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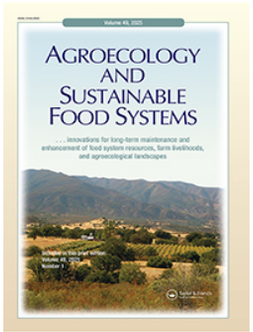

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How transformative is agroecological knowledge co-creation? Insights from a systematic literature review

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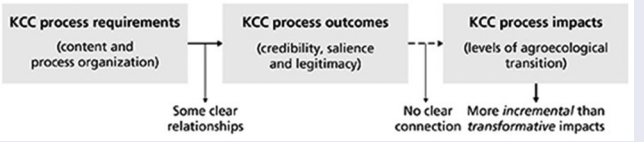
ABSTRACT

Knowledge co-creation (KCC) is imperative for agroecological development, yet the extent to which agroecological KCC processes balance scientific rigor, local relevance, and legitimacy, and the extent to which they connect to transformative agroecological farming remains poorly understood. Therefore, we systematically reviewed 58 peer-reviewed empirical studies that involved agroecological KCC. While we did not find a connection between the perceived credibility, salience, and legitimacy of the co-created knowledge and impacts on agroecological farming, we did find that KCC processes had mostly incremental, rather than transformative, impacts. We conclude that an increased focus on agroecological *principles*, going beyond agroecological *practices*, is needed.



KEYWORDS

Agroecosystems; sustainable agriculture; regenerative agriculture; nature-inclusive agriculture; governance; sustainability transitions; sustainable agri-food transitions

SUSTAINABLE DEVELOPMENT GOALS

SDG 12: Responsible consumption and production; SDG 13: Climate action; SDG 15: Life on land

Introduction

Agroecology is often advocated as an alternative to industrial agriculture to secure food production for a growing world population in a changing climate, while simultaneously addressing urgent challenges such as biodiversity recovery, climate change mitigation, and enhancement of rural livelihoods. Agroecology is based on ecosystem services such as nutrient cycling, soil

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conservation, and natural pest control in order to protect and enhance ecosystems, contribute to resilient and productive food production, and enhance farmers' and communities' livelihoods (Wezel et al. 2009).

How farmers work with agroecological principles and practices is dependent on and shaped by the specific characteristics of their context (e.g. soil and climate conditions and farmers' objectives, knowledge, and resources). Because of this, experimentation and learning about "what works" regarding agroecological knowledge cannot be easily transferred to other geographical contexts (Vermunt et al. 2020). Therefore, localized knowledge co-creation (hereafter: KCC) is a key element of agroecology (Barrios et al. 2020), and is thus vital for supporting farmers to implement agroecological practices and enhance these.

Yet, many food systems worldwide center around industrial or "productivist" agriculture, which is criticized because of how it silences the diverse knowledges and ways of knowing that are indispensable for agroecology and sustainable food systems. Many farmers rely on commercial advisors with little or no knowledge about, or an interest in, agroecology (Tittonell et al. 2020; see also Vermunt et al. 2022). Therefore, a collaboration between farmers and independent scientists and researchers is important to develop and obtain relevant agroecological knowledge. The main challenge in such forms of KCC is to strike a balance between efficiency (i.e. utilizing existing scientific and local knowledge rather than reinventing the wheel), scientific rigor and robustness, and local relevance and applicability.

There is a large and growing body of literature on such KCC for agroecology (e.g. Sachet et al. 2021; Utter et al. 2021). Still, we observe that a systematic overview of requirements for KCC processes among farmers and academic researchers is lacking, especially in relation to the extent to which these result in transformative changes in agroecological farming. With their literature review, Utter et al. (2021) examine existing documentation of and potential for KCC in the field of agroecology by focusing on actual KCC processes and their challenges and opportunities. Their analytical focus is solely on KCC processes, and does not say anything about the impacts of these processes on the ground (i.e. on changes in farming behavior). In a similar vein, Sachet et al. (2021) conducted a systematic literature review to understand the effect of participatory action research on agroecological transitions. They operationalized the concept of agroecological transitions based on a conforming/transforming dichotomy without further specification. This operationalization of "agroecological transitions" remains rather abstract, and again does not say much about the tangible impacts of KCC processes in terms of changes in farming behavior. This paper takes a first step in filling this gap by conducting a systematic literature review of scientific empirical studies that involved KCC processes in the context of agroecology.

The remainder of the paper is organized as follows: section two describes the theoretical foundations of this research; section three describes the research methods; section four presents the results of our analysis, and section five concludes and discusses our findings.

Theoretical framework

Introduction: conceptualising agroecology as a KCC process

KCC refers to a collaborative process in which stakeholders that differ in their epistemologies and capacities mutually exchange, create, and apply knowledge (e.g. Cash et al. 2003; Edelenbos, Van Buuren, and Van Schie 2011). The aim is to transform practice through an ongoing horizontal dialogue in which researchers and stakeholders are all considered co-researchers. A core assumption within agroecology is that there are no one-size-fits-all solutions, since different localities will differ in their physical and societal context. This calls for locally specific approaches that allow for learning "on-the-ground" (Vermunt et al. 2020).

To better understand how KCC processes might produce more transformative agroecological farming practices, the current section presents a framework consisting of three parts: i) desirable *impacts* in terms of more or less transformative agroecological farming practices (dependent variable); ii) KCC process *outcomes* in terms of the credibility and salience of the knowledge produced and the legitimacy of the process (intermediate variable); iii) KCC *process requirements* (independent variable) (Figure 1, also see Supplementary material 5 for a more detailed version of the conceptual framework).

Arrows indicate the expected connections between KCC process requirements, KCC process outcomes, and KCC process impacts. As our focus was

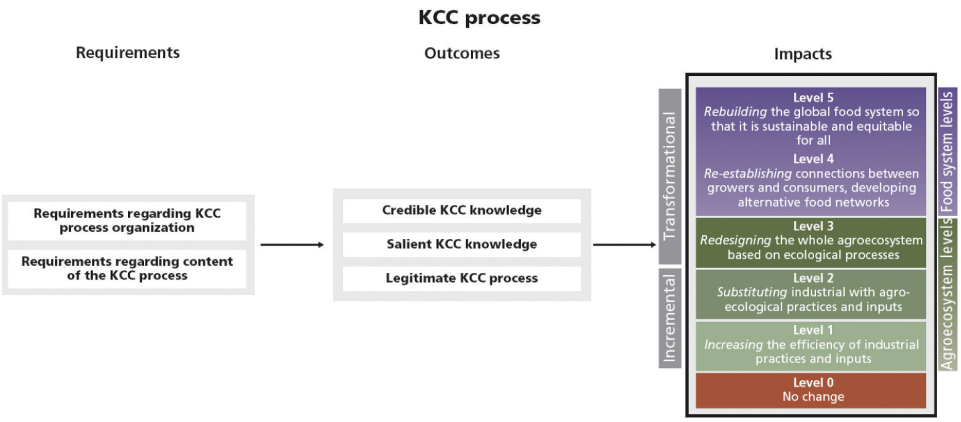

Figure 1. Conceptual framework: expected connections between variables.

more on understanding than it was on explaining the relationship between variables, these expected connections do not imply causation.

KCC impacts

Observable on-the-ground farming practices toward more agroecology constitute our dependent variable. How they can be measured and to what extent they can be labeled in normative terms (e.g. successful vs unsuccessful) is highly subjective. Gliessman (2015), using the Efficiency-Substitution-Redesign (ESR) framework proposed by Hill and MacRae (1996), provided a good starting point in conceptualizing what he calls "agroecological food system transitions". These have been defined as a shift from conventional to agroecological food production systems as the foundation of our local and global food systems. As visualized on the right-hand side of Figure 1, Gliessman distinguishes five levels toward such food system transitions: (1) *increasing* the efficiency of conventional farming practices and inputs; (2) *substituting* conventional with agroecological farming practices; (3) *redesigning* whole agroecosystems based on ecological principles; (4) *reestablishing* connections and networks between growers, consumers, and other stakeholders; (5) *rebuilding* the global food system so that it is sustainable and equitable after all[1].

Gliessman (2018) holds that agroecology constitutes a holistic framework or systems perspective for the conscious (re-)design of agroecosystems that support ecosystem services (and sustainable livelihoods). Agroecology's fundamental principle is to mimic processes in our natural environment, including how humans interact with agroecosystems through their livelihoods. From this perspective, *Levels 1* and *2* are incremental changes since they boil down to introducing another set of farming techniques to a conventional large-scale intensive farming system. At *Level 3* and higher, not just the individual elements within a farming system but also the relations between these elements are considered. This is where *transformative change* at farm level begins. While *Level 3* focuses on the level of agroecosystems, *Levels 4* and *5* consider the whole food system. The current study focuses mainly on *Level 3* and tries to assess the extent to which farmers and researchers managed to be *transformative* in redesigning agroecosystems based on ecological principles at farm- and field-level.

KCC process outcomes

Our intermediate variables consist of the outcomes of the KCC process in terms of credibility, salience, and legitimacy, as depicted in the middle of Figure 1. The choice for these intermediate variables was inspired by the literature on KCC processes for sustainable development

(e.g. Cash et al. 2003; Hegger et al. 2012). This strand of the literature attaches much importance to process-based variables and argues that the quality of science-policy-society *processes* is pivotal for explaining its ultimate impacts. The concepts of salience, credibility, and legitimacy have been derived from Cash et al. (2003) seminal publication on knowledge systems for sustainable development. These concepts are relevant for the field of agroecology as "*fostering co-creation processes that build relevance, credibility and legitimacy is integral to the crafting of* [agroecological] *knowledge that is useful [. . .]*" (Barrios et al. 2020, 234).

Cash et al. (2003) reserve the term **credibility** to whether an actor perceives information as meeting scientific plausibility and technical adequacy standards and whether sources are trustworthy or believable. Credibility can thus relate to various aspects, such as the instruments used for data collection, the type of data collected with these instruments, the type of findings derived from the data and the kind of explanation derived from the interpretation of findings (Tengö et al. 2014). Different stakeholders have different expectations regarding what constitutes credibility (Cash et al. 2003; Hegger et al. 2012). Researchers derive their judgement from scientific rigor, while farmers do so from everyday experience (De Wit et al. 2016). The knowledge that farmers perceive as credible is more likely to be received and used (Ingram et al. 2016).

Salience refers to the perceived relevance of co-produced knowledge (Cash et al. 2003). In agroecology, knowledge must be sufficiently tailored to farmers' local context (e.g. soil-, water-, climate, socio-economic conditions). Hence, it is of utmost importance to ensure a good fit between research questions on the one hand, and information needs on the other, by co-producing knowledge relevant and applicable to farmers' local circumstances (Lemos, Kirchhoff, and Ramprasad 2012). Farmers, in the end, are the ones with the power to decide whether they will implement agroecological farming practices; how and with what success scientifically derived knowledge and measures are implemented on the ground is mainly influenced by their decisions and behavior (Feola et al. 2015). The extent to which researchers are willing and able to cultivate an understanding of the local context in which farmers' decision-making is embedded is a vital element in fostering the salience of the knowledge being co-produced (Lacombe, Couix, and Hazard 2018).

Finally, **legitimacy** refers to the extent to which the produced knowledge has been respectful of the divergent values and beliefs of stakeholders, unbiased in its conduct and fair in its treatment of opposing views and interests (Cash et al. 2003). Taking into account these divergent values and beliefs enhances farmers' willingness to participate in the process and the perceived legitimacy of its outcomes (Tengö et al. 2014), thereby increasing the likelihood that the knowledge produced will be put into action.

Legitimacy is crucial in agroecology since this approach inherently recognizes the value of local knowledge and experiences, and the potential to empower farmers. The focus is shifted from seeing farmers as passive recipients of externally developed technology and expertise to active ones who co-constitute agroecological farming practices (Thompson and Scoones 2009).

KCC process requirements

Following Hegger et al. (2012), we assume that the success of KCC process outcomes in terms of credibility, salience, and legitimacy can be influenced by specific process requirements (our independent variable). We used Hegger et al.'s(2012) seven success conditions for joint knowledge production as our point of departure. However, to specify it to agroecology and simplify it, we restructured the success conditions into two categories of process requirements as explained below: (i) requirements regarding KCC process organization and (ii) requirements regarding the content of the KCC process.

Requirements regarding KCC process organization

One can expect that the success of KCC processes is enhanced when a **broad stakeholder coalition** is participating, because the inclusion of place-based knowledge in science is likely to positively influence the perception of credibility and salience (Hegger et al. 2012). In KCC processes more generally, but surely in the context of agroecology, a plea can be made for an actor base that is as diverse as possible to cater for the inclusion of heterogeneous viewpoints that might contribute to gaining a more holistic perspective on the issues at stake. Gender and generation diversity (especially the youth) should primarily be accounted for (Nyeleni Declaration 2015). This requires a **careful and representative selection of stakeholders** and actor **inclusion in an early stage of the process** (Burns et al. 2014).

Several scholars also stress the importance of KCC being an **iterative process** rather than a one-shot operation (Armitage et al. 2011). In addition, De Vente et al. (2016) point at the need for not just iterativity, but also **adaptiveness**: the process should be adjusted to participants' language and location. Hegger et al. (2012), amongst others, point at the need for an **organized reflection on participants' roles and responsibilities**. Participating actors should be and feel free to decide on the identity, position-(s), and responsibilities they are capable and willing to take on throughout the process (Timmermann and Félix 2015). Such high levels of autonomous decision-making contribute to adopting sustainable farming practices (Triste et al. 2018).

Hegger et al. (2012) also pay due attention to what actors can do themselves to optimize resources for the KCC process and have identified three **specific**

types of resources: (i) boundary objects, (ii) facilities and organizational forms that stimulate the interfacing and sharing of different forms of knowledge, and (iii) competencies (e.g. negotiation, interactional expertise). Lastly, they point to **innovative reward structures in science** as essential. Impacts from KCC processes differ from non-participatory and non-transdisciplinary research projects. Henceforth, they need to be evaluated differently than through the status quo measurements for scientific impact (e.g. the number of publications and citations) (Hegger et al. 2012). Both agroecological science and practice are knowledge-intensive and time and labor consuming. This is due to their participatory, inter-, and transdisciplinary character. Fundamental changes in the organizational culture of scientific research are thus required and will increase legitimacy perception (Hegger, Van Zeijl-Rozema, and Dieperink 2014).

Requirements regarding the content of the KCC process

It is essential **that divergent stakeholder perspectives are included through horizontal dialogue** that facilitates collective sense-making (Martínez-Torres and Rosset 2014). This is known in agroecology as *diálogo de saberes*, or: a conversation among different knowledges and ways of knowing. This concept embodies the need for cultivating what several authors coined as epistemic humility: an attitude that embraces biases, fallibilities, and strengths of different ways of knowing rather than assuming the superiority of just one of them (De Wit et al. 2016). It is through such dialogues and attitudes that, when linked to collective action, participating actors gain a clear understanding of project expectations and potential barriers and benefits (Martínez-Torres and Rosset 2014).

The success of KCC processes is likely to be enhanced when there is a **shared understanding of problem definition and goals** for the KCC process, as this may increase the perception of salience due to a good fit with actors' needs and interests (Hegger et al. 2012). This requires efforts to foster inclusiveness and create common ground by acknowledging and harmonizing differences in cultural and linguistic traits. While reaching a shared understanding may turn out challenging, this condition is vital for creating collaborative synergies across knowledge systems in the long run (Tengö et al. 2014).

Another requirement is that **the role(s) of researchers and their knowledge is clear** (Hegger, Van Zeijl-Rozema, and Dieperink 2014). Openness regarding intentions and expectations instead of hidden agendas is crucial when fostering perceptions of credibility and legitimacy of the process as it may increase trust in researchers (Hegger et al. 2012). It is vital for researchers to be transparent about the type of stakeholder engagement they envision. This includes: communication (dissemination of information to stakeholders who are considered passive recipients), consultation (gathering information

from stakeholders), or participation (a reciprocal process of communicating and learning between all stakeholders). By collaborating directly with farmers as co-creators, new roles emerge for scientific researchers, among which are confirming the scientific legitimacy of farmers' knowledge and experience by acknowledging them as experts in their own rights and translating these into an academic idiom for communication with other actors in the system (e.g. policymakers and civil society, De Wit et al. 2016).

Methods

Systematic literature review

The KCC process outcomes and -impact part of our conceptual framework were initially developed for use in another context than agroecology, namely regional climate change adaptation projects. As was stressed by its authors, its applicability to other contexts requires further empirical confrontation and refinement (Hegger et al. 2012). As starting point for such empirical confrontation, we conducted a systematic literature review (SLR) to take stock of empirical examples of good KCC practices in agroecology. An SLR is appropriate because it enables the identification and synthesis of key research findings by employing a transparent and protocol-driven approach (Okoli and Schabram 2010).

Review process

In 2022, a preliminary search was conducted, from which 13 useful publications were retrieved. In 2023, the official SLR was conducted by using the PRISMA-R guidelines (Rethlefsen et al. 2021) (also see Supplementary material 1 for the applied PRISMA-S checklist), and based on the following Boolean search string:

> TITLE-ABS-KEY "agro-ecological farming;" OR "agroecological farming;" OR "agro-ecology;" OR "agroecology;" AND "knowledge co-creation;" OR "knowledge cocreation;" OR "joint knowledge production;" OR "knowledge co-production;" OR "participatory action research;" OR "participatory science;" OR "participatory research;" OR "action research;" AND (farmer OR peasant OR smallholder)

The review procedure comprised four steps: (i) data gathering, (ii) data screening, (iii) data cleaning, and (iv) data analysis. Figure 2 summarizes these steps together with their outputs. Supplementary material 1 provides a more detailed elaboration on the execution of these steps.

The final sample consisted of $N = 58$ peer-reviewed empirical studies about agroecological KCC processes (also see Supplementary material 2 for an overview of the studies included). The sample contains studies published between December 2002 and December 2023 and thereby covers more than 20 years.

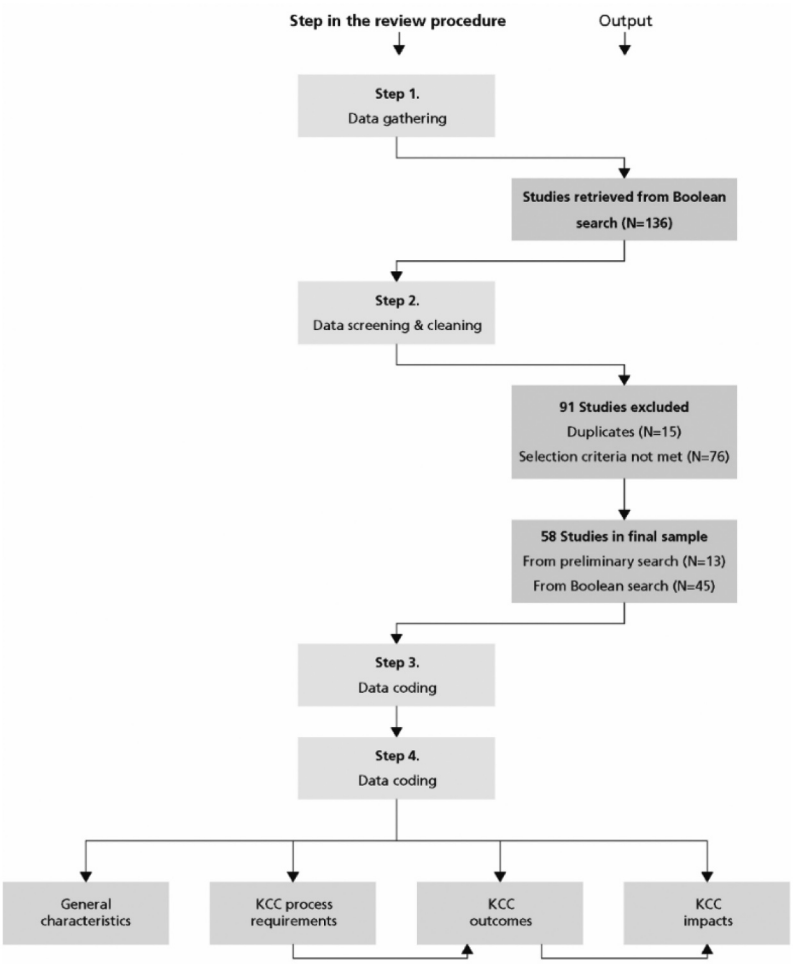

Figure 2. Review procedure and output.

We analyzed all studies in this sample by coding them in terms of (i) the independent variable (i.e. KCC process requirements), (ii) the intermediate variable (i.e. KCC process outcomes), and (iii) the dependent variable (i.e. KCC process impacts). Indicators for each of the concepts in our framework were coded as *completely met*, *partially met*, *not met*, *not mentioned*, or *unclear*. Supplementary material 3 contains an overview of how we operationalized the indicators and their scores; we added excerpts from the sample to give an impression of its practical application.

In addition, all studies were coded based on general characteristics (i.e. descriptive results, such as year of publication, country and continent where the study took place, time frames employed for the KCC processes and the actors that participated in these processes). All codes were registered in an Excel-file and converted into synthesis tables for further analysis (see Data availability statement). The first author did coding to guarantee consistency of

the coding process. The coding approach ended up being hybrid: while deductive coding was the starting point based on our theoretical framework, inductive coding was deemed necessary when making sense of some of the results. As the results are presented in the next section, the inductive approach will be mentioned explicitly whenever it applies. From each study, one KCC case was included in the sample (also see Supplementary material 1 for a justification). In two studies, multiple KCC impacts were presented. In the analysis, we refer to N in terms of the number of studies in our sample (58) when describing general characteristics, KCC process requirements, outcomes, and the connection between the latter two. We refer to N (= 62) in terms of the number of KCC impacts mentioned when it comes to analyzing their connection to KCC process outcomes (see e.g. Figure 5).

Results

General characteristics of the peer-reviewed empirical studies that involved agroecological KCC are presented first, followed by the findings for the dependent variable (i.e. *KCC process impacts*), the intermediate variable (i.e. *KCC process outcomes*), and the independent variable (i.e. *KCC process requirements*) respectively.

Descriptive results

Figure 3 presents a visual summary of the years in which the studies were published. As can be observed, the most notable increase in publications happened after 2018. These numbers seem to reflect an upsurge in the

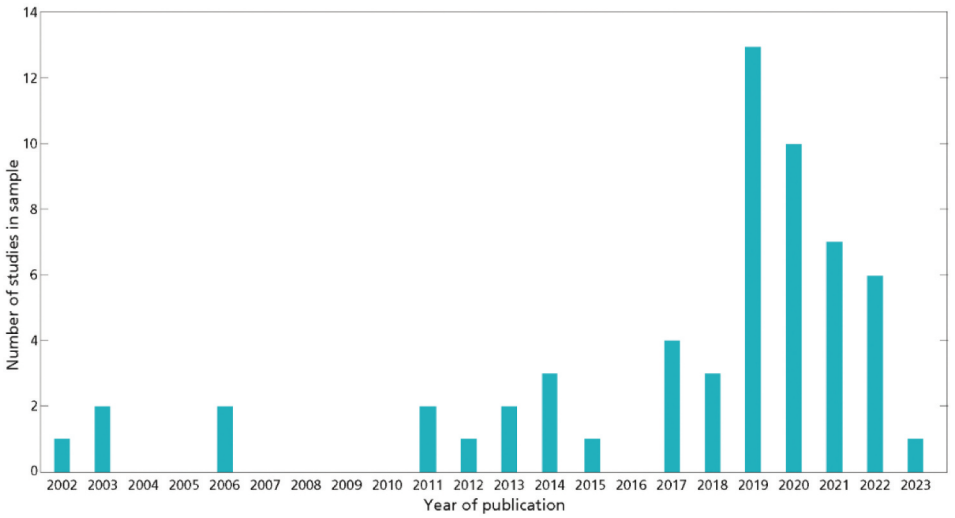

Figure 3. Year of publication (*N*=58) of studies found in the literature.

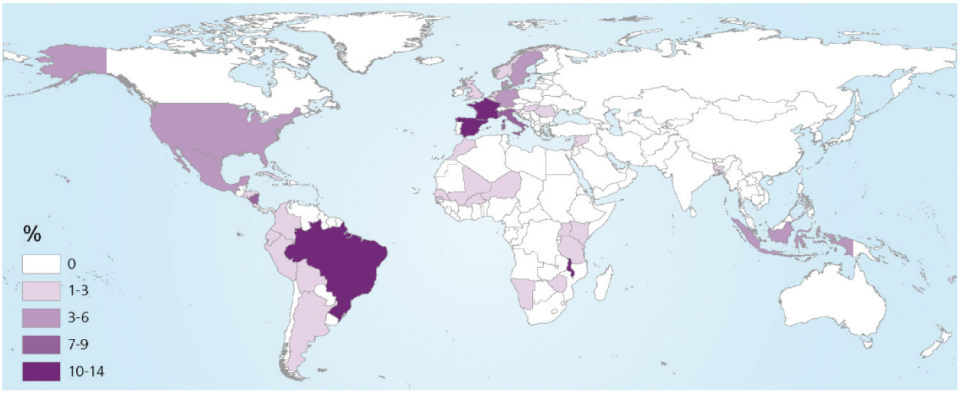

Figure 4. Geographical distribution of KCC studies (*N*=58).

Impact level	N	%
Level 4 - *Re-establishing* connections between growers, eaters and other stakeholders	5	8%
Level 3 - *Redesigning* the whole agro-ecosystem based on ecological processes	8	13%
Level 2.5 (additional transformation level)	5	8%
Level 2 - *Substituting* conventional with agro-ecological practices and inputs	16	26%
Level 1 - *Increasing* the efficiency of industrial inputs	1	2%
Level 0 - No change	6	10%
Impacts not mentioned	10	16%
Impacts unclear	11	18%
Total	**62**	**100%**

Figure 5. Distribution of types of KCC process impacts (*N* = 62).

phenomenon and scientific studies. A possible explanation for the initial increase in 2019 could be that during the second FAO International Symposium of Agroecology in 2018, scaling-up agroecology was proposed as a strategic approach to fostering sustainable food system transitions (Gliessman 2018). More than half of the studies in our sample (N = 31, 53%) employed a 1–5-year time frame. Another 12 studies (21%) used a time frame of 6–10 years, another three studies (5%) employed a time frame of less than a year, and one study (2%) used a time frame of more than 20 years. There were 10 studies (17%) in which the time frame was not mentioned.

An impression of the geographical distribution of the studies in our sample was gained by looking at the countries (see Figure 4) and continents (see Table 1 in Supplementary material 4) in which the studies took place. In the 58 studies in our sample, one study did not mention the study's country. While 41 countries are represented (see Figure 4), there were 81 mentions because of two studies that reported on KCC processes in different countries simultaneously. Our sample represents five continents (i.e. Africa, Asia, Europe, and North and South

America, see Table 1 in Supplementary material 4). There were 60 mentions of continents because two studies reported on KCC processes in different continents simultaneously.

KCC process impacts

The success of the KCC processes studied (or the lack thereof) was defined in terms of their impact on agroecological farming behavior, which was operationalized using the agroecological food system transformation levels as defined by Gliessman (2015). The results are summarized in Figure 5. Five studies (11%) reported impacts that did not fit into one of the five levels as defined by Gliessman (2015) and used in our analytical framework. These impacts referred to either *improvement of existing organic/agroecological farming practices* (N = 2), *horizontal scaling of agroecological farming practices* (N = 2) or *non-implemented redesign of agroecosystems based on ecological principles* (N = 1). Because these impacts seem to go beyond substitution of industrial practices and inputs with agroecological ones (*Level 2*), but do not yet seem to meet the re-design of whole agro-ecosystems based on ecological processes (*Level 3*), they seemed to have a better fit between *Level 2* and *Level 3*, which is why they were categorized as an additional *Level 2.5*.

As explained earlier, our analysis was primarily focused on assessing how farmers and scientific researchers managed to manifest *transformative* impact with their KCC process (as opposed to *incremental* impacts), which starts at *Level 3*. Eight studies (14%) in our sample reported such impacts, for example:

> During the first workshop (April 2021), the PAR group decided to use agroecological principles of functional design, biodiversity, multifunctionality, adapted scales, ecosystem services, circulation and plant nutrients as a basis for collective work on the design and development of agroforestry systems to be studied. (Study #28, p.4)

> The "seed house" favored the development of various collective action [. . .] For instance, in 2014, they started questioning the relevance of their farming practices in the use of these seeds. To tackle this issue, they launched a project on the agroecological redesign of their farming systems. (Study #40, p.525)

Five studies (9%) in our sample reported *Level 4* impacts (i.e. *Reestablishing connections between growers and consumers and other stakeholders, developing alternative food networks*). Another two studies (3%) reported impacts on *Level 2, Level 3*, and *Level 4* simultaneously, the latter being illustrated by the following quote:

> Although Gliessman (2010) defines agroecological transition in four progressive stages, in our case studies phase one was not present and phase 4 was developed in parallel to the redesign of the agroecosystem [phase three]. In fact, SFSC [short food supply chain]

development became the driving force for the change in the management of the agroecosystem in Morata de Tajuña" (p.143) [. . .] research techniques have been successful in initiating and accompanying agroecological transition processes, in involving farmers in the redesign of their farms [with high crop diversification, introduction of livestock for home consumption, planting of trees along the edges of vegetable plots, and composting of organic waste] to increase sustainability, and in building local organic food networks by the wider society. (p.144) [. . .] (Study #50, pp.143–144)

KCC process outcomes

The success of KCC process *impacts* was expected to depend on the extent to which the three KCC process outcome criteria (i.e. *credibility, salience*, and *legitimacy*) were simultaneously met as an intermediate result. The criteria were scored as either *not met*, *partially met*, or *completely met* (see Figure 6 below).

The three KCC process outcome criteria

In some of the studies in our sample there was no mention of the KCC process outcome criteria. This was the case for *credibility* in more than one-third of the sample (38%), followed by *salience* (22%) and *legitimacy* (17%). In some other

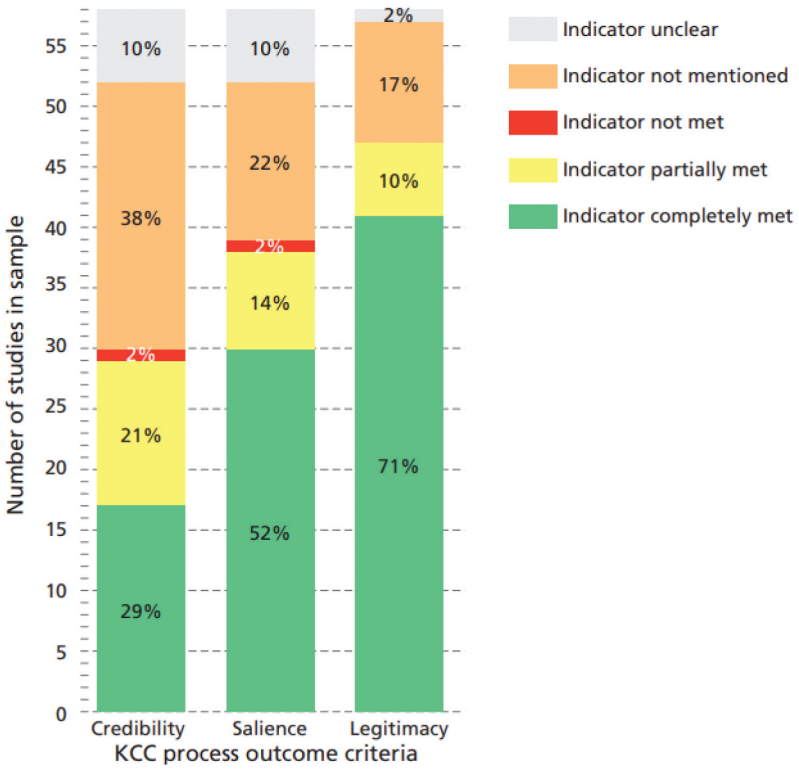

Figure 6. KCC process outcomes (*N*=58).

studies the extent to which a KCC process outcome criterion was met remained unclear. This was the case for *credibility* in six studies (10%), for *salience* in another six studies (10%), and for *legitimacy* in one study (2%). The *credibility* and *salience* criteria were both *not met* in one study (2%); for *legitimacy* there were no studies in which this criterion was reported to be *not met*. The extent to which a criterion was *completely met* was highest for *legitimacy* (71%), followed by *salience* (52%), and *credibility* (29%) (see Figure 6).

Credibility was considered *completely met* when participating actors perceived the co-created knowledge as valid (either implicitly or explicitly). This was the case in 17 studies (29%), for example:

> [...] once the clusters were made, we presented the results to the participants asking them for additional feedback or consensus. After all participants agreed with the co-produced backwards transition pathway we invited the participants to a debriefing session. (Study #18, p.1388)

Credibility was considered *partially met* when participating actors perceived the co-created knowledge as partially valid *or* if some of the participating actors perceived the co-created knowledge as valid. This was the case in 12 studies (21%), for example:

> Farmers pointed out that there were very large differences in the results between different regenerative farms on a number of LISQ [local indicators of soil quality]. They discussed the importance of making comparisons "fair," thus between regenerative and neighbouring conventionally managed fields, and not between regenerative farms because they were far from each other and the particular biophysical and climatic conditions of each regenerative farm could be constraining or stimulating the effectiveness of the different RA [regenerative agricultural] practices. (Study #7, p.197)

Salience was considered *completely met* when participating actors perceived the co-created knowledge as relevant (either implicitly or explicitly). This was the case in 30 studies (52%), for example:

> The use of EM [efficient microorganisms as a solution resulting from the knowledge co-creation process] was appreciated by agroecological farming families, since EM is produced locally at very low cost, does not harm human health or the environment, and controls the two important herbivores. (Study #5, p.11)

Salience was considered *partially met* when participating actors perceived the co-created knowledge as partially relevant *or* if some of the participating actors perceived the co-created knowledge as relevant. This was the case in eight studies (14%), for example:

> VSA tool adoption can be enhanced if participants see the usefulness of contributing to a common repository with their individual monitoring results that supports collaboration and large-scale landscape restoration. Since some farmers already recorded RA progresses using their own methods for their own use, it seems necessary to reinforce the

> potential advantages of systemizing and storing information collectively. (Study #7, p.200)

Legitimacy was considered *completely met* when the KCC process was fully respectful of divergent values, interests, and beliefs of participating actors. This was the case in 41 studies (71%), for example:

> The facilitators' ability to make participants express themselves and to establish dialogue between different mindsets in a respectful context was also highlighted [. . .] The interviewees perceived facilitators as people who listened and took all viewpoints into account without stigmatizing them. (Study #37, p.241)

Legitimacy was considered *partially met* when the KCC process was respectful of divergent values, interests, and beliefs of participating actors to some extent. This was the case in six studies (10%), for example:

> One of the greatest challenges to farmer engagement was the legacy of conventional top-down research and extension practices. Ingrained historical, social, cultural and educational norms have perpetuated complex and intersecting dynamics that have marginalized farmer agency and knowledge while favoring that of researchers, professors, scientists, extensionists (generally male), and those with formal education and high levels of literacy in a dominant (colonial) language. As such, farmers had been taking advice from various types of officers for years and often lacked the social legitimacy, personal confidence and skills to engage as equals. (Study #6, p.7)

Link between KCC process outcomes and KCC process impacts

While we expected a correlation between KCC process outcomes in terms of credibility, salience, and legitimacy on the one hand, and impacts on the other, our results do not reveal any clear patterns (see Figure 7 and Table 2 in Supplementary material 4). What does stand out is the observation that

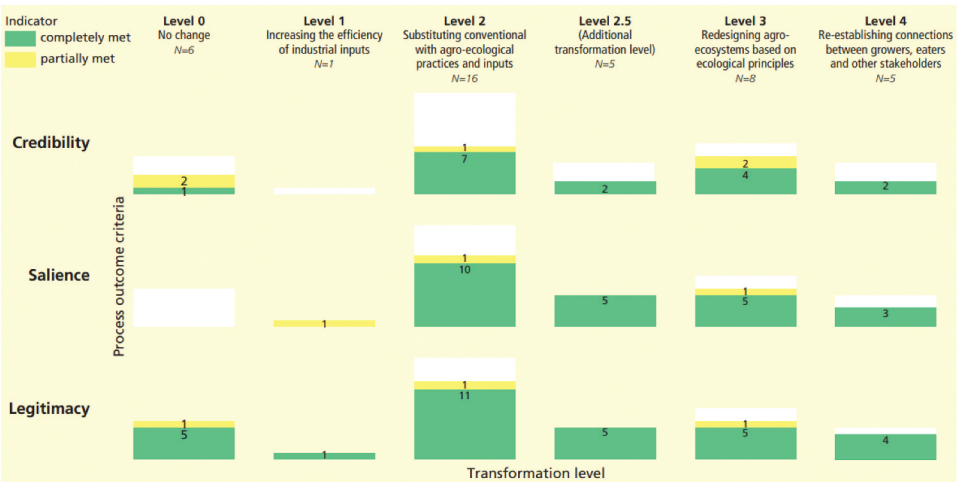

Figure 7. Link between KCC process outcomes and impacts.

legitimacy seems important for all levels of impact. This raises the impression that in order to obtain higher-level impacts, something more than credibility and salience is needed.

Figure 7 shows connections between KCC process impacts and KCC process outcome criteria (only for those studies that provided information on the different levels of KCC impacts). Note that the number of studies per impact level differs. The size of the boxes corresponds with these numbers. For example, there were 16 studies reporting Level 2-impact, and eight studies reporting Level 3-impact, so the size of the latter box is half of the size of the former.

KCC process requirements

Reported requirements regarding KCC process organization

Reported requirements regarding KCC process organization are summarized in Table 1 in the IDV-sheet in Supplementary material 5. The requirement of working with the **broadest possible actor coalition** was considered *completely met* in case this coalition went beyond the bare minimum of farmers and academic researchers by involving more than one other actor. This was the case in 42 studies (i.e. 72% of our sample). The broad actor coalition requirement was considered *partially met* when farmers, academic researchers, and one other actor were involved in the KCC process. This was the case in 10 studies (17%). See Figures 1 and 2 in Supplementary material 4 for more detailed information on the types of actors involved.

The requirement of a **careful and representative selection of stakeholders** was considered to be *completely met* when the selection of participating stakeholders was based on co-selected inclusion criteria *while* being a representative selection. This was the case in 13 studies (22%). The requirement was considered to be *partially met* in case the selection of participating stakeholders was based on co-selected inclusion criteria *or* if the selection of participating actors was representative. This was the case in 15 studies (26%). Because agroecology explicitly acknowledges the importance of women (Nyeleni Declaration 2015), the **inclusion of both male and female participants** was included in the conceptual framework as an additional requirement for KCC process organization. This requirement was *completely met* in 31 studies (53%), and *not mentioned* in the remaining 27 studies (47%). The importance of involving both male and female participants is illustrated by the following quote from one of the studies in our sample:

> "Women farmers – often sidelined in decision making processes regarding coffee due to their lower level of cooperative membership – used their newly available capital from AgroEco Coffee's Womens Unpaid Labour Fund to propose an alternative. Their willingness to experiment with agroecological renovation [elaboration of nine different soil and foliar applications, including compost, worm compost, effective microorganisms,

> biofertilizers etc.] created an alternative pathway to the same end-goal, slowly bringing along their male counterparts as the outcome of agroecological renovation becomes apparent." (Study #42, p.15)

The requirement of **early stakeholder involvement** was considered to be *completely met* when participants were involved during the (i) problem history phase, (ii) problem identification and structuring phase, or (iii) research design phase. This was the case in 40 studies (69%). The requirement was considered to be *partially met* when participating stakeholders were involved during one of the three subsequent phases: (iv) data collection phase, (v) data analysis and triangulation phase, and (vi) interpretation, reflection, and synthesis phase. This was the case in 18 studies (31%). This result may point to an issue with the coding scheme. It now seems as if in 69% of our sample participating actors were involved early in the process. While this is the case, the categorization of these research phases may not be so linear in practice. For example, in some of the studies, participants were involved in a KCC process with the mere goal to identify and structure the research problem at hand, while not being involved in the research design. That way, early involvement still does not do justice to the idea of horizontalism, in this case with regard to co-creation of research designs. This result might thus paint a somewhat skewed image.

The requirement of an **iterative and adaptive KCC process design** was considered to be *completely met* when the KCC process design was both iterative *and* adaptive. This was the case in 46 studies (79%). This high percentage may in part be explained by the fact that this was an aggregate indicator; separating iterativity from adaptivity would have been better. The requirement was considered *partially met* when the KCC process design was iterative *or* adaptive. This was the case in four studies (7%). The requirement of having **organized reflections on stakeholders' roles and responsibilities** was considered to be *completely met* in case which the process included an organized reflection on both stakeholders' roles *and* responsibilities. This was the case in 11 studies (19%). The requirement was considered to be *partially met* in case there was an organized reflection on roles *or* responsibilities, or in case there was one-way *communication* (as opposed to reflection) on roles and responsibilities. This was the case in three studies (5%). The requirement of **resources being present** was considered to be *completely met* in case all three types of resources were present. This was the case in 49 studies (84%). The requirement was considered to be *partially met* in case two out of three types of resources were present. This was the case in seven studies (12%). Examples of *boundary objects* are field trials and visits, games, and tangible outputs from (other) participatory activities, such as indicator ranking, farm- and timeline mapping, and cropping calendars. Examples of *facilities and*

organizational forms are focus group discussions, (participatory) workshops, technical support, and in some cases funding. Process facilitation and training in research and agroecology are examples of *competencies*.

The requirement of **innovative reward structures in science** was completely met in two studies (3%) and no*t met* in four studies (7%). An interesting observation here is that there was no mention of this requirement in 49 studies (84%).

Reported requirements regarding the content of the KCC process

Reported requirements regarding the content of the KCC process are summarized in Table 2 in the IDV-sheet in Supplementary material 5. The requirement of **including divergent stakeholder perspectives through horizontal dialogue** was considered to be *completely met* when participating stakeholders engaged in a *diálogo de saberes* (i.e. conversation among different knowledges and ways of knowing) as equals. This was the case in 48 studies (83%). This requirement was considered to be *partially met* when participating stakeholders engaged in a *diálogo de saberes*, but not as equals. This was the case in four studies (7%).

The requirement of having a **shared understanding of problem definitions and goals** was considered to be *completely met* when participating actors deliberated on the nature and denomination of the problem *and* on the type of outcome(s) to be expected (e.g. ideas, concepts, and solutions). This was the case in 33 studies (75%). This requirement was considered to be *partially met* when participating actors deliberated on either the nature and denomination of the problem *or* on the type of outcome(s) to be expected. This was the case in eight studies (14%).

The requirement of **the role of the researchers and their knowledge being clear** was considered to be *completely met* when researchers clearly expressed how they perceived their own role in the process as well as the role of their knowledge. This was the case in 13 studies (22%). The requirement was considered to be *partially met* when researchers expressed how they perceived their own role in the process *or* the role of their knowledge. This was the case in five studies (9%). There was no mention of this indicator in more than half of our sample (57%).

Link between KCC process requirements and KCC process outcomes

We then explored the connections between KCC *process requirements* and *process outcomes* (these are summarized in Tables 3 and 4 in Supplementary material 4). Percentages in these tables are used to express relative connections, indicating the share of our sample ($N = 58$) in which a specific combination of a *process requirement* score and *process outcome* criterion score was

found (i.e. *completely met*, *partially met*, etc.). The more evident connections are highlighted in yellow.

No clear connections could be found for some of the *process requirements*. This was the case for (i) **careful and representative selection of participants**, (ii) **organized reflection on stakeholders' roles and responsibilities**, and (iii) **innovative reward structures in science** (i.e. requirements regarding process *organization*), because these were hardly reported on. The same goes for the requirement of a **clear role for researchers and their knowledge** (i.e. requirement regarding the *content* of the process).

For the remaining requirements, some clear connections could be observed. In what follows, the percentages indicate the extent to which both the *process requirement* and *process outcomes* mentioned were scored as *completely met*. In other words: these percentages give an indication of the relative importance of a *process requirement* for ensuring that the co-created knowledge is perceived of as *credible* (C) and/or *salient* (S), and that the process through which this co-created knowledge came into life was perceived of as *legitimate* (L).

There is modest evidence that some of the *process requirements* matter in practice, especially for *legitimacy* and *salience* (and for *credibility* to a somewhat lesser extent). From the set of requirements regarding *process organization*, this was the case for **broad actor coalition** (L = 52%, S = 36%, C = 19%), **inclusion of both male and female participants** (L = 36%, S = 33%, C = 17%), **early stakeholder involvement** (L = 48%, S = 45%, C = 22%), an **iterative and adaptive KCC process design** (L = 59%, S = 45%, C = 28%), and the **presence of specific resources** (L = 62%, S = 50%, C = 28%). From the set of requirements regarding the *content* of process, this was the case for: the **inclusion of divergent perspectives through horizontal dialogue** (L = 66%, S = 50%, C = 28%) and **shared understanding of problem definition and goals** (L = 48%, S = 40%, C = 17%).

That these requirements seem to mostly matter for *legitimacy* and *salience*, raised the question as to what matters for *credibility*. Process requirements that seemed to matter most for this criterion were (i) an **iterative and adaptive process design** (in 28% of our sample both credibility and these process requirements were *completely met*), (ii) **the presence of specific resources** (also 28%), (iii) **the inclusion of divergent perspectives through horizontal dialogue** (again, 28%), and (iv) **early actor involvement** (22%). For *salience*, the four process requirements that seemed to matter most were: (i) the **inclusion of divergent perspectives through horizontal dialogue** (in 50% of our sample both *salience* and these requirements were *completely met*), (ii) the **presence of specific resources** (also 50%), (iii) **early actor involvement** (45%), and (iv) an **iterative and adaptive process design** (also 45%). Finally, four process requirements seemed to matter most for *legitimacy*: (i) the **inclusion of divergent perspectives through horizontal dialogue** (in 66%

of our sample both *legitimacy* and requirements *completely met*), (ii) the **presence of specific resources** (62%), (iii) an **iterative and adaptive KCC process design** (59%), and (iv) a **broad actor coalition** (52%).

Overall, our analysis shows that two process requirements appear to be conducive to all three criteria in practice: (i) the requirement of the **presence of specific resources** (i.e. requirement regarding KCC process organization) and (ii) the requirement of **including divergent perspectives through horizontal dialogue** (i.e. requirement regarding the content of the KCC process).

Discussion

Scientific studies that establish links between characteristics of agroecological KCC and transformative agroecological farming practices are emerging, but fragmented or abstract. That is why we lack an understanding of the level of transformative impacts of KCC processes on agroecological farming behavior. Therefore, as a first step toward more systematic empirical insights, this paper took stock of this scientific literature by reviewing 58 studies using a literature-derived KCC-model. Impacts of the KCC process were in most cases incremental rather than transformative. While we did not find a clear correlation between KCC process outcomes and impacts, we still have some key observations that, in our view, have implications for agroecological KCC.

KCC model: key observations

First, based on existing literature, we characterized the degree to which KCC process impacts on agroecological farming behavior were transformative in terms of levels ranging from 0 (i.e. *no change*) to 4 (i.e. *re-established connections between growers, eaters, and other stakeholders*) as the two extremes on our analytical continuum (also see Figure 5 on p.11). KCC process impacts were considered to be *transformative* as from *Level 3* (i.e. *redesigning agroecosystems based on ecological principles*); all preceding impact levels were considered to reflect *incremental* change. We identified an additional impact level, i.e. *Level 2.5*, which refers to either *improvement of existing organic/agroecological farming practices*, *horizontal scaling of agroecological farming practices* or *non-implemented redesign of agroecosystems based on ecological principles*. Our main finding was that the impacts of KCC processes on agroecological farming behavior mostly reflected *incremental change*, i.e. up to and including the additional *Level 2.5* (see Figure 5). This was the case in more than one-third of the KCC studies in our sample (i.e. 22 out of 58 studies). KCC process impacts were *transformative* in nearly a quarter of the sample: eight out of 58 studies (14%) were transformative at farm- and field-level (i.e. *Level 3*), and

another five out of 58 studies (9%) were transformative at food system level (i.e. *Level 4*).

We then explored connections between KCC process impacts and process outcomes, the latter expressed in terms of (i) the perceived quality of the co-created knowledge (i.e. *credibility* and *salience*) and (ii) the perceived quality of the processes through which this knowledge was co-created (i.e. *legitimacy*). In many studies, no indications were provided of the perceived credibility of the co-created knowledge. This was surprising as this would seem the basic quality criterion of scientific research (both in absolute terms – in more than half of the sample we could not find evidence of credibility, and in relative terms – "scores" on *salience* and *legitimacy* were more often reported). A reason might be that the studies often dealt with stakeholder interactions, which make it more logical to provide information related to salience and legitimacy but not necessarily about credibility. Or, it might mean that *credibility* was not seen as an issue and/or taken for granted. Overall, while a correlation between KCC process outcomes and impacts was expected, our results did not reveal clear patterns. Outcome criterion *legitimacy* did seem important for all impact levels. This finding seems to hint that in order to higher-level KCC impacts, something more than credibility and salience is required.

We continued exploring the importance of specific requirements for the organization of KCC processes in relation to KCC process outcomes, distinguishing the organization of KCC *processes* from the *content* of these KCC processes. We observed that for each of these two types of requirements, there was one specific requirement that appeared to be conducive to all three KCC process outcome criteria: (i) the requirement of the presence of specific resources (i.e. boundary objects, facilities, organizational forms and competencies as a requirement regarding organization of the KCC process) and (ii) the requirement of including divergent perspectives through horizontal dialogue (i.e. requirement regarding the content of the KCC process).

Strengths and limitations

Our research offers some valuable theoretical contributions. Knowledge gaps existed with regard to the organization and impacts of KCC processes on the ground which, in fact, are "*intense topics of debate*" (Gliessman 2022, 1116). Not only does our research contribute to these gaps and debates, it also contributes to theory on KCC dynamics: where the theory as formulated by Hegger et al. (2012) focused on the link between process conditions and outcomes, this research explicitly added a third relevant layer: process *impacts*. The value of our research is thus that it is the first study that explores the link between KCC process organization (in terms of *requirements* and *outcomes*) to

the success of these processes with tangible *impacts* (in terms of agroecological farming behavior).

This notwithstanding, we should acknowledge the following limitations of the study. A lot that is going on in agroecology in general, and agroecological KCC in specific, is either not published in academic research, published with different terminology, or not published at all. For example, an online survey on agroecological innovations during the first months of the COVID-19 pandemic in Latin America revealed and documented 123 initiatives (e.g. Tittonell et al. 2021); none of these initiatives were published individually in the scientific literature. Owing to the practice- and practitioner-centered character of agroecology, it is plausible to assume that there are accounts of KCC experiences described in gray literature that could have been relevant for answering our research question. At the same time, we believe that the focus on peer-reviewed publications contributes to the robustness of our findings.

Another potential limitation of our research has to do with the decision to only include peer-reviewed publications in which the research was explicitly framed in the context of *agroecology*. That some resemblance may be observed between agroecology and other agricultural approaches, mostly in terms of some of the farming practices employed, means that relevant findings in fields of related agricultural approaches were excluded from our analysis (e.g. sustainable agriculture, sustainable and ecological intensification, and organic-, conservation-, and regenerative agriculture). Nevertheless, as a distinctive feature of agroecology is that it considers the socio-political dimension of sustainable and just food system transformation at the core of its rationale (Tittonell et al. 2022), conceptual precision was considered to be indispensable (Gliessman 2023a).

Another limitation has to do with our coding and interpretation of the outcomes of KCC processes in the 58 studies, which required interpretation and with that, possible bias. Especially related to legitimacy, we based ourselves primarily on statements by researchers throughout the peer-reviewed studies, and not on direct statements from farmers and other stakeholders with regard to their perception of legitimacy of the KCC process.

A final limitation is that by choosing the framework from Hegger et al. (2012) as our starting point, we excluded other approaches. First, we did not touch upon the political nature of knowledge and knowledge production. We did not problematize whose knowledge "counts" and whose does not, and how this is related to power and social structures (e.g. Jasanoff 2004). Also in KCC processes, power and knowledge play a role (e.g. Cockburn 2015). At the food system level, agroecology and agroecological knowledge remain less legitimate than the thick legitimacy of the dominant industrial food production model (De Wit et al. 2016). Second, we did not integrate principles and best practices for agroecological KCC brought forward by other researchers (e.g. Méndez et al. 2017).

Transformative KCC: the way forward

In spite of the above limitations, our findings offer a good starting point for ways of thinking about a future research agenda, of which two will be discussed here.

The first line of thought centers around the call for increased "agroecological articulation" or, in other words, a shift in focus from the adoption of agroecological *practices* to agroecological *principles*. That the majority of KCC processes studied showed *incremental* rather than *transformative* impacts on farming behavior, implies that the focus of KCC projects is more on the implementation and/or improvement of agroecological farming *practices* than it is on the redesign of agroecosystems based on ecological *principles* (see e.g. Barrios et al. 2020). This is problematic, because central to the agroecological approach to food production is the importance of not just the individual elements within an agroecosystem, but even more so of the synergistic interactions between these elements. Resilience of an agroecosystem increases when individual elements fulfil multiple functions (i.e. agroecological *principles*, such as nutrient recycling, input reduction, soil health, and biodiversity), and when these functions in turn are supported by multiple elements (e.g. *practices*, such as crop rotation, cover cropping, composting, polycultures, agroforestry, crop-livestock integration, and green manure). Thus, when it comes to redesigned farming systems, merely implementing a set of agroecological practices is not enough. Instead, it starts from the application of agroecological principles (Nicholls, Altieri, and Vazquez 2017). Therefore, when the goal is to enhance transformative agroecology through KCC processes, the focus should not merely be on supporting the application of stand-alone agroecological farming practices but rather on the conscious redesign of entire agroecosystems based on ecological principles to facilitate climate resilient food systems through supporting multiple ecosystem services (Gliessman 2018).

The second line of thought for a future research agenda is that in order to obtain higher-level impacts, i.e. *transformational* impacts on at least agroecosystem level (and preferably beyond), something else is needed that transcends the perceived credibility and salience of the co-created knowledge (and the perceived legitimacy of the process itself, also see Runhaar, van der Windt, and van Tatenhove 2016). There are at least two recent approaches that could be used to expand our KCC-model, as they provide useful insights into what this "something else" could be when the goal is to manifest more and broader system, or: *transformative*, change.

The first approach being the *co-innovation approach*, which is a method for governing and managing *systemic-* (i.e. whole-farm) rather than incremental change projects, that combines three domains (i.e. a complex adaptive systems perspective, a social learning setting, and dynamic monitoring and evaluation,

see e.g. Rossing et al. 2021). This approach has shown to be useful when it comes to the (farmer-scientist negotiated) redesign of agroecosystems based on ecological principles and can, as long as thorough attention is being paid to the preparation phase of such projects, be used as a guide to out- and up-scaling of (research) projects that aim for ecological intensification of food production systems (Rossing et al. 2021).

Broadening the scope beyond what farmers and scientific researchers can do together, the second approach is the *three-gear engine* model as proposed by Tittonell (2023), which conceptualizes the levels and complexity in agroecological transitions. This model consists of three "gears" (from largest to smallest: enabling conditions, the innovation support system and the farming system), and the knowledge, innovation, and policies as "the oil in between the gears." While still being a hypothesis that needs to be tested (Tittonell 2023), this model suggests that small (or: slow) changes in the largest gear, i.e. the enabling conditions such as laws and policies that promote agroecology and the development of alternative markets and economies, may translate into faster changes in the two subsequent gears, i.e. through the innovation support system and particularly at the farming system level. Social (agroecological) movements have an active role to play when it comes to acceleration by pushing for changes in the enabling conditions (1st gear), and transdisciplinary science is indispensable when it comes to supporting both technical and organizational food system innovation (2nd gear). The time thus seems right for academic agroecologists to unite with those movements that push to scale out (i.e. geographical expansion) and scale up (i.e. vertical integration in formal institutions) agroecology: "*the cross-fertilisation of both efforts can create the most effective movement for transformative change*" (Gliessman 2023b, 329).

Notes

1. The levels and their sequence as proposed by Gliessman (2015) are mostly applicable to transitions that start from industrial agriculture (not from smallholder, family agriculture in Africa for example).

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Data availability statement

The authors confirm that the data that support the findings of this study are openly available via https://doi.org/10.6084/m9.figshare.26324185.

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