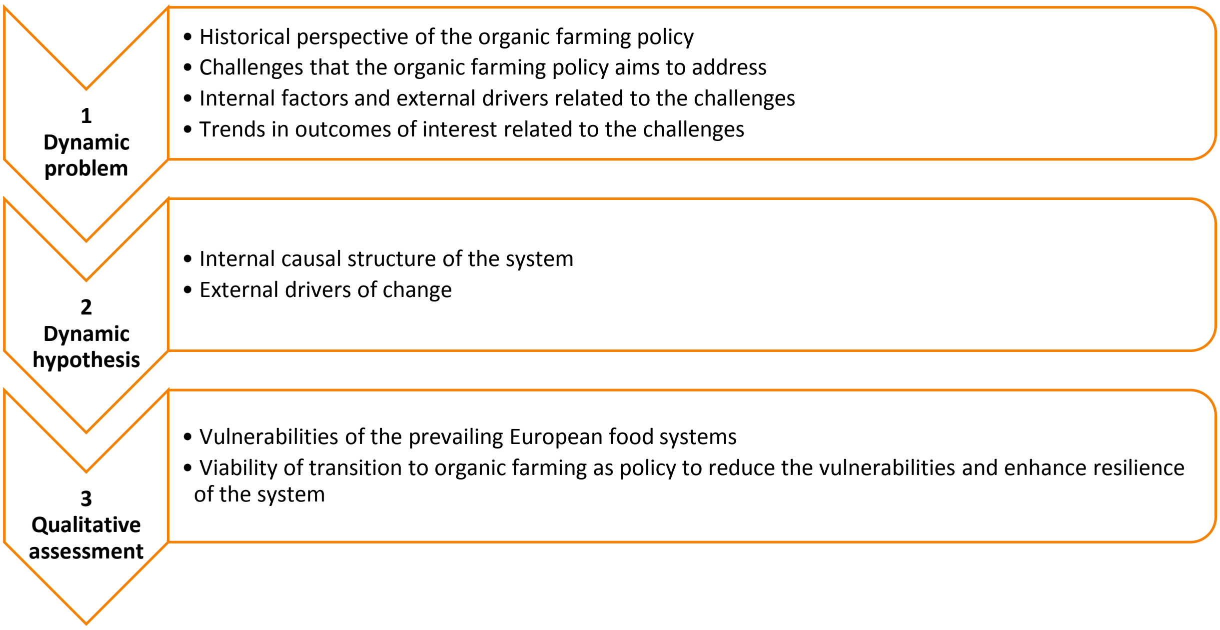

Figure 2 Adopted system dynamics approach

2.2 HISTORICAL PERSPECTIVE & CHALLENGES THAT ORGANIC FARMING POLICY ADDRESSES

Organic farming started at the end of 1920s as a social movement which was initiated by the Austrian spiritual philosopher Rudolf Steiner. The social movement gathered producers and interested individuals who were skeptical about the practices of conventional agriculture, in particular the costs and benefits related to the use of external inputs such as synthetic fertilizers and pesticides [42]. However, instead of protesting against the conventional way of farming, they opposed it by demonstrating an alternative approach to food production. The organic farming movement was then diversified by a number of other key people and first versions of organic standards were formulated by Demeter in Germany (1928) and Soil Association in the UK (1940) [43]. At the beginning of 1970s Roland Chevriot of Nature et Progrès envisioned the need to coordinate actions of the different organic farming movements and to enable scientific and experimental data on organic to cross borders. In order to realize this vision, he invited organic pioneers including Lady Eve Balfour, founder of the UK Soil Association, Kjell Arman from the Swedish Biodynamic Association and Jerome Goldstein from the Rodale Institute to join him in Versailles to set the International Federation of Organic Agriculture Movements (IFOAM) in motion [44]. IFOAM developed the influential Basic Standards for organic farming based on four principles – *health, ecology, fairness, care*. *Health* means that organic farming intends to produce high quality food without using mineral fertilizers, synthetic pesticides, animal drugs and food additives that may have adverse health effects. The *ecology* principle requires organic farming to fit in the cycles and balances in nature without exploiting it by using local resources, recycling, reuse and efficient management of minerals and energy. *Fairness* relates to organic farming as being a system that provides good quality of life, contributes to food sovereignty, reduces poverty and enhances social justice, enhances animal well-being and takes future generations into account. Finally, *care* is a principle that argues for applying precaution and responsibility before adopting new technologies in organic farming practices [18].

Until 1993, there was no governmental support available for organic farming. Therefore, the development of organic farming sector was based on private organic standards set to the IFOAM's Basic Standards and depended solely on consumer's willingness to pay. Originally consumers were motivated to pay price premiums for organic produce mainly because of more altruistic concerns over the environment, animal welfare and social justice. However, over time many consumers have increasingly seen organic food as healthier, safer and of higher quality than conventional food, and for these perceived features they have been willing to pay [15].

Since mid-1980s governments across Europe have started recognizing the potential of organic farming to address the increasing concerns about the negative environmental and other impacts of post-war agricultural development [43]. To this end, first governmental initiatives to support organic farming emerged at national level in countries like Denmark, Austria and Switzerland. At European level, the first regulation on organic farming and the labelling of organic farm produce and foods was introduced in 1993 (Council Regulation (EEC) No. 2092/91), which covered initially only plant products, but later rules on animal products were also added [15]. Having recognized demand from the organic sector for a strategic plan to develop organic farming in Europe, in 2004 the European Commission launched an Action Plan for Organic Food and Farming. The action plan included 21 initiatives to achieve the objectives of developing the market for organic food and improving standards by increasing efficacy, transparency and consumer confidence. As part of the action plan, the EU regulation has been substantially revised in 2007, resulting in Council Regulation (EC) No. 834/2007 defining core organic farming principles and the Commission Regulation (EC) No. 889/2008 setting out the detailed implementing rules. Both regulations came into force in 2009, with compulsory use of new European organic logo to follow in 2010. Again in 2014, after almost a two year in-depth review of the European policy on organic agriculture, the European Commission adopted a legislative proposal for a new regulation and approved a new action plan to help organic farmers, producers and retailers adjust to the proposed policy changes and meet future challenges. Despite the multiple amendments and revisions of the EU regulation, the core definition of organic farming as "*an overall system of farm management and food production that combines best environmental and climate action practices, a high level of biodiversity, the preservation of natural resources, the application of high animal welfare standards and production standards in line with the preference of certain consumers for products produced using natural substances and processes*" has remained unchanged over the years [45].

The EU regulation sets the minimum standards for all EU Member States while stricter rules can be developed by individual EU Member States or private associations. Nevertheless, since organic farming became part of a legislative process, the control over the sector has shifted from producers and interested individuals to commercial and public institutions (i.e., policymakers, research institutes, food industries, etc.) [15]. Against this background, organic farming has also become more and more an instrument of agriculture policy in the EU. Specifically, the harmonization of legal framework of rules on organic production at EU level has allowed the EU Member States to include organic farming as an option under the agri-environmental and other measures of the rural development programmes as well as extend governmental support for the sector into areas such as research, market development and consumer promotion [15].

The reason for governmental support to organic farming and using it as an instrument in the European agriculture policy are manifold [15]. Predominantly the European policy related to organic farming aims to address the following challenges: (I) correction of previous government intervention, (II) imperfect competition, (III) lack of information and transparency as well as (IV) market failure with respect to public goods. First, initially organic farming was supported by governments to correct the effects of previous state intervention on markets that led to serious food surpluses, apparent in, for instance, the well-known European Union 'milk lakes and butter mountains' in the 1990s. The lower productivity of organic farming was recognized by policymakers as a positive advantage and thus organic farming was used as an instrument to address the issue of overproduction (Commission Regulation (EEC) No. 4115/88). Second, European Commission introduced EU-wide harmonized rules for organic production (i.e., Council Regulation (EEC) No. 2092/91 and the following versions of the regulation) to tackle mainly the challenge of market failure with respect to imperfect competition between organic producers on the European internal agri-food market. Policymakers by introducing European regulation for organic farming intended to create a level-playing field for all producers within the UE, to enhance market transparency at all stages of production and processing as well as to improve the credibility of organic products in the eyes of consumers. Third, with Council Regulation (EC) No. 3/2008 information provision and promotion measures for agricultural products on the internal market and in third countries, policymakers aimed to address market failures due to lack of information and transparency and to open up new markets. The regulation was supported by a toolbox for promoting organic products developed as part of the EU Action Plan on Organic Food and Farming (2004). Fourth, possibly most importantly, organic farming was used as policy instrument to correct the market failure in the context of the provision of public goods, since it is considered as a land management concept that contributes to sustainable development and which is compatible with the need to preserve the natural environment and landscape and protect and improve natural resources. Accordingly through area payments under the framework of Common Agriculture Policy, all EU Member States could support conversion to and maintenance of organic farming.

To conclude, the policies for organic farming developed in Europe since the late 1980s aimed to address the challenges of food overproduction, heavy reliance on commodity support for conventional agriculture and deteriorating natural resources due to agricultural intensification. As mentioned earlier, the market for organic products was originally developed as a means to support the financial viability of farmers trying to deliver ecologically, socially and economically progressive objectives. Nowadays, however, the conditions that have impacted on organic farming policy development over the last decades have changed tremendously. Widespread policy support in most cases has eliminated the need for producers to rely on the market, while at the same time the success of the organic market has generated its own challenges with respect to organic principles and values. Besides, organic products are sourced not only locally, but the international trade of organic products is already a reality. Furthermore, state support for production has been decoupled and increasingly these resources are being diverted to agri-environmental and rural development programmes. Food surpluses as an issue have been replaced by renewed concerns about FNS in view of disturbances arising from various drivers of change. For instance, climate change along with biodiversity loss and pollution pose risks to continuity of the food system's ability to produce enough food. At the same time, the global economic crises severely constrain market growth and government ability to fund support programmes of this type.

From the analysis of historical background as well as present and emerging challenges that organic farming as policy should address the following questions emerge: is transition to organic farming as currently arranged (*inter alia*, EU-wide regulation, direct payments, price premiums) a viable policy to address the current and future vulnerabilities of the prevailing European food system? What policies are needed to make organic farming a significant contributor to resilient, sustainable and equitable FNS in Europe?

2.3 CAUSAL MECHANISMS OF THE HOTSPOT: EUROPEAN FOOD SYSTEM BASED ON CONVENTIONAL AGRICULTURE

In this section, we focus on analyzing causal mechanisms that constitute the European food system based on conventional agriculture and make it vulnerable to disturbances that emerge from within the system as well as from external drivers of change. The analysis leads to the following sections 2.4 and 2.5, in which we respectively identify several pertaining vulnerabilities of the European food system based on conventional agriculture and assess whether organic farming as policy has potential to address these vulnerabilities and bring resilience to the system.

2.3.1 Qualification of the hotspot: internal factors and external drivers of change

First, we identify internal factors of the European food system based on conventional agriculture that expose it to impacts of external drivers of change or determine its sensitivity and adaptive capacity. Table 1 provides overview of the most important internal factors along with their justification for leading to vulnerability.

Table 1 Overview of internal factors related to the hotspot

Internal factors	Rationale for leading to vulnerability	References
Crop / Animal yield	Yields indicate how much food can be produced for consumers and how much profits farmers can gain from a unit of agriculture land. Yields are point of exposure of the food system Yields losses in prevailing food system could have major, long-term and wide-range implications for both producers by undermining their livelihoods as well as consumers by reducing the amount of food available for consumption.	[46–48]
Agriculture land / Number of livestock	The majority of food production process takes place on agriculture land. Agricultural qualities of land (e.g. topography, altitude, soil type, and natural water and nutrient cycles) set limits on farming practices (e.g. number and size of livestock) that can take place on the farm. They also affect whether production can be intensive (when there is little land available) or extensive. The amount of agriculture land is limited and hence once degraded by inappropriate practices cannot be renewed easily.	[49–51]
Natural resources condition	Natural resources, such as healthy and fertile soils, are at the heart of any food production system and farmer livelihoods. Bad condition of natural resources makes thus conventional farmers sensitive to lack of access to external inputs, especially because the success of most low external input agriculture systems, depends on the health of natural resources.	[13,52]
Machinery	Machinery is a factor of increasing importance for performing food production activities, not matter whether in conventional or organic manner. Yet most of current machinery is diesel-powered. This implies increasing dependence on non-renewable, finite fossil fuels. In case of any disruptions in supply of fossil fuels, the ability to swiftly and efficiently produce food is restricted.	[5,53]
Labour	Labour is a critical factor of production in farming. Hence access to enough labourers is a major factors for determining how productive	[5,9]

	a farm can be and whether it is possible to switch between production systems characterized by different levels of labour intensity. The less labour intensive are conventional production systems, the less people are involved in food production and the lower share of the society knows how to produce food.	
Knowledge	Food producers need to know how to combine production inputs with ecosystems to be able to produce food. Knowledge-infrastructure (e.g. extension) in place can enable producers (e.g. farmers) to adapt to new conditions in a timely manner and change the current system. The dominance of conventional farming systems erodes the knowledge base necessary for successful implementation of alternative farming systems, in case of disruptions.	[54]
External inputs	Food producers depend on external inputs such as fertilizers, pesticides, diesel, hormones, antibiotics, feed, etc. to achieve desired yields. The higher is the dependence on external inputs, the more sensitive the food system is likely to be to constraints in their supply.	[5,9,52]
Profits	Food producers needs financial resources to purchase production inputs (i.e., invest in machinery, hire labour, purchase external inputs). Without sufficient profits or access to credit, farmers may not be able to acquire inputs and hence reap the benefits of higher crop yields/productivity, and in turn higher returns on their produce. Moreover, financial assets are indispensable to switch between food production systems.	[55]
Price of food	Price of food is one of the most important determinant of consumers access to food as well as revenues that food producers could gain from their operations. Unfair or volatile price of food could undermine how much food can be assessed by consumers as well as farmers livelihoods.	[56–58]
Food consumption	How much and what kind of food is demanded by consumers indicates both current sensitivity however also the opportunities for decreased demand. For example, Europeans waste approximately 30% of food annually as well as high resource intensive animal products constitute considerable share of their diet.	[19]

Second, in addition to internal factors, there are many external drivers of change that may disturb the European food system based on conventional agriculture. In Table 2 we provide overview of our analysis of external drivers using the categorization provided by TRANSMANGO conceptual framework along with examples and rationale for causing vulnerability of the food system.

Table 2 Overview of external drivers of change impacting on the hotspot

External driver category	Examples and rationale
Biophysical environments	▪ climate change, e.g., extreme weather events such as drought lead to crop failures ▪ crop pests, e.g., Phytophthora infestans (late blight) destroyed potato plantations and caused the Irish famine ▪ livestock diseases outbreaks, e.g., BSE caused a global animal health and food safety crisis with major implications also on the trade and export of animals and derived products ▪ human diseases outbreaks, e.g., flu pandemic could significantly reduce the labour input needed in food production ▪ natural disasters, e.g., ashes from volcanic eruptions could disrupt plant photosynthesis and cause crop failures
Policy	▪ geopolitical dynamics, e.g. trade arrangements, political tensions between countries could disrupt supply of external inputs, such as phosphate rock or fossil fuels, undermining food production in importing countries of the EU ▪ changes in governmental support and legislative framework, e.g., removal of milk quotas in the EU, changes in CAP or rules for organic production, introduce uncertainty and discourage food producers from investments

Society & culture	▪ demographic changes, e.g. population growth or ageing affect the amount and kind of food that is demanded ▪ changes in consumer values & ethical stances, habits & dietary preferences, e.g. shorting towards more meat-based diets puts substantial pressure on the condition of natural resources ▪ urbanization leads to loss of agriculture land to other purposes than food production ▪ social innovation, such as Community Supported Agriculture (CSA), if up-scaled could considerably change the functioning of the whole food system
Economy	▪ economic crisis, like in 2007-2008 and 2010-2011 could affect the price of both production inputs and food ▪ competition for natural resources from other industries, e.g., biofuels, decrease the amount of inputs available for food production ▪ price of natural resources, e.g., fossil fuels, phosphate rock, water, increase price can affect the farm gate price of production inputs such as fertilizers and thus undermine achieved yields
Science & technology	▪ technological innovation, e.g., GMOs, nanotechnology, precision agriculture, poses risks related to their unintended impacts (e.g., eutrophication caused by excessive use of fertilizers) and opportunities related to, for instance more sustainable use of natural resources

2.3.2 Identification of food system boundaries in relation to the hotspot

We frame the dynamic problem of vulnerability as the concern that the European food system when subjected to disturbances of different nature and origin would be unable to withstand them and hence cause its outcomes to considerably or permanently diverge from their desired level. Ericksen [35,36] distinguishes three groups of outcomes that can indicate vulnerability of the food system, namely failure to provide FNS as well as collapse of environmental and socio-economic welfare. The prevailing European food system based on conventional agriculture continuously faces the challenge of reconciling FNS, the viability of rural societies (socio-economic welfare) and low environmental impacts (environmental welfare). Hence, we set the food system boundaries around this threefold challenge by analyzing trends in its indicative outcomes along with outlining the associated activities, actors, assets and institutions that condition them as well as external drivers of change that could disturb the system (Figure 6).

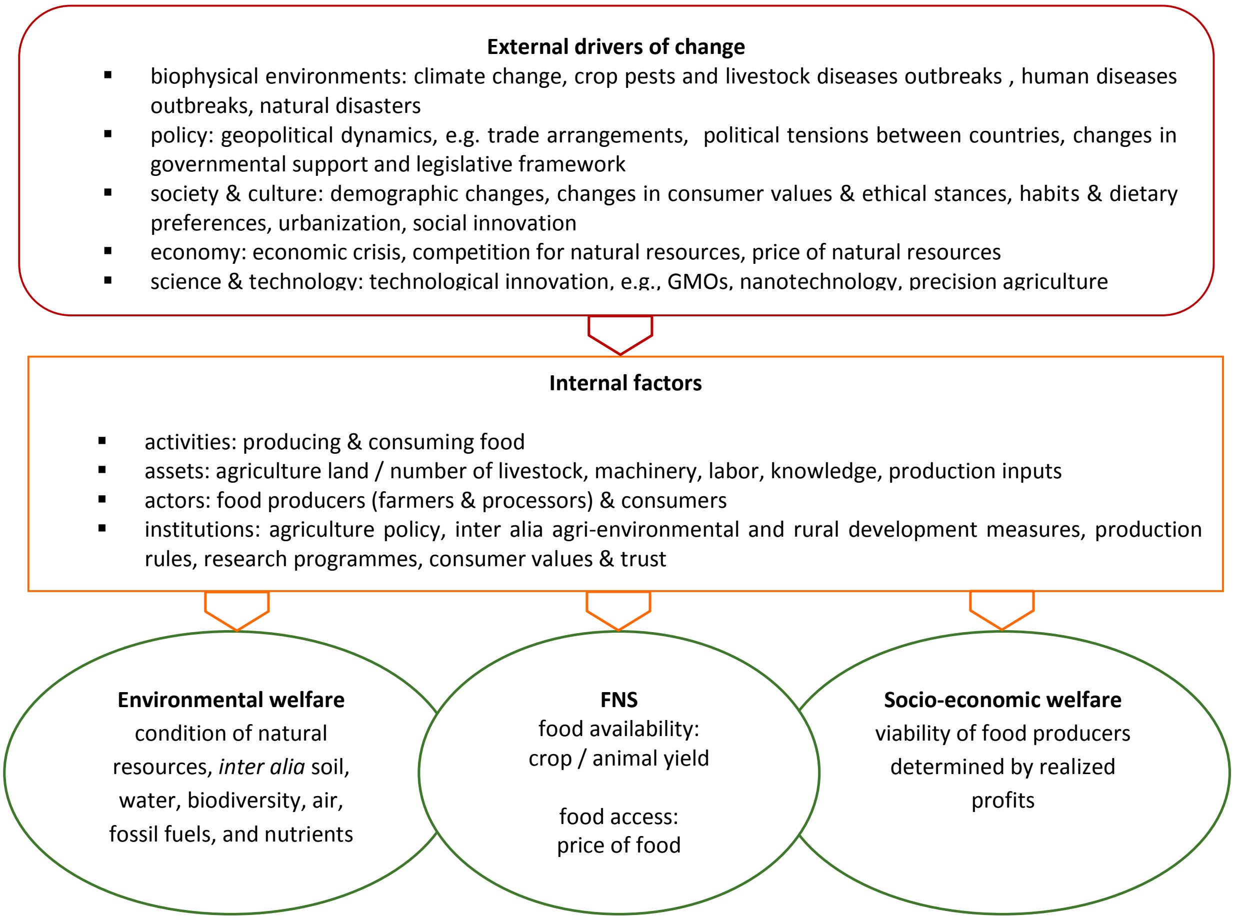

Figure 3 Outline of the food system boundaries in relation to the hotspot

2.3.2.1 Food and nutrition security

In the 1950s – 1960s European food producers were primarily concerned with the quantity of food they needed to supply for consumers to overcome the post-war shortages in food availability [59–61]. Over the years, the food system throughout the whole EU has moved from being based on traditional farming practices to intensive agriculture characterized by modern diesel-powered machines and productivity tools based on external inputs such as synthetic fertilizers and pesticides, artificial irrigation systems as well as proprietary, high-yielding seeds and breeds [2,62]. As a result, food production has experienced a leap forward, which has been attributed mainly to yield improvements rather than expansion of agricultural land. The story of English wheat is emblematic for the European context. It took nearly 1000 years for wheat yields to increase from 0.5 to 2 t/ha, but only 40 years to climb from 2 to 6 t/ha [2]. Simultaneously, despite the inherent tendency of agri-food markets to be volatile, the agricultural commodity prices and related food prices have exhibited a rather steady pattern of decline until about a decade ago. Accordingly, from the perspective of European consumers the food system has been uninterruptedly delivering desirable FNS outcomes. Food per each European has been available in surplus quantities – from around 3000 kcal/day in the 1960s to over 3400 kcal/day in the 21^{st} century in comparison with the needed 2000-2500 kcal/capita/day – and accessible at relatively low prices [1,2,63–66].

Yet within the new millennium several undesirable trends in crop yields and prices have emerged. The crop yields in some European regions (e.g., wheat in Northwest Europe or maize in South Europe) have reached or moved close to their plateaus [48,67]. This implies that the yields have not increased for long periods of time following an earlier period of desired steady linear increase and thus raises concerns over future food availability [48,67]. As regards the prices of agricultural commodities and food, their volatility has increased in the last decade. More specifically, sharp increases in food prices in 2007-2008 and 2010-2011 were followed by recurring periods of often severe price depressions. The high volatility in prices has created an uncertain environment with many undesirable consequences for consumers' access to food. The price hikes caused a rapid increase in consumer food prices, which reduced average EU household purchasing power by around one percent. Low income households (especially the 16% of EU citizens who live below the poverty line) were hit even harder [56,68].

Furthermore, despite increasing food availability Europe has not managed to guarantee FNS for all citizens. About 10% of the European households have been persistently unable to access meat or a vegetarian equivalent every second day – an amount generally recommended in European dietary guidelines [69]. At the same time, the proportion of overweight or obese people has continuously increased to reach over 50% in 2010 [70]. Although both of these undesirable trends are more political and distributional problems rather than agricultural issues per se, they indicate important failures in the socio-economic organization of food production and downstream food system activities.

2.3.2.2 Socio-economic welfare

FNS and consumers are only one side of the food system. The other side are the food producers, in a broader sense rural communities, and their viability. While the increase in yields has brought benefits to both consumers and producers, the decline in prices of agriculture commodities has been undesirable for the latter. Accounting for inflation, until 2005 European farmers experienced incessant real price declines in output and input prices, but with the former decreasing faster. Since then the trend in input prices has reverted and they started to increase, further widening the gap between input and output prices [71,72]. This cost-price squeeze has caused an undesirable decline in the realized profits from farm operations and threatened the farm's viability in the long term.

The widening gap between output and input prices has been counterbalanced by significant gains in labor productivity. This has been manifested by, *inter alia*, reduction in farm labor, decrease in number of farms and increase in the average farm size. To illustrate these trends, only since 2002 until 2010 the agricultural labor input in the EU decreased by as much as 32% (a drop of 4.8 million full-time equivalent jobs), while between the 2005 and 2013 the annual average rate of decline in the number of agriculture holdings stood at -3.7% and the average size of each farm in EU-27 rose in terms of hectares from 11.9 to 16.1 as well as in terms of the economic size expressed in European Size Units (ESU) [71,73,74].

Although the structural changes have diminished the gap between input and output prices, taking into account the total costs for own and other factors of production (land, labor, capital) still many of the European farms have been unprofitable with market revenues alone. To this end, throughout the last several decades governmental support (i.e., subsidies in different forms) has played an increasing role in farm profits [71]. As a result, the average dependence of farm profits on subsidies in the EU is now as high as 58% [75]. Moreover, in recent years the farm profits have become volatile and hence created a high level of uncertainty among food producers [76,77].

2.3.2.3 Environmental welfare

Farmers represent only around 5% of the European Union's (EU's) working population, yet they manage over 40% of the EU's land area, and generate important impacts on the environment [78]. Hence in addition to FNS and other socio-economic welfare, environmental welfare is of great importance as both a condition for and an outcome of applied agriculture practices.

Over the past decades, the loss of traditional farming to intensive agriculture has contributed to the transgression of a number of critical planetary boundaries [73]. Inappropriate agricultural practices and land use have been responsible for adverse impacts on natural resources condition such as pollution of soil, water and air, fragmentation of habitats and loss of biodiversity. The reforms of the Common Agriculture Policy (CAP) in the 1990s, 2003 and 2008 have increasingly integrated environmental protection measures, including obligatory crop rotation, grassland maintenance, and more specific agri-environment measures, aimed at climate change mitigation and biodiversity conservation. These measures have brought about some improvements such as decreasing GHG emissions and pesticide use. However, these improvements have not been sufficient as European agriculture still depends highly on external inputs. Consequently undesirable environmental outcomes like exceedance of nutrients, diffuse pollution to water and dramatic loss of biodiversity persist, further diminishing ecosystems' resilience. More efforts are called for to balance food production and the environment [81].

2.3.2.4 Signs of vulnerabilities and resilience

Table 3 summarizes our findings on the observed trends in indicative outcomes that the conventional European food system has delivered so far. In addition, looking through the lenses of sustainability, we outline the desirable and undesirable trends in the outcomes that could result from an exposure of the system to shocks and stresses. These trends serve as reference modes to which we refer back throughout the following vulnerability assessment.

Table 3 Summary of observed trends* in indicative outcomes of the European food system along with their desired/undesired trends in the face of disturbances based on the stakeholders vision

Indicative outcome	Observed trend [1]	Desirable trend [1]	Undesirable trend [1]	V/R BAU[2]
		Food and nutrition security		
Food production	↗	supply = demand	↘	+
Yield	↗→	↗	↘	-
Price of food [3]	↘↗	↘ stable	↗ volatile	-
		Socio-economic welfare		
Profits [4]	↘↗	↗	↘ volatile	-
		Environmental welfare		
Natural resource condition	↘	↗	↘	-

* time range of the observed trends are indicated in the text of the sections 2.3.2.1 – 3; [1] arrow indicates direction of trend in the particular outcome over time; [2] qualitative assessment of vulnerability(V)/resilience(R) in Business-As-Usual scenario, i.e., to the current impacts of driving forces, where (-) signifies vulnerability, (+) signifies resilience; [3] consumer perspective; [4] producer perspective

The European food production – one of the most important FNS outcomes – has been remarkably resilient to the impacts of distinct drivers of change over the last decades (Table 3). However, much of the food had been produced during a period of successful regional cooperation and supportive political environment, relatively stable climate, when farms were predominantly small-scale and diverse, natural resources appeared abundant and the human population was considerably smaller. Besides, despite the abundance of food production, apparently too much of the wrong kind of food at the wrong price has been provided, as the double burden of malnutrition (i.e., undernutrition and overweight) has continued in the EU.

A comparison of the observed trends in the remaining indicative outcomes – i.e., agriculture yield, price of food, profits, natural resources condition – with their desired levels, reveals emerging signs of the European food system's vulnerabilities to disturbances that have been at play so far (Table 3). The productivity of the current food system has come at the expenses of our natural and human resources. This poses severe risks to its continuity in delivering the fundamental FNS outcomes.

To conclude the analysis of indicative food system outcomes over time, it seems that the improvement of FNS outcomes in the last decades have come at the expense of other food system outcomes and that the European food system is gradually becoming more vulnerable to a wide range of disturbances. If the undesirable developments continue, the existing vulnerabilities of the food system might be further exacerbated or give rise to new vulnerabilities endangering the food production.

2.3.3 Description of causal mechanisms

Many processes underlie the trends described in section 3. In this section we adopt a feedback perspective and describe the underlying causal structure of the European food system likely to be generating the problematic trends (**Error! Reference source not found.**). The structure is composed of several reinforcing feedback processes – *mechanization* (R1a, Figure 4)*, intensification* (R1b, Figure 4) as well as *efficiency maximization* (R5, Figure 8) – that explain why food production grows regardless the direction of change in profits realized by food producers. When profits rise, food producers (re)invest in machinery and external inputs to increase food production, whereas when profits fall, food producers feel pressure to reduce production costs by maximizing efficiency and hence again increase food production using equal or even less inputs. Further, the central processes of *mechanization, intensification* and *efficiency maximization* are linked to other feedback loops of reinforcing (i.e., *labor reduction* (R1c, Figure 4), *compensation for degraded natural resources with external inputs* (R2, Figure 5), *organization of food production (*R3, Figure 6), *substitution of tacit with standardized knowledge (*R4, Figure 6)) as well as balancing (i.e., *degradation of natural resources* (B2, Figure 5), *regeneration of natural resources (*B2, Figure 5), *loss of tacit knowledge* (B3, Figure 6), *supply* (B4, Figure 7) *demand (*B5, Figure 7), *trade* (B6, Figure 7), *market expansion (*B7, Figure 8), *cost minimization (*B8, Figure 8)) nature. The interconnected feedback structure relates food production to other FNS, socio-economic and environmental outcomes. Based on this integrated feedback structure we explain how the ever rising food production emerges from within the same dynamics as the mounting pressures on human and natural resources that make the food production possible in the first place.

2.3.3.1 Under conditions of high or rising profits, mechanization and intensification lead to growth in food production

The structure of causes and effects linked together in a set of reinforcing feedback loops (Figure 4) – *mechanization* (R1a), *intensification* (R1b) and *labor reduction* (R1c) – operate in every capitalist market system. Food producers, having profit maximization as a goal, (re)invest in food producing inputs – land, labor (R1c, Figure 4), machinery (R1a, Figure 4) and external inputs (R1b, Figure 4) like fertilizers, plant protection products, seeds, feed, antibiotics, hormones, etc. The (re)investment is encouraged also by political and financial commitment of the EU to the agri-food industry (e.g., subsidies in different forms: direct payments, investment grants, intervention buying, private storage aid or export refunds, etc.). Explicitly, with the subsidies going into agriculture, food producers have both the security and the finance to (re)invest in production inputs.

The more inputs are used, *ceteris paribus*, the more output per hectare (or per animal), i.e., yield, can be achieved. In turn, multiplying the crop (or animal) yield by the limited amount of land area (or the number of animals) determines the food production that flows into the stock of food available for consumption. Food production, if sold on market, brings the producers profits. A share of the profits is reinvested in new production inputs, which are then used to increase the amount of food produced for sale. As long as profits are sufficiently high, the reinforcing feedback loops – R1a, R1b, R1c (Figure 4) – function in the food system and lead to a boost in food production.

Yet having a limited budget and a goal of maximizing profits, the investment decision on 'what' and 'how' to produce involves relevant trade-offs and thus is not straightforward. As regards 'what' to produce, shifts between crop and animal production (not shown in Figure 4 for clarity reasons) result from changes in relative production profitability and consumption patterns of the population [82]. For instance, a growing demand for animal-based food products, for example, increases the attractiveness of animal production. Hence, food producers allocate more land and other production inputs to animal production at the expense of crop production [82]. Similar tradeoffs occur when considering agricultural production for food and for other uses than food like biofuels, textiles, etc.

When deciding 'how' to produce, no matter whether this concerns crop or animal production (or other uses), to a certain extent labor can be substituted with machinery and external inputs. The feedback mechanism in Figure 4 shows that when fossil fuel and other external inputs are available and inexpensive, there is a strong incentive to invest and use diesel-powered machinery and off-farm sourced inputs instead of labor to increase yields [11]. In other words, higher costs of labor increase the attractiveness of investing in and using machinery and external inputs instead. The success of machinery and external inputs in delivering higher yields, translating into higher food production and accordingly higher profits strengthens itself leading to *mechanization* (R1a, Figure 4) and *intensification* (R1b, Figure 4) of farm practices. Simultaneously, because of decreasing reinvestment in labor and hence its replacement with machinery and external inputs, the stock of labor is forced into a reinforcing downward spiral, that gradually leads to *labor reduction* (R1c, Figure 4) [83,53].

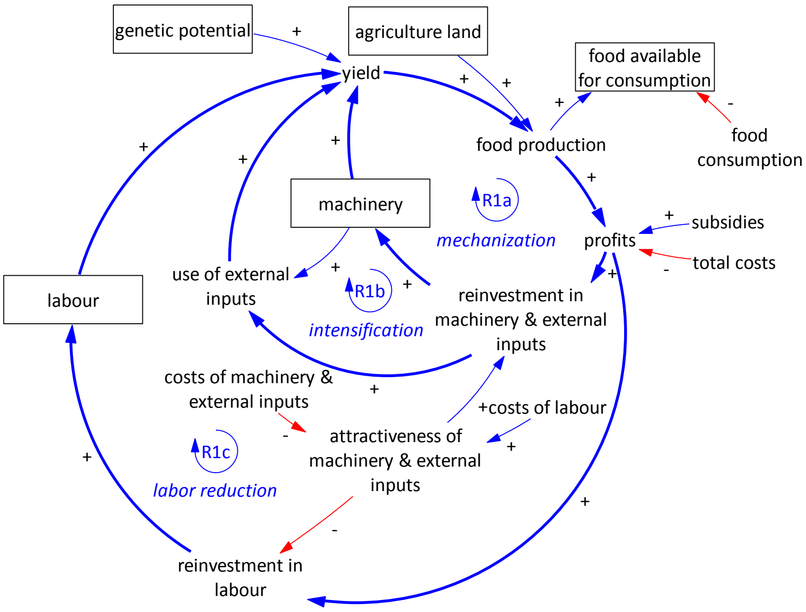

Figure 4 Causal loop diagram representing *mechanization* and *intensification* reinforcing feedback loops (respectively R1a, R1b) driving food production growth under conditions of rising profits; some links are omitted for visual clarity

2.3.3.2 Food production is embedded in ecosystems

This implies that food production is conditioned by natural resources such as soil, water, air, biodiversity, nutrients and fossil fuels. As the natural resource base is limited, food production cannot grow infinitely. The worse the conditions of natural resources, the lower yield can be achieved and/or the less agricultural land is available for food production. The flows – degradation (outflow) and regeneration (inflow) – that influence the stock of natural resources are determined, among other things, by the implemented management of agroecosystems (i.e., the 'what' and 'how' to produce). Intensive food production practices that depend on use of external inputs tend to degrade the productive natural resources by their overexploitation (e.g. phosphate rock [52,84,85], fossil fuels [86,87], etc.) and pollution (e.g., nutrient leaching [88], GHG emissions [89], etc.) [8,90–93]. For instance, the stronger the reinforcing feedback loops driving use of diesel-powered machinery (R1a, Figure 4) and synthetic nitrogen fertilizers (R1b, Figure 4), the more of the non-renewable fossil fuels [94] are exploited and the more GHG are emitted to the atmosphere [95]. Likewise, the more pesticides are used to combat pests and diseases, the lower is the biodiversity and biological control potential on farmland [96,97]. These practices increase the rate of degradation and translate thus into a more degraded natural resource base. The degradation rate increases with increasing animal production, as animal-based food products are particularly resource-intensive [98,99]. At the same time, in intensive food production systems practices that treat natural resources in a more regenerative way are minimal or even none. As the outflow (degradation) of natural resources is higher than the inflow (regeneration) of natural resources, then the condition of natural resources worsens, jeopardizing the food production.

There are two balancing feedback loops that regulate *degradation* (B1, Figure 5) and *regeneration* (B2, Figure 5) *of natural resources*. The goal of the two balancing feedback loops is to maintain the condition of natural resources in a stable state. The balancing feedback loop B1 (Figure 5) sets limits to overuse or pollution (degradation) of natural resources as their condition worsens. The limit is signaled to food producers through, for instance, declining yield or rising costs of acquiring non-renewable natural resources (e.g., phosphate rock, fossil fuels) when they become scarce. However, the signal is often either missing or too weak and too delayed for food producers to notice it and implement more environmentally benign practices that decrease degradation and/or increase regeneration on time [11,13,38]. The longer the food producers do not implement regenerative practices, the lower is the regeneration and, all else equal, the farther away the conditions of natural resources move from an optimal level, further increasing the need for regenerating natural resources (required regeneration) (B2, Figure 5).

Yet, external inputs can imitate some functions of the food producing natural resources (at least in the short-term). This feature allows food producers to substitute natural resources with external inputs in food production, when the condition of the former deteriorates [100]. As a result, food producers fall into a reinforcing spiral of *compensating for the degraded natural resources with the application of external inputs* (R2, Figure 5) rather than implementation of regenerative practices, which, in turn, further worsens the condition of natural resources. The reinforcing feedback loop driving substitution of natural resources with external inputs to produce food is a vicious circle that locks farmers into dependence on the use of external inputs.

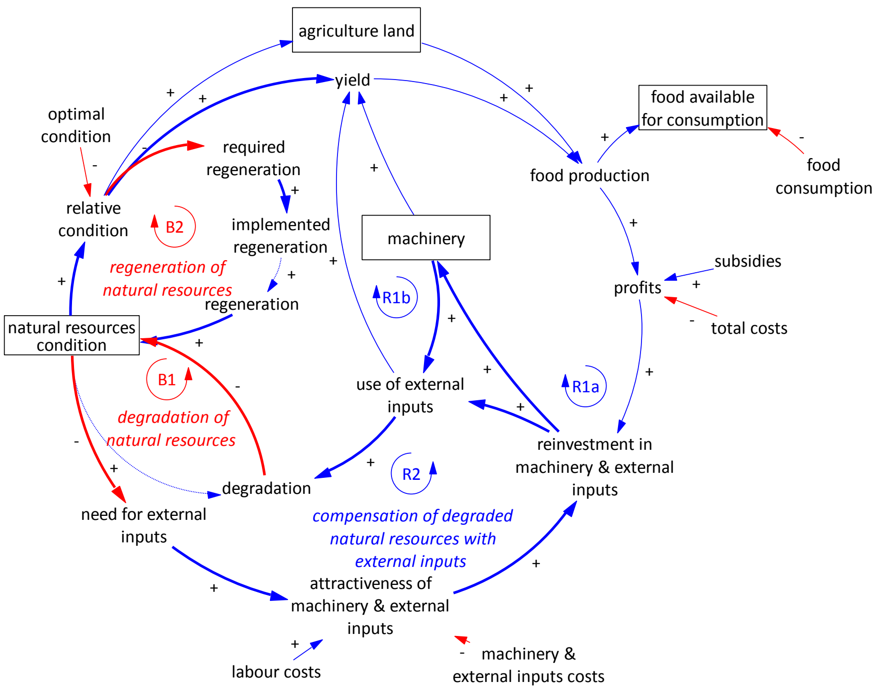

Figure 5 Causal loop diagrams representing the relationship between food production and natural resources condition (B2, B3, R3); some links are omitted for visual clarity

2.3.3.3 Food producers require knowledge to know how to best organize food production

Using knowledge food producers try combine so production inputs with ecosystem as to achieve the highest potential yield holding the costs constant. According to theorists, knowledge is perhaps the most relevant economic resource and learning the most important process [101]. In principle, the more one has of production inputs and knowledge, the more can be produced. Hence, the growth in food production is driven by accumulating inputs (e.g., land, labor, machinery, external inputs, etc.) (R1a, R1b, R1c, Figure 4) as well as knowledge that drives *organization of food production* processes (R3, Figure 6) [102].

Food producers gather knowledge while performing their activities and because of new learnings. Knowledge of food producers is a combination of tacit (or local) knowledge with standardized (or codified) knowledge [103]. The more knowledge of tacit and/or standardized nature food producers have, the stock of total knowledge increases and thus food producers are able to *organize food production* better (at least theoretically) realizing higher yield (R3, Figure 6).

In contrast to standardized knowledge, tacit knowledge of food producers implies an intimate knowledge of their land holdings, its fertility, composition and so on acquired through food producing practices (e.g., rotation, ploughing, etc.). The tacit knowledge is localized as it is closely tied to local ecosystem in which food production takes place. For instance, while the same principles of growing crops are widespread, tacit knowledge allows food producers to apply these principles differently in different local conditions and hence produce better results. With the widespread application of external inputs (*intensification*, R1b, Figure 4), which need not to be attenuated to local circumstances as simple standardized instructions on their use provided usually by input industry are sufficient for food producers to achieve desired yield, the relationship between food producers and local ecosystems is disrupted. Accordingly, the stock of tacit knowledge required to manage the local ecosystems fades away, whereas uniform and spatially standardized knowledge accompanying use of external inputs builds up and replaces the former type of knowledge [103]. The function of the balancing feedback loop B3 (Figure 6) is to signalize *loss of tacit knowledge* through decreasing yield. Yet the warning sign is hugely disregarded by food producers or masked by the large and powerful institutions which lie upstream (and downstream) of the farm [11,103].

The longer the importance of accumulating tacit knowledge for achieving better yield in the long-term remains unnoticed by food producers, the *substitution of tacit knowledge with standardized knowledge* (R3, Figure 6) progresses. This development locks food producers into a vicious circle (R3, Figure 6) of increasing reliance on the use of external inputs [103].

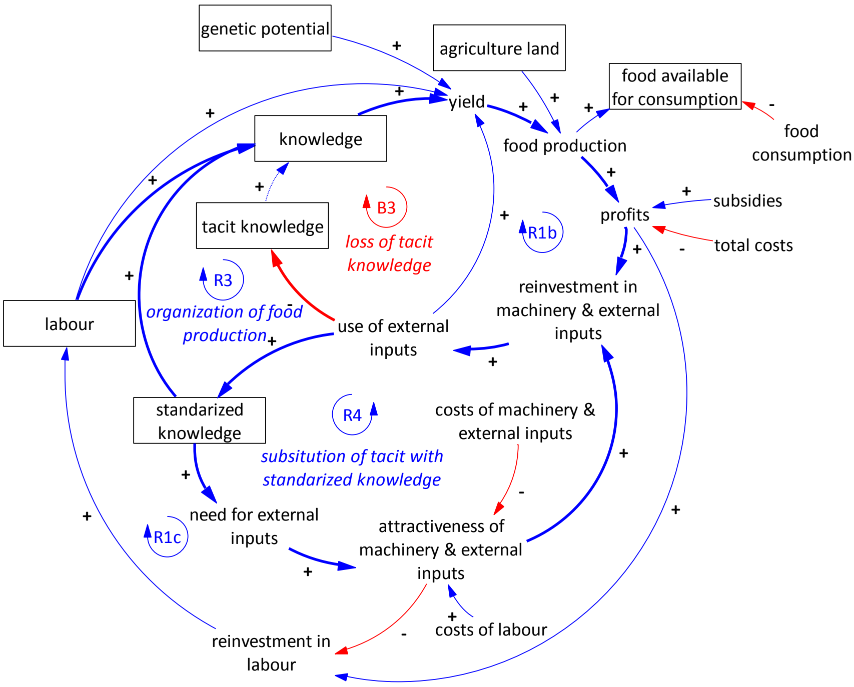

Figure 6 Causal loop diagrams representing the relationship between food production and knowledge (B8, R4); some links are omitted for visual clarity

2.3.3.4 *Produced food is supplied on an agri-food market which is a medium that allows consumers to access food*

On a competitive agri-food market, price balances food production with food consumption. The functioning of such a market is characterized by the interplay between two balancing feedback loops of *supply* (B4, Figure 7) and *demand* (B5, Figure 7), both of which in a globalized setting are influenced by *trade* arrangements (B6, Figure 7).

On the *supply* side (B4, Figure 7), a large number of food producers compete with each other. Specifically, producers reinvest (R1a, R1b, R1c, Figure 4) and produce food, increasing the amount of food available for consumption. Profits are realized when the amount of revenues gained from producing food exceeds the incurred production costs. As revenue is the product of the volume of food produced being sold and the price of the food, the higher the production and/or the higher price, *ceteris paribus*, the more profits food producers realize. Rising profits encourage existing food producers to reinvest and increase output (food production) as well as attract new entrants to the market. However, greater food production increases the stock of food available for consumption, which in turn, bids the price of food down. Declining price of food, all else equal, diminishes profits and hence discourages food producers from investing in increasing food production (B4, Figure 7).

On the *demand* side (B5, Figure 7), the population consumes (and wastes) the supplied food according to its purchasing power, dietary requirements for health and desires due to its lifestyle. The lower is the price of food, the more people have access to food and thus the more food is demanded. Higher food consumption diminishes the amount of food available for consumption, which translates into, all else equal, higher price of food (B5, Figure 7).

The state of the stock of food available for consumption indicates the balance between food production (as proxy for supply) and food consumption (as proxy for demand). The *supply* (B4, Figure 7) and *demand* (B5, Figure 7) balancing feedback loops cause the price of food to adjust until, in the absence of market imperfections and external disturbances, the market reaches an equilibrium characterized by a clearing price at which food production equals food consumption (i.e., the stock of food available for consumption is stable).

In a globalized world, however, in which markets are committed to open *trade*, there is an additional balancing loop B6 (Figure 7). Food producers export surplus of food production or are confronted with competitive imports, if the domestic food production is insufficient to meet the desired consumption. The imports add to the stock of food available for consumption, putting an additional downward pressure on price, and *vice versa* in case of exports. Hence, protective measures for reasons of food security or employment are a natural response of governments.

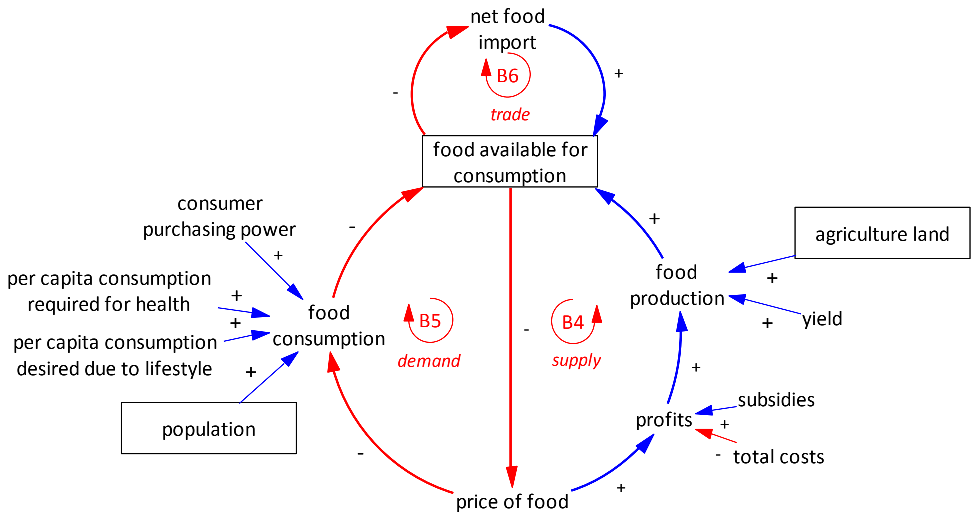

Figure 7 Causal loop diagram representing competitive market structure characterized by interplay between two balancing feedback loops of *supply* (B4, Figure 4) and *demand* (B5, Figure 4), both of which in a globalized setting are influenced by *trade* (B6, Figure 4); some links are omitted for visual clarity

2.3.3.5 Under conditions of low of falling profits, efficiency maximization leads to growth in food production

In addition to the amount of food sold, its price and subsidies, profits depend also on total costs incurred during food production. The higher are the total costs of production, the lower are the profits realized by food producers, all else being equal. If both trends – decreasing or stagnating price and growing costs of production – occur concurrently, food producers face a cost-price squeeze that causes profits to drop, farm debt to grow and a general loss of producer power. Food producers usually try to alleviate the undesirable downward pressure on their profits via a number of balancing processes aimed at *cost minimization* (B8, Figure 8).

When the profits are negative, many food producers, particularly the small- and medium-scale ones, abandon the industry altogether (Figure 8). Only those food producers remain in the agri-food business that are most efficient and/or have the most optimistic expectations on the future price and costs [35,39]. This is evident in the declining number of farms. Meanwhile, however, the total number of cultivated hectares of land remains more or less constant. Hence, farm size increases, meaning that overall there are fewer but larger farms. In fact, scale economies along with technical innovations and specialization reinforce each other are the most common routes to compensate for the falling profits by *minimizing costs* of food production through improved efficiency (B8, Figure 8) [40,41].

Although profits improve when food producers keep on *minimizing costs* through achieving higher efficiency (B8, Figure 8), a reinforcing mechanism resulting from *efficiency maximization* (R5, Figure 8) impedes their efforts. To produce food more efficiently means to produce more food with the same or less production inputs. The usual net result of *minimizing costs* (B8, Figure 7) and *maximizing efficiency* (R5, Figure 8) is that globally food production goes up, prices go down, and profits are again no longer possible even with the lower production costs. Food producers are locked into a vicious circle (R5, Figure 8), in which lower prices of food create a continuous pressure to minimize costs that forces them to become even more efficient if they are to survive at all. The farmers who lag behind and do not become efficient enough are lost in the price (or even cost-price) squeeze and leave room for the more successful food producers to expand [104].

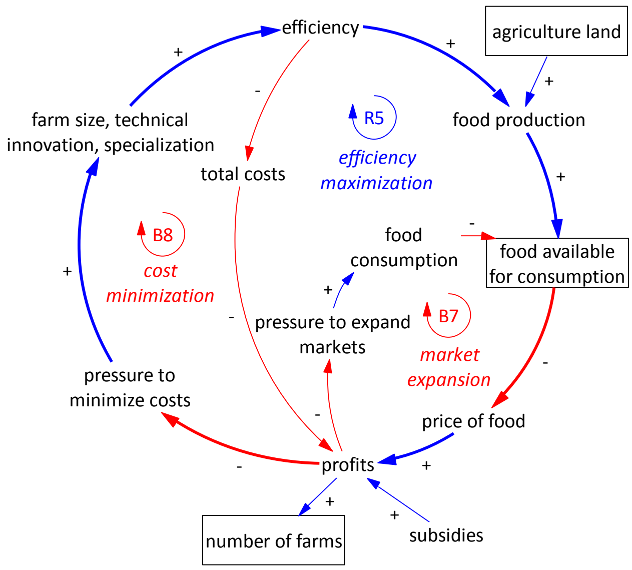

Figure 8 Causal loop diagram representing *efficiency maximization* reinforcing feedback loop (R4) driving food production growth under conditions of falling profits; some links are omitted for visual clarity

2.3.3.6 External drivers of change

In addition to the internal causal mechanisms, the functioning of the European food system is driven by the impact of multiple adverse and favorable external disturbances of various origin (e.g., socio-economic, ecological, technological, political etc.) [2,105]. Food system disturbances range from rapid and dramatic shocks (e.g., pest outbreaks, economic and political crises, weather events such as droughts, floods, or storms, fuel shortages, disease pandemics) to slow and moderate stresses (e.g., climate change, urbanization, population growth, changing consumption patterns), which do not function in isolation from one another, but co-occur and interact in many different ways [29,106,107].

2.4 VULNERABILITIES' PATHWAYS OF THE HOTSPOT

The integrated structure presented in **Error! Reference source not found.** allows us not only to identify what shocks and stresses the food system at stake, but also to systemically explore how the disturbances are conveyed throughout key feedback processes in the food system and generate vulnerabilities.

2.4.1 Vulnerability pathway I: Dependence on external inputs

The strong reinforcing feedback loops that drive food production through *intensification* (R1b, Figure 4) and *mechanization* (R1a, Figure 4) and concurrently degrade natural resources and erode tacit knowledge, give rise also to two additional strong reinforcing processes through which *degraded natural resources are compensated for with external inputs* (R2, Figure 5) and *tacit knowledge is substituted by standardized knowledge (*R4, Figure 6)*.* Both of the latter reinforcing feedback loops are examples of unintended processes that increasingly lock food producers into dependence on external inputs, the companies that provide them and the capitalist relationships of food production that frame their decisions [5,108]. The use of external inputs considerably changes food producing practices as well as agroecosystems in which they are applied, giving rise to unintended consequences (e.g., weed resistance, pollinator decline) that are then stabilized with new external inputs (e.g., stronger herbicide cocktails) that in turn end up reinforcing the dependency. The result is that food production is based on continuous reinvestments in engineered stabilizers rather than tacit knowledge and ecosystems resilience (condition of natural resources). Therefore, if for some reasons (e.g., fossil fuels scarcity, geopolitical tensions, economic crisis) external inputs were not available for food producers: first, it will take a long time for an alternative food production paradigm to become effective (because of, for instance, the need to rebuild the stocks of tacit knowledge and natural resources condition) and second, the outcomes could potentially be far more undesirable than that of a system which never used those stabilizers. Moreover, relying on a limited range of 'stabilizing' external inputs makes the food system particularly vulnerable to disturbances that operate beyond their scope of fixes such as unexpected and non-linear climate change and feedbacks.

2.4.2 Vulnerability pathway II: Striving for efficiency while losing resilience

The conventional European food system manages its growth and expansion based on ideas of maximizing efficiency realized through *inter alia* scale economies, specialization and technological innovation (i.e., balancing loop of *cost maximization* (B8, Figure 8) that perpetuates a strong reinforcing feedback loop of *efficiency maximization* (R5, Figure 8)). Food producers across Europe experience effects of the *cost minimization* processes in many different ways. Scale economies force many small- and medium-scale food producers out of the agri-food business entirely, which is evident in the declining number of farms. This trend along with the strong reinforcing spiral of *labor reduction* (R1c, Figure 4) translates into increasingly fewer people in society with knowledge and skills to produce food, implying further decline in the stock of tacit knowledge (Figure 6) as well as disruption in rural communities, both of which have been found crucial for resilience of food systems to shocks and stresses [14,21,109,110]. Besides, scale economies drive consolidation (i.e., growing farm size), and hence reduce the diversity of scale at which food producers operate. Specialization is apparent, for instance, in the trend towards a single dominant activity on farms and widespread monocultures. Currently, in the EU almost half of the holdings are specialized in cropping and 27% in livestock [111]. Accordingly, as the system specializes, the diversity of organizational forms as well as crops and animals decreases in the food system. Technical innovations (e.g., application of more and more specific fertilizers, herbicides and pesticides and genetic advances) to a great extent are in hands of few multinational corporations [5]. This narrows down sources of technical innovations as well as the range of choices of 'what' and 'how' to produce that food producers have. For instance, commercial seeds and breeds focus on a few traits in a few crops, forcing food producers to base their production on these traits. The three processes seem to favor each other, so that, for instance, the technical innovations (e.g., promotion of agrochemical use, biotechnology, single crop machinery, etc.) are most (costs) beneficial through scale economies [46] and specialization [5], [9], [99]. Common feature of all of these processes is that they increase efficiency of food production, but at the same time decrease diversity of different elements in the system. The latter is, in turn, crucial for absorption of shocks and stresses, adaptation and alternative solutions [9], [104]–[106]. Having low diversity in the food system allows disturbances to become augmented, both economically (e.g., food pricing controlled by few) and ecologically (e.g., contamination on a single farm can easily effect the entire country). Thus, it seems that through strong *efficiency maximization* loop (R5, Figure 8) food producers trade-off short-term productivity against long-term resilience.

In essence, vulnerabilities in the conventional European food system arise if disturbances strengthen the reinforcing feedback loops and further weaken or delays the balancing loops. For instance, climate change related shocks such as drought, flood or storm, will likely strengthen the *intensification* reinforcing feedback loop (R1b, Figure 4) because of yield losses. Yield losses increase the pressure on food producers to produce more, disregarding the balancing loops of *natural resources degradation and regeneration* (B1, B2 Figure 5), thus further lowering the stock of natural resources condition. When the stock depletes, yield declines, and translates into undesirable outcome of reduced food production and hence food insecurity.

2.5 ORGANIC FARMING AS POLICY TO ADDRESS THE HOTSPOT'S VULNERABILITIES

Based on the analysis in previous sections, we argue that the European food system based on conventional agriculture is vulnerable. An alternative approach to food system, which does not trade-off long-term resilience for productivity and stability, is called for [5,7–9]. King [14] lists several potential approaches for a resilient food system, including organic and biodynamic farming, permaculture, farmers' markets, community-supported agriculture and community gardens. In Europe organic farming is the fastest growing of all alternatives to the conventional food system, which is regulated at EU level and receives considerable public financial support. However, is transition to organic farming a viable policy for making the European food system more resilient?

2.5.1 Resilience pathway I: Low external input system

2.5.1.1 Potential

Organic farming as per definition is a low external input system with *inter alia* diversification and nutrient cycling at its heart. As mentioned in 2.5.1.1 and 2.5.2.1 it preserves higher stocks of natural resources and tacit knowledge as well as has better recognized and operating balancing loops (B1, B2, Figure 5; B3, Figure 6), food producers may thus escape from being locked into the dangerous dependence on external inputs (R2, Figure 5 ; R4, Figure 6).

2.5.1.2 Limitation

However, implementation of organic food production principles in practice is diverse and ranges from mere 'input substitution' to fundamental 'system redesign' [120]. This implies that there are organic food producers, of which practices diverge only slightly from conventional practices [27]. As organic food producers are not rewarded for continuous improvement, but have to comply just with minimum standards, they are incentivized to simply substitute prohibited with allowed inputs sourced from outside of the system. As a result they will be again locked into the vicious circles creating dependence on external inputs (R2, Figure 5 ; R4, Figure 6) with all its consequences for resilience of the prevailing food system.

2.5.2 Resilience pathway II: Striving for diversification

2.5.2.1 Potential

In addition to better environmental outcomes, many studies have found that organic food producers perform better also in socio-economic terms as compared to their conventional counterparts [112]. Simply looking at comparisons of organic versus conventional short-term profitability, organic seems to be a promising option to preserve viability of farms. Besides, organic food system is characterized also by diversity of markets (e.g., specialized organic food stores, farmers' markets and direct farm marketing, food baskets), through which organic food is provided to consumers. These two features – better financial performance and diversity of markets – suggest that potentially the internal market structure of the organic food system is different from the conventional one and that the system can address the vulnerabilities related to socio-economic organization of food production inherent in the latter.

2.5.2.2 Limitation

However, there are many signs indicating that organic food system based on certification of food production methods alone, falls into the same reinforcing mechanisms as conventional system and gives up its resilient features for efficiency (R5, Figure 8) and itself is vulnerable. For instance, establishing certification put barriers for smaller food producers to enter the sector, because of costs and because it facilitates larger retailers to sell organic products [9]. Hence, the organic food system becomes more and more consolidated and losses its diversity, which has consequences for contributing to resilience of the conventional European food system.

3 CONCLUSIONS

In this paper, we have proposed a new way to help policymakers understand the food system's vulnerabilities and assess whether organic farming can enhance its resilience. For this, we adopted a system dynamics approach to capture the dynamic complexity of the food system. We have identified a number of key systemic vulnerabilities, including the degradation of the natural resource base of food production, the erosion of its knowledge base, its dependence on external inputs, the latent instability on agri-food markets and the strive for efficiency. We have argued that organic farming has the potential to address these vulnerabilities, but at the same time risks of falling into the same systemic pitfalls through a process of conventionalization. More specifically, organic farming as a food system has to be carefully designed and implemented to overcome the contradictions between the dominant socio-economic organization of food production and the ability to implement holistic understanding of organic principles on a broader scale. Further research needs to identify policy interventions that allow organic farming to reach its full potential avoiding these pitfalls.

4 ACKNOWLEDGEMENTS

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