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Environmental impacts of organic agriculture and the controversial scientific debates

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Abstract The environmental impacts of organic agriculture have been controversially discussed in the scientific community for many years. There are still conflicting views on how far organic agriculture can help address environmental and resource challenges, and whether its promotion is an appropriate policy approach to solving existing socioecological problems. So far, no clear perspective on these questions has been established. How can this be explained? And is there a "lock-in" of the scientific discourse? The aim of this paper is to retrace the scientific discourse on this topic and to derive possible explanations as to why environmental impacts of organic agriculture continue to be assessed differently. To this end, a qualitative content analysis was conducted with a sample of n = 93 scientific publications. In addition, expert interviews were conducted to verify the results of the literature analysis. Two main lines of discussion were identified: first, the extent to which aspects of food security should be included in the assessment of environmental aspects (thematic frame); second, the extent to which net environmental impacts or possible leakage effects because of lower yield levels should be considered (spatial frame). It is concluded that the polarizing debate mainly results from the often-binary initial question (is organic agriculture superior to conventional agriculture?). Further, aspects that have been insufficiently illuminated so far, such as the choice of reference units or normative basic assumptions in scientific sustainability assessments, should be given greater consideration in the discourse.

Keywords Lock-in · Sustainable agriculture · Leakage effects · Reference unit · Binarity · Research framing

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Introduction

Organic agriculture (OA) is considered a particularly environmentally friendly way of farming based on the interconnected principles of health, ecology, fairness, and care (IFOAM 2021). Especially in the European Union (EU), policymakers have therefore advocated an expansion of the area under organic management. In Germany, for example, a growth target was set in 2001: the aim is to achieve a 20% share of organically managed land (BMEL 2019). More recently, the EU Commission's Farm to Fork Strategy has called for at least 25% of agricultural land in the EU to be farmed organically by 2030, in view of the expected positive environmental and resource-related effects (European Commission 2020).

The political support of OA and its advantages in environmental protection have been the subject of intense political and scientific discussions for more than twenty years (Sanders 2016). Repeatedly, several scholars have provided empirical evidence for the relative advantages of OA (cf. Reganold and Wachter 2016; Stolze 2000), whereas others have produced contrary findings and concluded the opposite (cf. Bergström and Kirchmann 2016; Trewavas 2001).

Thus, there is reason to assume that scientific debates on the relative merits of OA have taken place in an overall fruitless way since the beginning of the political support debates. This is especially true for the question of what role OA is to play nationally and internationally in addressing the critical socioecological problems facing agriculture.[1] In this context, there is an urgent need to solve such environmental issues related to critically exceeded planetary boundaries, as proposed by Steffen et al. (2015), that are primarily impacted by agriculture, e.g., biosphere integrity and biogeochemical flows. This highlights the importance of science being able to provide clear and well-justified conclusions about environmental impacts of alternative agricultural systems. The question thus arises as to whether there is a "lock-in" of scientific debate.

Against this background, this paper does not provide additional evidence whether or in which areas OA provides greater environmental performance than conventional agriculture (CA). Rather, it attempts to analyze comprehensively the controversial assessments of OA in scientific debates in terms of the underlying argumentation. Further, it explores the question of why such disparate views still exist in the scientific community. Specifically, the aim of this paper is to retrace the scientific discourse on this topic in order to derive possible explanations why environmental impacts of OA continue to be assessed controversially in the scientific community.

Material and methods

Systematic literature search

The analyzed material is scientific publications that were obtained through a systematic literature search. The literature search was based on the four-phase flow diagram of the PRISMA Statement[2] (cf. Moher et al. 2009) and is illustrated in Fig. 1. It consisted of a search string-based query[3] of the online database Scopus (n = 22 cases) and a complementary web-based search via Google and Google Scholar, mainly using the snowball system (n = 71 cases).

The search string query was conducted in English as it could be assumed that the publications relevant to the discourse to be analyzed are mainly written in English. The search string was not limited to specific environmental dimensions as the interest in knowledge was focused on argumentations that move across different performance areas. Further, it was assumed that the term "yield" is a strong indicator of a publication's relevance to the subject matter, as studies that do not consider yield in any form are unlikely to comprehensively address the question of how to evaluate environmental performance and impacts of any agricultural system.

The complementary search was intended to include relevant literature not captured by the Scopus inquiry, as well as literature that is not subject to peer-reviewed publication but contributes to the debates under investigation. In total, the dataset

[1] Today, the scope of agricultural production is extended far beyond the provision of food and includes numerous environmental and resource-related challenges. In a global context, agriculture's most critical environmental impacts include soil and water degradation, habitat fragmentation and biodiversity loss, freshwater withdrawal, disrupted nitrogen and phosphorus cycles, and greenhouse gas emissions (Foley et al. 2011). At the same time, hunger is on the rise again with over 800 million people undernourished or lacking sufficient nutrients, while overweight and obesity are also increasing rapidly across the globe, leading to a "triple burden" of malnutrition (Gómez et al. 2013; HLPE 2017; Ingram 2020). Such challenges increasingly gain traction in science and policy arenas, not least due to the overarching debate on climate change, making evident the interconnectedness between global warming and food systems and thus its socioecological consequences (IPCC 2019).

[2] The PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) Statement comprises guidelines that address conceptual and practical advances in the science of systematic reviews (cf. Moher et al. 2009).

[3] Search string (applied on 28/01/2020): *TITLE-ABS-KEY (("organic farm*" OR "organic agricul*") AND ("environment* impact" OR "environment* effect") AND yield).*

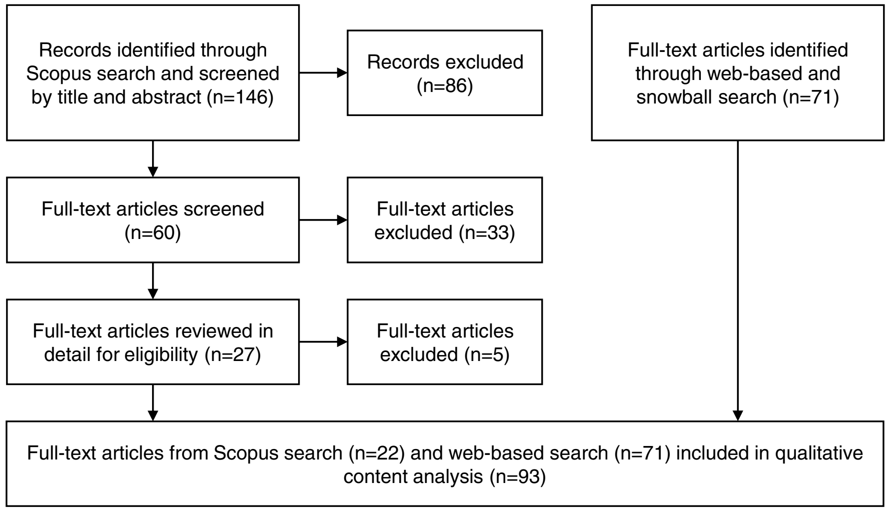

Fig. 1 Flow diagram of the systematic literature search combined of a string-based Scopus search and a web-based search (modified according to Moher et al. (2009))

consisted of n = 93 scientific publications. The full record of the analyzed cases is provided in Online Resource 1.

Qualitative content analysis

To obtain the desired information from the retrieved cases, a qualitative content analysis was carried out. The content structuring qualitative content analysis applied here is based on Mayring (2015) and Kuckartz (2018). The analysis was conducted using the data analysis software MAXQDA 2020 (VERBI Software 2019). To obtain the content-related information from the analysis units, i.e., scientific publications, these were coded, which is equivalent to categorizing text segments (Kuckartz 2018). The codebook (including the coding frame with all main and sub-codes that were used and the code descriptions with application examples) is provided in Online Resource 2.

Due to the explorative and descriptive orientation of the research aim, a mixed form of a-priori code creation and code creation directly on the material, i.e., deductive-inductive coding, was applied (Kuckartz 2018). The starting point for code creation was a coding frame consisting of relatively few codes, which were derived from the first examination of texts during the process of literature search as described above. Central publications in this examination were Gomiero et al. (2011), Meemken and Qaim (2018), and Sanders and Heß (2019).

Expert interviews

In addition to the scientific publications, qualitative data were obtained in four expert interviews. The interviews specifically aimed at exploring i) possible explanations for the course of the scientific debates and ii) lessons to be learned for the ongoing discourse.

The interviewees were considered suitable experts based on their academic careers and scientific research that has contributed and is closely related to the debates under investigation. All interviewees hold professorships at various international universities, including the research areas of organic agriculture, sustainable land use and food systems, ecology, agricultural economics and development, and sustainability science.

The interviews were conducted via video calls and followed a semi-structured guideline to meet the explorative research objective. All the interviews took place after the literature analysis had been completed. The transcripts of the interviews (provided in German language in Online Resource 3, including the transcription system in Table S1) were then qualitatively analyzed.

Results

The environmental impacts of OA were first comprehensively described by Stolze (2000). Based on the literature available at the time, the authors concluded that OA—like any type of agriculture—entails

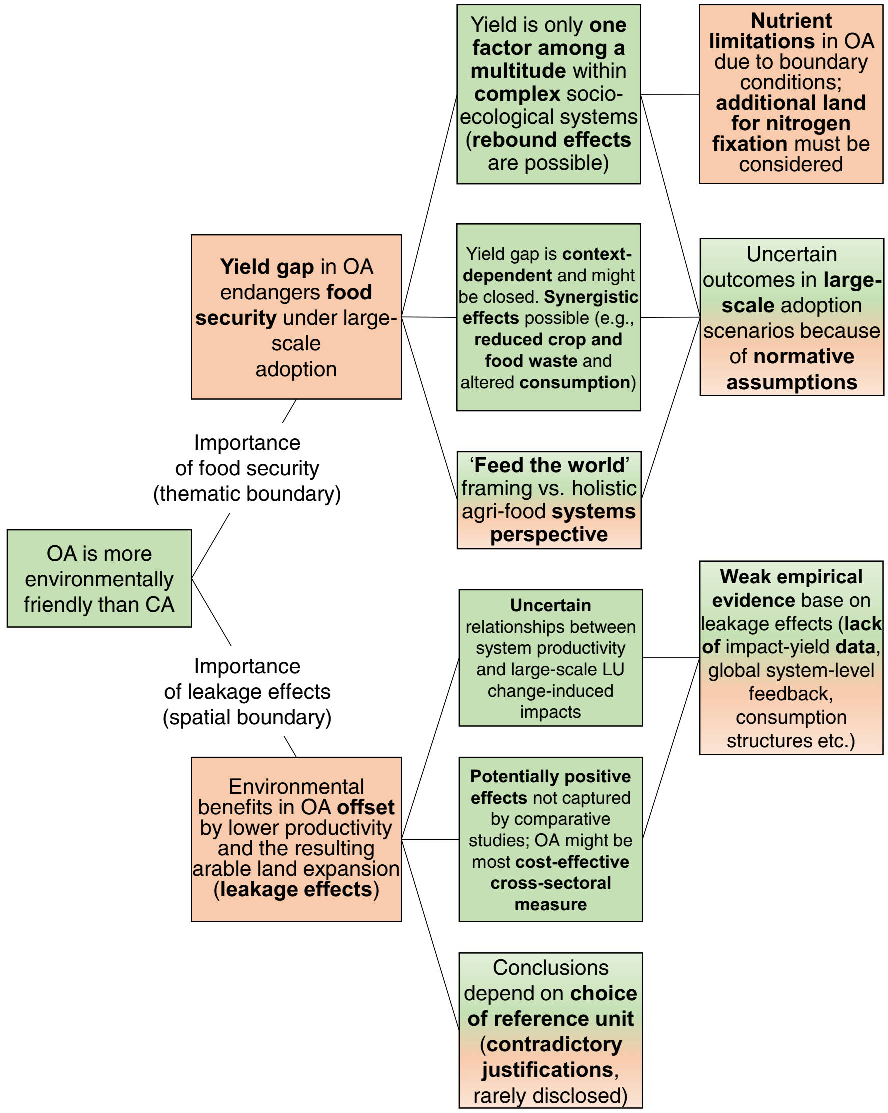

Fig. 2 Two identified lines of discussion that trace back to two key counterarguments against environmental benefits of organic agriculture (OA). The two lines illustrate the ambiguity regarding the thematic and spatial boundary in the debates. Each box depicts a set of subsumed arguments. A change of color between two boxes indicates the relativization of the preceding one. Mixed-colored boxes indicate that both relativizing and affirming arguments are subsumed in the box. The terms in bold type are highlighted in italics in the text (own illustration)

environmental impacts, but that these impacts are less harmful than in CA. This finding was subsequently affirmed by further literature (cf. Gomiero et al. 2011; Reganold and Wachter 2016; Sanders and Heß 2019). However, the conclusion that the environmental performance of OA is superior to that of CA, or simply put, "OA is more environmentally friendly than CA," is not shared by all scientific studies.

Over the past twenty years or so, two key counterarguments have been raised claiming that OA is not superior to CA regarding environmental impacts. As discussed further in detail below and illustrated schematically in Fig. 2, numerous studies argue that impacts on *food security* should be considered in the face of productivity issues when assessing environmental impacts. Second, it is argued that the assessment should also consider potential *leakage effects* given different land use (LU) efficiencies, i.e., it should not only consider the spatially immediate impacts of organic systems. Based on these intertwined counterarguments, two lines of scientific discussion have emerged in which the two counterarguments are reinforced or relativized, respectively. Thus, the main ambiguity is how broadly to draw the thematic (chapter *Importance of food security in assessments of environmental impacts*) and spatial (chapter *Importance of leakage effects in* *assessments of environmental impacts*) frames in the assessments.

Importance of food security in assessments of environmental impacts

It becomes clear that the first line of argumentation (Fig. 2) can be traced back to the fundamental critique of OA regarding lower productivity. This is commonly considered problematic with reference to increasing population growth and the overarching goal of *food security* (cf. Goklany 2002; Kirchmann et al. 2007). Consequently, a relevant component of these debates is the *yield gap* between organic and conventional systems, which are mainly discussed in light of a few key meta-studies (cf. Ponisio et al. 2015; Ponti et al. 2012; Seufert et al. 2012). In addition, the concept of yield stability, i.e., the temporal variability and reliability of production, has been argued to be important when comparing organic and conventional agriculture regarding food security (cf. Knapp and van der Heijden 2018).

In the context of yield gaps, the empirical evidence to date clearly points to lower average yields in OA (cf. Meemken and Qaim 2018). However, beyond averages, it has also been noted that the available data are *highly context-dependent*, i.e., there is considerable variability depending on system and site characteristics; it is also argued that biases in study selection (e.g., by geographic location) should be taken into account in meta-analyses, as well as the multitude of yield-limiting factors that have been insufficiently understood to date (cf. Lorenz and Lal 2016; Seufert 2019). In general, it is increasingly recognized that yield is only *one factor among a multitude* of complex economic and ecological interrelationships that need to be included in the sustainability assessment of different farming systems (cf. Ponisio and Ehrlich 2016; Seufert and Ramankutty 2017). This argument has been put forward by researchers calling for a more holistic agri-food *systems perspective* beyond productivity aspects (cf. IPES-Food 2016) by greater inclusion of ecosystem services (cf. van der Werf et al. 2020) when it comes to assessing the relative merits of alternative farming systems. In particular, it is argued that a primary focus on yields and "eco-efficiency" assessments does not sufficiently address ecological or nutritional issues, as, for example, *rebound effects* may occur in complex LU systems (cf. Ponisio and Kremen 2016) or efforts to *reduce crop and food waste* need to be taken into account regarding the goal of food security (cf. Müller et al. 2016).

Accordingly, some researchers emphasize the benefits of OA for sustainable food systems and argue that yield gaps could be closed in the long term if, for example, agroecological conditions and changes in dietary behavior were promoted or possible *synergistic effects* of large contiguous areas of OA were taken more into consideration (cf. Fess and Benedito 2018; Müller et al. 2017; Ponisio et al. 2015). Others disagree, sometimes vehemently, invoking *nutrient limitations* in organic systems or the erroneous equation of yield ratios between individual crops with system productivity in some comparative studies, as *additional land for nitrogen fixation* would be needed in OA (cf. Connor 2018; Kirchmann et al. 2016; Leifeld 2016).

Consequently, the existing limitations of empirical evidence on yield gaps not only influence discussions on food security, but also significantly influence discussions on the assessment of environmental impacts of OA. Although a "conventional wisdom" in scientific discourse has already been described by Holt-Giménez et al. (2012), which advocates a combination of organic and conventional methods with the aim of increasing productivity in a sustainable manner (cf. Meemken and Qaim 2018), this has not led to a reduction in controversial debates. For example, Tal (2018: 9) notes that the binary organic vs. conventional debates foster "a tendency on both sides of the […] divide to caricaturize the other and cherry pick extreme examples of environmentally problematic practices." Seufert and Ramankutty (2017: 1) also roughly divide the discourse into those researchers promoting OA as a solution to sustainable food security challenges and others who "condemn it as a backward and romanticized version of agriculture that would lead to hunger and environmental devastation."

Accordingly, along the debates on the role of OA in global food security, arguments have been identified that address the policy relevance of certain scientific issues. In this context, it is striking that the question of whether OA can "*feed the world*" is a type of framing (cf. IPES-Food 2016) that has persisted throughout the period in which the analyzed literature was published (cf. Goklany 2002; Meemken and Qaim 2018; Müller et al. 2017; Ponti et al. 2012). Again, however, there is disagreement regarding the appropriate focus of research questions. Tittonell (2013), for example, considers the "feed the world" framing as oversimplified and thus not very policy-relevant, whereas others argue that this very question is crucial (Niggli 2015) or an interesting thought experiment (Meemken and Qaim 2018).

In addition, there are previously marginalized narratives that argue from the political economy perspective of unequal global power relations, thus criticizing Western industrialized development narratives, and highlighting the importance of food sovereignty (cf. Scoones et al. 2019). Overall, it becomes clear that the discussions about the role of OA in the context of food security are strongly influenced by *normative assumptions* on socioeconomic and agricultural development and are correspondingly divergent.

Importance of leakage effects in assessments of environmental impacts

Regarding environmental impacts, which are condensed in a second line of discussion (Fig. 2), the lower yield performance of OA and the resulting lower land use (LU) efficiency emerge as the main points of criticism, analogous to the first line of discussion. Here, the aspects regarding yield gaps, as described above, are reflected in the use of the concept of *leakage effects* as a prominent reasoning.

Overall, the discussions on environmental merits of OA predominantly appear as tradeoff analyses. Regarding biodiversity effects, for example, the general argumentation dominates that local biodiversity benefits of OA are *offset* or even turn into disadvantages due to higher land requirements when expanded (cf. Tuck et al. 2014). In this context, the logic of leakage effects assumes that an expansion of generally more extensive OA may lead to LU intensification elsewhere, resulting in net negative environmental impacts, e.g., higher greenhouse gas (GHG) emissions through LU change or biodiversity loss through habitat conversion (cf. Bergström and Kirchmann 2016; Gabriel et al. 2013; Kirchmann et al. 2007; Kirchmann 2019; Leifeld 2016; Searchinger et al. 2018).

By the same token, OA is criticized in terms of increased nutrient leaching, assuming that large-scale conversion would lead to arable land expansion to meet the unchanged (or increasing) demand for agricultural products due to yield gaps (cf. Bergström and Kirchmann 2016; Tuomisto et al. 2012). Although there are studies that find lower eutrophication potential in OA (cf. Schader et al. 2012) and more efficient nutrient use on a given area (cf. Mäder et al. 2002; Niggli 2015) due to system boundaries, some researchers also point out that a *lack of data*, especially on water conservation, does not allow robust general conclusions (cf. Kusche et al. 2019; Seufert and Ramankutty 2017). Further, regarding biodiversity and GHG emissions, estimating the effects of large-scale adoption of OA is argued to be ambiguous because there exists *uncertainty* about the relationship between yield-levels and land in production or conversion of natural habitat (cf. Ponisio and Kremen 2016; Reganold and Wachter 2016; van der Werf et al. 2020).

In addition, there are arguments indicating that so far unmeasured and *potentially positive effects* of OA are not covered by comparative studies conducted to date (cf. Clark and Tilman 2017; Tuck et al. 2014); e.g., positive biodiversity effects from large contiguous areas of OA (cf. Meng et al. 2017; Stein-Bachinger et al. 2019). Hence, some authors argue that expanding OA might be the most *cost-effective* strategy from the perspective of integrated policy measures that address improvements in multiple environmental dimensions simultaneously (cf. Jespersen et al. 2017).

The role of reference units in environmental impact assessments

What further becomes clear from the above is that study results and their conclusions regarding the benefits of OA significantly depend on the *choice of reference unit*. That is, whether environmental impacts are expressed per unit of farmed area or per unit of produced output. The central role of the reference units in environmental impact assessments becomes particularly clear regarding nutrient leaching and GHG emissions (cf. Halberg et al. 2005; Schader et al. 2012).

As Meemken and Qaim (2018) summarize, most evidence suggests that OA has lower environmental impacts in terms of GHG emissions when expressed per unit area, and higher impacts per unit output, respectively. However, as Sanders and Heß (2019) point out, in many studies the choice of the appropriate reference unit—despite its centrality to the results and conclusions—is inadequately justified. The latter authors argue that the question of the appropriate reference unit from a societal perspective[4] needs

[4] This refers to the environmental dimensions of biodiversity, water protection, climate protection, and climate adaptation. The reference units for assessing impacts on soil fertility (area) and resource (N and energy) efficiency (output) were considered immanent (Sanders and Heß 2019).

further scrutiny by considering i) the spatial scope of a solution to reduce environmental impacts (is the public environmental good to be provided on a local or global scale?), ii) the regional characteristics of environmental impacts (how scarce are specific public environmental goods in a region?), and iii) the risk and extent of leakage effects (does the provision of a public environmental good in one region result in negative environmental impacts in another region?).

Regarding the (rarely explicit) backing argumentation for the use of different reference units, c*ontradictory justifications* could be identified in the present study. Some scholars argue that the primary use of the output-reference is misleading because absolute, rather than relative (to the yield), environmental impacts are decisive; thus, the primary focus on the output-reference would not do justice to the complexity of goods and services provided as well as to the systems approach of OA[5] (cf. Müller et al. 2016; Niggli 2015; Ponisio and Kremen 2016).

On the other hand, it is argued that expressing environmental impacts per unit area is misleading if it does not take into account system productivity (which is usually lower in OA) and LU efficiency; thus, in the context of a growing world population and global environmental impacts, yield units would be the primarily relevant reference (cf. Kirchmann 2019; Meemken and Qaim 2018; Tuomisto et al. 2012). It is noteworthy in this context that already about twenty years ago, Geier (2000) stated that there is no consensus on the use of the functional unit within the life cycle assessment (LCA) methodology[6] and thus the main problem is the question of when it is reasonable to relate environmental impacts to the output and when to the area. The disparate views on the appropriate choice of reference units that since have been brought forward illustrate the difficulty to debate environmental impacts within consistent thematic and spatial boundaries.

The partly contrary argumentation is aggravated by a *weak empirical evidence* base on leakage effects that could result from an expansion of OA, especially on a global scale. For example, Seufert and Ramankutty (2017) note that potential impacts of a *large-scale* shift to OA are highly *uncertain* due to, among other issues, existing knowledge gaps on system-level feedback effects that ultimately influence future food production and demand. Other studies emphasize that regarding leakage effects, analogous to the implications for food security, it is crucial in an assessment of OA to also include dietary habits and the origin of demanded foods (cf. Haller et al. 2020; Müller et al. 2017). Accordingly, the German Advisory Council on Global Change has recently pointed out that the argument of leakage effects cannot be the sole focus when aiming to safeguard globally important ecosystems, but the various dimensions of leakage must be embedded in *cross-sectoral measures* that go far beyond issues of domestic LU efficiency (WBGU 2020).

Synopsis of the expert interviews

In addition to the qualitative content analysis of the literature, four expert interviews were conducted and qualitatively analyzed. Across all interviews, it became clear that the nexus of science, policy, and values[7] that has so far led to research agendas and political initiatives to promote OA (or the general transformation toward sustainable agricultural systems) needs to be adapted to the increasingly complex problem situation described in the Introduction. At the same time, the barriers that might impede such adaptation were addressed. In this context, the interviews also repeatedly referred to the formation of entrenched positions (sometimes referred to as

[5] For example, Müller et al. (2016: 16) argue that single-criteria assessments such as emissions per unit output disregard negative externalities, e.g., through the production of synthetic inputs or concentrate feed. Similarly, the IPES-Food (2016: 68) finds that classical measures of agricultural productivity systematically undervalue benefits of diversified systems; thus, new "measures of success" should be established which account for, e.g., total resource flows and interactions between the agricultural sector and the wider economy.

[6] Within the LCA methodology, the term "functional unit" is used (according to the "function" attributed to a studied system) and "serves as the reference basis for all calculations regarding impact assessment" (Arzoumanidis et al. 2020: 1). Thus, in the context of this study, "functional unit" can be considered synonymous with the term "reference unit" (cf. van der Werf et al. 2020).

[7] As Douglas (2016: 475) states, "Policy influences which science we pursue and how we pursue it in practice, as well as how science ultimately informs policy. Values inform our choices in these areas, as values shape the research agendas scientists pursue, the issues debated as we decide on policy, and what counts as sufficient warrant in any given case".

Table 1 Synopsis of the expert interviews with regard to statements on possible explanations for the controversial scientific debates and on possible ways to alleviate controversy

Possible reasons for the course of the debates	-. The fact that organic farming practices are unified by legal definition, whereas conventional ones are not, favors black and white argumentation -. Disagreement on normative issues of global agricultural and food systems development (e.g., whether there is a need for productivity increase or the extent to which changing dietary patterns and food waste should be included) -. Path dependencies related to value systems in scientific communities (e.g., regarding "feed the world" narratives or the notion of naturalness in agricultural systems) influence objectivity of research questions -. Lack of awareness and reflection (especially in natural sciences) about the role of framing research and its implications for discourses -. Increasing influence of different interest groups on academic research as well as incentive systems of scientific journals perpetuate polarizing debates
Possible ways to alleviate controversy	-. Fostering context-specific "sustainable" systems that are not necessarily bound to the regulatory requirements of OA (e.g., hybrid/mixed farming systems, integration of biotechnology, conservation agriculture) -. Fora and more frequent opportunities for researchers to exchange across disciplinary boundaries to emphasize systems thinking -. Critical reflection on prevailing (scientific) paradigms and addressing normative dimensions related to agriculture's role for societal goals

"paradigms" or "camps") through established academic networks and associated normative foundations that may be dominant in the investigated scientific discourse. The resulting implications are discussed in the chapter *Reasons for the lock-in and what to learn from it*.

Table 1 shows the synopsis of statements across all interviews that are related to possible explanations for the course of the scientific debates or to possible ways to alleviate the persisting controversies.

Discussion

Lock-in of scientific discourse

The analysis at hand shows that two lines of discussion have emerged along two main arguments that relativize the environmental performance of OA in terms of lower productivity. Strikingly, from an argumentative point of view, these lines do *not* show a substantial development over the course of the last twenty years or so.

Against this background, the present analysis provides evidence for the validity of the assumption formulated at the beginning that the scientific discourse on the relative environmental merits of OA have taken place in an altogether little fruitful manner. In summary, since the beginning of the political support debates, no scientific consensus could be formulated on the extent to which an expansion of organically managed land, which is politically embedded in many places, will help address the environmental and resource challenges.

Certainly, it is not the goal of research to produce as homogeneous scientific knowledge as possible. However, in view of the long period of debates and the partly opposing positions that continue to exist in academic circles, it is remarkable that the productive nature of scientific research in the sense of formulating syntheses has not sufficiently taken place. Given the urgency of environmental and resource problems to be solved and that OA has gained much attention as a possible strategy, the course of scientific debates appears even more problematic.

Thus, we argue that a "lock-in" of scientific debate prevails. Various reasons for and implications of this development are conceivable and will be discussed in the following chapter.

Reasons for the lock-in and what to learn from it

First and foremost, it appears that the binary initial question regarding relative merits of OA compared to CA favors a polarizing discussion space. Accordingly, conclusions are likely to move in dichotomies. This has already been addressed by Mehrabi et al. (2017) in the context of alternative approaches to conventional intensification. The authors argue that binary "organic versus conventional" system classifications have exceedingly poor explanatory power; this holds, especially for making clear evidence-based decisions regarding socioecological outcomes of different farming systems on a global scale. Thus, they advocate "more contextual and outcome-based experiments of farming practices" to turn away from "divisive discourse" (Mehrabi et al. 2017: 721) and to promote socioecological benefits of different farming systems.

Further, the expert interviews suggest that the research and development of "hybrid" farming systems might be a way to foster the debates on sustainable agriculture. Other researchers already have called for the deliberate reframing of binary research questions regarding a more differentiated consideration of the multilayered ecological problems and approaches to solutions (cf. Kremen 2015; Seufert and Ramankutty 2017; Shennan et al. 2017). In this context, a final settlement of the "ideologically charged 'organic versus conventional' debate" (Seufert et al. 2012: 231) seems important to avoid fruitless discourse.

Indeed, alternative concepts beyond the organic-conventional dichotomy increasingly diversify both scientific and societal discussions about sustainable agriculture. For example, the agroecology concept is gaining recognition in policy-making (cf. Bisoffi 2019; FAO 2018), but other (partly interrelated) concepts such as conservation agriculture (cf. Kassam et al. 2019; Page et al. 2020), sustainable intensification (cf. Cassman and Grassini 2020; Pretty et al. 2018), ecological intensification (cf. Kernecker et al. 2021; Kremen 2020), or regenerative agriculture (cf. LaCanne and Lundgren 2018; Lal 2020) are also being debated internationally.[8] However, in the European context, OA continues to be the key benchmark for "greening" conventional systems (WBAE 2020). Regarding the "growing enthusiasm" for regenerative agriculture, Giller et al. (2021: 22), in line with the reasoning of this paper, see "the need for agronomists to be more explicit about the fact that many of the […] dichotomies that frame public, and to some degree the scientific debates about agriculture, have little if any analytical purchase."

Moreover, although the emphasis on inter- and transdisciplinary research (cf. Veerman et al. 2020) to meet the complex problem space seems like a logical conclusion, it can be assumed that it is no panacea. As Bruhn et al. (2019) point out, such endeavors would ideally be structured in a reflexive and co-creative way to advise transformative policy. However, it is not only the issue of lacking standardized frameworks and different traditions and vocabularies of the various disciplines involved (cf. Garibaldi et al. 2017) that needs to be overcome. When operationalizing sustainability in agri-food systems, also different value systems and related normative assumptions of the involved researchers must be considered (cf. Fischer et al. 2014; Halberg et al. 2005; Kuyper and Struik 2014; Thompson 2010).

Consequently, overcoming ideological barriers between supporters and critics of OA is also recognized as a prerequisite for developing and implementing more sustainable farming systems and their research (cf. Eyhorn et al. 2019; Meemken and Qaim 2018). In general, however, the expert interviews suggest that "path dependencies" regarding certain narratives of agricultural development and a lack of awareness in natural sciences as to how the framing of research questions are embedded in scientific discourse might be major obstacles for such deliberation.

In this context, the argument made by Sanders and Heß (2019) on inadequate justifications for appropriate reference units can be taken further in light of the present results. The backing argumentation, as described in the chapter *The role of reference units in environmental impact assessments*, reveals that basic normative assumptions in the choice of a reference unit are an implicit part of the discussions and likely are conducive to a polarizing overall debate. For example, there is the question of whether (arable) land is understood as a substitutable input to the agricultural production process or as an integral part of the agroecosystem (cf. Berlin and Uhlin 2004; Tuomisto et al. 2012). Or the question of which "purpose" agricultural systems primarily are to fulfill in the societal context (cf. Leifeld 2016; Ponisio and Kremen 2016) and which framework is to be prioritized in the assessment of environmental

[8] For a characterization of some of the mentioned concepts, see Garibaldi et al. (2017). For discussions about different perspectives on agricultural intensification to foster sustainability and the associated scientific controversy, see Kuyper and Struik (2014) and Struik et al. (2014).

Table 2 Characterization of different perspectives on agricultural sustainability according to Douglass (1984) and Thompson (2010)

Three schools of agricultural sustainability according to Douglass (1984)	
Food sufficiency	This school sees agriculture as an instrument for feeding the world and sustainability is largely a matter of sufficient food production (cf. Halberg 2012; Thompson 2010). "In this group we find the defenders of the modern 'conventional', industrialised agriculture currently represented by the term 'sustainable intensification'" (Halberg 2012: 984)
Stewardship/ecological integrity	In this view, "it is agriculture itself that must be sustainable. It is not simply a matter of agriculture making society sustainable by ensuring that there is enough to eat" (Thompson 2010: 205). Thus, major concerns are the ecological balance and the biophysical limits to agricultural production, which are associated with "environmentalism" (cf. Alrøe et al. 2006; Halberg 2012)
Community/social sustainability	"Sustainability as community shares the concern for ecological balance, but with special interest in promoting vital, coherent rural cultures" (Alrøe et al. 2006: 83). It suggests that small-scale, diversified, family-run farms based on self-reliance and holism are more beneficial to sustaining vibrant rural communities than industrially organized farms, thus including "alternative" farming, i.e., the roots of modern OA (cf. Alrøe et al. 2006; Halberg 2012; Thompson 2010)
Two overall concepts for sustainability in agriculture according to Thompson (2010)	
Resource sufficiency	Can be described as "'accounting approach' that focuses […] on how we can measure and calculate the proper balance between present resource use and future needs" based on input/output relations seen from without the system (Alrøe et al. 2006: 83). The LCA method represents a specialized resource sufficiency perspective for environmental assessments (cf. Halberg 2012). Conceptualizations of agricultural sustainability revolve around resource "measurement problems" (Thompson 2010: 240)
Functional integrity	Here, based on an ecological perspective, agricultural sustainability is conceptualized in terms of a system's capacity for self-regeneration, i.e., "Humans and nature form vulnerable socioecological systems that have crucial elements […] which must be regenerated and reproduced over time" (Alrøe et al. 2006: 83). Hence, this perspective "has strong similarities with the principles of organic agriculture" (Halberg 2012: 984)

impacts accordingly. Here, it becomes clear that different understandings of sustainability are implicitly involved, which can be subsumed under the terms "resource sufficiency" and "functional integrity"[9] (cf. Halberg 2012; Thompson 2010).

Table 2 characterizes these two concepts according to Thompson (2010) and the "three schools of defining agricultural sustainability" (Halberg 2012: 983–984) according to Douglass (1984), on which the former are based.

Importantly, Halberg (2012) recognizes that the different schools of agricultural sustainability according to Douglass (1984) are still present in contemporary debates, "but many users of the sustainability term seem not to be fully aware of the normative content" (Halberg 2012: 983). Hence, the confounding influence that the sustainability term potentially has on binary scientific debates at hand is pointed out by Seufert (2019: 196): "critics argue that organic agriculture may actually not be more sustainable than conventional agriculture […]" while advocates of OA "argue that the jury on comparative yields […] is still out […] or that yields are not the right metric to assess farming systems by."

However, no substantial discussion of these frameworks, which are influenced by value systems when at work in the assessment of environmental impacts of OA, could be identified in the analyzed literature. It can therefore be assumed that the choice of a reference unit can be an entry point for critical reflection on the inevitable associated normative basic assumptions in environmental impact assessments and that the overall discourse could thus gain in transparency.

[9] Note that Müller et al. (2016), for example, use the term "resource sufficiency" for describing approaches that reduce wastage or the consumption of animal products regarding climate change mitigation in food systems. They further argue that for an encompassing sustainability assessment of OA it is crucial to consider not only "efficiency" and "sufficiency" measures but also the "consistency" of resource use, i.e., approaches to optimal resource use that address "the question of the roles different resources play in the context of a sustainable food system" (Müller et al. 2016: 42).

Conclusion

The paper aimed at retracing the scientific discourse on environmental impacts of OA and exploring why these continue to be assessed controversially. It could be shown that the debates are characterized by a "lock-in" which is complicated by persisting disagreement in the scientific community on appropriate thematic and spatial boundaries for the assessment of environmental impacts.

We conclude that it appears central to overcome binary questions to alleviate the consequent polarizing logic of the debates under investigation. Thus, the question arises, for example, to what extent comparative case studies that aim to quantify environmental impacts between OA and CA under controlled conditions can make a substantial contribution to the political debate on the future role of OA.

The paper further suggests that the insufficient empirical evidence, particularly on leakage effects and on studies directly linking yield data and environmental impacts on the same fields or farms, complicates the debates. It cannot be assumed, however, that gathering more data will be the sole key to reducing controversy. Consequently, it is increasingly appropriate to discuss the usefulness of research questions by considering a broader view of societies' underpinnings facing increasing global crises. Researchers engaged with environmental impact assessments of agriculture should therefore be aware of their role in the process of co-creating narratives and thus exerting power (cf. Scoones et al. 2019). This is especially true for the implicit operationalization of different sustainability concepts, which is often mediated by the choice of reference units.

Against this background, basic normative assumptions should be more strongly reflected and disclosed when assessing environmental impacts of alternative farming systems. As Nielsen et al. (2019) point out, when considering agricultural LU from the perspective of complex human–environment land systems, there is a need for increased discussion about the normative implications of the scientific research process. Here, it appears crucial to create discussion spaces for agricultural research to appropriately consider the normative aspects that are intrinsic to the sustainability assessments of alternative farming systems. This could make the scientific debates at hand more productive and lead to greater transparency in advising political transformation processes of agri-food systems.

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Declarations

Consent for publication All interviewees signed a declaration of consent in which they consented to the anonymized excerpt publication of the collected data.

Conflicts of interest The authors have no conflicts of interest to declare that are relevant to the content of this article.

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