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An innovation perspective to climate change adaptation in coffee systems

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\textbf{A B S T R A C T}

Climate change is expected to have strong implications for smallholder coffee farmers and implementing adaptation measures would lessen their vulnerabilities. Adaptation measures have been identified in literature, but how these can be implemented remains unclear. Current certification programmes have the potential to provide guidance on how sustainability criteria can be addressed and taken up by farmers. We identify climate change adaptation options, their scale of application, and the necessary implementation steps. We show that implementation complexity strongly increases with the degree of climate change. With modest climatic changes, incremental adaptations might suffice, but more substantial climatic change will require radical social-institutional changes for adaptation uptake and interventions. For the majority of smallholders the implementation of any measure is largely constrained by a lack of access to knowledge networks and training material, organisational changes for adaptation uptake and interventions. For the majority of smallholders the implementation of incremental adaptations might suffice, but more substantial climatic change will require radical social-institutional changes for adaptation uptake and interventions. For the majority of smallholders the implementation of any measure is largely constrained by a lack of access to knowledge networks and training material, organisational changes for adaptation uptake and interventions. For the majority of smallholders the implementation of any measure is largely constrained by a lack of access to knowledge networks and training material, organisational changes for adaptation uptake and interventions.

1. Introduction

Coffee production is an important livelihood for millions of smallholders across the tropics (Läderach et al., 2017). Climate change is expected to increase the temperature in coffee growing areas, change precipitation patterns and enhance climate variability with severe impacts expected on coffee yield and quality if no adaptation takes place (Läderach et al., 2017; Ovalle-Rivera et al., 2015). Climatic suitability for Arabica coffee (\textit{Coffea arabica}) is projected to decrease strongly in Meso-America and East Africa. The decrease in Arabica is likely to be offset by increases in areas suitable for Robusta coffee (\textit{Coffea canephora}), particularly in Meso- and South America, Indonesia, and West and East Africa (Magrach and Ghazoul, 2015; Ovalle-Rivera et al., 2015). Besides the direct effects of increasing temperature and altered rainfall patterns on coffee plant growth, climate change may also increase the risks of pest and disease incidence (Avelino et al., 2015; Jaramillo et al., 2011; Magrach and Ghazoul, 2015), although empirical evidence is still scarce (Ghini et al., 2011).

Various adaptation options and measures have been identified in literature, but it is not always clear to what extent these can minimize the impacts of climate change (Harvey et al., 2014; Läderach et al., 2017; Rahn et al., 2014). Some adaptation options may only require incremental modifications in current farming practices, others may need radical changes in production system structures (Rickards and Howden, 2012). The existing coffee systems are part of larger, so-called, sociotechnical (agricultural) systems, defined as relatively stable configurations of institutions, rules, practices and knowledge networks (Smith et al., 2005). Techniques and practices are highly intertwined within value chains, organisational structures, regulations and policy (Markard et al., 2012), and continuously evolve to produce commodities more efficiently (Smith et al., 2005). Climate change will similarly put pressure on the coffee value chain and may lead to larger fluctuations in coffee supply and therefore higher volatility of coffee prices received by smallholders. Measures therefore need to be developed and implemented to make smallholder systems more resilient to climate change (Lipper et al., 2014).

Beyond developing adaptation measures, a better understanding is needed on how their implementation is organised (Tittonelli et al.,...
Frequently mentioned adaptation measures to climate change for coffee systems. Table 1

| Frequently mentioned adaptation measures | Scale of operation | References |
|-----------------------------------------|--------------------|------------|
| Tree windbreaks                         | Farm               | Lin (2011), Rahn et al. (2014), Läderach et al. (2017) |
| Shade systems                           | Farm               | Campanha et al. (2005), Lin (2009, 2011), Siles et al. (2010), Souza et al. (2012), Nesper et al. (2019), Rahn et al. (2018b) |
| Integrated pest management              | Farm               | Bedino et al. (2008), Jaramillo et al. (2009), Lin (2011), Boreux et al. (2013), Mariño et al. (2016), Nesper et al. (2017) |
| New crop varieties                      | Farm               | van der Vossen et al. (2015) |
| Diversifying income                     | Farm               | Mijatović et al. (2013), Vaast et al. (2015), Jezeer et al. (2017) |
| Water and soil conservation             | Farm               | Lin (2010), Nesper et al. (2017) |
| Landscape forest cover (soil water conservation and temperature buffering) | Landscape | Seneviratne et al. (2010), Minang et al. (2014) |
| Landscape forest cover (pollination and pest control) | Landscape | Kellerman et al. (2008), Avelino et al. (2012), Boreux et al. (2013), Pavageau et al. (2018) |
though this encourages the replacement of native shade trees by shade trees can account for as much farm income as coffee does, all-forests, pepper vines growing up the stems of exotic wood, fruit or spice trees (Vaast et al., 2015). In Indian coffee agro-(Vaast et al., 2015). Additional sources of income may also include fuel provided by shade trees (Jezeer et al., 2017) and crop diversification 2.4. Diversifying systems

of varieties and breeding efforts might adapt coffee to climate change. Despite the potential, it is still unclear to what extent adequate selection will require breeding efforts to produce new climate resilient varieties.

2.3. New crop varieties

It is likely that many coffee farming systems are currently not using the best adapted varieties for their specific context (i.e., climate, soil, shade level conditions) and there seems to be ample opportunity for using existing varieties to adapt to a changing climate. Improved crop varieties can better withstand higher temperatures, are more resistant to pests and diseases and can be better adapted to increased shade in agroforestry systems (van der Vossen et al., 2015). Recent efforts are targeting coffee breeding specifically to adapt varieties to agroforestry systems (CIRAD, 2017). Arabica grafted on Robusta root stocks can provide improved drought tolerance (van der Vossen et al., 2015). Knowledge on which variety is best suited for a specific context is still limited and international multilocational variety trials conducted by World Coffee Research and partners are currently underway to provide more insights. To benefit from improved varieties, good agricultural management practices regarding nutrients and pruning need to be met, which requires more than simple access to seeds. Furthermore, despite the existing variability in genotypes, drastic impacts of climate change will require breeding efforts to produce new climate resilient varieties. Despite the potential, it is still unclear to what extent adequate selection of varieties and breeding efforts might adapt coffee to climate change.

2.4. Diversifying systems

Additional sources of income beyond the principle crop can be provided by shade trees (Jezeer et al., 2017) and crop diversification (Mijatović et al., 2013). In Costa Rican coffee agroforests, timber revenues contribute up to 15% and 34% of additional household income (Vaast et al., 2015). Additional sources of income may also include fuel wood, fruit or spice trees (Vaast et al., 2015). In Indian coffee agroforests, pepper vines growing up the stems of exotic Grevillea robusta shade trees can account for as much farm income as coffee does, although this encourages the replacement of native shade trees by Grevillea-dominated systems (Garcia et al., 2010). Additional sources of income from more diverse systems contribute to resilience to climate change (including fluctuating coffee production and market prices) and can therefore be an effective adaptation strategy.

2.5. Soil and water conservation at plantation level

A diversity of native shade cover trees can also favour the maintenance of soil quality. Such trees provide a richer leaf litter and year-round soil surface protection from heavy rainfall (Nesper et al., 2017). Appropriate selection of shade tree species is crucial. In India, shading with exotic trees, such as Grevillea robusta, is less effective at maintaining soil quality on account of seasonal leaf shedding and reduced litter decomposition rates (Nesper et al., 2017).

2.6. Forest conservation at landscape scales

Forest areas close to coffee plantations can improve the local climate and potentially lessen climate extremes by conserving soil moisture and through albedo effects (Seneviratne et al., 2010), and contribute to pest control, pollination, water and soil erosion regulation, wind protection, and carbon sequestration (Minang et al., 2014). High species diversity supported by forest cover across the landscape can maintain these services and enhance community resilience to climate change (Chaplin-Kramer et al., 2011; but see Karp et al., 2018). Deforestation and forest degradation could therefore substantially exacerbate climatic vulnerabilities.

Relations between ecosystem processes and ecosystem services are, however, complex and may have counter effects (Boreux et al., 2013). In Southern India, native forest patches in the landscape matrix provided some pollination benefit, but this varied with landscape pattern across scales, and among pollinating bee species (Pavageau et al., 2018). Some co-flowering native shade trees might even have a negative effect on coffee pollination as they compete with coffee when pollinators are locally limited (Boreux et al., 2013).

Forest cover can provide pest control by predators, such as birds (Kellerman et al., 2008), and the spatial configuration of forest relative to coffee plantations is crucial (Avelino et al., 2012). Pest control services by birds appear most effective in forest landscapes with scattered coffee plots (Avelino et al., 2012). Limited wind flow in forested areas can inhibit dispersal of coffee leaf rust, while in large blocks of open non-shaded plantations pathogen epidemics can increase substantially (Avelino et al., 2012).

3. Adaptation measures in certification systems

Numerous voluntary certification standards exist, currently certifying about 53% of total coffee production (Panhuysen and Pierrot, 2018), and ranging from business-to-business programs to business-to-consumer programs. But only a few rely on external audits (Lambin et al., 2017). Business-led programs such as Nespresso AAA, Starbucks or 4C (Global Coffee Platform) have developed guidelines but are not certified by external organizations. Hence, their effectiveness is difficult to assess (e.g., Lambin et al., 2017). The standards of Rainforest Alliance, UTZ, Fair Trade and Organic are accredited by external organizations (Soto and Le Coq, 2011), and are currently covering 24.8% of total coffee production (Panhuysen and Pierrot, 2018).

The four standards mention comparable criteria to farm management in terms of broad potential adaptation measures (Table 2), such as integrated pest management (Soto and Le Coq, 2011), creation of buffer zones (trees), and water and soil conservation practices. Yet few tangible climate adaptation measures are specified. In relation to shade trees, criteria differ among the standards while criteria may also change

2 In January 2018, Rainforest Alliance and UTZ merged but a new joint standard has yet not been developed. We have therefore analysed their codes of conduct separately.

3 Fair Trade and Organic mainly focusses on respectively the social or environmental aspects of sustainability. Therefore, some farmer co-operations use and comply to both standards for their commodities.
Table 2
Criteria to farm management which are related to climate change adaptation derived from the codes of conduct of the Rainforest Alliance, Fair Trade, UTZ and Organic standards. See supplementary material for information sources. SAN = Sustainable Agriculture Network, FLO-CERT = Fair Trade Labelling Organisations - Certificate, IFOAM = International Federation of Organic Agriculture Movements, OCIA = Organic Crop Improvement Association International.

| Aspect                          | Rainforest Alliance | Fair Trade | UTZ          | Organic                      |
|---------------------------------|---------------------|------------|--------------|------------------------------|
| Organisation level              | Individual/Cooperation | Cooperation | Individual/Cooperation | Individual                    |
| Accreditation                   | SAN                 | FLO-CERT   | UTZ (SAN since 2018) | IFOAM, OCIA                  |
| Climate change references in codes of conduct | Assess risks associated with climate change | Reducing emissions by energy consumption, increasing carbon sinks | Diversification of production and/or other sources of income. Reduce energy consumption | Energy consumption from renewable sources |
| Tangible climate change actions in guidance documents | Prevent land degradation by planting native species. Increase of farm carbon stocks | Carbon accounting (CDM or Gold Standard) | Apply risk assessment. Use of more pest resistant species. Include more shade providing trees | No specific guidance documents |
| Deforestation                   | No conversion of high conservation value ecosystems, from November 1, 2005 onwards | No deforestation or degradation of primary forest occurred since 2008 | No deforestation of primary forest | No clearing of high conservation value areas in the preceding 5 years before compliance with this standard |
| Restoration activities           | Yes                 | Yes        | Yes          | Yes                          |
| Establishment of buffer zones   | Yes                 | Yes        | Yes          | Yes                          |
| Agroforestry systems            | Yes                 | No criteria | Yes          | Yes                          |
| Number of shade trees           | A minimum of 12 trees per hectare | No criteria | An “adequate number” per hectare, depending on local conditions | A minimum of 10 species per production area |
| Canopy density, shade level and strata | At least 15% total native vegetation coverage across the farm or groups of farms, minimum regional canopy cover of 40% | No criteria | No criteria | Minimum canopy cover of 40% |
| Type of shade trees             | Native tree species | No criteria | Non-invasive, nitrogen fixing trees | Non-native species no more than 20% of shade trees. Inga spp., no more than 50% of the trees. Only organic fertilizers |
| Fertilizer use                  | Organic and non-organic fertilizers, with organic priority | Providing training on fertilizer use | Organic and non-organic fertilizers, with organic priority | Pesticides are prohibited |
| Chemicals use                   | May be used if legally registered | May be used if legally registered | May be used if legally registered | Integral part of the organic system |
| Integrated Pest Management      | Must be applied     | Can be applied with additional training and monitoring | Must be applied |                                    |
| Water use and conservation      | Water conservation program, maintaining natural vegetative cover | Water conservation program and training | Water conservation program | Water conservation program |
| Prevention soil erosion         | Soil erosion program and maintain vegetative ground cover | Identify land at risk of soil erosion and provide training | Soil erosion program and soil conservation techniques | Program to prevent erosion and minimize loss of topsoil |
| Energy and climate change       | Diminish emissions of greenhouse gases and increase sequestration | Monitoring energy consumption, increase energy efficiency and use of renewable sources | Risk assessment of climate change impacts. Increase energy efficiency | Energy consumption from renewable sources and energy efficiency |
Planting tree windbreaks, and introducing new crop varieties may reduce the degree of climate change impacts (Fig. 1; Rickards and Howden, 2012). Howden, 2012). Production systems and the institutions supporting them (Rickards and Howden, 2012) require more radical socioecological changes in ambiguous (Kates et al., 2012), incremental options can be seen as differences between incremental and transformative adaptations can be - to fundamental transformative options (Kates et al., 2012). Although smallholder farmers (traditionally) may apply shade management, the general trend has been the conversion of shade systems to sun systems, also by smallholders. In a number of coffee producing countries, the areas under (traditional) shade systems have decreased from 33.4% of total coffee area in 1996 to 24% in 2012 (Jha et al., 2014). This reduction is most pronounced in Latin America (up to 68% reduction in agroforestry area), while in upcoming coffee producing countries, such as Vietnam, mostly sun plantations have been established (Jha et al., 2014).

Most radical transformations are expected at the highest degree of climate change impacts, and may include switching to other crops, increasing off-farm labour, or abandoning agriculture (Läderach et al., 2017). Other ways to cope with climate change is to make better use of landscape processes, such as improved watershed management or landscape level pollination or pest management (see Section 2.6). Such management requires various landscape interventions, for which farmers will become increasingly dependent on the actions and decisions made by other (landscape) actors.

As Kates et al. (2012) and Rickards and Howden (2012) pointed out, the difficulties to implement options, and transformative adaptations in particular, depend on the uncertainties of climate change and the associated risks and benefits, the perceived costs of actions and the suite of institutional and behavioral barriers. Kates et al. (2012) and Rickards and Howden (2012) however, do not discuss the barriers that may also be related to the sociotechnical transitions that are needed to change ‘business as usual’ to new sustainable practices including climate change adaptation.

Innovation theories increasingly emphasize innovation as a key process in such sustainable societal challenges (Hekkert and Negro, 2009) and a suite of frameworks have emerged to analyze this process. The Technical Innovation System (TIS) framework (Hekkert and Negro, 2009), which has also been reframe as Agricultural Innovation Systems in the case of agriculture (Klerkx et al., 2010), addresses uptake of innovations, such as adaptation measures. This uptake requires sound entrepreneurship, knowledge networks and diffusion, and the creation of common rules and design. The TIS framework identifies seven functions in innovation that can be applied to implementation of potential adaptation measures (Table 4).

In certification systems the functions described in Table 4 are largely met. For example, certification gives competitive advantage through niche market promotion and access (Market Formation), mobilizes financial resources such as green premiums or higher prices for better quality products, invests in training by providing material (Knowledge Development and Diffusion), and creates legitimacy to address social and environmental sustainability issues. Certification

4. Implementation complexity

The identified adaptation measures (Section 2) range between incremental – defined as extensions of actions that can be readily applied - to fundamental transformative options (Kates et al., 2012). Although differences between incremental and transformative adaptations can be ambiguous (Kates et al., 2012), incremental options can be seen as measures that can be implemented in incumbent systems, while transformative options require more radical socioecological changes in production systems and the institutions supporting them (Rickards and Howden, 2012).

The need for either incremental or radical changes depends on the degree of climate change impacts (Fig. 1; Rickards and Howden, 2012). Incremental options, such as water and soil management improvement, planting tree windbreaks, and introducing new crop varieties may suffice to respond to modest climate change, and can be implemented in high productive sun systems (Table 3). With increasing climate change impacts, more substantial system adaptations are required (Table 3). System adaptations include adding a shade tree layer to coffee monoculture (sun systems), product diversification and integrated pest management (Läderach et al., 2017). Although smallholder farmers (traditionally) may apply shade management, the general trend has been the conversion of shade systems to sun systems, also by smallholders.

**Fig. 1.** Three levels of climate adaptation in coffee cultivation in relation to the degree of impacts of climate change. Adapted from Rickards and Howden (2012).
falls short, however, on landscape transformational adaptations. Although some landscape aspects are addressed in certification, such as the deforestation commitments, landscape integration is beyond the capabilities and remits of current certification schemes.

Moreover, it is also clear that the large majority of independent smallholders will have difficulties in implementing a suite of adaptation options, largely due to a lack of resources and capabilities, limited access to technical and market knowledge, and insufficient institutional support (Borsky and Spata, 2018). This raises the questions on how independent smallholders can be supported to adapt to climate change, and how certification systems might enable transformative adaptations in smallholder systems at landscape scales.

5. Scaling up adaptation measures beyond certification

Apart from strengthening smallholder capabilities, implementing system and transformative adaptation measures requires long-term visions, the involvement of other landscape and value chain actors, adaptation of public policies, and the creation of new incentives and markets.

5.1. Development of long-term visions

Implementing adaptation options requires large and long-term investments of smallholders, value chain actors and governments for both on-farm measures and interventions at landscape scale. The returns might not be immediately apparent or tangible. Uncertainties about the value of such long-term investments, particularly in view of unclear policy goals of governments and potentially changing value chains, will make actors reluctant to implementing adaptation measures. Hence, a certain degree of legitimacy of adaptation implementations needs to be created in the context of climate change (e.g., Hekkert and Negro, 2009). Large research programs, such as the CGIAR (Consortium of International Agricultural Research Centers) Climate Change Agriculture and Food Security (CCAFS) program are addressing this issue by developing joint scenarios and visioning of plausible futures (Vervoort et al., 2014). Also the Global Coffee Platform is explicitly designed to facilitate such visioning (Panhuysen and Pierrot, 2018).

To further shape visioning, landscape approaches purport to engage with diverse stakeholders across multiple spatial scales and sectoral interests to develop shared futures (Sayer et al., 2013; Scherr et al., 2012). The roles and commitments of value chain actors are, however, often ignored (Marshall, 2015; Milder et al., 2014). Coffee production and processing are ‘vertically’ organised in international value chains (Mithöfer et al., 2017). There are few links across actors who produce different commodities in the same landscape, and ‘horizontal integration’ across different production systems is lacking, which might promote more effective landscape wide-management for environmental benefits and social wellbeing (Deans et al., 2017). This would require governments to provide incentives and legislation, while the roles and commitments of value chain actors need to be further stipulated (Mithöfer et al., 2017). Landscape scale coordination of adaptation options thus requires multi-stakeholder negotiations, continuous learning, and long-term funding (Cundill and Fabricius, 2010; Sayer et al., 2013) for which the Global Coffee Platform and the Sustainable Trade Initiative have both set up a landscape program (IDH, 2017).

5.2. Creation of incentives and supporting institutions for adaptation uptake

Although the outcome of visioning processes may point at stimulating shade systems, in many coffee producing countries smallholders are increasingly supported by governmental incentives, research institutes and extension services to increase yields and to transform (traditional) shade systems to sun systems (Jha et al., 2014). Moreover, certification programs are not well-designed to provide solutions for the adaptation options that require transformational changes at landscape scales. Adaptive landscape transformation requires new policy frameworks, institutional arrangements, and appropriate financial investments (e.g., Harvey et al., 2014). However, lack of funding, distrust among private and public partners, and weak institutions currently complicate such interventions (Cundill and Fabricius, 2010; Scherr et al., 2012).

One mechanism for financing climate adaptation measures is payments for ecosystem services (PES). In Peru, for example, carbon credits

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Table 3

| Type of adaptation | Aim | Possible associated adaptation measures | Implementation complexity |
|--------------------|-----|----------------------------------------|--------------------------|
| Incremental adaptation | Maintain current production system (sun systems) with some adaptation measures | Farm-level water and soil management, planting tree windbreaks, introduce new crop varieties | Low |
| Systems adaptation | Enhance resilience of production system, partly by changing sun systems into shaded systems | Add shade trees, diversify production and income, integrated pest management | Medium |
| Transformational adaptation | Landscape integration of shade systems | Integrated landscape management, forest conservation and watershed management | High |

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Table 4

| Function | Description |
|----------|-------------|
| Guidance of the Search | The adaptation measures need to have a positive effect, visibility and clarity that need to be shared among government, landscape actors and value chain actors. Policy goals to adaptation implementation may provide legitimacy to systems and transformative adaptation. Expectations need to be included to generate a momentum for change. |
| Creation of Legitimacy | Adaptation measures need to become part of an incumbent regime or replace the regime. Parties with vested interests, like value chain actors will often oppose this since it will put pressure on their current economic interests. |
| Market Formation | Adaptation measures may come at higher costs (opportunity costs) relative to the incumbent production system. Value chain actors may therefore need to create temporary niche markets for experimentation. Tax regimes or payments (incentives, subsidies) may also support farmers. |
| Farmer Activities | The farmer has to incorporate adaptation measures and generate (new) opportunities in coffee production while coping with increasing climate change. |
| Knowledge Development | Research and knowledge development should support farmers in taking relevant adaptation measures. |
| Knowledge Diffusion | Networks are essential to exchange information. Farmers depend on both public networks (governmental extension services), farmer cooperation’s and private value chain actors. |
| Resource Mobilisation | Both financial and human resources need to be supported by value chain actors and/or farmer cooperatives since it is unlikely farmers alone can bear the costs. |
generated by reforestation in upper watersheds are sold to coffee businesses in the value chain, a mechanism called ‘insitituting’ (Amrein et al., 2015). While PES has been well publicised, its implementation and uptake has also been limited, mainly due to high transaction costs that disproportionately exclude poor smallholders (Wunder, 2008). Moreover, PES programs do not yet address climate change, but positive results have been found for water services that are clearly linked with climate change (Porras et al., 2008). To be effective, implementation of PES requires a balanced mix of private, institutional and government instruments such as sound (participatory) land-use governance and planning that should include zoning of particular land uses in watersheds (Ferraz et al., 2013).

5.3. Market formation

Group certification, in which farmer cooperatives are certified rather than individual farmers, is applied by some standards. This allows sharing the burden of high transaction costs. Even so, the net added value of certification can still be questionable, as certification costs remain high relative to price premiums secured (Latynski and Berger, 2017). Group certification does, however, offer the possibility for more efficient participation in PES schemes, where the ecosystem benefits of land management can be realized and verified at aggregated landscape scales (Ghazoul et al., 2009). Recognizing this, the alternative landscape labelling approach has been suggested (Ghazoul et al., 2009). This jurisdictional approach to certification is gaining considerable traction in international discussions (Hart et al., 2014) as it enhances inclusiveness, and integrates PES with bundled-commodity certification systems.

5.4. Smallholder knowledge development, networks and capabilities

Strengthening local capacities and improving access to insurance, technical support and markets for sustainable products are key ingredients for smallholders. Agricultural and forestry extension services need to be strengthened to provide local support for adaptation measures to farmers (Schorroth et al., 2009). For example, multi-stakeholder initiatives, such as the SAFE (Sustainable Agriculture Food Environment) platform, Sustainable Coffee Challenge and Coffee & Climate (Panhuysen and Pierrot, 2018) develop knowledge infrastructures for smallholder coffee farmers. Adaptation options are further elaborated in the context of smallholder climate change resilience. Yet, knowledge production and diffusion are still rather scattered which makes it difficult to prepare independent smallholders for climate change.

5.5. Mobilizing resources for smallholders

Implementation of adaptation options by smallholders requires a different finance model because a production lag will occur between implementation and obtaining positive returns (Basak, 2017). Medium to long-term financing must allow smallholders to make the necessary investments. New climate-smart agriculture programs of the World Bank and FAO are currently developing financial instruments that especially target climate adaptation measures (FAO, 2013).

Furthermore, access to crop insurance can support farmers in coping with the impacts of climate change and insurance can be coupled to other adaptation measures. For example, Giné and Yang (2009) analysed the take-up of a weather insurance product by groundnut and maize farmers in Malawi and found that the rate of take-up was higher when insurance was combined with finance for hybrid seeds.

Donor interventions might aid farmers in their systems and transformative adaptations. The effectiveness of financial aid can, however, be undermined by low willingness to implement supportive policies, unfavourable commodity prices, or limited knowledge network formation (Hansen and Nygaard, 2013). As Hansen and Nygaard (2013) argue, donor interventions could also lead to the creation of new arenas in which conflicts over resources, interests, interpretations, and rationalities can inhibit necessary transformations. Governmental interventions are therefore needed to efficiently steer (private) financial support to smallholder farmers.

5.6. Concluding remarks

Although tangible climate change adaptation measures are inexpensive, many organisational issues are currently hampering the implementation at farm and landscape scale. Using the functions from innovation management, we show many obstacles have to be overcome for effective implementation. Independent farmers need access to knowledge networks, financial and appropriate training. Moreover, there are currently large hurdles to be overcome to cover increased costs. Certification systems can aid implementation since knowledge structures, resources, and market formation are largely in place, while sustainability goals are acknowledged and addressed. Yet certification only address market niches, and scaling up certification of coffee farmers globally remains challenging. Nonetheless, certification processes and the standards that they represent can be used to leverage good practice for climate change adaptation as well as broader sustainability goals. This would require a refinement of certification systems, including considering their role in catalysing transformational adaptations at landscape scales.

Appendix A. Supplementary data

Supplementary material related to this article can be found in the online version, at doi:https://doi.org/10.1016/j.envsci.2019.03.017.

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