Review Article

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Innovation-Sustainability Nexus in Agriculture Transition: Case of Agroecology

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Abstract: Different governments and international organizations have shown interest in agroecology as a promising pathway for transition to sustainable agriculture. However, the kinds of innovation needed for agro-ecological transition are subject to intense debate. The scale of this debate is itself an indicator of the complicated relation between innovation and sustainability in the agro-food arena and beyond. This review paper analyses the potential of agro-ecology in agricultural sustainability transitions. It also explores whether agro-ecological transition is a sustainable innovation (cf. ecological, green, open, social, responsible). Furthermore, the paper investigates the potential contribution of agro-ecological transition to sustainability, using the 3-D (Direction, Distribution and Diversity) model of the STEPS centre. Agroecology is one of the few approaches that can harmoniously combine innovation and sustainability in agriculture while promoting genuine transition to agro-food sustainability since it embraces all dimensions of sustainability (environmental, economic, social/cultural/ethical). Nevertheless, it can be taken for granted neither that all traditional practices can be classified as 'agro-ecological' nor that all farmer-led innovations can be included in the agro-ecological repertoire. Moreover, the relationship between the three aspirations of agroecology (science, movement and practice) needs further elaboration in order to maximise potential for agriculture transition.

Keywords: agroecology; agro-ecological transition; sustainability transitions; sustainable innovation; sustainability-oriented innovation.

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1 Introduction

Innovation has been defined in many different ways (Menrad and Feigl 2007; OECD and Eurostat 2005; SCAR-EU 2012; STEPS Centre 2010; Sterrenberg et al. 2013) and may mean different things (Schumpeter 1934; Shaver 2016). According to Stummer et al. (2010), innovations can be categorized according to innovation type (product, service, process, market), dimension (objective or subjective), scope of change (radical, incremental, reapplied), or how innovation was created (closed or open). The OECD and Eurostat (2005) distinguish product, process, marketing and organisational innovations. Innovation as a concept is strongly linked to that of knowledge, which is fundamental in the move towards sustainable practices (Grin et al. 2010) and plays an important role in transition to sustainable food systems (Loconto 2016). However, knowledge (as well as innovation) needed to make the transition into agricultural sustainability is often contested and inconclusive (Atie et al. 2008; Levin et al. 2012; Peters and Pierre 2014).

The modern theory of innovation provides a number of concepts and insights similar to that of transition (Lachman 2013; Twomey and Gaziulusoy 2014; Tyfield 2011). The common term 'transition' is often used interchangeably with the term 'systems innovation'. Loorbach and Rotmans (2010) define transition as "*a fundamental change in structure (e.g. organizations, institutions), culture (e.g. norms, behavior) and practices (e.g. routines, skills)*". Embracing the goal of transition towards sustainable systems, the notion of 'sustainability transition' was coined (Falcone 2014; Geels 2011; Kemp and van Lente 2011; Lachman 2013; Sustainability Transitions Research Network 2010). Markard et al. (2012:956) define sustainability transitions as "*long-term, multi-dimensional and fundamental transformation processes through which established socio-technical systems shift to more sustainable modes of production and consumption*".

Sustainability transitions are needed also in the agro-food arena to move towards sustainable food systems (e.g. HLPE 2014; El Bilali et al. 2018; El Bilali 2018b). IPES-Food (2015) pointed out that a multi-directional flow of

knowledge between the worlds of science, policy and practice is needed to foster a genuine transformation of food systems, which is necessary in making the transition towards sustainability. Transition will most likely not depend on one or even a small number of technological innovations, but is likely to arise from a constellation of mutually interacting systems of innovations (Twomey and Gaziulusoy 2014). This is particularly true in the case of food systems where social innovations also seem important. According to Hinrichs (2014), social and organizational innovations are as central to sustainability transitions in food systems as any particular innovative technology. In fact, transition to sustainable agro-food systems requires complex and holistic changes in which social innovation plays as big a role as technological innovation (IPES-Food 2015).

Innovation has become a key issue in the discussion about the relation between agriculture and sustainability (e.g. EIP-AGRI 2013; FAO 2013 2012; Global Harvest Initiative 2016; IPES-Food 2015). It is widely admitted that the transition to agricultural sustainability requires 'sustainable innovation' (e.g. El Bilali 2018a). Different models of sustainability-oriented innovation have been promoted. The Network for Business Sustainability (2012) identified multiple definitions relating to Sustainability-Oriented Innovation (SOI): eco-innovation, ecological innovation, environmental innovation, frugal innovation, green innovation, inclusive innovation and social innovation. In fact, there is a growing emphasis on 'responsible' (European Commission 2013), 'sustainable' (Charter and Clark 2007; Chonkova 2015), 'social' (Caulier-Grice et al. 2012; European Commission 2017; Mulgan et al. 2007; Nicholls and Murdock 2012; Osburg 2013), 'open' (Chesbrough 2003; Christensen et al. 2005) and 'ecological' (Carrillo-Hermosilla et al. 2010; Charter and Clark 2007; Fussler and James, 1996; Kemp and Foxon 2007; Kemp and Pearson 2008; Reid and Miedzinski 2008) innovation as a way of combining harmoniously innovation and sustainability. Sustainable innovation means paying attention to ecological integrity along with the diversity of social values; encouraging plural innovation pathways; promoting fairer und wider distribution of the benefits of innovation; and fostering inclusive and participatory governance of innovation processes (STEPS Centre 2010).

There are different pathways leading towards transition to sustainable agriculture and food systems. In fact, there are several contending paradigms and narratives about sustainable agriculture and ways to achieve it (e.g. Elzen et al. 2017; Levidow 2011; Van der Ploeg 2009). Nevertheless, agroecology is considered one of the most prominent and promising pathways (e.g. Duru et al. 2014; FAO 2018; Gazzano and Gómez Perazzoli 2017; Huang and McCullough 2013; Isgren and Ness 2017; Meek 2016; Miles et al. 2017; Ollivier et al. 2018; Wezel et al. 2016). In fact, agroecology is gaining ground, both in developed and developing countries, within the debate on how to address the systemic problems faced by agriculture (Gazzano and Gómez Perazzoli 2017; Isgren and Ness 2017). The transformative potential of agroecology is nowadays widely recognised not only by many agroecology scholars and organic agriculture movements [e.g. International Federation of Organic Agriculture Movements (IFOAM) – Organics International] (Hilbeck and Oehen 2015), but also by a number of international organisations [e.g. United Nations Conference on Trade and Development (UNCTAD), World Bank, FAO (FAO 2015; IAASTD 2009; FAO 2018d)], and expert panels such as IPES-Food (IPES-Food 2016).

This review paper aims to cast light on innovation-sustainability nexus in agro-ecological transition. Section 2 analyses the potential of agro-ecological transformation in agriculture sustainability transitions. Section 3 explores whether agro-ecological transition is a sustainable innovation (cf. ecological, open, social, responsible, green); while section 4 investigates the contribution of agro-ecological transition to sustainable development against the 3-D dimensions (Direction, Distribution and Diversity) suggested by the STEPS centre.

2 Agro-ecological transition

Agroecology (Altieri 1980; Dalgaard et al. 2003; Gliessman 1998; Gliessman 2015; Wezel and Soldat 2009), is an approach that dates back to the beginning of the 20th century (e.g. Friederichs 1930; Hanson 1939; Harper 1974). It links together science, practice and movements focused on social change (Wezel et al. 2011) through the integration of participatory, transdisciplinary and change-oriented research and action (Ernesto Méndez et al. 2013; Gliessman 2016). Dalgaard et al. (2003) consider agroecology as the study of interactions between living organisms (plants, animals), humans and the environment within agricultural ecosystems. Meynard (2017) points out that agro-ecology is far from a simple merger between agronomy and ecology; it is an innovative and multidisciplinary (natural, economic and social sciences) project that connects politics and action. Simply put, agroecology is an approach that utilizes ecological principles to design and manage productive, resilient and sustainable farming and food systems (Gliessman 2015; IPES-Food 2016).

Recently, small farms and food sovereignty gained momentum in the overall discourse on agroecology (Altieri 2009). More and more peasants' movements and civil society organisations (e.g. *La Via Campesina*) propose agroecology as an alternative system to resist the growth-oriented innovation system in agriculture with its inevitable consequences for rural areas (Rosset and Martinez-Torres 2013), thus placing focus on the bio-politics of not only nourishing humanity, but also access to resources and distributive justice (Anonymous 2014). According to Tittonell (2015), agroecology describes relations between humans, ecosystems, traditional farming, innovation and technology. The integration of the three practical forms of agroecology (scientific discipline, agricultural practice, social movement) and linkage with other food movements (e.g. food sovereignty) have provided a collective-action to contest the dominant agro-food regime and create agro-food alternatives (Levidow et al. 2014). The agro-ecological philosophy and message have also profoundly influenced and shaped other alternative agro-food movements and communities such as permaculture (e.g. Ferguson and Lovell 2014; Maye 2018), conservation agriculture (e.g. Vankeerberghen and Stassart 2016) and organic agriculture (e.g. Lampkin et al. 2017).

Agro-ecological practices embrace soil fertility management, pest control, biodiversity conservation, agroecosystem integrity etc. Agro-ecological practices pay particular attention to ecosystem services and biological processes such as biological pest control, symbiotic nitrogen fixation, agrobiodiversity and habitat diversity as well as integration of crop and livestock production (Lampkin et al. 2017; Wezel et al. 2014). However, while agro-ecological transition referred mainly to the transformation of crop systems towards more ecological practices and techniques; an increasing number of articles deal with livestock agro-ecological transition (Dumont et al. 2013) in different countries such as France (Beudou et al. 2017; Ryschawy et al. 2017) and Australia (Cross and Ampt 2017). In fact, agro-ecological transition reduces greenhouse gas (GHG) emissions and mitigates the impact of livestock on climate change (Dumont et al. 2013; Martin and Willaume 2016). Similarly, while the agro-ecological approach initially focused on agroecosystems, it now deals more and more with the broader agro-food system.

The agroecology narrative diagnoses the problem with existing agro-food systems as profit-driven agro-industrial monoculture systems that undermine farmers' knowledge and make them dependent on external inputs while increasing the distance between consumers and agri-producers (Levidow 2015a). By promoting the development of 'coupled innovations', agroecology reconnects the dynamics of innovation in agriculture and food, with a view to improving the whole agri-food system (Meynard et al. 2017).

Francis et al. (2003) and Gliessman (2006) expanded agroecology understanding and scope by putting a stronger emphasis on the notion of sustainable food systems with agroecology being "*the science of applying ecological concepts and principles to the design and management of sustainable food systems*" (Gliessman 2006). Agroecology promotes transition towards a sustainable agro-food system that restores ecosystem services, enhances human welfare and promotes community-based economic development (Miles et al. 2017). Therefore, agroecology is presented as a way of transforming and redesigning food systems, from the farm to the fork, with the goal of achieving environmental, economic and social sustainability (Gliessman 2015; Gliessman 2016). In fact, current agro-ecological thinking focuses on critique of the whole agro-food regime rather than just the 'green revolution' (Elzen et al. 2017; Holt-Giménez and Altieri 2013). That's to say that agroecology aims to stimulate the development of alternative thinking about the future of agriculture and strengthen ecological processes in agricultural systems while addressing the problems of concentration, alienation and access to land, along with other issues such as food sovereignty and family agriculture (Gazzano and Gómez Perazzoli 2017). In fact, agroecology has a significant contribution to the persistence of family agriculture (Babin 2015; McCune et al. 2017; Santamaria-Guerra and González 2017). Gliessman (2015) proposed a five-level framework for classifying food system change thanks to agroecology approaches and practices (Box 1). This clearly shows that agro-ecology is also presented as a food system transformation pathway. According to the High Level Panel of Experts on Food Security and Nutrition (HLPE 2017) any process of transformation or transition to sustainability in agriculture and food systems should take into account agroecology in order to contribute to achieving sustainable food security and nutrition.

To counteract the negative effects of intensification and globalisation, many scholars (e.g. Altieri 2009, 2002; Gliessman 2006) proposed to orient agricultural research more towards the needs of peasants and smallholders that are at risk through technocratic farming systems. Agro-ecological innovation is key to the transition towards sustainability in the current agro-food system (Levidow 2015). Thanks to many social and grassroots movements (e.g. *La Via Campesina*), the Latin American agroecology agenda has inspired transformational strategies in other world regions (Table 1), such as in Europe (e.g. Féret

Box 1: Levels of agro-food system changes thanks to agro-ecological approaches.

- Level 1: Increase the efficiency of industrial and conventional practices in order to reduce the use and consumption of costly, scarce, or environmentally damaging inputs.
- Level 2: Substitute alternative practices for industrial/conventional inputs and practices.
- Level 3: Redesign the agroecosystem so that it functions based on a new set of ecological processes.
- Level 4: Re-establish a more direct connection between those who grow food and those who consume it.
- Level 5: On the foundation created by the sustainable farm-scale agroecosystems achieved at Level 3, and the new relationships of sustainability of Level 4, build a new global food system, based on equity, participation, democracy, and justice, that is not only sustainable but also helps restore and protect earth's life support systems upon which we all depend.

Source: Gliessman (2015).

and Moore 2015; IPES-Food 2018). Indeed, according to the EU's Standing Committee on Agricultural Research (SCAR-FEG 2009), agro-ecological principles should be given priority in agriculture research agendas in the European Union. The European organic sector promotes agro-ecological research with the concept of 'eco-functional intensification' linking farmers' knowledge and innovation with scientific research (Niggli et al. 2008). This new understanding of 'agro-ecological innovation' is promoted by a European alliance involving civil society organisations and farmers (ARC2020 and Friends of the Earth Europe 2015).

Agroecology represents a good example of transition toward sustainable farming and food system. It regenerates agroecosystems and advocates sustainable use of natural resources (Cross and Ampt 2017). Agro-ecological practices and innovations are diverse and multifaceted. Pant (2016) analysed agro-ecological innovations in soil and water conservation, crop improvement, crop intensification and market differentiation. It emerges that agro-ecological transition goes beyond 'regreening of agriculture' and represents a clear example of 'strong ecological modernisation' or 'strong ecologisation' of agriculture based on ecosystem services provided by biodiversity (Duru et al. 2014).

Despite its well-documented positive impacts, agro-ecological transition faces context-specific technical, political, social, cultural and economic obstacles (Beudou et al. 2017). Moreover, agro-ecological approaches may have, in the short-term, trade-offs against productivity and potentially negative impacts on profitability (Lampkin et al. 2017) and these may affect widespread uptake. However, one of the main obstacles to niche agro-ecological innovations is opposition from established players in the agricultural regime, such as the agriculture research system (Prasad 2016). Other obstacles to agroecology are linked to all barriers to diversity and diversification in agro-food systems that arise from a range of policies and regulations tailored to the needs of the industrial food system (e.g. food safety rules, seed legislation, intellectual property protection legislation) (IPES-Food 2016). Concepts of participation, 'conscientization' and autonomy, are central in agro-ecological movements and they represent the backbone of the political ecology of the agro-ecological transition (Moore 2017). However, policy advocacy is often hampered by the apolitical history of agroecology movements (Isgren and Ness 2017), historically strong only at the local level; so much so that Gonzalez de Molina (2013) highlights the necessity for a 'political agroecology' to endow agroecology with the necessary political instruments and approaches to upscale it to regional and national levels. Therefore, the agroecology movement should engage more actively in politics in order to foster largescale agro-ecological transition in the food system. Agro-ecological initiatives are also constrained by cultural politics (i.e. conflicting values about appropriate types of agriculture) and associated environmental (e.g. historical land use), cognitive (e.g. conception of space) and relational (e.g. agricultural extension) mechanisms (Meek 2016).

3 Sustainability of agro-ecological transition as a system innovation

Many alternative agro-food movements have a critical attitude towards innovations especially those of a technical/technological nature. Agroecology is one such movement widely cited by scientists with the intention of opening up scientific preoccupation and contesting the technocratic governance of agricultural innovation, oriented towards commercial benefits, agricultural intensification and

Table 1: Examples of events and policies on agroecology and/or agro-ecological transition in different countries and world regions

Item	Country / region	Examples	Source
International and regional symposia on agroecology organized by FAO	Italy	1st International Symposium on Agroecology for Food Security and Nutrition *18–19 September 2014, Rome*	FAO 2015
	Brazil	Regional Seminar on Agroecology in Latin America and the Caribbean *24–16 June 2015, Brasilia*	FAO 2016a
	Senegal	Regional Meeting on Agroecology in Sub-Saharan Africa *5–6 November 2015, Dakar*	FAO 2016b
	Thailand	Multi-stakeholder Consultation on Agroecology for Asia and the Pacific *24–26 November 2015, Bangkok*	FAO 2016c
	China	International Symposium on Agroecology for Sustainable Agriculture and Food Systems in China *29–31 August 2016, Kunming (Yunnan)*	FAO 2017a
	Hungary	Regional Symposium on Agroecology for Sustainable Agriculture and Food Systems in Europe and Central Asia *23–25 November 2016, Budapest*	FAO 2017b
	Italy	Regional Conference for the Near East "*Agroecology: Adapting to Climate Change in Semi-arid Areas for a Sustainable Agricultural Development*" *7–11 May 2018, Rome*	FAO 2018a
	Italy	Second International Symposium on Agroecology "*Scaling Up agroecology to achieve the Sustainable Development Goals (SDGs)*" *3–5 April 2018, Rome*	FAO 2018c
Other recent events on agroecology	Mali	4th Conference of West Africa on Ecological and Organic Agriculture *5–6 December 2017, Bamako*	FAO 2018b
	Portugal	1st Iberian Meeting on Agroecological Research (ibagreco) *22–23 November 2018, Évora*	Agroecology Europe 2018
	Spain	VII International Agroecology Congress *30 May–1 June 2018, Córdoba*	
	Sweden	20th International Conference on Agroecology and Organic Farming (ICAOF 2018) *12–13 July 2018, Stockholm*	
	France	International conference and workshop on agroecology *25–27 October 2017, Lyon*	
	Brazil	Agroecology Conference (Brasilia Agroecologica 2017) *11–14 September 2017, Brasilia*	
Legal frameworks and policies promoting agro-ecological approaches	Brazil	National Policy for Agroecology and Organic Production (PNAPO - 2012)	World Future Council 2018
	Denmark	Organic Action Plan for Denmark: Working together for more organics (2011-2020, updated in 2015)	
	Ecuador	Quito's Participatory Urban Agriculture Programme (AGRUPAR - 2002)	
	India	Sikkim's Sate Policy on Organic Farming (2004) and Sikkim Organic Mission (2010)	
	The Philippines	Kauswagan: From Arms to Farms Programme (2010)	
	Senegal	Ndiob's vision to become a green and resilient municipality (2014) and its Agriculture Development Programme (2017)	
	USA	Los Angeles' Good Food Purchasing Policy (2012)	
	World (UN Environment)	The Economics of Ecosystems and Biodiversity for Agriculture and Food Evaluation Framework (TEEBAgriFood - 2018)	

expansion of global trade (Elzen et al. 2017). Agroecology is not against innovation in general, only to certain types. In fact, the Institute for Agriculture and Trade Policy (2013) points out that agroecology "*is by definition an innovative, creative process of interactions among small-scale producers and their natural environments*". However, agroecology faces the task of challenging the dominant models of innovation in agriculture. Beside technological-scientific innovation, it also embraces know-how, social and organisational innovation forms (IFOAM EU Group et al. 2012). Agroecology promotes social and organisational innovation as an alternative strategy across the whole agro-food chain with the aim of strengthening connection between agro-ecological farmers and consumers to support their innovations. These agro-ecological initiatives are variously known as short food supply chains (SFSCs) or alternative agro-food networks and they are clear examples of social innovation (Galli and Brunori 2013). Such new agro-ecologically-inspired local networks and citizen-community alliances can counterweight the dominant agri-food system (Fernandez et al. 2013).

Innovation has always occurred in agriculture cf. farmers' innovations (e.g. Richards 1985). However, many scholars dealing with the agro-food system do not feel comfortable with the current narrow definition of innovation, meaning technological and commercialised innovation. This innovation model ignores existing farmers' knowledge and undervalues their capacity to innovate (Levidow 2015). It has privileged laboratory-based and scientific knowledge in research agendas at the expense of farmers' agro-ecological knowledge (Vanloqueren and Baret 2009). This process was seen as causing profound social or cultural changes (Godin 2015, 2008) that are not always seen as positive for farming and rural communities.

The term 'agro-ecological innovation' is nowadays widely used in the literature (e.g. Blazy et al. 2011, 2010; Hubert et al. 2017; Prasad 2016; Salliou and Barnaud 2017) and this clearly shows that agro-ecological practices and techniques, mostly based on local and traditional knowledge, are considered innovative in many local contexts. In fact, agroecology represents a new relationship to knowledge and innovation (Meynard 2017). According to Holt-Giménez and Altieri (2013), agroecology is "*knowledge intensive (rather than capital intensive), tends toward small, highly diversified farms, and emphasizes the ability of local communities to generate and scale-up innovations through farmer-to-farmer research and extension approaches*".

Agroecologists use different innovative grazing and cropping strategies. Agro-ecological groups and communities of practice champion locally appropriate technologies and participatory methods in research and extension (Isgren and Ness 2017). Demeulenaere and Goldringer (2017) consider agro-ecological transition, especially practices related to selection and exchange of seeds, as radical and breakthrough innovations. Agro-ecological groups and movements are driven and fashioned by innovators who collaborate via mutual engagement, joint enterprise and shared repertoire (Cross and Ampt 2017). They often exist on the margins of conventional agri-innovation systems (Cross and Ampt 2017; Isgren and Ness 2017; Miles et al. 2017; Prasad 2016) and challenge existing research and extension paradigms regarding innovation (Cross and Ampt 2017; Isgren and Ness 2017).

Agroecology represents a promising alternative pathway for innovation. It can be considered not only ecological but also as 'socially responsible innovation' (cf. Tilman et al. 2002) as it contributes to addressing grand challenges of our time, such as degradation of natural resources; malnutrition/food insecurity; poverty and climate change as well as associated socio-ethical issues (De Schutter 2011; Pereira et al. 2015).

Agroecology also has many similar characteristics to '*open innovation*' (e.g. Chesbrough 2003; Christensen et al. 2005); so much so that agroecology calls for a more open approach towards knowledge management and sharing to ensure a wider access to knowledge and innovation or what McCune et al. (2017) refer to as the 'counterhegemonic process of internalization and socialization of agroecological knowledges'. This is particularly the case with participatory breeding that is promoted by agroecology (e.g. Malandrin and Dvortsin 2013). In fact, the management of collective rights and intellectual property rights (IPR) is particularly problematic and challenging in the agricultural sector (HLPE 2017). In this regard, biotechnologies raise many ethical concerns (EGE 2008) as they could pave the way for market predominance by a few companies, which might impact innovation and the local economies in developing countries. Therefore, agroecology stresses innovation and knowledge as public goods (cf. Stiglitz 2007) and agro-ecological movements struggle against the 'patenting' of biological resources and privatisation of germplasm e.g. hybrid corn (Lewontin and Berlan 1990). In this context can be also seen the defence of seed sovereignty and resistance against – both direct (e.g. application of IPR to living materials) as well as indirect (e.g. establishing seed certification requirements and quality standards) – outlawing of informal systems of seed exchanges (e.g. Wattnem 2016). However, open source networks and platforms not only deal nowadays

with the exchange of seeds and living materials but also machines/technological innovations. One example of such a platform is the Open Source Ecology; a network of farmers, engineers, architects and supporters, whose main goal is the eventual manufacturing of 50 of the most important machines (e.g. tractors) necessary for modern agriculture (Open Source Ecology 2018).

Agro-ecological innovations are by nature *ecological* and *green*. In fact, the adoption of agro-ecological practices, techniques and processes helps to decrease environmental impact and reduce pollution and other negative impacts of resource use. Agro-ecological practices are also 'green' as they are based on natural resource use coupled with little or none environmental impact. In fact, agro-ecological innovations represent a good example of 'strong ecological modernisation' in agriculture (Duru et al. 2014). Evidence shows that agro-ecological approach is associated with positive environmental impacts such as increased biodiversity and agrobiodiversity (e.g. Blesh and Wolf 2014; Lampkin et al. 2017; Lanka et al. 2017; Salliou and Barnaud 2017), improved resource use and reduced emissions (e.g. Lampkin et al. 2017). According to Lampkin et al. (2017) agroecology brings about an increased focus on 'ecological innovation' alongside the more traditional emphasis on technological innovation in the agro-food sector.

It is widely admitted nowadays that to meet sustainability challenges, more attention should be paid to social innovations, grassroots innovators and processes (Leach et al. 2012; Loconto et al. 2017; Moulaert 2013; Smith and Seyfang 2013). Social innovations are considered good not only for the economy but also for the society (Caulier-Grice et al. 2012) as they engage with social problems in a way that is more efficient, fair, and as effective or sustainable as existing solutions (Phills et al. 2008). Nevertheless, social innovations are not value-neutral but rather are socially and politically constructed, and context-dependent (Caulier-Grice et al. 2012). Agro-ecological innovations have many features of *social innovation*. In fact, they meet the social needs of farmers (including smallholders in developing countries); lead to new or improved relationships; or develop new collaborations between multiple stakeholders (e.g. agroecology movements, groups and communities of practice). Furthermore, all the eight common features of social innovation identified by Caulier-Grice et al. (2012) apply to agroecology i.e. cross-sectoral, open and collaborative, grassroots and bottom-up, *pro-sumption* (cf. production-consumption) and co-production, mutualism, creating new roles and relationships, better use of assets and resources, and developing assets and capabilities.

Agro-ecological innovation can be considered as a 'transformative social innovation' (Prasad 2016) that emphasizes the roles of social movements and the reengagement of vulnerable communities in societal transformation. In fact, agroecology has always had an important social component. For instance, small-scale and family-based agro-ecological agriculture is based on the social activism of self-mobilised organizations and people aiming to stop neoliberal politics undermining the sustainability of rural ways of life (Santamaria-Guerra and González 2017). Moreover, agro-ecological practices contribute to social well-being and are accessible to farmers in emerging and developing countries.

In general, agro-ecological movements and groups are grassroots and bottom up and they have the essential characteristics of communities of practice (COPs). They promote a wide range of farmer-driven innovations or peasant innovations and favour transfer of local and traditional knowledge among farmers (Cross and Ampt 2017; das Chagas Oliveira et al. 2012). These peasant networks (e.g. *campesino a campesino*) allow farmers to be empowered as agricultural innovators (Holt-Giménez 2010). One merit of agroecology is that of valuing local knowledge of farmers while mixing it with scientific knowledge (Meynard 2017) thus opening up the innovation arena to the contribution and input of farmers and local communities. For instance, Isgren and Ness (2017) show that in western Uganda, agroecology movement takes the form of a civil society network that links farmer groups and non-governmental organizations.

Agroecology is also an integral component of 'social farming', which represents a social innovation in many rural areas (González et al. 2014). Agroecology, as a social innovation, helps creating a new dynamism in rural areas (among others, through creation of multi-stakeholder networks) and contributes to sustainable rural development (e.g. Snapp and Pound 2011). Agroecology-inspired social networks also increase cooperation between rural and urban social actors (Rover et al. 2017).

According to Levain et al. (2015), operationalising ecological intensification in the context of socio-technical transition towards agroecology represents a 'system innovation'. Agroecology is an approach that integrates environmental, social and economic sustainability and aims to promote a sustainable design and management of agroecosystems. In fact, agro-ecological practices and processes produce environmental and social benefits along with economic value. Evidence shows that agro-ecological innovations make possible sustainable land use, assure an increase in income, and maintain family employment (das Chagas Oliveira et al. 2012). Moreover,

agroecology plays an important role in supporting the livelihoods of smallholder farmers (Lanka et al. 2017). Therefore, agroecology seems appropriate to ensure a sustainable management of resources involved in agricultural production, while promoting food security/sovereignty and protecting the rural landscape (Bocchi et al. 2012).

Having said that, it can be taken for granted neither the sustainability of all peasant innovations nor that all traditional practices can be classified as 'agro-ecological'. Maybe for this reason the IPES-Food (2016) calls for a 'paradigm shift' not only from industrial agriculture but also from subsistence farming to diversified agro-ecological systems. However, Pant et al. (2014) note that current agro-ecological approaches have provided a limited understanding of transformations to sustainability in subsistence agrarian economies. Moreover, as Ely et al. (2016) show, the so-called 'indigenous innovation pathway' (that may imply also the use of transgenic crops) is not synonymous of agro-ecological pathway. There is also the risk of convergence of agro-ecological niches with the dominant discourse around commercialization in agriculture (Isgren and Ness 2017), thus inducing a conventionalisation of the agro-ecological approach or simply its incorporation into the 'corporate-environmental food regime' (Levidow 2015). Therefore, a fundamental question remains whether agroecology will conform to the dominant agro-food regime or help to transform it (Levidow et al. 2014). This concern was also expressed by Giraldo and Rosset (2018) as follows "*there is an enormous risk that agroecology will be co-opted, institutionalized, colonized and stripped of its political content*". Likewise, Pant (2016) used the term 'paradox of mainstreaming agroecology' to refer to an apparent contradiction between upscaling agro-ecological niche innovations and the concerns for loosing core principles and values of agroecology in the mainstreaming process. As a result, it is fundamental to scrutinise the sustainability of agro-ecological transition.

4 Agro-ecological transition: direction, distribution and diversity questions

The contribution of agro-ecological transition to sustainable development is assessed against the 3-D's (Direction, Distribution and Diversity) of the STEPS Centre (Box 2).

The *direction* of change advocated and promoted by agroecology is clearly towards a 'strong ecologisation' of agriculture (Duru et al. 2014). That's to say a model of agriculture that is based on ecosystem services provided by biodiversity (e.g. Peeters et al. 2013). According to IPES-Food (2016) a fundamental shift in the direction of agroecology is likely to be the only way to set agriculture and food systems on sustainable footing.

The increasing recognition that hunger is fundamentally a distributional question tied, among others, to poverty and social exclusion (e.g. Sen 1981) led to a growing understanding that increases in food production have to occur predominantly within developing countries if they are to have an impact on food security (e.g. Pretty et al. 2011). This is central to the discourse in agroecology and underpins collaboration with food sovereignty and the right to food initiatives. Therefore, the issue of *distribution* (cf. distributive justice) is a central tenet in the agroecology movement (Anonymous 2014) as it aims to address social inequity and injustice. Agroecology is orientated towards food sovereignty, equitable resources distribution, and rights-based approaches (Giménez and Shattuck 2011). However, the question "*[...] could food systems based around diversified agroecological farming*

Box 2: Questions regarding innovation for sustainable development.
In a Manifesto on innovation, sustainability and development, the STEPS Centre (2010) called for a radical shift in how we think about and perform innovation to move towards innovation for sustainability and sustainable development. This means nothing less than a radical change in the whole innovation process (agenda setting, monitoring, evaluation, funding). For that, three arrays of questions related to direction, distribution and diversity, should be addressed, the 3 D's:

- Technical, social and political Directions for change: What is innovation for? Which kinds of innovation, along which pathways? And towards what goals?
- Distribution: Who is innovation for? Whose innovation counts? Who gains and who loses?
- Diversity: What – and how many – kinds of innovation do we need to address any particular challenge?

succeed where current systems are failing, namely in reconciling concerns such as food security, environmental protection, nutritional adequacy and social equity" (IPES-Food 2016:6) is complex and does not admit simple answers. Moreover, Gómez et al. (2013) point out that even agroecology research and publications follow a 'colonial pattern' where industrialized countries lead publishing and conduct studies both in industrialized and non-industrialized countries. Another question linked with equity is that of legitimacy. Also in this regard, agroecology has a hard and long way to go in order to confirm and convince about its legitimacy as an alternative and more sustainable agro-food system (e.g. Montenegro de Wit and Iles 2016).

Experiences regarding agricultural transitions in many countries (e.g. the Netherlands) show the importance of nurturing and dealing with *diversity* as a part of successful transition governance (Grin 2012). Also research on agro-ecological transition emphasises not only the diversity of innovations to promote but also the diversity of local actors to coordinate, therefore the need to implement a holistic and transdisciplinary approach to agro-ecological transition (Duru et al. 2014). It seems that agroecology can accommodate the diversity of farms (e.g. Blesh and Wolf 2014) and agro-ecological practices can be adapted and adopted by farmers in different biophysical and socio-cultural contexts, both in developed and developing countries. In fact, there are different connotations of agroecology even within the same country e.g. USA (Huang and McCullough 2013). Moreover, agroecology tries to address the root causes of standardization and specialization - that have decreased the diversity of scale, form and organization across the agro-food system (Hendrickson 2015) - and strengthens linkages between biological and cultural diversity in landscapes (Plieninger et al. 2018).

Sustainable intensification shows the variety of agendas and visions regarding sustainable agriculture. In general, sustainable intensification agendas promote a 'toolkit' of various options and techniques for reconciling higher productivity with environmental sustainability (Constance et al. 2016). Meanwhile, counter-hegemonic global food movements embrace agroecology. They promote a concept of 'eco-functional intensification' (Niggli et al. 2008). However, there are also some attempts to reconcile these two opposed agendas. For instance, Buckwell et al. (2014) consider agroecology one of the pathways to achieve sustainable intensification in Europe together with biodynamic, organic, integrated, precision and conservation agriculture. Likewise, the European Innovation Partnership for Agricultural Productivity and Sustainability (EIP-AGRI) encompasses different approaches such as sustainable intensification, organic farming and low-external input systems (EIP-AGRI 2013).

Agroecology is considered an agricultural intensification pathway also in Sub-Saharan Africa. In fact, agroecology is considered as a pathway to achieve 'ecological intensification' (e.g. Bonny 2011; Doré et al. 2011; Levain et al. 2015; Tittonell 2014) in agriculture. However, according to Levain et al. (2015), the concept of 'ecological intensification' relies upon 'semantic ambivalences and epistemic tensions'. The diversity of soil, climatic, economic, social and political conditions results in a large spectrum of pathways to sustainable intensification. The PROIntensAfrica project (a Horizon 2020 coordination and support action) identified four different pathways to sustainable intensification of the agri-food system in Africa: conventional agriculture pathway; eco-technical pathway; agroecology pathway; and organic agriculture pathway. According to PROIntensAfrica (2017) "*The agroecology pathway is based on convergence of agronomy and ecology. Maximization of productivity or production are not the main goals of this pathway, rather the optimization of outputs while the farm systems are retained in a healthy state. Intensification in this sense is subordinated to social and economic development and autonomy of the production systems and of the farm*".

Agro-ecological methods, but not necessarily agro-ecological principles, were also adopted by some conventional agriculture actors, such as agrochemical companies and some governments. These have incorporated agro-ecological methods into 'sustainable intensification' agendas. For instance, in Europe, the nascent 'sustainable intensification' (neoproductivism) agenda selectively incorporates agro-ecological practices within a broader toolkit including biotech (Levidow 2015a). Such a move and process was criticized by many farmers' organisations, NGOs and social movements (ARC2020 and Friends of the Earth Europe 2015; Levidow 2015a; Levidow et al. 2014).

The example of agroecology also shows the interrelations between direction, distribution and diversity dimensions. Adoption of agro-ecological transition as a direction of change in agriculture sector also implies changes in the distribution of benefits, risks and costs. Appraisal of the direction of context-specific innovation in agroecology takes into account also equal distribution of benefits, one of the objectives of the agroecology movement being to address social inequity and injustice issues by changing power structures and improving the whole governance of the agro-food system. Furthermore, the agroecology movement takes a serious

view of direction and distribution questions and for that it deliberately pursues diverse innovation pathways to accommodate different needs and aspirations, including those of marginalised and poor groups such as small-scale farmers in the Global South. This, in turn, implies that the agro-ecological approach pays attention not only to technical/practice-related innovations but also to social and organisational ones.

Nevertheless, there are also some tensions between agroecology and innovation, such as those found by Foran et al. (2014), but also synergistic interactions between agroecology and agricultural innovation systems. Although the agroecology movement succeeded to a large extent in finding a synthesis/symbiosis among and combining the dimensions of direction, distribution and diversity of innovation, some tension remains with respect to these issues. Agroecology is considered at the same time as a science, a movement and a practice (Wezel et al. 2011, 2009) but there might be some tension about these three aspirations of agroecology. In fact, agroecology as a science is promoting innovations in agroecosystem management but the agro-ecological movement is mainly promoting traditional agricultural practices, considered by some as farmer-led innovations. Tension persists not only among the three aspirations and dimensions of agroecology but also within the same dimension (e.g. science/research). According to Levidow et al. (2014), the tension between 'conform versus transform' roles (conforming to the dominant agro-food regime or transforming it) is evident in three areas of the European agro-ecological research: participatory plant breeding, farm-level agroecosystems development, and short food-supply. This is also about the source of agro-ecological innovation to be prioritized as agroecology tries to avoid establishing any hierarchy or value system between innovation by farmers and innovation from scientific research and it even promotes a stronger collaboration between scientists and farmers (cf. participatory research and extension). Nevertheless, this tension in agro-ecological research is emblematic of the difficulty of maintaining harmony between agro-ecology as a science, on the one hand, and agroecology as a social movement and practice, on the other hand. Similarly, such a tension exists also between agroecology as a social movement and 'institutionality' (Giraldo and Rosset 2018). While 'institutionalisation' can be considered as an indicator of agroecology success and its scaling up, it might also strip the agro-ecological movement of its freedom of manoeuvring and action as well as of its label as an 'alternative' movement.

5 Conclusions

Agroecology is a promising pathway of transition to sustainable agriculture. In fact, agro-ecological transformation holds the potential of contributing to genuine agriculture sustainability transition. Moreover, agro-ecological transition can be considered as a sustainable innovation because it is ecological (agro-ecological practices are harmonious with ecosystems), green (based on natural resource use and with positive or neutral environmental impact), open (agro-ecological practices can be used by anybody, they are not patented and they are accessible by farmers in developing countries), social (it contributes to social well-being in rural areas and agro-ecological movements are bottom up/grassroots, inclusive). Therefore, agroecology embraces all dimensions of sustainability (environmental, economic, social/cultural/ethical) and pays attention to ecological integrity of agro-ecosystems along social values diversity, encouraging plural transformation pathways, promoting fairer und wider distribution of benefits, fostering inclusive and participatory processes. Nevertheless, it can be taken for granted neither the sustainability of all peasant and farmer-driven innovations nor that all traditional and indigenous practices can be classified as 'agro-ecological'.

Furthermore, the contribution of agro-ecological transition to sustainable development is obvious. In fact, the direction of change promoted by agroecology is clearly towards more ecology and, consequently, more sustainability in agriculture and food systems. However, one should be aware that agro-ecology might not be considered the only pathway of transition towards sustainability and the diversity of options should be defended. In other words, agroecology should not be transformed into a new 'regime'. Moreover, while benefits of agroecology are widely and, to a large extent, equally distributed to small-scale farmers in the Global South, that does not mean that there are no losers in the agro-ecological transition, as in any change process.

Last but not least, the relationship among the three aspirations of agroecology (science, movement and practice) needs further elaboration in order to keep the transformative potential of agroecology, but also its 'image' as a 'sustainable innovation' i.e. one of the few approaches that harmoniously combines innovation and sustainability in agriculture and food system and promotes agro-food sustainability transitions.

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