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# Can sustainability certification enhance the climate resilience of smallholder farmers? The case of Ghanaian cocoa

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## ABSTRACT

Sustainability certification has been posited as a key governance mechanism to enhance the climate resilience of smallholder farmers. Whilst many certifications now include climate resilience in their standards, their ability to deliver this for smallholders remains untested. We take the case of the 2015–16 drought-shock to cocoa production in Ghana to examine whether certification can enhance smallholder climate resilience. We used a novel transdisciplinary methodology combining participatory outcome definition with household surveys, biophysical measurements, satellite data and counterfactual analysis. Utilising our climate resilience framework, we find that certification has a strong effect on the adoption of basic management, e.g. fertilization, but a weak influence on more complex resilience strategies, e.g. agroforest diversification. Beyond certification, we identify strong regional patterns in resilience. These findings suggest that certification has some potential to enhance climate resilience but greater focus on facilitating diversification and adapting to sub-national contexts is required for improved effectiveness.

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## Introduction

A transition to a more sustainable food system is necessary given the range of issues that our current system is both facing and generating, including, poverty, biodiversity loss, deforestation and climate change (Christiaensen et al., 2011; Godfray et al., 2014; Newbold et al., 2015; Vermeulen et al., 2020). However, achieving a more sustainable food system is a non-stationary target. Changes in climate, trade connectivity, population and dietary preferences are constantly shifting the context within which food is being produced and consumed (Alexander et al., 2015; Lesk et al., 2016; Puma et al., 2015). These changes bring both gradual stresses, such as reduced yields and worsening trade conditions, and abrupt shocks, such as political crises and floods, that can drastically affect the functioning and reduce the sustainability of the food system (Cottrell et al., 2019).

New and improved strategies to achieve a sustainable food system must reflect these changing global contexts, shocks, and stresses. Resilience, the ability of a system to cope with shocks and maintain overall function (Folke, 2006; Holling, 1973; Walker, 2019), has emerged as a useful concept

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for guiding the governance and management of food systems in the face of these evolving threats (Pimm et al., 2019; Schipanski et al., ; Tendall et al., 2015). Within the broader field of resilience, climate resilience has emerged as a priority topic in smallholder food production in the global South (Dixon & Stringer, 2014; Ifejika Speranza, 2013; Kangogo et al., 2020; Whitfield et al., 2019), since these producers are particularly vulnerable to both gradual changes in climate and extreme events (Harvey et al., 2014.; Nyantakyi-Frimpong & Bezner-Kerr, 2015). Enhancing the climate resilience of smallholders is not only critical to their own well-being (incomes, food security, and livelihoods; Shiferaw et al., 2015; Suweis et al., 2015), but may also help reduce the impacts of climate shocks on the wider economy, by making supply more stable (Chavez et al., 2015) and prevent additional losses of native ecosystems through preventing farmers from seeking out new agricultural areas (Biazin & Sterk, 2013).

The degree to which international governance initiatives can improve smallholder resilience remains an under-researched topic (Delaney et al., 2018). Given the growing influence of corporate actors on global food systems, private sector sustainability initiatives, including company commitments, certification programs, and direct investments, have been presented as a promising leverage point for improving food system sustainability (Garrett et al., 2016; Lambin et al., 2014; Newton et al., 2013; Swinnen, 2016; Van der Ven et al., 2018). Among this suite of potential interventions, sustainability certifications (i.e. voluntary environmental and social standards adopted at the farm or cooperative level, which are audited by third-party organisations), have become a popular mechanism to enhance the climate resilience of smallholder farmers (Verburg et al., 2019). Sustainability certifications have seen prolific growth in recent years, with over 20 million hectares of agricultural land now certified globally (ITC, 2019). For over a decade, certification programs, including UTZ, Rainforest Alliance, Fairtrade and Organic have acknowledged the evolving climate risk and have attempted to build climate resilience elements into their standards (Lemeilleur & Balineau, 2016). Many certifications explicitly include a selection of resilience-related pathways in their theory of change, standards and training, such as climate awareness education and adaptation training (IFOAM, 2017; SAN, 2011; UTZ, 2017).

There has been considerable debate in the literature about the effectiveness and equity of sustainability certification, including how issues of power, governance, and legitimacy influence environmental and social outcomes (Garrett et al., 2018; Glasbergen, 2018; De la Plaza Esteban et al., 2014; Meemken et al., 2019; Tscharnkte et al., 2015). Similarly, several attempts have been made to build replicable frameworks to assess smallholder climate resilience (Dixon & Stringer, 2014; Ifejika Speranza et al., 2014). However, there remains a gap in testing the ability of sustainability certification to deliver climate resilience. In general, certification studies relating to resilience have focused on one type of certification or one sub-component of resilience (e.g. adaptive capacity) and have not investigated responses and outcomes to a shock (Heckelman et al., 2018; Jacobi et al., 2015). Elements that have received focus include how certifications influence farmers': i) capacities to adapt to climate change (Borsky & Spata, 2013; Frank & Penrose-Buckley, 2012), ii) perceptions of climate change (Otieno et al., 2017) and iii) ability to communicate to the consumer (Lemeilleur & Balineau, 2016). However, to the best of the authors' knowledge, there have been no causal inference studies assessing the ability of sustainability certification to enhance the climate resilience of smallholders.

To fill this research gap, we assessed what role sustainability certification can play in enhancing the resilience of smallholder farmers to climate shocks. We do this by taking the case of smallholder cocoa production in Ghana, the second largest cocoa producer in the world, and comparing certified and non-certified systems, namely: UTZ, Rainforest Alliance (RA) and Organic. We focus on UTZ, RA and Organic certifications as they are prominent both globally as well as in Ghana. In addition, these certifications have made specific attempts to address climate resilience in their standards. The resilience of these different systems is assessed in the face of a drought shock that occurred across West Africa in 2015–2016. Using this case, our study provides three major contributions: i) a novel co-designed framework to operationalize the concept of climate resilience for smallholder farmers; ii)

a new perspective on the potential effects of sustainability certification on climate resilience; and iii) an empirical analysis of this relationship between certification and climate resilience. This work thus has the potential to inform the future design of certification approaches to address climate resilience, as well as broader government, company, and civil society approaches to tackle this important issue.

## Materials and methods

The study was designed in three phases. These are i) transdisciplinary generation of the climate resilience indicator framework, ii) resilience assessment based on biophysical and socio-economic data collection and processing, and iii) causal inference analysis.

### *Case selection and case introduction*

In Ghana, cocoa is produced predominantly by smallholder farmers and is the source of income for over 800,000 families (CGIAR, 2018). Cocoa production is climate sensitive, and vulnerable to predicted changes in the West African climate (Lahive et al., 2014). Schroth et al. (2016) predict that the decrease of dry season rainfall and increased maximum temperatures will reduce the suitable area for cocoa production in Ghana by 41% by 2050. The severe 2015–2016 El Niño-driven drought experienced in Ghana provides a case study of an extreme event that is predicted to become more common place, in the already drought prone context of the West African monsoon (Shanahan et al., 2009; Sylla et al., 2016).

Smallholder cocoa production in Ghana provides an important case to understand the role of sustainability certification in climate resilience, as certification programs are expanding rapidly in the region and the challenges of cocoa farms in the region (i.e. capital scarcity, low incomes, and increasing climate vulnerability) typify those faced by smallholder farmers across the tropics (Cohn et al., 2017). Several studies have looked at the role that different measures, such as enhanced shade cover (Blaser et al., 2018) and irrigation (Hutcheon et al., 1973), can play in reducing the impact of climate shocks on cocoa production, as well as factors influencing their adoption (Akrofi-Atitianti et al., 2018). Previous studies have also evaluated cocoa sustainability certification against several objectives, including income, poverty reduction, labor, biodiversity, environmental services and natural capital (Astrid Fenger et al., 2013; Gockowski et al., 2013; Meemken et al., 2019). However, none of these studies have looked at the ability of certifications to catalyze the adoption of climate resilience measures and strategies.

### *Transdisciplinary generation of the climate resilience indicator framework*

We adopted a transdisciplinary research approach to generate a climate resilience indicator framework, for the purpose of assessing the different sustainability certifications' impact on cocoa farmers (Pohl et al., 2017). Transdisciplinary research involves, inter alia, the co-framing of problems between stakeholders and scientists and are chosen here to co-frame climate resilience with farmers and cocoa value chain stakeholders (Lang et al., 2012). Allowing relevant stakeholders an opportunity to give input is critical given the polarization of power in such tropical commodity value chains, which often results in framings of sustainability issues that are inequitable towards local land users (Nelson & Tallontire, 2014).

In this case, the transdisciplinary research approach involved setting up a stakeholder platform, building on a previous project (Joerin et al., 2018). This platform included several actors from the certified and non-certified elements of the cocoa value chain in Ghana, specifically, farmers, certifiers, transporters, licensed buying companies, cocoa processors, input companies, insurers and the Ghanaian government (COCOBOD the Ghana Cocoa Board). The approach had three stages i) stakeholder workshop (30 participants), ii) focus groups with cocoa farmers (6 groups with 9 to 21 farmers each), and iii) expert interviews (7 interviewees) with value chain stakeholders.

In the transdisciplinary activities, we presented the stakeholders with a framework of resilience for food systems modified from Tendall et al. (2015), which they were familiar with through the previous project. This framework included the components of: *Robustness*, *Recovery* and *Adaptability*. *Robustness* was considered as the ability of a farm system to reduce the impact of a shock, through general good agricultural practice, as well as specific climate resilient measures and strategies. For *Robustness*, we accommodate the dynamics of shock experience, dividing it into three aspects *preparation*, activities before a shock, *response*, activities during a shock and *impacts*, the outcome of the shock. *Recovery* was considered the process by which farmers return to their 'normal' or new system state. For the *Adaptability* component, cf. adaptive capacity, we considered farmers' ability to alter the socio-ecological system to increase their robustness and enhance recovery to existing and future threats (Gallopín, 2016). We investigated *Adaptability* at the household scale, using the Sustainable Rural Livelihoods Framework to identify assets (i.e. resources, stores, claims, and access, which provide the means to engaging in activities) that can be utilized in adaptation (Chambers & Conway, 2015). However, criticism of adaptive capacity assessment has centred on the ability of households to utilize such assets, therefore we include mobilizing and enabling factors, related to market integration, training, and governance (Eakin et al., 2014; Mortreux & Barnett, 2017; Pelling & High, 2005).

Through participatory activities, researchers and stakeholders together specified relevant indicators of these resilience components. Firstly, through a series of group activities at the workshop we asked participants to map their cocoa production knowledge and experiences to the resilience framework described. This was then refined with cocoa farmers in focus groups in the Eastern and Western Region where our study sites were located. Finally, semi-structured interviews, with cocoa farmers and other value chain stakeholders were used to validate this framework. Table 1 maps the individual variables we collected and then used to assess farmers' resilience to drought.

There are multiple mechanisms by which the stakeholders co-generated indicators for cocoa farmers' overall climate resilience. From a robustness perspective, there are indicators that are connected to maintaining the status-quo of cocoa production, via reduced exposure to climate hazards (e.g. fire belts, shade tree incorporation) and enhanced tree health (e.g. good agricultural practices, water harvesting). As well as robustness indicators that are connected to redundancy in the livelihood system (e.g. crop diversity, income diversity). Regarding the recovery mechanisms co-identified by the cocoa value chain stakeholders, these can be grouped into two broad categories, sales of diverse assets to replenish financial capital (e.g. livestock, household assets) and alternative sources of income (agricultural or non-agricultural work). From an adaptability perspective, stakeholders co-selected indicators across diverse asset types that provide resources to implement resilience enhancing measures (e.g. primary forest for seed resources), access to knowledge to inform livelihood system modification (e.g. cocoa production groups), and factors to mobilize these assets (e.g. market opportunities via integration to supply chains). In our study, we do not aggregate these indicators and therefore do not weight them relative to each other based on their different respective contributions to overall climate resilience. We reflect on this further in the discussion.

## **Resilience assessment data collection and processing**

### **Study area**

The data collection for the socio-economic and biophysical elements of the resilience assessment was performed in four districts of Ghana, Juabeso district (Western Region) and Fanteakwa South, Abuakwa North, and Suhum districts (Eastern Region). These regions, 'Western' and 'Eastern' (henceforth), provide contrasting agroecological and socio-economic conditions under which to explore the role of certification on climate resilience. Western is a forest frontier region where cocoa production is still expanding into primary forest areas, whereas in Eastern the primary forest has already been removed and is now a mosaic of secondary forest and agricultural land (Figure 1).

**Table 1.** Climate resilience aspects, from indicator framework, included in certification schemes studied. In addition, COCOBOD is the government body responsible for cocoa in Ghana and provides general extension to all cocoa farmers. (COCOBOD, 2016; IFOAM, 2017; Naturland, 2014, 2020; SAN, 2011; UTZ, 2015).

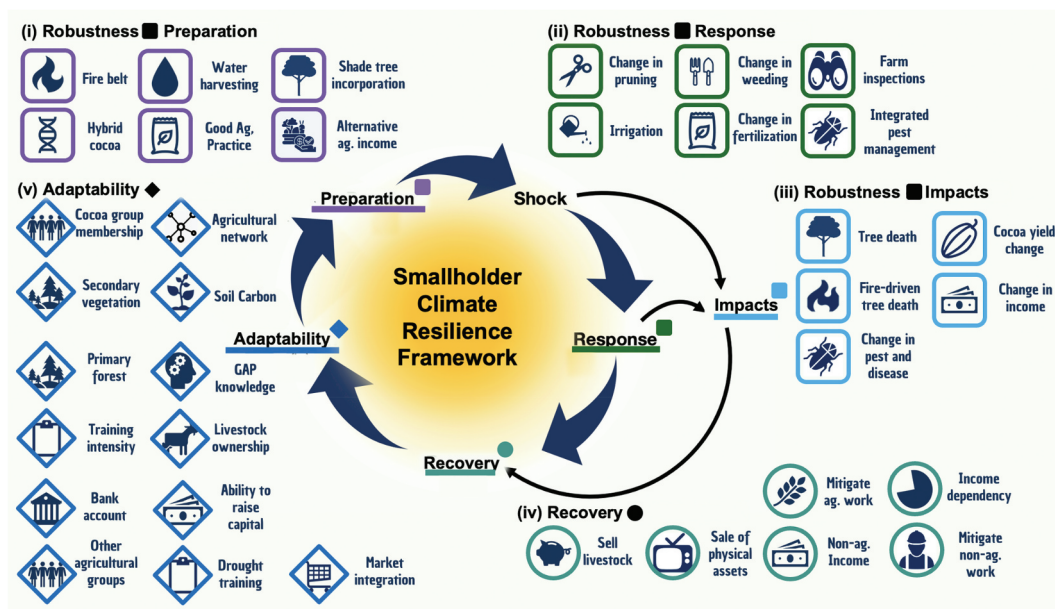
Resilience Component	Aspect	Organic	UTZ	Rainforest Alliance	COCOBOD
<b>Robustness</b>	Explicit climate resilience goal	✓	✓	✓	✓
	Climate specific module	✗	✓	✓	✗
	Drought resistant seedlings	→	👥	→	✗
	Crop diversification	→	🕒	✗	→
	Income diversification	✗	🕒	✗	→
	Shade tree cover	✓	✓	✓	→
	Shade enhancement plan	→	→	✓	✗
	Soil structure management	→	→	→	✗
	Cover crops	→	✗	✓	→
	Smart fertilization	✓	🕒	🕒	✗
<b>Recovery</b>	Water harvesting	✗	🕒	→	→
	Climate record keeping	✗	✗	→	✗
	Group savings mechanisms	✗	✗	✗	✗
<b>Adaptability</b>	Insurance	✗	✗	✗	✗
	Group governance	👥	👥	👥	✗
	Farm management planning	→	→	✓	→
	Training on climate aspects	👥	👥	👥	✗
	Climate risk assessment	✗	→	→	✗
	Training on general aspects	→	👥	👥	→
	Community engagement	→	→	👥	✗

✓ Present/Mandatory 🕒 Mandatory after year X → Recommended 👥 Group mandatory ✗ Not present in standard

Western is historically wetter than Eastern with an average annual rainfall of 1370 mm versus 1260 mm, respectively (Funk et al., 2015). During 2015 and 2016 both regions suffered a drought lasting 20 months (authors analysis of data from Osborn et al., 2018). During this period the study regions experienced lower than average rainfall and higher than average temperatures, resulting in Palmer Drought Severity Index values dropping below -2 (moderate drought) for more than consecutive 9 months (see Supplementary Materials, SM1).

The distribution of certified cocoa area in Ghana is: 19% UTZ, 14% Fairtrade, 8% RA and less than 1% organic (ITC, 2019). The town and district of Suhum, 60 km North of Accra, as well as the neighbouring districts of Fanteakwa South and Abuakwa North have been a center of organic and UTZ cocoa production in Ghana since 2007. A private sector cocoa licensed buying company with a focus on organic cocoa has catalyzed the uptake of organic production in the region, facilitating the use of organic inputs and coordinating farmer group formation and certification audits. As of 2019, there are over 2750 organic farmers certified in the region. UTZ certification has also been catalyzed from this hub and there are over 800 certified farmers in these districts. For RA certification, there is a concentration in Western Region around the town of Juabeso in Juabeso District (Figure 1). Since 2010, RA has been certifying farmers in the Juabeso District. These farmers have been some of the first to be trained on the climate module of the Sustainable Agriculture Network Standard (SAN, 2011). RA has led a landscape approach in the area forming landscape management boards and





**Figure 1.** Climate resilience indicator framework for smallholder cocoa farmers as defined by farmers and value chain actors during the participatory process. Indicators are divided between the resilience components robustness, recovery and adaptability. (ag. = agricultural).

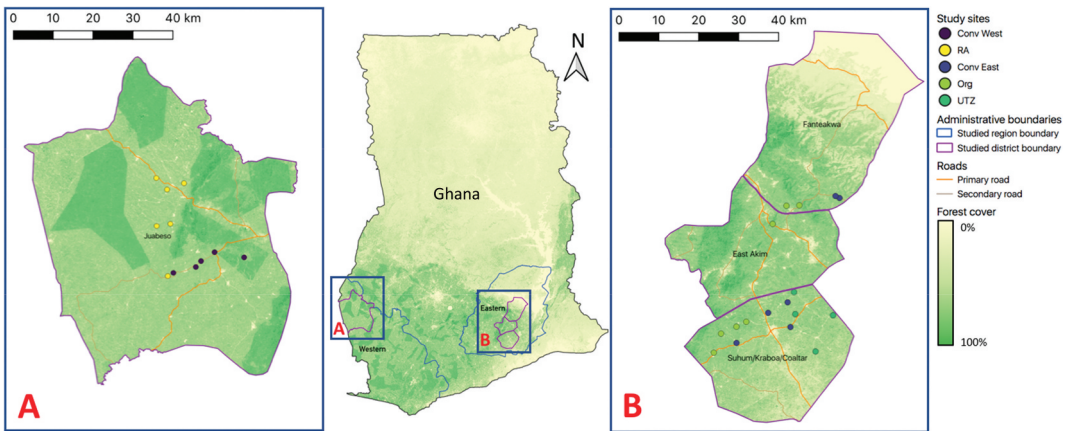
community cocoa growing groups. Over 3000 farms in the district are now certified. The standards of the three certifications assessed were reviewed for the presence of climate resilience aspects, the results of this review are summarized in [Table 1](#).

### Sampling

The socio-economic and biophysical elements of the resilience assessment were carried out with a stratified (village population) random sample of farmer groups, taken from lists of all the Organic and UTZ groups located in Fanteakwa South, Abuakwa North and Suhum districts, Eastern Region, and all the RA groups in Juabeso district, Western Region. To establish a counterfactual of how climate resilient local cocoa producing households would be in the absence of certification, control groups of non-certified farmers were sampled in both regions. The control group was taken from a stratified random sample of villages in the districts where certified groups were not present and farmers were selected randomly from the purchasing clerk lists of the government run cocoa purchaser in Ghana (Produce Buying Company). Originally a total of 480 households were sampled. After discarding several interviews due to missing data, 457 households were included in the analysis, describing 846 cocoa plots (non-certified Eastern  $n = 104$ , Organic  $n = 80$ , UTZ  $n = 60$ , non-certified Western  $n = 105$  and RA  $n = 108$ ). Biophysical measurements were taken on a randomly selected subsample of 66 cocoa plots, stratified by certification treatment and excluding plots that had not been certified for at least 5 years (non-certified Eastern  $n = 12$ , Organic  $n = 13$ , UTZ  $n = 10$ , non-certified Western  $n = 16$  and RA  $n = 15$ ).

### Data collection

To assess the impact of certification on the climate resilience indicators ([Figure 1](#)), we carried out a survey between July and August 2018 using a digitized questionnaire on tablets. The questionnaire was designed based on the process described in the section 'Transdisciplinary generation of the climate resilience indicator framework' and included the following sections: household characteristics, cocoa plot management, cocoa production, marketing, drought shock experience,



**Figure 2.** Map of the sampled cocoa communities. centre: country scale map of Ghana. (a): western region. (b): eastern region. symbols show location of sampled communities with the type of certification present in the community specified. Forest cover in 2000 from

preparedness, response, impacts, recovery and adaptability. Cocoa production was recalled by farmers at the plot level and was verified with their individual COCOBOD passbooks (farmers record of cocoa transactions) and certification audit data. Gross cocoa income was estimated from the passbook transactions and farmers' recall of production volumes and prices (list of all socio-economic variables in SM2).

For the biophysical indicators, in each sampled cocoa plot we mapped the perimeter using a GPS device and a 0.05 ha (20 m x 25 m) data collection area was randomly located within the perimeter. A 100 m transect was then placed through the centre of this 20 m x 25 m area to capture the maximum variation in topography across the whole cocoa plot for soil sampling. Five soil samples were taken from the first 30 cm depth of soil at 25 m intervals along this transect. These samples were then composited, air dried and passed through a 2 mm sieve. These samples were dried at 105°C to constant weight and ground using a ball mill. The samples were analyzed for total C and N content using a dry combustion analyzer (CN-2000, LECO Corp.). Within the 0.05 ha area, we assessed cocoa tree density, shade tree density and identified all shade tree species. On-farm tree species richness was based on the count of shade tree species identified on each plot. Shade cover was analyzed for each plot using the GPS polygon of the plot perimeter. QGIS was used to identify the proportion of shade cover by identifying shade tree canopy polygons ( $n = 66$ ) from satellite photo interpretation from Google and Bing base maps (list of all biophysical variables in SM3).

## Data analysis

### Econometric methods

To evaluate the impact of sustainability certification schemes on smallholder farmer climate resilience indicators we used Coarsened Exact Matching (CEM; Iacus et al., 2016), followed by estimation of the average treatment effect on the treated (ATT). A key challenge in evaluating the impact of certification schemes on smallholder farmer outcomes is the non-random nature of farmer participation in such schemes. By matching certified sampled farmers to non-certified farmers using observable characteristics, such as age and farm size, we can reduce selection bias (the degree to which underlying attributes that may be correlated with climate resilience influence adoption). Many studies evaluating the impact of sustainability certification use a propensity score matching (PSM) approach; however, it has recently been shown that using propensity scores for matching can



increase imbalance, model dependence and bias (King & Nielson, 2019). To overcome these flaws with the PSM approach, we chose to use CEM, which is a member of the generalized class of matching methods known as 'Monotonic Imbalance Bounding' (Iacus et al., 2016). This implies that the imbalance between the treated and control groups is chosen ex-ante, via allocating observations into strata, before the matching, and post-hoc sensitivity tests do not have to be carried out.

First, we defined the control variables that are to be matched between the treatment (certified) and control (non-certified) samples, within each region. The control variables (age, education years, household size, gender of household head, total farm size and farm ownership) were chosen based on theoretical and empirical evidence that they influence the probability of being certified and associated outcomes, but are not affected by certification (Blackman & Naranjo, 2012; Lampach & Morawetz, 2016). We manually defined the strata boundaries based on institutional knowledge (regarding the Ghanaian education system, demographics and farm size); a table of the strata boundaries is presented in SM4. Following this, the CEM algorithm temporarily coarsened the control variables into the strata that we defined. The observations were placed into strata based on their non-coarsened control variables. Strata that did not include at least one control and one treatment observation were pruned from the data set. The matching outcomes can be found in SM5. The remaining matched data, i.e. observations occurring in the same strata, were then used to estimate ATT with the original non-coarsened values. We estimated ATT as the mean difference in the outcome variable between matched certified and non-certified farmers. The analysis was carried out using R (R Core Team, 2020) and the MatchIt package (Ho et al., 2011).

### ***Regional comparison***

Regional comparisons between non-certified farmers in the Eastern and the Western region were made using independent two sample t-tests of unmatched data.

## **Results**

### ***Resilience enhancing features of sustainability certifications and government extension programmes***

All three certification standards (Organic, UTZ, RA), as well as the curriculum for the government extension system, made explicit reference to enhancing climate resilience being a goal of their respective programmes (Table 1). The key mechanisms by which the three sustainability certifications may catalyse changes in livelihood systems that enhance climate resilience include: training, auditing, group formation, price premiums and providing infrastructure for the supply of adaptation. These broad goals translate into specific activities promoting resilience that are included in their farmer training but less into integrated supply chain initiatives, such as risk transfer or insurance. Of the four programmes, RA and UTZ demonstrate a clearer focus on climate resilience by having specific modules in their farmer training programmes focused on climate. In terms of the scope of resilience components that are promoted via these four programmes, there is a strong focus on robustness, via productivity enhancement, and more limited focus on adaptability, via group formation and training. No specific activities are stipulated that are intended to support recovery from a climate shock. A key difference between the three certifications and government extension, in terms of scope relating to resilience, was that the certifications included multiple aspects relating to adaptability, e.g. group governance and community engagement, whereas government extension focus was much more limited. A distinction between the three certifications, in terms of scope, is that RA and UTZ had a more active focus on adaptability than Organic, for example, by including climate risk assessments. Beyond this, RA had more immediate mandatory aspects than UTZ and Organic. Government extension had the least stringent set of stipulations with no mandatory resilience

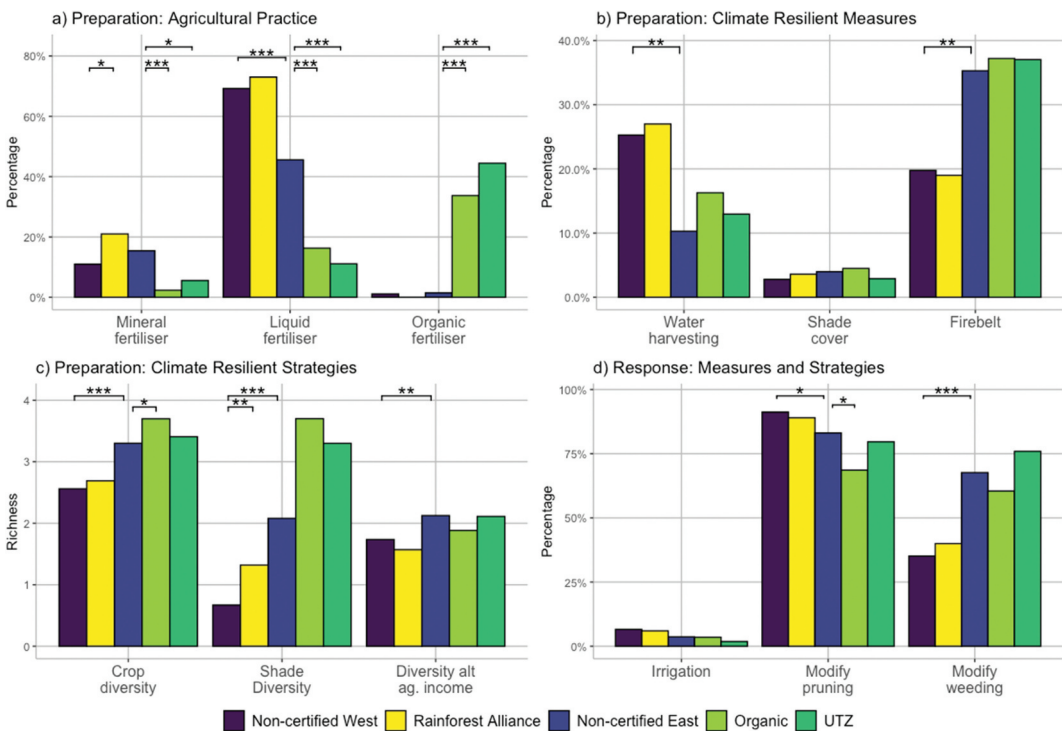
related requirements. Organic focussed on a narrower range of resilience aspects versus RA and UTZ. RA and UTZ adopted time bound changes, whereas the Organic standard stipulates either compulsory or recommended.

## Robustness

In terms of robustness, the econometric analysis reveals the strong effect that certification has on the adoption of basic agronomic practices and the lack of effect on the adoption of more complex resilience enhancing measures and strategies (Figure 3, SM6)

## Preparation

All certification programs had a significant impact on the use of inputs on cocoa farms (Figure 3a, SM6). For Organic farmers, we see clear effects on management in terms of fertilization, with less farmers using mineral fertilizer (−14.9 percentage points (pp),  $p < 0.01$ ) or inorganic liquid fertilizer (−20.5 pp,  $p < 0.01$ ) amendments and more farmers using organic alternatives (33.3 pp,  $p < 0.01$ ). This pattern is replicated for UTZ farmers (mineral −10.1 pp,  $p < 0.1$ , liquid −31.6 pp,  $p < 0.01$ , organic 44.1 pp,  $p < 0.01$ ). On the other hand, RA farmers are more likely to use mineral fertilizer than their non-certified counterparts (11.7 pp,  $p < 0.1$ ). Beyond certification there are significant regional patterns in input use, with Western farmers more likely to use liquid inorganic fertilizer (70% of farmers vs 45%,  $p < 0.01$ ).



**Figure 3.** Effect of certification on robustness indicators (a) preparation: agricultural practices (percentage using measure) (b) preparation: climate resilient measures (percentage using measure, shade cover is % of plot area) (c) preparation: climate resilient strategies (richness is number of different shade-tree or crop species or income types (non-cocoa agricultural products)) (d) response: measures and strategies used in the face of a drought (percentage using measure). Means are presented for all indicators after matching. Significance of average treatment effect on the treated and also difference between non-certified in the two regions (\* $p < 0.10$ , \*\* $p < 0.05$ , \*\*\* $p < 0.01$ ).

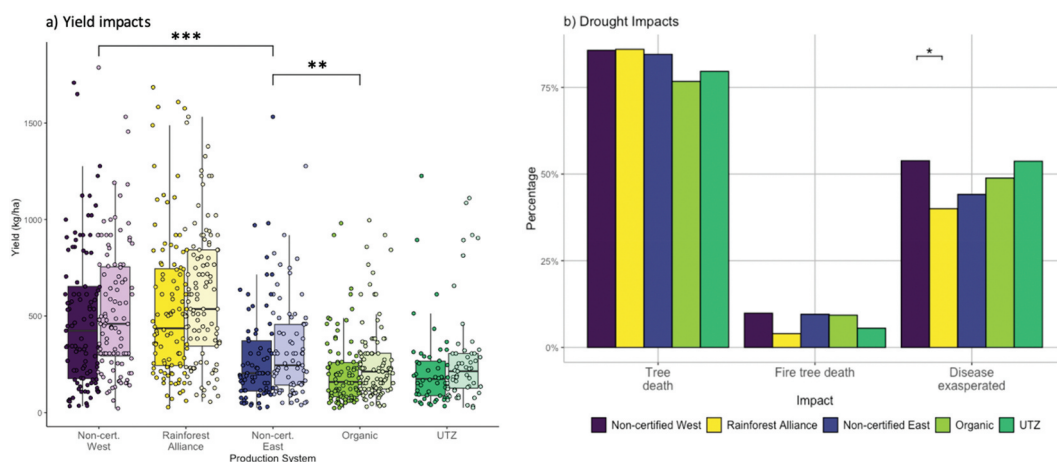
Certification had no significant impact on climate resilient measures taken in preparation for a drought (Figure 3b, SM6). Certified farmers were no more likely than non-certified farmers to use hybrid cocoa seedlings, enhance shade cover, use water harvesting or construct fire belts. The predominating effect was regional for the measures, i.e. using hybrid varieties (Eastern 54% vs Western 37%,  $p < 0.05$ ), fire belt construction (Eastern 35% vs Western 20%,  $p < 0.05$ ), and water harvesting (Eastern 10% vs Western 29%,  $p < 0.05$ ).

The adoption of climate resilient strategies, a suite of coordinated measures, were in general not affected by certification (Figure 3c, SM6). There was no effect of certification on the diversification of farm income sources (UTZ – 0.04 income sources ( $p = 0.79$ ), Organic – 0.23 ( $p = 0.21$ ), RA – 0.14 ( $p = 0.31$ )). There was, however, a significant regional difference in the diversity of agricultural income streams (Eastern mean number of income sources 2.09 vs Western 1.75,  $p < 0.05$ ). For crop diversity, marketed and self-consumption, Organic certification had a small effect, increasing diversity by 0.6 crops per person on average ( $p < 0.1$ ). The other certifications had no significant effect. In Eastern, certification had no effect on the diversity of shade trees on cocoa farms but there were significant regional effects seen, with Eastern having a mean species richness of 3.1 and Western of 0.7 ( $p < 0.05$ ). In Western, RA f

Certification has no significant effect on the use of responsive measures during the 2015–16 drought (Figure 3d and SM6). Very few farmers had irrigation available to them as a response option (4.8%) and certification did not make farmers more likely to adopt this measure. Plot management practices, i.e. pruning (82% farmers decreasing activity) and weeding (54% decreasing activity), were modified by the majority of farmers in the face of drought, but there is no evidence that this was linked to certification.

## Impacts

Yields were substantially higher in Western ( $540 \text{ kg ha}^{-1}$ ,  $p < 0.01$ ) versus Eastern ( $304 \text{ kg ha}^{-1}$ ) for the 'normal' 2017–18 season (Figure 4a). Within Western, they were higher on RA farms ( $+ 58 \text{ kg ha}^{-1}$ ,  $p = 0.13$ ) relative to non-certified farms, whereas in Eastern they were lower for Organic ( $- 59 \text{ kg ha}^{-1}$ ,  $p < 0.05$ ) and for UTZ ( $- 49 \text{ kg ha}^{-1}$ ,  $p = 0.13$ ) versus non-certified farms. As the government sets



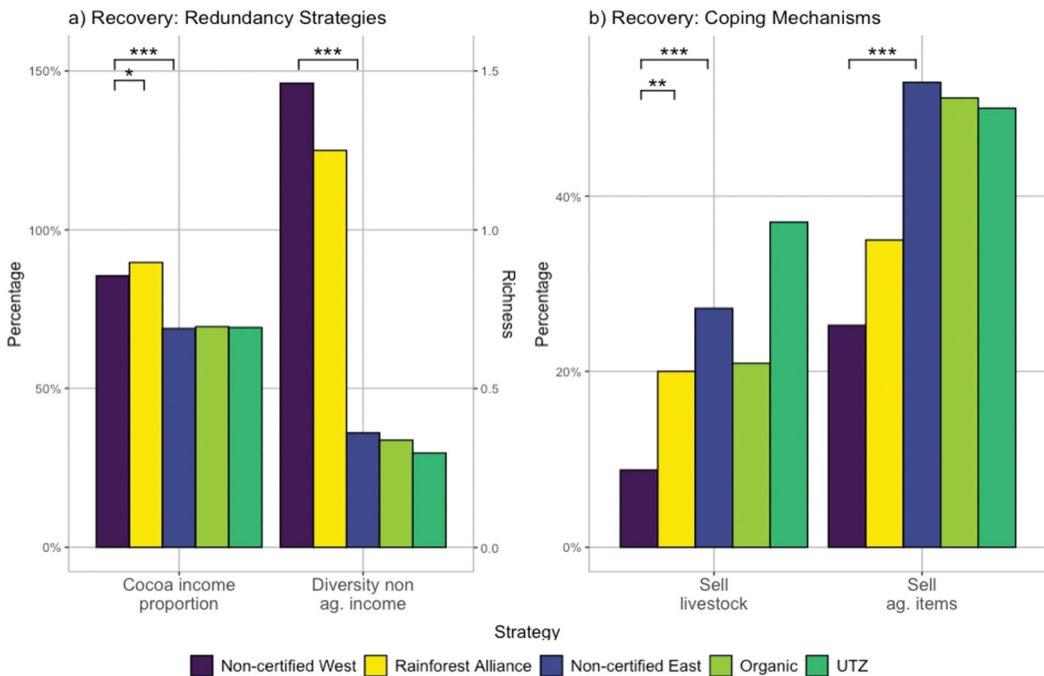
**Figure 4.** Impacts of 2015–2016 drought. (a) yield impacts (total of major and minor harvest) in drought season 2015–16 (dark color) and 'normal' season 2017–2018 (light color). yields are included from plots with cocoa trees over the age of four years at the end of the season described. Stars denote significant differences between yields within 2017–18 (after matching for certified versus non-certified) (b) percentage of farmers experiencing drought impacts as measured by tree death, fire induced tree death, and disease exasperation. Means are presented for all indicators after matching. Significance of average treatment effect on the treated (\* $p < 0.1$ , \*\* $p < 0.05$ , \*\*\* $p < 0.01$ ).

cocoa prices for all farmers, incomes were directly proportional to yields. Cocoa prices for the 2015–16 and 2017–18 seasons were 6.7 GHC kg<sup>-1</sup> and 7.6 GHC kg<sup>-1</sup> respectively (1 USD = 5.77 GHC). However, premiums were received by both certified and non-certified farmers to varying extents (46% of non-certified Eastern, 96% UTZ, 94% Organic, 37% non-certified Western, 97% RA) and values (mean per 64 kg bag: 15 GHC non-certified Eastern, 19 GHC UTZ, 26 GHC Organic, 11 GHC non-certified Western, 13 GHC RA).

Comparing the 'drought' year of 2015–16 to the 'normal' year of 2017–18, reported cocoa yields were on average lower by 70 kg ha<sup>-1</sup> ( $p < 0.01$ ) across the total sample in 2015–16. Non-certified farmers in Eastern lost on average 54 kg ha<sup>-1</sup> versus 60 kg ha<sup>-1</sup> in Western. Certification did not reduce these yield impacts, nor did it reduce other drought impacts (tree death, fire tree death, disease), with the exception of RA certification, which was associated with lower farmer reports of cocoa tree disease exasperation ( $-0.16$  pp,  $p < 0.1$ ; [Figure 4b](#), SM6). It was common for farmers (82% of all farmers) across all certifications and regions to experience the death of one or more cocoa trees due to drought.

## Recovery

We found different recovery strategies between certified and non-certified farmers ([Figure 5](#), SM7). RA farmers had a significantly higher dependence on cocoa income than non-certified farmers (2.5 pp,  $p < 0.1$ ) (which reduces their ability to recover), however, RA farmers were more likely to sell livestock to raise financial capital during the drought than non-certified farmers (13.5 pp,  $p < 0.05$ ), (which enhances recovery). In Eastern, certification had no discernable impact on recovery. Regional differences were much larger than those associated with certification. Farmers in Western had

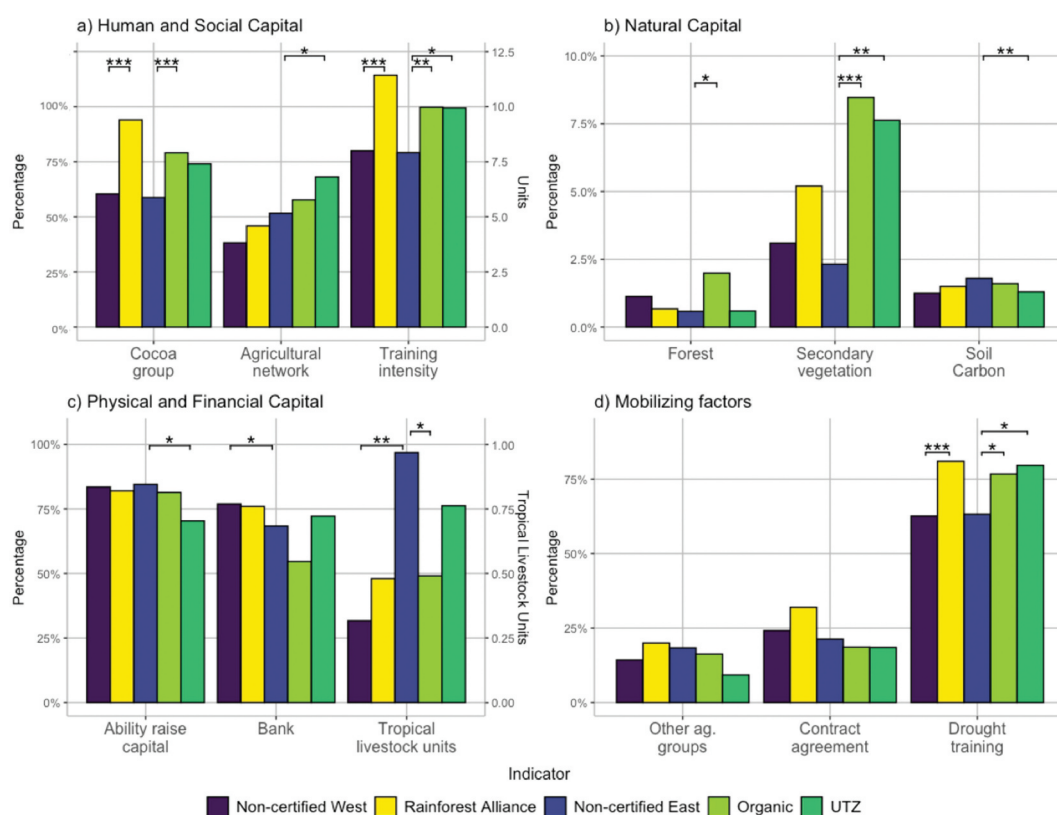


**Figure 5.** Effect of certification on recovery indicators: (a) redundancy strategies that reduce reliance on cocoa (proportion of cocoa income and diversity of non-agricultural income) (b) coping mechanisms to respond to the aftermath of a shock (selling of livestock or selling of agricultural items). Means are presented for all indicators after matching. Significance of average treatment effect on the treated and also difference between non-certified in the two regions (\* $p < 0.10$ , \*\* $p < 0.05$ , \*\*\* $p < 0.01$ ).

a greater diversity of non-agricultural income streams, which should aid recovery, although had higher dependency on cocoa income in general (Eastern 68% of total income vs Western 86%,  $p < 0.01$ ). While farmers in Eastern more frequently sold off physical assets, such as livestock (Eastern 25% vs Western 8.6%,  $p < 0.01$ ) and agricultural equipment (Eastern 54% vs Western 29%,  $p < 0.01$ ).

## Adaptability

Certification was associated with greater adaptability via larger agricultural networks for farmers (UTZ + 3.13 people,  $p < 0.1$ ) and membership in cocoa producer groups for Organic (26 pp,  $p < 0.01$ ) and RA (35 pp,  $p < 0.01$ ), as well as a moderate increase in training frequency for RA and Organic farmers (Organic farmers 3 more training days per 5-year period ( $p < 0.05$ ), RA farmers 4 more ( $p < 0.05$ ); Figure 6, SM8). Regarding natural capital, Organic and UTZ farmers had 7% ( $p < 0.01$ ) and 4% ( $p < 0.05$ ) more uncultivated secondary vegetation. Certification had a small positive effect on the proportion of farm area remaining as forest for Organic farmers (1.6 pp,  $p < 0.1$ ) and a negative effect on soil carbon stocks for UTZ farmers (- 0.67% carbon content,  $p < 0.05$ ) but otherwise there was no effect of certification on these aspects. For physical capital, Organic farmers owned significantly fewer livestock than non-certified farmers, by 0.36 Tropical Livestock Units ( $p < 0.1$ ), the equivalent to a young donkey.



**Figure 6.** Effect of certification on adaptability indicators: (a) human and social capitals (percentage of farmers participating in a cocoa group, size of agricultural network (people) and number of trainings per 5-year period) (b) natural capital (percentage of forest and secondary vegetation on farm, percentage of carbon in soils) (c) physical and financial capital (percentage of farmers with ability to raise capital or access to bank accounts, tropical livestock units per household) **d) Mobilizing factors** (percentage of farmers with access to non-cocoa agricultural groups, with contract agreements with cocoa licensed buying companies and who received drought specific training). Means are presented for all indicators after matching. Significance of average treatment effect on the treated and also difference between non-certified in the two regions (\* $p < 0.10$ , \*\* $p < 0.05$ , \*\*\* $p < 0.01$ ).

Certified farmers were more likely to have received specific drought training (UTZ 26.1 pp,  $p < 0.1$ , Organic 21.7 pp,  $p < 0.1$ , RA 23.9 pp,  $p < 0.01$ ). Certified farmers were not significantly more likely to be part of non-cocoa agricultural groups. Regarding market integration, certified farmers were not significantly more likely to have a purchase agreement with a licensed buying company.

## Discussion

The climate resilience indicator framework, developed through this transdisciplinary research, allowed us to assess the ability of sustainability certification to deliver 'climate resilience', defined inclusively with farmers and cocoa value chain stakeholders. Our findings suggest that sustainability certification has marginally enhanced climate resilience for smallholder cocoa farmers in Ghana, via changes in robustness and adaptability to drought. Certification is associated with enhancement of some aspects of robustness, via changes in input use, but does not lead to more transformative climate resilience enhancement, via the adoption of specific drought resilient measures and strategies as proposed in the certification standards. Consequently, we find no influence of certification on yield responses to drought. Certification is associated with improvement in some adaptability indicators, mostly via social and knowledge capital dimensions (access to cocoa producer groups and training programs). However, drought recovery potential is more strongly influenced by regional differences, rather than certification.

### ***Certification enhances some aspects of robustness and adaptability via changes in input use, farm diversity, as well as social and knowledge capital***

Our findings that certified farmers modify their input use, Organic switching to non-artificial inputs, RA using less pesticides but more fertilizer and UTZ using less pesticides, are consistent with prior studies of UTZ-certified-cocoa in Cote D'Ivoire (Ingram et al., 2014) RA-certified-coffee in Uganda (Vanderhaegen et al., 2018) and Organic-certified-coffee in Costa Rica (Blackman & Naranjo, 2012; Ibanez & Blackman, 2016). We expect that the increased fertilizer use by RA farmers is linked to increased intensity of good agricultural practice (GAP) training. Support is also found in the literature for our finding that certified farmers have higher adaptability in the form of group memberships, training, and higher levels of natural capital (Akrofi-Atitianti et al., 2018; Borsky & Spata, 2013b; Jacobi et al., 2015; Maguire-Rajpaul et al., 2020). For example, Jacobi et al. (2015) show that Organic-certified farmers in Bolivia have larger agricultural networks than conventional farmers. In Ghana, Akrofi-Atitianti et al. (2018) show that openness to cocoa group membership is greater amongst RA and Organic farmers.

Contrary to prior studies that suggest certification often leads to greater specialization (Rueda & Lambin, 2004; Van Rijsbergen et al., 2016), we found that Organic farms have slightly higher diversity of crops in their systems, and RA farms have slightly higher shade-tree diversity (SM6, Figure 3c). However, these effect sizes are relatively small and whilst this demonstrated that these programmes can influence diversification, it also demonstrates that programmes need to be further modified to make them more effective in this regard. Diversity is thought to improve resilience by conferring redundancy in the face of a shock as well as offering ecosystem services, such as reducing pest pressure, that might offset other climate stresses (Loguerio et al., 2020). Additionally, such diversification can help address concurrent challenges from market variability and shocks (Bowman & Zilberman, 2013). However, our results also demonstrate that the higher crop diversity does not necessarily translate into higher income-stream diversity (Figure 3c). Farmers reported that this was due to limited local demand for alternative products and also challenges in bringing fresh produce to market before they rot. This reveals a potential opportunity for sustainability certification programmes, in collaboration with local actors, to focus on developing alternative markets to support more impactful diversification with respect to resilience and livelihoods more broadly.



Building resilience is a dynamic process – the state a system is in before a shock is also relevant to the outcomes during and after a shock. In this sense, yields are a crucial variable as they strongly influence the baseline wellbeing of the farm, particularly with respect to income. Regarding yield outcomes in a ‘normal’ year, we find that RA have greater productivity than conventional, Organic has lower productivity, and UTZ has no significant difference (Figure 4a). These results contrast with a study in Western Ghana which reported higher yields for Organic farms (Akrofi-Atitianti et al., 2018). We expect that these yield differences are linked to fertilizer use and losses from pests and disease. In our study area, the premiums paid to organic farmers for each bag (64 kg) of cocoa produced, on average 26 GHC (4.5 USD or 7% producer price), do not fully compensate the lower yields, corroborating predictions based on premium-yield relationships (Nalley & Dixon, 2012). For RA farmers, higher incomes from higher yields and premiums (13 GHC, 2.25USD on average), place them in a stronger position to confront a shock. Whilst the premiums paid to farmers are generally in line with the certifications agreed value, sometimes payments channelled via farmer organisations do not reach farmers. It is worth noting that often LBCs also pay a premium to non-certified farmers to secure supply. Despite these premiums, persistently low cocoa prices translate into low incomes which impede farmers’ investment in resilience enhancing strategies (Thompson, 2021). This highlights cocoa price as an obvious leverage point, if meaningful action is to be taken by the industry to enhance farmer resilience.

### ***Transformative changes to the farming system are less common***

Whilst we have not provided weightings for different indicators contribution to overall climate resilience in this study, we suggest a hierarchy in terms of how much each indicator contributes to climate resilience, with those indicators linked to more transformative processes (e.g. crop diversification) contributing more than the adoption of individual technologies (e.g. mineral fertilizer). Despite higher levels of training for certified farmers (Figure 6, SM8), we find a dichotomy in the adoption of more basic, required, and auditable agronomic practices (e.g. fertilization) versus more complex adaptation strategies (e.g. diversified incomes), with high adoption of basic strategies and low adoption of more complex aspects (Figure 3). While agronomic practices likely have clearer importance to cocoa farmers, the lack of impact on more complex drought adaptive measures (e.g. water harvesting) and resilience enhancing strategies (e.g. diversified agricultural income) is problematic from a broader perspective, since these have been identified as critical to enhancing climate resilience (Abdulai et al., 2018; Bunn et al., 2019; Maguire-Rajpaul et al., 2020). The lack of impact from certification on yield response to drought can be understood from the lack of impact on climate related adaption at the production system level (Figures 3 and 4).

### ***Broader contributions to improved resilience are limited by the commodity-focus of existing certifications***

The lack of impact on adopting more complex measures may be due to the single commodity focus of the certifications assessed. This result is supported by studies from Ghana and Bolivia that find certified farms have higher agricultural diversity but lower or similar income diversity (Akrofi-Atitianti et al., 2018; Jacobi et al., 2015). This narrow focus tends to conflict with imperatives to diversify farming systems to reduce vulnerability to climate and market shocks and the need to develop alternative crop markets to support this diversification. It also reflects the marginalization of farmers vis-à-vis the supply chain actors that have encouraged these commodity-centered forms of governance to meet their own objectives (Bastos Lima & Persson, 2020). Farmers have generally had limited power to influence how certification systems are developed, for example, to better accommodate diverse livelihood portfolios (Winters et al., 2015).

To deliver climate resilience, we see from the indicator framework (Figure 1), that multiple types of modifications; measures, strategies and asset structure; can be made by cocoa farmers to their livelihood systems. These modifications vary in complexity, from fire inspections to diversifying incomes, and feasibility, from pruning to installing irrigation. Companies and civil society actors focused on sustainability certification that can help catalyze these changes in livelihoods system, include training, auditing, group formation, price premiums and providing infrastructure for the supply of adaptation (Baffoe-Asare et al., 2020; Borsky & Spata, 2013; Lebel et al., 2006; Verburg et al., 2019). Our findings show that these mechanisms are strong at enabling adoption for measures that have high feasibility and low to medium complexity, such as enhanced fertilization. For more complex strategies, the current delivery mechanisms are not, on their own, able to catalyze the uptake of measures that have lower feasibility and higher complexity, such as diversifying agricultural income. In terms of adoption theory, the current delivery mechanisms are able to increase awareness but not necessarily motivation, do not enhance risk bearing capacity and do not increase supply of adaptation (Fankhauser & McDermott, 2014; Marra et al., 2003). Notable exceptions that can inform the improvement of delivery mechanisms, include; RA supply of shade trees and the licensed buying company supply and financing of organic fertilizers to Organic and UTZ farmers.

### ***Certification has the potential to influence recovery from shocks***

Despite similarities in the sensitivity to drought in terms of yield losses for certified and non-certified farmers, certification showed a significant effect on some of the recovery mechanisms employed, such as selling livestock (Figure 5, SM7). This showed that certification has the potential to influence the recovery component of resilience, an aspect that has not been investigated before. These differences in selling livestock (RA with higher propensity) are likely to be influenced by differences in asset structure that has been driven by the certification process, such as RA promoting small livestock rearing. What is not seen are changes in recovery strategy driven by certification directly. Currently certification standards do not focus explicitly on drought recovery mechanisms. This could be an opportunity to apply the resilience lens to certification program design. Though we caution that our findings also highlight the importance to understand the local context in terms of coping mechanisms, as highlighted by Hirons et al. (2018), so as to design such approaches intelligently.

### ***The importance of underlying regional attributes in certification program design***

Beyond certification effects, we find that regional differences predominated in terms of resilience metrics for farmers, across robustness, recovery and adaptability. This is an important finding as these differences are not explained solely by agroecological differences (e.g. climate and soil type) and exemplify that socio-economic differences are critical too (Adger, 2003). Our findings show differences in livelihood systems between Eastern and Western, where Eastern livelihoods are characterized by the post-forest frontier agricultural mosaic, diversification, intermediate cocoa reliance and more livestock, while Western livelihoods are shaped by the forest-frontier; high cocoa reliance, younger and larger farms. In addition, in Western, this greater cocoa specialization coupled with younger farms may also explain greater use of inputs, including liquid fertilizer and insecticides. These regional differences in livelihood system are also supported by Abdulai et al. (2018) in terms of income diversification. Our study allowed to identify a link between these different livelihood structures and the resilience of producers to shocks, for example, livestock ownership and choice of recovery mechanisms, as well as natural capital and adaptability. These factors are rooted in the economic geography of Ghana, with Western undergoing agricultural transformation much later than Eastern (Knudsen & Agergaard, 2015).

Given recent suggestions to plan for climate resilient transformation using agro-climatic zoning (Bunn et al., 2019), we suggest that the underlying socio-economic structures that affect climate resilience should be critically considered in regional zoning for certification. The mechanisms by which certification can enhance resilience are also moderated by this regional context, for example, the higher yielding forest-frontier Western Region makes premium payments to certified farmers more effective compared to the lower yielding Eastern Region. Beyond this, differences in agroforest diversity and proximity to large urban areas, both higher in Eastern Region, mean that strategies to enhance resilience via alternative agroforest income streams also have different potentials. These differences within the national context of Ghana can be expected to be mirrored in other commodity producing countries, in terms of forest-frontier regions versus post-forest transition agricultural mosaic regions, and therefore efforts to contextualize certification to these sub-national contexts should be made. In addition, we would expect wider differences between the Ghanaian context and other commodity producing countries to further moderate the effects of certification on climate resilience. For example, we would expect differences in access to and stability of domestic markets for alternative agroforest products between West African and South American cocoa producing countries to influence the effectiveness of farm diversification strategies in enhancing resilience (Cerdeira et al., 2014; Russell & Franzel, 2004).

### ***Strengths, challenges and limitations of the study***

The resilience concept is championed as useful for guiding policies, programmes and interventions but it is rarely operationalized for their evaluation, particularly in a quantitative manner. In operationalizing this concept, we faced several challenges that are summarized here. Firstly, a key question in the resilience literature ‘for whom?’ (e.g. Cretney, 2014) was overcome with the transdisciplinary research approach allowing us to co-define resilience from the farmers’ perspective. This approach allowed us to respond to another key question ‘to what?’, by narrowing our focus to climate, as farmers identified drought and heatwave as dominant challenges, whilst acknowledging other related risks, such as pests and disease. Another key challenge was attributing indicators to the three resilience components (robustness, recovery, adaptability). This was resolved in the workshop with stakeholders highlighting the cyclical nature of shocks, with activities and outcomes (potential indicators) occurring at a point in time before, during or after a shock. Whilst activities occurring at each of these time points may influence outcomes at other points in the cycle, it was useful from the assessment perspective to frame the indicators in this way as it matched farmer experiences (Figure 2).

The framework we developed is specific to smallholder cocoa production; however, the vast majority of indicators are relevant to other forms of smallholder production and therefore it can, with local specification, be replicated and applied to other contexts. In addition, by using the CEM approach we have been able to make a comparison that accommodates for farmer self-selection into certification schemes; nevertheless, CEM has limitations with the ‘curse of dimensionality’ meaning that the selection of additional control variables leads to ever greater trade-offs between reducing bias and increasing standard error. Beyond this, the interdisciplinary approach, combining the socio-economic survey with biophysical measurements, allowed us to operationalize the resilience framework by evaluating both household and on-farm resilience enhancing pathways. A limitation in this approach is that biophysical measurements are limited to plot-level and do not incorporate landscape scale attributes that could also impact the farmers’ resilience. Conducting the study post-shock is also a limitation as we are unable to track the changes in capitals as a result of the shock, although sales records for cocoa proved useful in clarifying yield recall. Key additional limitations include: reliance on farmer recall in a setting where record keeping is limited, as well as heterogeneity in the time that farmers have been part of certification schemes.

## Conclusion

This article examined whether sustainability certifications can deliver climate resilience benefits to cocoa farmers in Ghana, the second largest cocoa producing region in the world. Using a novel, co-produced resilience indicator framework, we found that certification has strong effects on aspects of farm management that support resilience, but the effects of certification become weaker as the complexity of the resilience-enhancing practices increase. Thus, we find that sustainability certification in its current form is not a sufficient tool for improving the climate resilience of smallholders. Specifically, existing certifications suffer from major gaps between ambition and implementation on the ground, in terms of standards, training, adopted practices and outcomes. However, sustainability certification appears to have indirect benefits for climate resilience, by supporting group formation and strengthening good agronomic practices.

Despite their potential to support some farm and institutional transitions, sustainability certifications may also pose risks to developing climate resilient farming systems. As currently designed such certifications focus heavily on a single commodity, which stands at odds with the potential benefits associated with diversification and multifunctional farming. In addition, we find that accommodating the sub-national regional context as being critical to the effectiveness of certification delivering climate resilience. Therefore, we suggest sustainability certification should be considered as part of a policy mix, that supports the farming system as a whole, not just a single commodity, and builds on broader collaborations by certifiers and the public and private sector to bridge the gaps in adaptation pathways.

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## References

- Abdulai, I., Vaast, P., Hoffmann, M.P., Asare, R., Jassogne, L., Van Asten, P., Rötter, R.P., & Graefe, S. (2018). Cocoa agroforestry is less resilient to sub-optimal and extreme climate than cocoa in full sun. *Glob. Chang. Biol.*, 24(1), 273–286. <https://doi.org/10.1111/gcb.13885>
- Adger, W.N. 2003. *Social aspects of adaptive capacity*, in: *climate change, adaptive capacity and development*. Imperial College Press:29–49 [https://doi.org/10.1142/9781860945816\\_0003](https://doi.org/10.1142/9781860945816_0003)

- Akrofi-Atitianti, F., Ifejika Speranza, C., Bockel, L., & Asare, R. (2018). Assessing climate smart agriculture and its determinants of practice in Ghana: a case of the cocoa production system. *Land*, 7(1), 30. <https://doi.org/10.3390/land7010030>
- Alexander, P., Rounsevell, M.D.A., Dislich, C., Dodson, J.R., Engström, K., & Moran, D. (2015). Drivers for global agricultural land use change: the nexus of diet, population, yield and bioenergy. *Glob. Environ. Chang*, 35, 138–147. <https://doi.org/10.1016/j.gloenvcha.2015.08.011>
- Astrid Fenger, N., Skovmand Bosselmann, A., Asare, R., & de Neergaard, A. (2017). The impact of certification on the natural and financial capitals of Ghanaian cocoa farmers. *Agroecol. Sustain. Food Syst*, 41(2), 143–166. <https://doi.org/10.1080/21683565.2016.1258606>
- Baffoe-Asare, R., Danquah, J.A., & Annor-Frempong, F. (2013). Socioeconomic factors influencing adoption of codapep and cocoa high-tech technologies among small holder farmers in central region of Ghana. *Am. J. Exp. Agric*, 3(2) 277–292. <https://doi.org/10.9734/AJEA/2013/1969>
- Bastos Lima, M.G., & Persson, U.M. (2020). Commodity-centric landscape governance as a double-edged sword: the case of soy and the cerrado working group in Brazil. *Front. For. Glob. Chang*, 3, 27. doi:10.3389/ffgc.2020.00027
- Biazin, B., & Sterk, G. (2013). Drought vulnerability drives land-use and land cover changes in the rift valley dry lands of Ethiopia. *Agric. Ecosyst. Environ*, 164, 100–113. <https://doi.org/10.1016/j.agee.2012.09.012>
- Blackman, A., & Naranjo, M.A. (2012). Does eco-certification have environmental benefits? Organic coffee in Costa Rica. *Ecol. Econ*, 83, 58–66. <https://doi.org/10.1016/j.ecolecon.2012.08.001>
- Blaser, W.J., Oppong, J., Hart, S.P., Landolt, J., Yeboah, E., & Six, J. (2018). Climate-smart sustainable agriculture in low-to-intermediate shade agroforests. *Nat. Sustain*, 1(5), 234–239. <https://doi.org/10.1038/s41893-018-0062-8>
- Borsky, S., & Spata, M. (2018). The impact of fair trade on smallholders' capacity to adapt to climate change. *sustain. Dev*, 26, 379–398. <https://doi.org/10.1002/sd.1712>
- Bowman, M.S., & Zilberman, D. (2013). Economic factors affecting diversified farming systems. *Ecol. Soc*, 18(1), 33. <https://doi.org/10.5751/ES-05574-180133>
- Bunn, C., Läderach, P., Quaye, A., Muilerman, S., Noponen, M.R.A., & Lundy, M. (2019). Recommendation domains to scale out climate change adaptation in cocoa production in Ghana. *Clim. Serv*, 16, 100123. <https://doi.org/10.1016/j.cliser.2019.100123>
- Cerda, R., Deheuvels, O., Calvache, D., Niehaus, L., Saenz, Y., Kent, J., Vilchez, S., Villota, A., Martinez, C., & Somarriba, E. (2014). Contribution of cocoa agroforestry systems to family income and domestic consumption: Looking toward intensification. *Agrofor. Syst*, 88(6), 957–981. <https://doi.org/10.1007/s10457-014-9691-8>
- CGIAR, 2018. CCAFS science supports Ghana's steps towards climate resilient cocoa production. <https://ccafs.cgiar.org/publications/ccafs-science-supports-ghanas-steps-towards-climate-resilient-cocoa-production-800000#.X4hhNi8RpQI>
- Chambers, R., & Conway, G. (1992). *Sustainable rural livelihoods: Practical concepts for the 21st century*. Institute of Development Studies (UK).
- Chavez, E, Conway, G., Ghil, M., & Sadler, M. (2015). *An end-to-end assessment of extreme weather impacts on food security*. Nature Climate Change, 5(11), 997–1001. <https://doi.org/10.1038/NCLIMATE2747>
- Christiaensen, L., Demery, L., & Kuhl, J. (2011). The (evolving) role of agriculture in poverty reduction-An empirical perspective. *J. Dev. Econ*, 96(2), 239–254. <https://doi.org/10.1016/j.jdeveco.2010.10.006>
- COCOBOD, 2016. *Manual for cocoa extension in Ghana*. <https://ccafs.cgiar.org/publications/manual-cocoa-extension-ghana#.X4hmri8RpQI>
- Cohn, A.S., Newton, P., Gil, J.D.B., Kuhl, L., Samberg, L., Ricciardi, V., Manly, J.R., & Northrop, S. (2017). Smallholder agriculture and climate change. *Annu. Rev. Environ. Resour*, 42(1), 347–375. <https://doi.org/10.1146/annurev-environ-102016-060946>
- Cottrell, R.S., Nash, K.L., Halpern, B.S., Remenyi, T.A., Corney, S.P., Fleming, A., Fulton, E.A., Hornborg, S., John, A., Watson, R.A., & Blanchard, J.L. (2019). Food production shocks across land and sea. *Nat. Sustain*, 2(2), 130–137. <https://doi.org/10.1038/s41893-018-0210-1>
- Cretney, R. (2014). Resilience for whom? Emerging critical geographies of socio-ecological resilience. *Geography Compass*, 8(9), 627–640. <https://doi.org/10.1111/gec3.12154>
- de la Plaza Esteban, C., Visseren-Hamakers, I.J., & de Jong, W. (2014). The legitimacy of certification standards in climate change governance. *Sustain. Dev*, 22(6), 420–432. <https://doi.org/10.1002/sd.1568>
- Delaney, A., Evans, T., McGreevy, J., Blekking, J., Schlachter, T., Korhonen-Kurki, K., Tamás, P.A., Crane, T.A., Eakin, H., Förch, W., Jones, L., Nelson, D.R., Oberlack, C., Purdon, M., & Rist, S. (2018). Governance of food systems across scales in times of social-ecological change: A review of indicators. *Food Secur*, 10(2), 287–310. <https://doi.org/10.1007/s12571-018-0770-y>
- Dixon, J., & Stringer, L. (2015). Towards a theoretical grounding of climate resilience assessments for smallholder farming systems in sub-Saharan Africa. *Resources*, 4(1), 128–154. <https://doi.org/10.3390/resources4010128>
- Eakin, H.C., Lemos, M.C., & Nelson, D.R. (2014). Differentiating capacities as a means to sustainable climate change adaptation. *Glob. Environ. Chang*, 27, 1–8. doi:10.1016/j.gloenvcha.2014.04.013

- Fankhauser, S., & McDermott, T.K.J. (2014). Understanding the adaptation deficit: why are poor countries more vulnerable to climate events than rich countries? *Glob. Environ. Chang*, 27, 9–18. <https://doi.org/10.1016/j.gloenvcha.2014.04.014>
- Folke, C. (2006). Resilience: The emergence of a perspective for social–ecological systems analyses. *Global Environmental Change*, 16(3), 253–267. <https://doi.org/10.1016/j.gloenvcha.2006.04.002>
- Frank, J., & Penrose-Buckley, C. (2012). *Small-scale farmers and climate change: how can farmer organisations and fairtrade build the adaptive capacity of smallholders?* International Institute for Environment and Development. <https://pubs.iied.org/16518IIED/>
- Funk, C., Peterson, P., Landsfeld, M., Pedreros, D., Verdin, J., Shukla, S., Husak, G., Rowland, J., Harrison, L., Hoell, A., & Michaelsen, J. (2015). The climate hazards infrared precipitation with stations - A new environmental record for monitoring extremes. *Sci. Data*, 2(1), 1–21. <https://doi.org/10.1038/sdata.2015.66>
- Gallopin, G.C. (2006). Linkages between vulnerability, resilience, and adaptive capacity. *Glob. Environ. Chang*, 16(3), 293–303. <https://doi.org/10.1016/j.gloenvcha.2006.02.004>
- Garrett, R.D., Carlson, K.M., & Rueda, X. (2016). Assessing the potential additionality of certification by the round table on responsible soybeans and the roundtable on sustainable palm oil. *Environ. Res. Lett* 11, no. 4 (2016): 045003. <https://doi.org/10.1088/1748-9326/11/7/079502>
- Garrett, R.D., Levy, S., Gollnow, F., & Rueda, X. (2021). Have food supply chain policies improved forest conservation and rural livelihoods? A systematic review. *Environmental Research Letters*, 16(3), 033002. <https://doi.org/10.1088/1748-9326/abe0ed>
- Glasbergen, P. (2018). Smallholders do not eat certificates. *Ecol. Econ*, 147, 243–252. doi:10.1016/j.ecolecon.2018.01.023
- Gockowski, J., Afari-Sefa, V., Sarpong, D.B., Osei-Asare, Y.B., & Agyeman, N.F. (2013). Improving the productivity and income of Ghanaian cocoa farmers while maintaining environmental services: what role for certification? *Int. J. Agric. Sustain*, 11(4), 331–346. <https://doi.org/10.1080/14735903.2013.772714>
- Godfray, J., Beddington, J.R., Crute, I.R., Haddad, L., Lawrence, D., Muir, J.F., Pretty, J., Robinson, S., Thomas, S.M., & Toulmin, C. (2010). Food security: the challenge of feeding 9 billion people. *Science*, 327(5967), 812–818. <https://doi.org/10.1126/science.1185383>
- Harvey, C.A., Lalaina Rakotobe, Z., Rao, N.S., Dave, R., Razafimahatratra, H., Rabarijohn, R.H., Rajaofara, H., & Mackinnon, J. L. (2014). Extreme vulnerability of smallholder farmers to agricultural risks and climate change in Madagascar. *Philosophical Transactions of the Royal Society B: Biological Sciences* 369(1639), 20130089. <https://doi.org/10.1098/rstb.2013.0089>
- Heckelman, A., Smukler, S., & Wittman, H. (2018). Cultivating climate resilience: A participatory assessment of organic and conventional rice systems in the Philippines. *Renew. Agric. Food Syst*, 33(3), 225–237. <https://doi.org/10.1017/S1742170517000709>
- Hirons, M., Boyd, E., McDermott, C., Asare, R., Morel, A., Mason, J., Malhi, Y., & Norris, K. (2018). Understanding climate resilience in Ghanaian cocoa communities—advancing a biocultural perspective. *Journal of Rural Studies*, 63, 120–129. <https://doi.org/10.1016/j.jrurstud.2018.08.010>
- Ho, D., Imai, K., King, G., & Stuart, E. (2011). MatchIt: nonparametric preprocessing for parametric causal inference. *Journal of Statistical Software*, 42 (8), 1–28. <http://www.jstatsoft.org/v42/i08/>
- Holling, C.S. (1973). Resilience and stability of ecological systems. *Annual Review of Ecology and Systematics*, 4(1), 1–23. <https://doi.org/10.1146/annurev.es.04.10173.000245>
- Hutcheon, W.V., Smith, R.W., & Asomaning, E.J.A. (1973). Effect of irrigation on the yield and physiological behaviour of mature Amelonado cocoa in Ghana. *Trop. Agric. (Trinidad Y Tobago)*, 50 p. 261–272.
- Iacus, S.M., King, G., & Porro, G. (2012). Causal inference without balance checking: Coarsened exact matching. *Polit. Anal*, 20(1), 1–24. <https://doi.org/10.1093/pan/mpr013>
- Ibanez, M., & Blackman, A. (2016). Is eco-certification a win-win for developing country agriculture? Organic coffee certification in Colombia. *World Development*, 82, 14–27. doi:10.1016/j.worlddev.2016.01.004
- Ifejika Speranza, C. (2013). Buffer capacity: Capturing a dimension of resilience to climate change in African smallholder agriculture. *Reg. Environ. Chang*, 13(3), 521–535. <https://doi.org/10.1007/s10113-012-0391-5>
- Ifejika Speranza, C., Wiesmann, U., & Rist, S. (2014). An indicator framework for assessing livelihood resilience in the context of social-ecological dynamics. *Glob. Environ. Chang*, 28, 109–119. <https://doi.org/10.1016/j.gloenvcha.2014.06.005>
- IFOAM, 2017. *Organic agriculture countering climate change*. <https://www.ifoam.bio/organic-agriculture-countering-climate-change> (accessed 10 July 2020)
- Ingram, V., Waarts, Y., Ge, L., Van Vugt, S., Wegner, L., Puister-Jansen, L., Ruf, F., & Tanoh, R. (2014). *Impact of UTZ certification of cocoa in Ivory Coast*. Assessment framework and baseline. [https://www.utz.org/wp-content/uploads/2016/03/Impact-of-UTZ-certification-of-cocoa-in-Ivory-Coast\\_2014.pdf](https://www.utz.org/wp-content/uploads/2016/03/Impact-of-UTZ-certification-of-cocoa-in-Ivory-Coast_2014.pdf)
- ITC, 2019, *The State of sustainable markets 2019*. Intracen. <https://www.intracen.org/uploadedFiles/intracenorg/Content/Publications/Sustainable%20markets%202019%20web.pdf>
- Jacobi, J., Schneider, M., Pillco Mariscal, M., Huber, S., Weidmann, S., Bottazzi, P., & Rist, S. (2015). Farm resilience in organic and nonorganic cocoa farming systems in Alto Beni, Bolivia. *Agroecol. Sustain. Food Syst*, 39(7), 798–823. <https://doi.org/10.1080/21683565.2015.1039158>



- Joerin, J., Dawoe, E., Krutli, P., Benabderrazik, K., Hauenstein, S., Aning, S., Pomaa, A., Thom, B., Thompson, W., Assefa, K., & Six, J. (2018) *Resilience of the Cocoa Value Chain in Ghana*. ETH Zürich. <https://ethz.ch/content/dam/ethz/special-interest/usys/ias/enhancing-resilience-dam/documents/AERTCvc-cocoa-final.pdf>
- Kangogo, D., Dentoni, D., & Bijman, J. (2020). Determinants of farm resilience to climate change: the role of farmer entrepreneurship and value chain collaborations. *Sustainability*, 12(3), 868. <https://doi.org/10.3390/su12030868>
- King, G., & Nielson, R. (2019). Why propensity scores should not be used for matching. *Political Analysis*, 27(4), 435–454. [doi:http://doi.org/10.1017/pan.2019.11](http://doi.org/10.1017/pan.2019.11)
- Knudsen, M.H., & Agergaard, J. (2015). Ghana's cocoa frontier in transition: The role of migration and livelihood diversification. *Geogr. Ann. Ser. B, Hum. Geogr.*, 97(4), 325–342. <https://doi.org/10.1111/geob.12084>
- Lahive, F., Hadley, P., & Daymond, A.J. (2019). The physiological responses of cacao to the environment and the implications for climate change resilience. A review. *Agron. Sustain. Dev.*, 39(1), 1–22. <https://doi.org/10.1007/s13593-018-0552-0>
- Lambin, E.F., Meyfroidt, P., Rueda, X., Blackman, A., Börner, J., Cerutti, P.O., Dietsch, T., Jungmann, L., Lamarque, P., Lister, J., Walker, N.F., & Wunder, S. (2014). Effectiveness and synergies of policy instruments for land use governance in tropical regions. *Glob. Environ. Chang.*, 28, 129–140. [doi:10.1016/j.gloenvcha.2014.06.007](https://doi.org/10.1016/j.gloenvcha.2014.06.007)
- Lampach, N., & Morawetz, U.B. (2016). Credibility of propensity score matching estimates. An example from Fair Trade certification of coffee producers. *Appl. Econ.*, 48(44), 4227–4237. <https://doi.org/10.1080/00036846.2016.1153795>
- Lang, D.J., Wiek, A., Bergmann, M., Stauffacher, M., Martens, P., Moll, P., Swilling, M., & Thomas, C.J. (2012). Transdisciplinary research in sustainability science: Practice, principles, and challenges. *Sustainability Science*, 7(1), 25–43. <https://doi.org/10.1007/s11625-011-0149-x>
- Lebel, L., Anderies, J.M., Wilson, J., Hughes, T.P., Hatfield-Dodds, S., Folke, C., Campbell, B., Campbell, B., Folke, C., Hatfield-Dodds, S., Lebel, L., Anderies, J.M., Wilson, J., Hughes, T.P., Hatfield-Dodds, S., Folke, C., & Campbell, B. (2006). Governance and the capacity to manage resilience in regional social-ecological systems. *Ecol. Soc.*, 11(1). <https://doi.org/10.5751/ES-01606-110119>
- Lemeilleur, S., & Balineau, G. (2016). *Tackling the climate change challenge: what roles for certification and ecolabels? Climate change and agriculture worldwide*. Springer Netherlands. [https://doi.org/10.1007/978-94-017-7462-8\\_22](https://doi.org/10.1007/978-94-017-7462-8_22)
- Lesk, C., Rowhani, P., & Ramankutty, N. (2016). Influence of extreme weather disasters on global crop production. *Nature*, 529(7584), 84–87. <https://doi.org/10.1038/nature16467>
- Loguercio, L.L., Santos, L.S., Niella, G.R., Miranda, R.A.C., de Souza, J.T., Collins, R.T., & Pomella, A.W.V. (2009). Canopy-microclimate effects on the antagonism between *Trichoderma stromaticum* and *Monilophthora perniciosa* in shaded cacao. *Plant Pathol.*, 58(6), 1104–1115. <https://doi.org/10.1111/j.1365-3059.2009.02152.x>
- Maguire-Rajpaul, V.A., Khatun, K., & Hiron, M.A. (2020). Agricultural information's impact on the adaptive capacity of Ghana's smallholder cocoa farmers. *Front. Sustain. Food Syst.*, 4, 28. [doi:10.3389/fsufs.2020.00028](https://doi.org/10.3389/fsufs.2020.00028)
- Marra, M., Pannell, D.J., & Abadi Ghadim, A. (2003). The economics of risk, uncertainty and learning in the adoption of new agricultural technologies: where are we on the learning curve? *Agricultural Systems*, 75(2–3), 215–234. [https://doi.org/10.1016/S0308-521X\(02\)00066-5](https://doi.org/10.1016/S0308-521X(02)00066-5)
- Meemken, E.M., Sellare, J., Kouame, C.N., & Qaim, M. (2019). Effects of fairtrade on the livelihoods of poor rural workers. *Nat. Sustain.*, 2(7), 635–642. <https://doi.org/10.1038/s41893-019-0311-5>
- Mortreux, C., & Barnett, J. (2017). Adaptive capacity: Exploring the research frontier. *Wiley Interdiscip. Rev. Clim. Chang.*, 8(4), e467. <https://doi.org/10.1002/wcc.467>
- Nalley, L.L., & Dixon, B.L. (2012). Necessary price premiums to incentivize Ghanaian organic cocoa production: A phased, orchard management approach. *HortScience*, 47(11), 1617–1624. <https://doi.org/10.21273/HORTSCI.47.11.1617>
- Naturland, 2014. *How to grow organic cocoa*. [https://www.naturland.de/images/UK/Producers/Naturland\\_compensium\\_organic\\_cocoa.pdf](https://www.naturland.de/images/UK/Producers/Naturland_compensium_organic_cocoa.pdf), accessed July 2020
- Naturland, 2020. *Naturland standards on production – Permanent Tropical Plantations*. [https://www.naturland.de/images/UK/Naturland/Naturland\\_Standards/Standards\\_Producers/Naturland-Standards-on-Production.pdf](https://www.naturland.de/images/UK/Naturland/Naturland_Standards/Standards_Producers/Naturland-Standards-on-Production.pdf), accessed July 2020
- Nelson, V., & Tallontire, A. (2014). Battlefields of ideas: Changing narratives and power dynamics in private standards in global agricultural value chains. *Agric. Human Values*, 31(3), 481–497. <https://doi.org/10.1007/s10460-014-9512-8>
- Newbold, T., Hudson, L.N., Hill, S.L.L., Contu, S., Lysenko, I., Senior, R.A., Börger, L., Bennett, D.J., Choimes, A., Collen, B., Day, J., De Palma, A., Díaz, S., Echeverria-Londoño, S., Edgar, M.J., Feldman, A., Garon, M., Harrison, M.L.K., Alhusseini, T., ... Purvis, A. (2015). Global effects of land use on local terrestrial biodiversity. *Nature*, 520(7545), 45–50. <https://doi.org/10.1038/nature14324>
- Newton, P., Agrawal, A., & Wollenberg, L. (2013). Enhancing the sustainability of commodity supply chains in tropical forest and agricultural landscapes. *Glob. Environ. Chang.*, 23, 1761–1772. <https://doi.org/10.1016/j.gloenvcha.2013.08.004>
- Nyantakyi-Frimpong, H., & Bezner-Kerr, R. (2015). The relative importance of climate change in the context of multiple stressors in semi-arid Ghana. *Glob. Environ. Chang.*, 32, 40–56. <https://doi.org/10.1016/j.gloenvcha.2015.03.003>
- Osborn, T.J., Barichivich, J., Harris, I., van der Schrier, G., & Jones, P.D. (2018). Drought [in "State of the Climate in 2017"]. *Bulletin of the American Meteorological Society*, 99, 536–537. <https://doi.org/10.1175/2018BAMSStateoftheClimate.1>

- Otieno, P., Ogotu, C., Mburu, J., & Nyikal, R. (2017). Effect of global-GAP policy on climate change perceptions of smallholder French beans farmers in Central and Eastern Regions, Kenya. *Climate*, 5(2), 27. <https://doi.org/10.3390/cli5020027>
- Pelling, M., & High, C. (2005). Understanding adaptation: what can social capital offer assessments of adaptive capacity? *Glob. Environ. Chang.*, 15(4), 308–319. <https://doi.org/10.1016/j.gloenvcha.2005.02.001>
- Pimm, S.L., Donohue, I., Montoya, J.M., & Loreau, M. (2019). Measuring resilience is essential to understand it. *Nat. Sustain.*, 2(10), 895–897. <https://doi.org/10.1038/s41893-019-0399-7>
- Pohl, C., Krütli, P., & Stauffacher, M. (2017). Ten reflective steps for rendering research societally relevant. *GAI*, 26(1), 43–51. <https://doi.org/10.14512/gaia.26.1.10>
- Puma, M.J., Bose, S., Chon, S.Y., & Cook, B.I. (2015). Assessing the evolving fragility of the global food system. *Environ. Res. Lett.*, 10(2), 24007. <https://doi.org/10.1088/1748-9326/10/2/024007>
- R Core Team. (2020). *R: A language and environment for statistical computing*. R Foundation for Statistical Computing. URL <http://www.R-project.org/>
- Rueda, X., & Lambin, E.F. (2013). Responding to globalization: impacts of certification on Colombian small-scale coffee growers. *Ecol. Soc.*, 18(3). <https://doi.org/10.5751/ES-05595-180321>
- Russell, D., & Franzel, S. (2004). Trees of prosperity: agroforestry, markets and the African smallholder. *Agroforestry Systems*, 61(1), 345–355. <https://doi.org/10.1023/B:AGFO.0000029009.53337.33>
- SAN, 2011. *Sustainable agriculture network (SAN): climate module criteria for mitigation and adaptation to climate change*. <https://www.rainforest-alliance.org/lang/sites/default/files/site-documents/climate/documents/SAN-Climate-Module-January2011.pdf>
- Schipsanski, M.E., MacDonald, G.K., Rosenzweig, S., Chappell, M.J., Bennett, E.M., Kerr, R.B., Blesh, J., Crews, T., Drinkwater, L., Lundgren, J.G., & Schnarr, C. (2016). Realizing resilient food systems. *Bioscience*, 66(7), 600–610. <https://doi.org/10.1093/biosci/biw052>
- Schroth, G., Läderach, P., Martinez-Valle, A.I., Bunn, C., & Jassogne, L. (2016). Vulnerability to climate change of cocoa in West Africa: patterns, opportunities and limits to adaptation. *Sci. Total Environ.*, 556, 231–241. doi:10.1016/j.scitotenv.2016.03.024
- Shanahan, T.M., Overpeck, J.T., Anchukaitis, K.J., Beck, J.W., Cole, J.E., Dettman, D.L., Peck, J.A., Scholz, C.A., & King, J.W. (2009). Atlantic forcing of persistent drought in West Africa. *Science*, 80-.). 324(5925), 377–380. <https://doi.org/10.1126/science.1166352>
- Shiferaw, B., Tesfaye, K., Kassie, M., Abate, T., Prasanna, B.M., & Menkir, A. (2014). Managing vulnerability to drought and enhancing livelihood resilience in sub-Saharan Africa: technological, institutional and policy options. *Weather Clim. Extrem.*, 3, 67–79. <https://doi.org/10.1016/j.wace.2014.04.004>
- Suweis, S., Carr, J.A., Maritan, A., Rinaldo, A., & D'odorico, P. (2015). Resilience and reactivity of global food security. *Proceedings of the National Academy of Sciences*. 112(22), 6902–6907. <https://doi.org/10.1073/pnas.1507366112>
- Swinnen, J.F.M. (2007). *Global supply chains, standards and the poor: how the globalization of food systems and standards affects rural development and poverty*. CAB International Publishing. <https://doi.org/10.1079/9781845931858.0000>
- Sylla, M.B., Nikiema, P.M., Gibba, P., Kebe, I., & Klutse, N.A.B. (2016). Climate change over West Africa: recent trends and future projections. In JA Yaro and J. Hesselberg (eds.), *Adaptation to climate change and variability in rural West Africa* (pp. 25–40). Springer International Publishing. [https://doi.org/10.1007/978-3-319-31499-0\\_3](https://doi.org/10.1007/978-3-319-31499-0_3)
- Tendall, D.M., Joerin, J., Kopainsky, B., Edwards, P., Shreck, A., Le, Q.B., Kruetli, P., Grant, M., & Six, J. (2015). Food system resilience: Defining the concept. *Glob. Food Sec.*, 6, 17–23. <https://doi.org/10.1016/j.gfs.2015.08.001>
- Thompson, W. (2021). *Enhancing smallholder farmer climate resilience in cocoa and banana global food value chains*. ETH Zurich. <https://doi.org/10.3929/ethz-b-000504801>
- Tscharntke, T., Milder, J.C., Schroth, G., Clough, Y., DeClerck, F., Waldron, A., Rice, R., & Ghazoul, J. (2015). Conserving biodiversity through certification of tropical agroforestry crops at local and landscape scales. *Conserv. Lett.*, 8(1), 14–23. <https://doi.org/10.1111/conl.12110>
- UTZ, 2015. *UTZ code of conduct cocoa module 1.1 – 2015*. [https://utz.org/?attachment\\_id=3275](https://utz.org/?attachment_id=3275), accessed 10 July 2020
- UTZ, 2017. *UTZ theory of change 2017*. [https://utz.org/?attachment\\_id=13887](https://utz.org/?attachment_id=13887), accessed 10 July 2020
- van der Ven, H., Rothacker, C., & Cashore, B. (2018). Do eco-labels prevent deforestation? Lessons from non-state market driven governance in the soy, palm oil, and cocoa sectors. *Glob. Environ. Chang.*, 52, 141–151.
- van Rijsbergen, B., Elbers, W., Ruben, R., & Njuguna, S.N. (2016). The ambivalent impact of coffee certification on farmers' welfare: a matched panel approach for cooperatives in central Kenya. *World Development*, 77, 277–292. <https://doi.org/10.1016/j.worlddev.2015.08.021>
- Vanderhaegen, K., Akoyi, K.T., Dekoninck, W., Jocqué, R., Muys, B., Verbist, B., & Maertens, M. (2018). Do private coffee standards 'walk the talk' in improving socio-economic and environmental sustainability? *Glob. Environ. Chang.*, 51, 1–9. <https://doi.org/10.1016/j.gloenvcha.2018.04.014>
- Verburg, R., Rahn, E., Verweij, P., van Kuijk, M., & Ghazoul, J. (2019). An innovation perspective to climate change adaptation in coffee systems. *Environ. Sci. Policy*, 97, 16–24. <https://doi.org/10.1016/j.envsci.2019.03.017>

- Vermeulen, S.J., Campbell, B.M., & Ingram, J.S.I. (2012). Climate Change and Food Systems. *Annu. Rev. Environ. Resour.* 37 (1), 195–222. <https://doi.org/10.1146/annurev-environ-020411-130608>
- Walker, B. (2020). Resilience: What it is and is not. *Ecology and Society*, 25(2), 11. <https://doi.org/10.5751/ES-11647-250211>
- Whitfield, S., Beauchamp, E., Boyd, D.S., Burslem, D., Byg, A., Colledge, F., Cutler, M.E.J., Diden, M., Dougill, A., Foody, G., Godbold, J.A., Hazenbosch, M., Hiron, M., Ifejika Speranza, C., Jew, E., Lacambra, C., Mkwambisi, D., Moges, A., Morel, A., , and White, P.C.L. (2019). Exploring temporality in socio-ecological resilience through experiences of the 2015–16 El Niño across the tropics. *Glob. Environ. Chang.* 55, 1–14. doi:10.1016/j.gloenvcha.2019.01.004
- Winters, P., Kuo, H.-W., Niljinda, C., Chen, B., Alves-Pinto, H.N., Ongun, M., Daryanto, S., & Newton, P. (2015). Voluntary certification design choices influence producer participation, stakeholder acceptance, and environmental sustainability in commodity agriculture sectors in tropical forest landscapes. *J. Sustain. For.* 34(6–7), 581–604. <https://doi.org/10.1080/10549811.2015.1017884>