Co-designing a research agenda for climate adaptation in El Salvador's coffee sector
A transdisciplinary perspective

Teodoro, Jose Daniel; Marselis, Suzanne; Maiello, Antonella; Häger, Achim

DOI
10.1016/j.envsci.2024.103678

Publication date
2024

Document Version
Final published version

Published in
Environmental Science and Policy

Environmental Science and Policy 153 (2024) 103678

Contents lists available at ScienceDirect

Environmental Science and Policy

journal homepage: www.elsevier.com/locate/envsci

Co-designing a research agenda for climate adaptation in El Salvador's coffee sector: A transdisciplinary perspective

Jose Daniel Teodoro [a], Suzanne Marselis [b,*], Antonella Maiello [c], Achim Häger [d]

[a] Resilience Lab, Faculty of Technology, Policy and Management, Delft University of Technology, Delft, the Netherlands
[b] Institute of Environmental Science, Faculty of Science, Leiden University, the Netherlands
[c] Institute of Public Administration, Faculty of Governance and Global Affairs, Leiden University, the Netherlands
[d] Leiden University College The Hague, Faculty of Governance and Global Affairs, Leiden University, the Netherlands

ARTICLE INFO

Keywords:
Stakeholder encounter
Transdisciplinary research
Salvadoran coffee
Climate resilience
Research co-design
Agriculture

ABSTRACT

The inclusion of social actors is widely acknowledged as a precondition for just and sustainable adaptation strategies to climate change. The integration of diverse types of scientific and local knowledge contributes to a better understanding of problems and increases the relevance of science at the local scale. In this study, we - an interdisciplinary team of scientists - employed a transdisciplinary methodology to enable the discussion of collaborative action the Salvadoran coffee sector needs to adapt to current and future impacts of climate change. Through a stakeholder encounter we elicited knowledge exchange among stakeholders to generate (i) a collective awareness of the experiences of climate impacts and (ii) outline a research agenda to facilitate a transdisciplinary climate change adaptation strategy. We used a suite of standard and participatory data-gathering methods, including desk research, in-depth informal conversations, questionnaires, field visits, small-group discussions, and a one-day workshop. In this paper, we present the methodological approach and the outcomes of the transdisciplinary research process. We ultimately outline a collectively generated research agenda using the input of stakeholders who partook in the workshop.

1. Introduction

The adverse effects of climate change are already increasing stress on agricultural systems around the world. Extreme temperatures, droughts and flooding are affecting food security and livelihoods of hundreds of millions of people, especially small-scale producers in low-income countries in the tropics and subtropics (IPCC, 2022). Every additional increment in warming will substantially increase climate hazards and further undermine food security and our ability to eradicate poverty and inequalities in vulnerable regions, including Southern Asia and Africa, as well as Central America (Hallegatte et al., 2016; IPCC, 2022). Participatory processes that enable the inclusion of local ecological knowledge are essential in the adoption of effective climate change adaptation strategies (IPCC, 2022). Top-down generic solutions tend to neglect local knowledge (Anggraeni et al., 2019; Dannevig et al., 2012; Reed, 2008), overlooking unique features within agricultural regions (Dannevig et al., 2012), and thus leading to maladaptation (IPCC, 2022).

To address these challenges, research in climate and environmental governance has increasingly employed transdisciplinary research approaches (Ghodsvali et al., 2019; Jacobi et al., 2022; Jantsch, 1972; Karrasch et al., 2022; Maiello et al., 2013; Nicolescu, 2006). We understood transdisciplinarity as an inclusive epistemology, aimed at the co-production of innovative, context-relevant knowledge that occurs as the collaborative exchange of different kinds of contents – practical, relational, traditional, political, technical, organizational – and through the *encounter* of the actors who hold these kinds of knowledge (Klenk et al., 2015; Klenk and Meehan, 2017; Max-Neef, 2005). The involvement of societal stakeholders in research improves scientists' awareness of the everyday challenges in the implementation of science-based solutions. Integrating the knowledge and language of practitioners and local actors, adds new layers of complexity to the framing for the analysis of a research problem, increasing research relevance (Bernstein, 2015; Jahn et al., 2012; Pohl, 2010; Stokols et al., 2003). Jagannathan et al. (2020) distinguish between *Scope 1* and *Scope 2* co-production processes, meaning between projects that aim at more pragmatic outcomes (Scope 1), like actionable language, eliciting common interests between researchers and practitioners, helping build up a community of practice and those aiming at transformative, that is more

* Correspondence to: Einsteinweg 2, 2333 CC Leiden, the Netherlands.
E-mail address: s.m.marselis@cml.leidenuniv.nl (S. Marselis).

https://doi.org/10.1016/j.envsci.2024.103678
Received 3 February 2023; Received in revised form 8 January 2024; Accepted 14 January 2024
Available online 30 January 2024

structural/radical changes (Scope 2). Transdisciplinary science is the epistemological rationale that underpins our research.

This research focusses on a stakeholder-led adaptation strategy to climate change in the coffee agricultural sector in El Salvador. Inclusive research approaches are not completely new to the Salvadoran context, especially in the environmental and agricultural domains. Méndez and his co-authors have carried out multiple years (from 1999 to 2017) of participatory action research (PAR) with small-scale coffee farmers (Méndez et al., 2017; Méndez, 2008; Bacon et al., 2005). Bendito et al. (2016) investigated the Salvadoran disaster adaptation and prevention, concluding with a call for a transdisciplinary approach in the Salvadoran context, both to include marginalized voices (for example, youth and women) and to trigger a transformative mindset and language (for example, moving from the notion of natural disaster to the human-based disasters). Valencia et al. (2012) applied PAR in the context of forest conservation, in the *Cinquera* Natural Area. Carmona-Galindo et al. (2021), studying Chagas disease, advocated for transdisciplinarity in the definition of adaptation strategies. While all these previous works uphold more transdisciplinary projects in the Salvadoran context, only part of them concretely applied a kind of co-production, and none for a research agenda design, that is at the very early stage of the creative process of knowledge generation (Mauser et al., 2013). Moreover, none of these preliminary works engages with a critical reflection of the process. In most cases, participatory/co-production-related papers conclude with a recommended protocol for actions, neglecting the underlying tensions and relational dynamics of the knowledge co-creation (Turnhout et al., 2020). Our research work built upon the awareness of this research gap and relies on a more critical attitude in transdisciplinary research (Jagannathan et al., 2020; Turnhout et al., 2020; Klenk et al., 2017). We tried to contribute to the co-production practices in the broader field of environmental science and policy in a trifold way. First, we set the scope of our stakeholder engagement at the very early stage of the research process, i.e., at its conception and design, at the agenda setting. Second, we engaged with a broader range of societal actors, beyond disciplinary and sectoral boundaries, reaching out cross-gender and cross-generational groups. Third, we tried to critically reflect on the achievements, pitfalls and perspectives generated through the relations, i.e., the *encountering* (Klenk and Meehan, 2017) with our stakeholders. In one word, we tried to co-design a research agenda together with selected stakeholders. We understand research co-design with Mauser et al. (2013) as the definition of scientific relevance together with academic and non-academic research partners, meaning the identification of research focus, scope and scale through the stakeholder encounter.

By implementing a mix-method approach, we explore transdisciplinary knowledge through various tools and activities with local stakeholders of the coffee sector. The main objective was still within a Scope 1 kind of co-production, to elicit and facilitate knowledge exchange among stakeholders intended to generate (i) a collective awareness of the experiences of climate impacts and (ii) outline a research agenda that may facilitate a successful climate change adaptation strategy. This study is guided by the following questions: How do different stakeholders of the El Salvador coffee sector experience climate change? Which climate change adaptation strategies are prioritized by a diverse group of stakeholders in a transdisciplinary approach? What would a transdisciplinary research agenda for Salvadoran coffee climate change adaptation informed by the diversity of knowledge and perceptions look like?

This article begins with a description of the case study, highlighting the relationship between climate change and coffee in El Salvador. Next, we elaborate on the method of the transdisciplinary research, including the tools employed in this study (e.g., participatory workshops, informal conversations and surveys) that enabled the co-creation of new knowledge (i.e., outputs), and the description of the team composition. Different outputs are presented together with a discussion about their contribution to the wider narrative. In the conclusion, we discuss and reflect on the findings, outlining a collectively generated research agenda.

2. Case study description

We focus on the coffee agricultural sector in El Salvador, located in Central America, a region highly vulnerable to climate change (IPCC, 2022). Ninety percent of the agricultural production in the region is rain-fed, and small-holder farms provide livelihoods for over 2 million families (Donatti et al., 2019; Stewart et al., 2022). Droughts and floods have disproportionately affected food security in rural Central America during the past decade (IPCC, 2022). Moreover, the region is affected by increasing heat extremes and intensified tropical storms (IPCC, 2022, 2021). Temperatures are further projected to increase up to 2.4 °C by 2050, under a moderate scenario (RCP 4.5) (Imbach et al., 2018). Future rainfall projections are uncertain due to the region's varied topography and comparatively sparse ground-based data (IPCC, 2021; Stewart et al., 2022). Reduced precipitation and increased droughts are predicted for northern Central America (Maurer et al., 2009), whereas the south of the region may face more extreme precipitation events (Imbach et al., 2018). Declining crop yields and loss of suitable growing areas are predicted for staple and cash crops including rice, beans, maize, plantains and coffee. Coffee is particularly affected, because increasing temperatures and changing rainfall patterns may decrease the suitable production area by up to 40% during this century (Donatti et al., 2019; Hannah et al., 2017).

Climate change hits the coffee sector at a time of multiple crises, which reinforce each other. Since the late 90 s, coffee farmers have been facing unprecedented price fluctuations, due to market deregulation (Goodman, 2008). In Central America, nearly 80% of coffee farmers own less than 7 ha (Avelino et al., 2015), which means they commonly lack the resources to absorb price shocks. High production costs and low profitability lead to migration, the abandonment of coffee farms, and an aging population of remaining farmers (Goodman, 2008; Harvey and Pilgrim, 2011). The resulting lack of investment and maintenance render coffee plants more susceptible to diseases, such as coffee leaf rust, caused by the fungus *Hemileia vastatrix* (Villarreyna et al., 2020). Coffee rust is favored by increasing temperatures and changes in rainfall patterns. The disease has become an epidemic across Central America, including El Salvador in 2012 (Avelino et al., 2015). Between 2012 and 2014, during the peak of the recent coffee rust epidemic, production in Mexico and Central America declined by more than 20% (FAOSTAT, 2022), which further worsened the economic situation of coffee producers and farm workers (Avelino et al., 2015), and thus, their ability to adapt to climate change.

Coffee production in El Salvador has changed drastically in the past decades. In the seventies, El Salvador produced nearly 200,000 metric tons of green, dried coffee beans making El Salvador the 5th largest coffee producer (Bonilla, 2021). A combination of devastating hurricanes (e.g., Hurricane Mitch in 1998) and volatility in global market prices led to the Salvadoran coffee crisis of 2001 (Blackman et al., 2007). After the outbreak of coffee leaf rust, production in El Salvador decreased by 60% from 2012 to 2013. Currently, coffee exports are only 2% of total exports, at a production rate of ~35,000 metric tons (Bonilla, 2021).

The current effects of climate change in El Salvador include the increase in temperatures and potential evapotranspiration. Dry season precipitation is decreasing in the north, whereas rainfall is increasing during the coldest quarter of the year in south-eastern coffee regions (Fernandez-Kolb et al., 2019). Future climate change is expected to decrease the optimal regions for growing coffee in El Salvador (Bunn et al., 2018; Fernandez-Kolb et al., 2019).

Adaptation approaches at the farm-level to these current and future changes in climate include, e.g., the use of permanent shade, crop and/or income diversification, and the use of climate and fungus-resistant coffee plant varieties. Recently these approaches have been combined

in the climate-smart coffee framework proposed by International Center for Tropical Agriculture (Fernandez-Kolb et al., 2019). They highlight their own framework as a 'snapshot of a developing baseline created to initiate discussion,' but do not yet provide a way forward towards implementation of such climate-smart practices, strategies and enablers.

3. Methodology

Building upon Klenk et al. (2015); Klenk and Meehan (2017), we approach the transdisciplinary work not as an assertive process of engagement but rather as a *stakeholder encounter*. Stakeholder encounter is defined by Klenk et al. (2015) as a process of co-learning through a reciprocal engagement that is both proactive and iterative rather than a dogmatically-prescribed procedure based on pre-established blueprints (i.e., designed outside the context) and based on researchers' convenience. We aimed to identify a societally relevant research focus through the exploration of the context. In doing that, we invested considerable time in preparing the collaborative field, through a process that scholars have defined as *preflection* (Bacon et al., 2005) and which for us consisted of two main moments: 1) mapping the context, diachronically (over the history of the country) and synchronically, through the identification and outreach of the current ecosystem of actors; 2) encountering and engaging these actors through meetings, conversation, surveys and an in-situ workshop. We took advantage of the interdisciplinary composition of our team to identify and engage the largest diversity of actors. We also seized this interdisciplinary aspect in a reflective way, by drawing the conclusions of our work and the learned lessons for future research. Our research team is made of four people, a data scientist, with a background in geography and environmental science; a climate scientist with a background in political and economic geography; a forest scientist, with experience in coffee agriculture, and a political scientist, with experience in public participation and transdisciplinary research. The four of us had past research work experience and strong personal ties with Latin America and could perfectly understand Spanish. Two fluently speak Spanish. One of us is a Salvadoran citizen, who was born and raised in the country, with a rooted local network. Our composition worked as an enabling factor, allowing us to activate contacts with multiple societal actors, from National governmental agencies to scientific and knowledge institutions, to NGOs and social movements, to emphasize complementary aspects of coffee adaptation, from the agricultural to the political. On the other hand, it also steered our research decisions, resulting in inevitable selection biases that we discuss in the last section.

3.1. Stakeholder mapping and outreach

We started this stage with a broad desk research (academic literature, media outlets, governmental reports and webpage) and the more we searched the more we were able to replace the vague and, at times misleading, word of "stakeholder" (Canfield et al., 2021) with specific groups and names. Following Reed et al. (2009), we maintained a laxed definition for stakeholder identification, with an understanding that stakeholders have various types of relational connections with other stakeholders and we wanted to capture a broad range of actors. We compiled a registry with contact information and all listed stakeholders were approached to introduce the research project and invite them to participate in a short survey and videocalls. We handled this task with a sense of discovery and always disclosed to participants the limitations of our knowledge (Méndez et al., 2017, pg. 4). This means that we approached stakeholders with the aim of an open knowledge exchange and shaped the relationship with them as a mutual learning process. In doing so we used humility (Mendéz et al., ibid) acknowledging our limited awareness of the local context and recognizing their competences and specific perspectives. At the same time, our aim was not only to learn but also to give back, by bringing relevant insight to our emerging Salvadoran network. The type of content we sought to bring was related to climate impact on forest and agriculture and related adaptation strategies and the transdisciplinary method in designing climate governance scenarios. We used this stage of the process to expand our understanding of the local social-ecological context and learn about the climate-related challenges. During initial contact, respondents were also asked to nominate other stakeholders in the coffee sector interested in climate change adaptation. Thus, we employed a snowball approach in the identification of and outreach to stakeholders (Leventon et al., 2016).

3.2. Stakeholder encounter

The goal of the fieldwork was to immerse the research team into the everyday experiences of local stakeholders and improve the understanding of the challenges posed by climate change. This second stage of our approach consisted of applying three different techniques: in-field visits, questionnaires, and a final workshop.

3.2.1. Field visits

There were two types of field visits: outdoor visits to coffee farms and indoor meetings with stakeholders at their workplaces. The visits to the two coffee farms: one small-sized farm located in the coffee region Bálsamo and a medium-sized farm in the coffee region of Apaneca-Ilamatepec. When visiting the farms, we collected first-hand observational data about the ecological, social, and economic conditions of the coffee farms. Conversations always highlighted the climate stresses and shocks the coffee plants are experiencing and affecting production. Moreover, field visits enabled stakeholders to share their stories, and describe their relationships with their work and land, and their underpinning values and priorities. Extensive field notes were written down during the tours and informal conversations. We always asked for oral consent before starting to take notes and for written consent in the few cases we wanted to use part of these notes for publications.

Other small-group meetings with government representatives included the *CSC*, the *ESCO*, and a class of 3rd-year bachelor students from the *ENA* (See Table 2, for the full names) which enabled us to engage with the challenges of a climate-resilient coffee sector from the youth perspectives. Throughout our interactions leading up to the workshop, we continued snowball sampling with the aim to reach the

Table 1
Outline of the participatory workshop including descriptions of all activities organized during the workshop.

Type	Activity	Description
Dissemination	presentations	Thematic presentations by various stakeholders, including climate science and agroecological research.
Interaction	World Café	Groups of participants discussed two questions about climate impacts and adaptation practices.
Dissemination	presentations	Thematic presentations by various stakeholders, including an introduction to transdisciplinary science and social networks.
Interaction	Network mapping*	Participants grouped by stakeholder type were asked to generate a list of relevant stakeholders and their relations in terms of information and financial flows.
Dissemination	presentations	Thematic presentations by various stakeholders, including an update by the ministry of agriculture on the policy landscape.
Interaction	Stakeholder questions	Participants identify knowledge gaps in the process of adapting the coffee sector to climate change.
Interaction	Workshop evaluation	Participants filled out a brief evaluation form about their experiences from the workshop (included in Appendix B).

* The network mapping activity yielded insightful data which was excluded from this study and left for additional research.

Table 2
Registry of identified Stakeholders in El Salvador's coffee sector.

	Public Institutions	Coffee business actors (farmers, producers, exporters)	Civil society organizations (NGOs, social movements)	Education facilities and scientific institutions	International organizations and institutions
Desk outreach	CENTA (International centre for agricultural and forestry technology) SNET (National service of territorial study) Banca Agropyme (Mortgage Bank) CSC (Salvadoran Coffee Council, governmental agency) MAG (Ministry of Agriculture) ESCO (National Government Cooperation Agency)	Abad coffee cooperative Santo Domingo estate and product VENTA de agricultura Agroeco estate Herandez (small coffee farm) El pino coffee cooperative Cuzacachapa coffee cooperative FESACORA (Agrarian reform coffee union) APECAFE (Small coffee producer association) Technoserve consultancy group Alliance for the coffee sector PROMECAFE (Consultancy group)	ORMUSA (Women organization for peace) MSM (Salvadoran women movement) CRC (Local Reconstruction Committee) CESTA (Environmental NGO) Salvanatura (Envrionmental NGO) APES (Salvadoran journalist association) UNES (Salvadoran ecological unit) IM-Defensoras (Mesoamerican women initiative for human rights)	PROCAFE (Salvadoran foundation for coffee research) Zamorano university Matias Delgado university World coffee research CGIAR (Consultancy group for International Agricultural Research) ENA national school of agriculture	USAID Italian cooperation agency (CI) Spanish embassy Fairtrade certifier
In-field/ Work-shop snowball	MINED (ministry of education) MARN-DOA (Environmental threats observatory, ministry of environmental resources) MITUR (Tourism ministy) BANDESAL (Development bank) CASATUR (Tourism chamber) ISTA (Salvadoran institute for agriculture transformation) Municipalities Agricultural commission of congress	Seed Banks Coffee processors Fertica NCBA CLUSA UCAFES Cooperativas UCRAPROBEX Coop BFA - Bank	ADESCO (Community development associations) MODES (Salvadoran NGO movement for solidarity development) MOVIAC (Climate change victims association)	FEWSNET (Famine early warning system nework) FAC Ciéncia Agronómicas	MOCCA (USDA Initiative for coffee and cacao producers)

most diverse and widest group of stakeholders for the in-person workshop.

3.2.2. *Questionnaire*

Throughout the field research, we asked encountered stakeholders to complete a short questionnaire about their perceptions of climate change in the Salvadoran coffee sector. This questionnaire gauged the respondents' perception on climate change impacts and adaptation options (the complete questionnaire is presented in English and Spanish in Appendix A).

3.2.3. *Workshop*

The participatory workshop had four main goals: (1) exchange knowledge about climate change impacts to all parts of the coffee value chain, (2) identify climate change adaptation avenues and challenges, (3) enable interaction and collaboration among stakeholders to support climate adaptation efforts in the coffee sector, and (4) ask participants to nominate research questions and contribute to the design of climate adaptation research. The attendance list of the workshop was capped at 30 attendees.

To accomplish the goals of the workshop, we designed a program that aimed to balance the allocation of time between knowledge dissemination and knowledge acquisition (Table 1).

The data collected from the 1-day workshop included written input by individuals or groups, audio recordings from group activities and plenary discussions. These data were analyzed after the field visit.

The world café session generated the output of large pieces of paper with the collective notes of the participants. The information in these sheets of paper was digitized into word documents. The digitized text was coded inductively by all authors separately, while comparing and discussing emerging themes across workshop participants (Linneberg and Korsgaard, 2019). The four sets of codes were jointly discussed to fine-tune the consistency of the coding process. The coding took place on the original Spanish data. Final codes were translated to English. Using the codes, we were able to identify emerging themes regarding the two prompted questions: (1) *How do you perceive the effects of climate change in your daily life?* and (2) *How do you think the coffee sector in El Salvador can adapt to the impacts of climate change?* Finally, we present a collectively-generated view of climate change impacts and responses.

To address the third question of the study, participants were asked to submit research questions. A total of 51 questions were submitted by participants, with all participants submitting at least one question. These questions were digitized in a word document, cleaned from duplicates, rephrased for clarification and grouped into categories. The categories resulted from the analysis of the questions. This final list of questions was shared with the workshop participants two months after the workshop. Each registered participant was asked to indicate which five questions they considered most important. They were also given the opportunity to add any additional questions that arose in the last two months.

4. Results and discussion

4.1. *Stakeholder outreach and mapping: learning from and with the local actors*

The stakeholder landscape in the coffee sector of El Salvador was mapped through a two-step approach: the desk research and the snowball process. As we got acquainted with the history and current context of El Salvador, we filled in our stakeholder registry (map) and organized it into societal categories (Table 2). This resulted in an initial list of 39 stakeholders, who we partially reached out to and invited to the workshop. The stakeholder registry covered five categories of relevant actors: (1) public institutions, (2) coffee business actors (e.g., farmers,

producers, exporters), (3) civil society organizations (NGOs and social movements), (4) Education facilities and scientific institutions, (5) international organizations and institutions (Table 2).

The identification and classification of our stakeholders resulted from an open-ended, context-informed, process. The desk research and the online meetings with actors such as ENA's Director, members of the Ministry of the Environment, national agricultural experts, and local NGOs revealed three important points. First, the need for us as a group of academics to develop a common language among ourselves and with stakeholders, to enable clear and constructive dialogue. Second, the role coffee has played and still plays in the identity and culture of the country, including the role of place-based organizations and outmigration. Third, the predominance of technological solutions in the current coffee climate adaptation discourse and the focus of the agro-technical aspects (crops, genetics, pests combat and prevention), neglecting structural social and cultural dimensions (e.g., strong inequalities within the coffee sector, in terms of wealth, gender and generational participation).

As for the first point, after a broad online meeting, on June 30th, 2022, with participants from the Ministry of Agriculture, ENA and other agriculture experts, we realized we should not use the word "*transdisciplinarity*" during the preliminary outreach process. Stakeholders perceived the concept as vague and could not grasp its relevance for the Salvadoran coffee sector. While we were introducing ourselves as an interdisciplinary team, they were expecting a transfer of usable technical information from our side. This prompted us to find a better way to introduce transdisciplinary research, without using the term.

As for the second point, while not apparently connected to climate change and coffee, through our desk research and later our stakeholder encounter, we realized we had to engage with women groups. Historically, especially during and soon after the civil war, women have been playing a key role in the Salvadoran rural economy (Hecht et al., 2006; Viterna, 2013). We reached out to three women's organizations, of whom two registered for the participatory workshop. The informal conversations with the President of the Women's Movement (MSM) allowed us to reflect on the social structure of the Salvadoran coffee sector, in between large-scale landowners, who have been the elite of the country, and many small coffee producers. Through these conversations, we learned that the members of MSM collectively manage a small coffee farm and offer training activities for women on coffee farming. Two non-agricultural important aspects arose during the outreach: the generational gap in (coffee) agriculture and (out)migration. Odette Varela, director of the National School of Agriculture (ENA), and expert on agroindustry and agribusiness, said during our online meeting on 20 June 2022 *"We are an agriculture country […] but people do not want to work in the field [.] young people are not working in agriculture"*. El Salvador is experiencing large-scale movement from the rural areas to cities, as many other countries, but has also been characterized by a high emigration rate, with 3 out of 10 Salvadorans currently living in the U.S. (Contreras, 2022). Foreign remittance account for 24% of National GDP (World Bank, 2020) and in the past, this has been an important part of the government's development strategy (Wiltberger, 2014). While the emigration rate is slightly decreasing compared to previous years (World Bank, 2017), outmigration is still an issue of concern.

As for the third point, encountered stakeholders showed a clear prominent interest in technological solutions for climate adaptation strategies. This was also reflected in the snowball sampling outcomes, where respondents consider technically-oriented actors more important than socially-oriented actors and, eventually, in the country's strategies for climate adaptation (Hernández et al., 2022).

4.2. Perceptions of climate change

Results from the questionnaire about the perceptions of climate change show a general awareness of the threats of climate change (Table 3). Researchers rate their understanding of climate risks higher, but it appears that knowledge may not be transferred to younger generations most effectively. Moreover, coffee producers expressed they had little knowledge of where to seek help in adapting to climate change.

It was expressed by all respondents, with no exception, that they experience the effects of climate change in their lives. Multiple stakeholders stated during conversations and the participatory workshop that the climate in El Salvador has changed notably in the last decades and more intense climate events have been experienced in recent years. Most respondents of the questionnaire are aware of the risks of climate change to the coffee sector and the need for adaptation. All stakeholder groups share the view that diversification of agricultural crops is essential to increase resilience to climate change.

Researchers reported feeling slightly more confident about their level of knowledge on climate change and their ability to recognize the effects of climate change. Out of all groups, coffee producers (farmers) reported knowing the least about the sources of support for climate adaptation issues (Fig. 1).

Producers feel the highest urgency of the climate problem, covering clearer and radical positions (never neutral). In contrast, government

Table 3
Average and standard deviation of responses to perceptions questionnaire, shown by stakeholder type. All statements on perceptions of climate change were rated on a Likert scale from 1 to 5 corresponding to "strongly disagree (1)", "disagree (2)", "neutral (3)", "agree (4)" and "strongly agree (5)". The students answered these questions through an online form, with all questions mandatory before submitting the form. All other respondents filled out the questionnaire on paper, questions (g), (h) and (i) were located on the back of the questionnaire and not noticed and answered by all respondents.

	All respondents	Producers	Researchers	Government	Students
(a) I have enough knowledge about climate change	3.6 ± 1.0 (n = 58)	3.5 ± 0.9 (n = 11)	3.8 ± 0.7 (n = 8)	3.6 ± 0.9 (n = 13)	3.4 ± 1.1 (n = 22)
(b) Climate change will have a negative effect on coffee production in El Salvador	4.6 ± 0.6 (n = 58)	4.5 ± 0.9 (n = 11)	4.6 ± 0.5 (n = 8)	4.5 ± 0.7 (n = 13)	4.7 ± 0.6 (n = 22)
(c) I understand exactly the risks of climate change in coffee in El Salvador	4.1 ± 0.9 (n = 58)	4.0 ± 0.9 (n = 11)	4.0 ± 0.9 (n = 8)	3.8 ± 0.9 (n = 13)	4.2 ± 0.7 (n = 22)
(d) The coffee sector has to drastically adapt to climate changes	4.3 ± 0.9 (n = 58)	4.5 ± 0.8 (n = 11)	4.6 ± 0.7 (n = 8)	4.2 ± 1.3 (n = 13)	4.2 ± 0.9 (n = 22)
(e) The coffee sector has the potential to contribute to resilience to climate impacts	4.5 ± 0.7 (n = 57)	4.6 ± 0.5 (n = 10)	4.6 ± 0.5 (n = 8)	4.8 ± 0.6 (n = 13)	4.2 ± 0.9 (n = 22)
(f) Diversification of agricultural crops is essential to increase climate resilience	4.6 ± 0.6 (n = 58)	4.5 ± 0.7 (n = 11)	4.5 ± 0.9 (n = 8)	4.6 ± 0.8 (n = 13)	4.6 ± 0.5 (n = 22)
(g) I do not recognize the effect of climate change on the local environment in which I live and/or work	2.3 ± 1.4 (n = 52)	1.9 ± 0.9 (n = 7)	1.3 ± 0.8 (n = 7)	2.1 ± 1.2 (n = 12)	2.9 ± 1.5 (n = 22)
(h) I know where to find support for climate change adaptation issues	3.0 ± 1.2 (n = 53)	2.1 ± 1.7 (n = 7)	2.9 ± 1.5 (n = 8)	3.3 ± 0.9 (n = 12)	3.1 ± 1.1 (n = 22)
(i) Climate change is already affecting my life and the natural environment in which I live	4.4 ± 0.9 (n = 54)	4.5 ± 1.1 (n = 8)	4.4 ± 1.1 (n = 8)	4.4 ± 0.8 (n = 12)	4.3 ± 0.7 (n = 22)

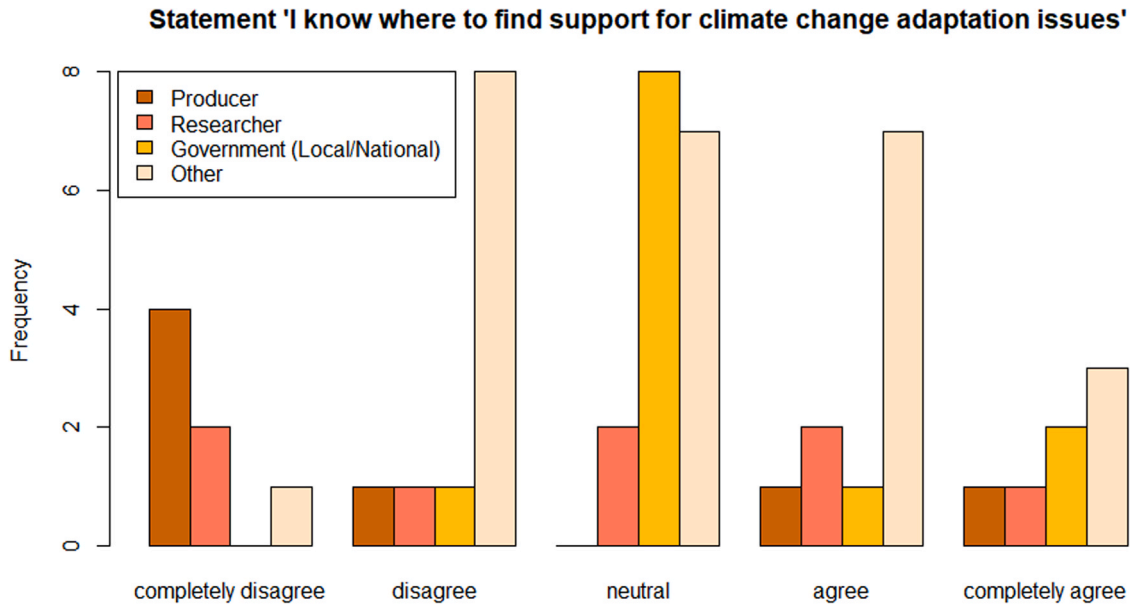

Fig. 1. Distribution of answers from different stakeholder groups to the statement "I know where to find support for climate change adaptation issues". Coffee producers generally appeared to be the least aware of where to find support, whereas government representatives seemed most informed regarding this topic. Category 'other' included students, seed and coffee traders and 'other' as specified in the questionnaire (Appendix A).

employees were often neutral and never in complete disagreement with the survey statements (Table 3). Taken together, the results of this small sample of Salvadoran coffee-sector actors show that there is no room for climate skepticism in this context, also corroborated by the other data of this research. These findings are in line with (Harvey et al., 2018) who conducted similar research among Central American farmers (among which 188 coffee farmers). The feeling of uncertainty and of a knowledge gap, expressed here, especially by coffee producers, is a common trait with their European counterparts, as resulted from a study on climate change perceptions by European farmers (Ricart et al., 2018).

4.3. Workshop

4.3.1. The world café

The first world café question regarded how climate change effects are perceived by the different stakeholders in their daily lives. Many observations related to changes in observed weather patterns (Table 4): increased variability (n = 9), increased rainfall and temperatures (n = 5), extreme weather events (n = 5), and droughts (n = 3). Examples include *'higher temperatures'*, *'unpredictable precipitation patterns'*, *'more frequent hurricanes'* and *'drying up of water resources.'* Related to that, changes and uncertainty in the implementation of agricultural practices (n = 6) were mentioned, including *'it is difficult to create work plans for the year due to weather changes.'* Increases in pests and diseases (n = 5) were also mentioned frequently. Financial consequences (n = 5) such as *'changes in market prices'* and societal consequences (n = 6), including *'traffic jams'* and *'higher energy consumption'*, were mentioned as well. Other environmental consequences (n = 4) such as the *'acceleration of biological life cycles'* and health & mental health consequences (n = 3) including the *'psychological effect on the population'* were mentioned as well. Finally, lower agricultural yields (n = 2) have been observed.

The second world café question, related to adaptation strategies to climate change, revealed the potential adoption of many best agricultural management practices (n = 31 out of n = 45). To retain more detail on the topic of best management practices, we subdivided this code into different subcategories. Most mentions by participants related to coffee plant diversification (n = 8), including the *'Sowing of varieties resistant to different conditions: pests, soil, agroecological condition'*, *'resistant varieties'* and the *'planting of grafted coffee plants.'* Mentions of soil conservation (n = 5) related to a.o. *'the use of life or dead barriers'* and *'the application of organic material'*. Diversification with other crops (n = 4) was also mentioned and included the production of *'more sub-*

Table 4
Final codes from the world café outputs to Questions 1 and 2. n indicates the number of answers assigned to the categories. Note that the 'best management practices' code (n = 31) has been divided into subcategories to retain the many nuances provided under this category.

World Café Q1: "How do you perceive the effects of climate change in your daily life?"		World Café Q2: "How do you think the coffee sector in El Salvador can adapt to the impacts of climate change?"			
Final code	*n*	*Final code*	*n*	*Subcategory of best management practices*	*n*
Increased variability in weather patterns	9	Best management practices	31	Coffee plant diversification	8
Changes in agricultural practices	6	Cultural and societal changes	5	Soil conservation	5
Societal consequences	6	Information	4	Crop diversification	4
Increased rainfall and temperatures	5	Technological development and innovation	3	Integrated management	3
Increase in pests, plagues and diseases	5	Financial support	2	Coffee processing	3
Financial consequences	5			Shade management	3
Extreme weather events	5			Water harvesting	2
Environmental consequences	4			Biodiversity	2
Health & mental health consequences	3			Reduced herbicides	1
Droughts	3			Fertilizers	1
Lower agricultural yields	2			Sowing	1
Total	*53*	*Total*	*45*	*Total*	*31*

products' and '*coffee with beekeeping'*. Several practices related to coffee processing (n = 3) were mentioned as well, including *'proper management of waste water.'* Integrated management practices were mentioned to deal with pests and diseases and climate change resiliency in general. Other practices related to working with high biodiversity on the farm (n = 2), harvesting of water (n = 2), management of shade trees (n = 3), proper application of herbicides (n = 1) and fertilizers (n = 1) and the time of sowing (n = 1). Cultural and societal changes (n = 5), including policy changes, were coded in sentences like *'Focus on civil society and its well-being'* and the '*generation of friendlier public policies'* among others. Access to Information (n = 4) including *'Producer training and awareness'* and capacity building and the development of new technologies (n = 3) were mentioned as well. Finally, financial support (n = 2) was mentioned in terms of investments.

Consistent with the perception results, the world café small group discussion confirmed that climate change is already affecting the range of stakeholders. Farmers experience this in many ways and especially through the frustration with weather unpredictability and the need to adapt their agricultural practices to the new irregular climatic cycles. According to the participants, climate change also affects daily life in urban areas (for example because of floods and increasing traffic jams), with psychological repercussions and impacts on the overall quality of life. The observations of climate change are consistent with other studies reporting high temperatures, droughts, extreme events and unpredictable weather patterns among the most important climate impacts reported by coffee farmers in the region (Harvey et al., 2018). There is also consensus that these climate change impacts are reducing the area that is optimal for coffee production and that strong adaptation measures are required to maintain the sector viable (Fernandez-Kolb et al., 2019; Jawo et al., 2022; Pham et al., 2019).

Regarding solutions, the second world café discussion reveals two prevailing attitudes. On the one hand the search for and confidence in innovation, best management practices, and references to traditionally employed techniques (like diversification). On the other hand, interestingly, the development and sharing of practical knowledge appeared to be deemed more relevant than financial support. This speaks for the motivation and strong (cultural as well as emotional) ties of Salvadoran coffee stakeholders. This represents a context-specific element which deserves attention for the design of climate adaptation strategies, since it constitutes at the same time a strength and a weakness. On the one hand, it is a strong motivator in incremental adaptative measures. On the other hand, the emotional/cultural ties can represent a barrier to more structural necessary changes, for example, downscaling large farms and diversifying the agricultural business.

Although the adaptation strategies identified by the participants were mostly consistent with previous studies based on small-holder surveys (Harvey et al., 2018) or systematic literature reviews (Donatti et al., 2019; Jawo et al., 2022; Pham et al., 2019) there were some interesting differences in the prioritization or frequency with which these strategies were mentioned. Whereas workshop participants would rate measures, such as coffee plant diversification, crop diversification and soil conservation similarly important as previous studies, agroforestry practices were mentioned much less frequently. One possible reason could be that coffee is already predominantly grown under shade trees in El Salvador (CSC, 2020). It is also notable that the increased use of fertilizers and pesticides, as well as irrigation, which are often applied or recommended elsewhere (Donatti et al., 2019; Fernandez-Kolb et al., 2019; Harvey et al., 2018; Pham et al., 2019) were not mentioned by the participants. It is possible that these measures are considered very costly, especially when the profitability of coffee production is low (Avelino et al., 2015), and that ecosystem-based approaches, such as soil conservation or diversified crops are more accessible for farmers (Harvey et al., 2018). In this context, it is also evident that access to capacity building (information) and financial support are key enabling factors for climate change adaptation (Fernandez-Kolb et al., 2019). Finally, it should be noted that transformative adaptation measures, such as shifting crop areas or migration (Donatti et al., 2019; Pham et al., 2019), were not discussed by the participants.

4.3.2. Stakeholder-nominated questions

Participants submitted fifty-one questions during the final interactive session of the workshop. The type of submitted questions was very varied in terms of domains. After the workshop, a final list of thirty-two questions were clustered them into categories: (a) cultivation practices, (b) information, (c) inter-generational, (d) business & economy, (e) holistic approach, (f) strategies & value chain, (g) climate science (h) cultural change, and (i) enablers. The full list of nominated questions can be found in Appendix C. We reached out to all participating stakeholders two months after the workshop to ask them to indicate the five questions they deem most relevant. Only 12 of the 30 stakeholders contributed to the ranking of questions (complete ratings in appendix C). The questions that were indicated as most important related to the themes of cultivation practices, information, inter-generational, business & economy and strategies and value chain (Table 5). The question rated as most important was related to the types of innovations (such as practices) that must be adopted at the farm-level to increase resilience to climate change.

The compiled questions offer a unique perspective on research priorities of the participants from the Salvadoran coffee sector. Recent, comprehensive papers based on literature reviews or stakeholder participation usually cover a broader geographical range (Mesoamerica or global), and often refer to additional smallholder farming systems besides coffee (see, e.g., Harvey et al., 2018; Donatti et al., 2019; Jawo et al., 2022; Pham et al., 2019).

Questions 1 and 3 are very broad and indeed elaborated in more detail by different participants. Research needs about adaptation measures are often discussed in the context of cost-effectiveness and accessibility (e.g. Baca et al., 2014, Donatti et al., 2019; Harvey et al., 2018). Research needs about climate change impacts on coffee have been identified e.g. by Bouroncle et al. (2017), Donatti et al. (2019) and Pham et al. (2019) and focus on farmer vulnerability and shift of suitable coffee areas. These studies can help to further refine locally tailored research needs on these questions in collaboration with local stakeholders.

Question 2 is highly relevant in the context of systemic and transformative adaptation (Fernandez-Kolb et al., 2019), however, it has apparently not been discussed widely in terms of future research directions with the exception of cocoa (de Sousa et al., 2019). In this case,

Table 5
Final list of open questions submitted by stakeholders during the final session of the workshop. Votes resulted from the final request to stakeholders to indicate the five questions they considered most important.

Category	Question	# Votes
Cultivation practices	1. What types of innovations (such as practices) must be adopted to be resilient to climate change?	8
	2. What are other crops more resilient to climate change and therefore could replace coffee?	4
Information	3. What is the scientific relationship between climatic factors and coffee production in order to predict the effects of climate on coffee production?	5
Inter-generational	4. Is the next generation ready to continue with the coffee business?	4
Business & Economy	5. What are, and how to measure, the eco-systemic (environmental) services provided by coffee plantations in order to generate economic benefits for producers?	4
Strategies & Value Chain	6. How would you expect to develop strategies or incentives for sustainable coffee production in abandoned areas? (This to avoid deforestation and loss of productive areas).	4

research needs about suitable alternative crops and markets could be further refined with local stakeholders.

The remaining questions bring critical societal aspects into the scientific discussion on climate and agriculture (Q4 and Q5 in Table 5). On the one hand, many other structural problems of the Salvadoran context (e.g., inequalities, democratization, participation of political and economic power), were not mentioned in the discussion. This may be a result of a low representativeness in the engaged group of stakeholders. On the other hand, research needs about intergenerational problems, the anxiety of young producers as well as the concern with reviving abandoned areas, were brought forwards by participants, while have been discussed by only few authors (see e.g., Méndez et al., 2017 on cross-generational collaborations and Richards and Méndez, 2014 on payment for ecosystem services). This shows the added value of the transdisciplinary method and the importance of approaching the conversation with stakeholders as an encounter. Participatory processes are especially relevant in the case of coffee production, where decision-making is strongly influenced by aspects of culture and local identity (Tucker et al., 2010). Encountering, rather than engaging from a top-down perspective, allowed each participant to be aware of their own subjectivity (Klenk and Meehan, 2017) and power to contribute to the discussion, regardless of their background. This conclusion was highly corroborated by the results of the workshop evaluation.

4.3.3. Workshop evaluation

At the end of the workshop, there were sixteen participants remaining (excluding the research team) and they were asked to complete a short evaluation survey. In the first question, the participants reflected on what they had learned during the workshop. The most-often mentioned themes related to acquiring new information on climate change in general (6 people) and the effects of climate change (3) and climate vulnerability (1). Also, the concepts *inter-* and *trans*disciplinarity (4), the use of a stakeholder-led scientific method (3 people), and an increased understanding of the different actors and their roles and perspectives were mentioned frequently (7). Many participants also indicated they had learned about different challenges in the coffee sector (5) and possibilities for adaptation strategies (4) and had gained a greater awareness of the government plans (2).

In the second question, the participants indicated whether they made new connections, and most participants completely agreed (n = 10) or agreed (n = 4), while two participants remained neutral. The third question revealed that most participants completely agreed (n = 11) that the workshop had changed their vision on how to address climate change adaptation in the coffee sector, 2 participants agreed with the statement, 2 remained neutral and 1 completely disagreed. The participants that indicated their vision changed, explained this with statements such as "*because I heard multiple viewpoints*" and *"Interacting with different actors in the value chain allows knowing their points of view and knowing what each one can achieve with their activities."* The participant that completely disagreed wrote, "*I have knowledge of climate change and its potential impact on various crops, in addition to considering that a transdisciplinary and multi-sectoral approach is needed."*

During the initial stages of the outreach, we encountered skepticism in stakeholders surrounding the idea of transdisciplinarity. The stakeholders we approached were unfamiliar with, and a little apprehensive about, the concept, but often at the same time interested enough to choose to partake. At the end of the field research, we registered a much higher interest and confidence towards the transdisciplinary method. Participants, not only recognized the added value of acquiring knowledge through co-production, but also that they can be active agents in this process. This emancipatory component of the transdisciplinary approach was especially recognizable in small farmers and some of the women farmers who took part in the event.

5. Conclusions and future research agenda

Here, we outline our findings in four subsections: process, context, research agenda, and final remarks.

5.1. Process

For many stakeholders, the transdisciplinary method was a new concept. During our initial outreach to the stakeholders, we encountered much apprehension towards the concept. After we introduced the topic of transdisciplinarity during our field visits and the workshop, the support for this method increased. One first conclusion is that generating a common vocabulary is an essential part of the process. While this is not news in the environmental science and policy debate, our work offered two elements of empirical relevance. First, the importance of investing in the *preflection* (Méndez et al., 2017) stage of the research and using this stage to dig into the local context, both synchronically (looking back at its past and history) and diachronically (mapping its present). This bidirectional mapping process allowed us to have a diversity of voices in our workshop. It is not obvious and not common in the El Salvador coffee sector to have in the same room, discussing at the same table, young and old farmers, small and large land-owners, national government and women movement representatives, as well as financial and academic institutions. This kind of blending is a key element previous participatory research in El Salvador has pointed as critically lacking (Bendito and Barrios, 2016; Méndez et al., 2017; Méndez, 2008). Even though not in a balanced composition and strongly skewed towards governmental actors, we were able to elicit this kind of encounter. Moreover, while we acknowledge that this is still at a Scope 1 level of co-production (Jagannathan et al., 2020), that it was not representative or balanced, our results show it still offered a unique opportunity for cross-pollination and to broaden up an arena of dialogue normally open to usual suspects (older, educated, wealthy, white, men). Our procedure is for this point of view widely replicable also in different settings and geographical contexts, and anywhere it is possible to invest time in *preflection* work, studying the context, exploring it through adventure in outreach (Klenk and Meehan, 2017) and actor mapping. The second, process-related element, has to do with the counter-side of this *adventurous* encounter approach, that is its inherent multiple biases. Our research team, even though strongly interdisciplinary and made of well-balanced and complementary expertise, was still made of four mostly Western academics, with no connections with more marginalized Salvadoran communities involved in the coffee sector (for instance, indigenous communities, peasants, low-income farmers or operational level employees of the coffee export sector). These elements have generated a strong selection bias. Many of the stakeholders identified, especially in the realm of organized civil society, were not reached out, never replied to our multiple emails, and did not attend the workshop. Attending a workshop requires time, which many activists or lower-income people do not have. Logistically, for many of them, it would not have been possible to reach the capital city. Finally, they may also not trust or feel comfortable being in the same room with elites, such as government people and academics. Hence, rather than naively recommending more transdisciplinary research, it is relevant to investigate the reasons behind the limited participation of societal actors who are key for the Salvadoran climate resiliency in general and coffee sector in particular.

5.2. Context

Our desk and field research resulted in important findings regarding the specific context in which this research was carried out. From our research, it is evident that there is a heritage of traditional knowledge linked to the cultivation of coffee in El Salvador as well as strong cultural and emotional bonds with the land. The coffee sector in El Salvador is strongly impacted by climate change, in some cases exacerbating

existing vulnerabilities. All participants shared the need to transition to a sustainable resilient coffee sector. The involvement of local stakeholders enabled access to local knowledge in the development of successful adaptation strategies. Different coffee-growing regions will require different levels of adaptation, ranging from 'incremental' adjustments to entirely changing the economic activities in areas where growing coffee is no longer a viable option.

A vulnerable component we revealed is that knowledge about climate risks and coffee adaptation solutions is not transferred effectively among stakeholders and the lack of information and resources hinders the adaptation potential. The transdisciplinary method allowed to identify research questions which concern understudied, societally-relevant problems.

5.3. Research agenda

The combined input from stakeholders on all phases of the research process, carefully described in Section 4.3.2, can be synthesized into two short-term research agenda directions and two research gaps. Research directions are intended to provide clear research projects with the potential for enabling exponential future research while providing timely policy and management solutions on the ground. Each direction is phrased as a question:

1. What are climate change adaptation practices that can be readily adopted by farmers within the given constraints and are specific to the local conditions of different growing regions?
2. What changes are required at which organizational level to implement such strategies at the farm level and throughout the coffee value chain?

We recognize the following research gaps (I.e., knowledge voids) that should be addressed to enable the transition to a sustainable coffee sector. Research gaps (I.e., voids) reflect the lack of information in the broader scientific literature as well as in accessible information to local stakeholders that are fundamental in the process of adaptation. Each gap is phrased as a question.

1. How can farmers be enabled to implement more costly (but proven) adaptation strategies and what are feasible ways to improve the value chain in coffee production such as through better access to (local) markets or the redistribution of capital as payments for ecosystem services?
2. How can the flow of information be improved in such a way that existing data can be shared more effectively with local farmers, including the development of e.g. early warning systems?

5.4. Final remarks

As a kind of action research, transdisciplinarity always entails an intervention, and being aware of the context and the underpinning power dynamics is paramount. We preferred this kind of intervention, that was conscious, *preflective* (based on a preliminary in-depth familiarization with the context), rather than none. We fully recognize that this is at the level of Scope 1 co-production (Jagannathan et al., 2020), just knowledge exchange and not yet transformative, but we deemed this an important start which we actioned through just a small research grant. We acknowledge that sustained engagement is important, for the future, and we are already working on that, for example, by involving Master thesis student in working with some of the selected stakeholders.

Author statement

The authors declare that this work is original and not published elsewhere.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability

Data will be made available on request.

Acknowledgements

We sincerely thank all stakeholders who contributed their valuable knowledge, insights and time to this study. We would also like to express our gratitude to the Global Transformations and Governance Challenges program at Leiden University for funding the field component of this study through a seed grant. We also thank the Liveable Planet program of Leiden University for enabling the formation of the research team.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.envsci.2024.103678.

References

Anggraeni, M., Gupta, J., Verrest, H.J.L.M., 2019. Cost and value of stakeholders participation: a systematic literature review. Environ. Sci. Policy 101, 364–373. https://doi.org/10.1016/j.envsci.2019.07.012.

Avelino, J., Cristancho, M., Georgiou, S., Imbach, P., Aguilar, L., Bornemann, G., Läderach, P., Anzueto, F., Hruska, A.J., Morales, C., 2015. The coffee rust crises in Colombia and Central America (2008–2013): impacts, plausible causes and proposed solutions. Food Secur 7, 303–321. https://doi.org/10.1007/s12571-015-0446-9.

Baca, M., Läderach, P., Haggar, J., Schroth, G., Ovalle, O., 2014. An integrated framework for assessing vulnerability to climate change and developing adaptation strategies for coffee growing families in Mesoamerica. PLoS One 9 (2), e88463.

Bacon, C., Méndez, V.E., Brown, M., 2005. Participatory Action-Research and Support for Community Development and Conservation: Examples from Shade Coffee Landscapes of El Salvador and Nicaragua; Center for Agroecology and Sustainable Food Systems (CASFS). University of California, Santa Cruz, CA, USA.

Bendito, A., Barrios, E., 2016. Convergent agency: encouraging transdisciplinary approaches for effective climate change adaptation and disaster risk reduction. Int. J. Disaster Risk Sci. 7, 430–435.

Bernstein, J.H., 2015. Transdisciplinarity: a review of its origins, development, and current issues. J. Res. Pr. 11.

Blackman, A., Ávalos-Sartorio, B., Chow, J., 2007. Shade coffee & tree cover loss: lessons from El Salvador. Environ.: Sci. Policy Sustain. Dev. 49, 22–33.

Bonilla, T. 2021. Estadisticas Cafetaleras Al 30 de junio de 2021, informe oficial.

Bouroncle, C., Imbach, P., Rodríguez-Sánchez, B., Medellín, C., Martinez-Valle, A., Läderach, P., 2017. Mapping climate change adaptive capacity and vulnerability of smallholder agricultural livelihoods in Central America: ranking and descriptive approaches to support adaptation strategies. Clim. Change 141, 123–137.

Bunn, C., Castro, F., Lundy, M. , 2018. The impact of climate change on coffee production in Central America. CCAFS report.

Canfield, M., Anderson, M.D., McMichael, P., 2021. UN Food Systems Summit 2021: dismantling democracy and resetting corporate control of food systems. Front. Sustain. Food Syst. 5, 661552.

Carmona-Galindo, V.D., Sheppard, C.C., Bastin, M.L., Kehrig, M.R., Marín-Recinos, M.F., Choi, J.J., Castañeda de Abrego, V., 2021. Chromatic and Morphological Differentiation of Triatoma dimidiata (Hemiptera: Reduviidae) with Land Use Diversity in El Salvador. Pathogens 10 (6), 753.

Contreras, I., 2022. Fleeing from violence the impact of a Gangs' Truce on Salvadoran Emigration. SSRN Electron. J. https://doi.org/10.2139/ssrn.4246427.

CSC, 2020. El Cultivo del Café en El Salvador - Cosecha 2019/2020. San Salvador.

Dannevig, H., Rauken, T., Hovelsrud, G., 2012. Implementing adaptation to climate change at the local level. Local Environ. 17, 597–611. https://doi.org/10.1080/13549839.2012.678317.

Donatti, C.I., Harvey, C.A., Martinez-Rodriguez, M.R., Vignola, R., Rodriguez, C.M., 2019. Vulnerability of smallholder farmers to climate change in Central America and Mexico: current knowledge and research gaps. Clim. Dev. 11, 264–286. https://doi.org/10.1080/17565529.2018.1442796.

FAOSTAT, 2022. Crops and livestock products [dataset].

Fernandez-Kolb, P., Castro-Llanos, F., Martinez-Valle, A., Siles, P., Läderach, P., Lundy, M., Bunn, C., 2019. Climate smart coffee in El Salvador. Cali, Colombia.

Ghodsvali, M., Krishnamurthy, S., de Vries, B., 2019. Review of transdisciplinary approaches to food-water-energy nexus: A guide towards sustainable development. Environ. Sci. Policy 101, 266–278. https://doi.org/10.1016/j.envsci.2019.09.003.

Goodman, D., 2008. The international coffee crisis: a review of the issues. in: Confronting the Coffee Crisis. The MIT Press, pp. 3–26. https://doi.org/10.7551/mitpress/9780262026338.003.0001.
Hallegatte, S., Bangalore, M., Bonzanigo, L., Fay, M., Kane, T., Narloch, U., Rozenberg, J., Treguer, D., Vogt-Schilb, A., 2016. Shock Waves: Managing the Impacts of Climate Change on Poverty. World Bank,, Washington, DC. https://doi.org/10.1596/978-1-4648-0673-5.
Hannah, L., Donatti, C.I., Harvey, C.A., Alfaro, E., Rodriguez, D.A., Bouroncle, C., Castellanos, E., Diaz, F., Fung, E., Hidalgo, H.G., Imbach, P., Läderach, P., Landrum, J.P., Solano, A.L., 2017. Regional modeling of climate change impacts on smallholder agriculture and ecosystems in Central America. Clim. Change 141, 29–45. https://doi.org/10.1007/s10584-016-1867-y.
Harvey, C.A., Saborio-Rodríguez, M., Martinez-Rodríguez, M.R., Viguera, B., Chain-Guadarrama, A., Vignola, R., Alpizar, F., 2018. Climate change impacts and adaptation among smallholder farmers in Central America. Agric. Food Secur 7, 57. https://doi.org/10.1186/s40066-018-0209-x.
Harvey, M., Pilgrim, S., 2011. The new competition for land: food, energy, and climate change. Food Policy 36, S40–S51. https://doi.org/10.1016/j.foodpol.2010.11.009.
Hecht, S.B., Kandel, S., Gomes, I., Cuellar, N., Rosa, H., 2006. Globalization, forest resurgence, and environmental politics in El Salvador. World Dev. 34, 308–323. https://doi.org/10.1016/j.worlddev.2005.09.005.
Hernández, M.R., Hernández J.C., Flores M.E. , 2022. Propuesta de medidas de creación de infraestructura de adaptación al cambio climático y crecimiento económico verde para El Salvador.
Imbach, P., Chou, S.C., Lyra, A., Rodrigues, D., Rodriguez, D., Latinovic, D., Siqueira, G., Silva, A., Garofolo, L., Georgiou, S., 2018. Future climate change scenarios in Central America at high spatial resolution. PLoS One 13, e0193570. https://doi.org/10.1371/journal.pone.0193570.
IPCC, 2021. IPCC Technical Summary. https://doi.org/https://doi.org/10.1017/9781009157896.002.
IPCC, 2022. Climate Change 2022: Impacts, Adaptation and Vulnerability Contribution of Working Group II to the IPCC Sixth Assessment Report. https://doi.org/doi:10.1017/9781009325844.
Jacobi, J., Llanque, A., Mukhovi, S.M., Birachi, E., von Groote, P., Eschen, R., Hilber-Schöb, I., Kiba, D.I., Frossard, E., Robledo-Abad, C., 2022. Transdisciplinary co-creation increases the utilization of knowledge from sustainable development research. Environ. Sci. Policy 129, 107–115. https://doi.org/10.1016/j.envsci.2021.12.017.
Jagannathan, K., Arnott, J.C., Wyborn, C., Klenk, N., Mach, K.J., Moss, R.H., Sjostrom, K. D., 2020. Great expectations? Reconciling the aspiration, outcome, and possibility of co-production. Curr. Opin. Environ. Sustain. 42, 22–29.
Jahn, T., Bergmann, M., Keil, F., 2012. Transdisciplinarity: between mainstreaming and marginalization. Ecol. Econ. 79, 1–10. https://doi.org/10.1016/j.ecolecon.2012.04.017.
Jantsch, E., 1972. Inter- and transdisciplinary university: a systems approach to education and innovation. High. Educ. (Dordr.) 1, 7–37. https://doi.org/10.1007/BF01956879.
Jawo, T.O., Kyereh, D., Lojka, B., 2022. The impact of climate change on coffee production of small farmers and their adaptation strategies: a review. Clim. Dev. 1–17. https://doi.org/10.1080/17565529.2022.2057906.
Karrasch, L., Grothmann, T., Michel, T.A., Wesselow, M., Wolter, H., Unger, A., Wegner, A., Giebels, D., Siebenhüner, B., 2022. Integrating knowledge within and between knowledge types in transdisciplinary sustainability research: seven case studies and an indicator framework. Environ. Sci. Policy 131, 14–25. https://doi.org/10.1016/j.envsci.2022.01.014.
Klenk, N., Fiume, A., Meehan, K., Gibbes, C., 2017. Local knowledge in climate adaptation research: moving knowledge frameworks from extraction to co-production. Wiley Interdiscip. Rev.: Clim. Change 8 (5), e475.
Klenk, N.L., Meehan, K., 2017. Transdisciplinary sustainability research beyond engagement models: toward adventures in relevance. Environ. Sci. Policy 78, 27–35. https://doi.org/10.1016/j.envsci.2017.09.006.
Klenk, N.L., Meehan, K., Pinel, S.L., Mendez, F., Lima, P.T., Kammen, D.M., 2015. Stakeholders in climate science: Beyond lip service? Science (1979) 350, 743–744. https://doi.org/10.1126/science.aab1495.
Leventon, J., Fleskens, L., Claringbould, H., et al., 2016. An applied methodology for stakeholder identification in transdisciplinary research. Sustain Sci. 11, 763–775. https://doi.org/10.1007/s11625-016-0385-1.
Linneberg, M.S., Korsgaard, S., 2019. Coding qualitative data: a synthesis guiding the novice. Qual. Res. J. 19, 259–270. https://doi.org/10.1108/QRJ-12-2018-0012.
Maiello, A., Viegas, C.V., Frey, M., D. Ribeiro, J.L., 2013. Public managers as catalysts of knowledge co-production? Investigating knowledge dynamics in local environmental policy. Environ. Sci. Policy 27, 141–150. https://doi.org/10.1016/j.envsci.2012.12.007.
Maurer, E.P., Adam, J.C., Wood, A.W., 2009. Climate model based consensus on the hydrologic impacts of climate change to the Rio Lempa basin of Central America. Hydrol. Earth Syst. Sci. 13, 183–194. https://doi.org/10.5194/hess-13-183-2009.
Mauser, W., Klepper, G., Rice, M., Schmalzbauer, B.S., Hackmann, H., Leemans, R., Moore, H., 2013. Transdisciplinary global change research: the co-creation of knowledge for sustainability. Curr. Opin. Environ. Sustain 5, 420–431. https://doi.org/10.1016/j.cosust.2013.07.001.
Max-Neef, M.A., 2005. Foundations of transdisciplinarity. Ecol. Econ. 53, 5–16. https://doi.org/10.1016/j.ecolecon.2005.01.014.
Méndez, V.E., 2008. Farmers' livelihoods and biodiversity conservation in a coffee landscape of el salvador. In: Bacon, C., Méndez, V.E., Gliessman, S.R., Goodman, D., Fox, J.A. (Eds.), In Confronting the Coffee Crisis: Fair Trade, Sustainable Livelihoods and Ecosystems in Mexico and Central America. The MIT Press, Cambridge, MA, USA, pp. 207–236.
Méndez, V.E., Caswell, M., Gliessman, S.R., Cohen, R., 2017. Integrating agroecology and participatory action research (PAR): lessons from Central America. Sustainability 9 (5), 705.
Méndez, V.E., Caswell, M., Gliessman, S.R., Cohen, R., 2017. Integrating agroecology and participatory action research (PAR): lessons from Central America. Sustainability 9 (5), 705.
Nicolescu, B. 2006. Transdisciplinarity: past, present and future.
Pham, Y., Reardon-Smith, K., Mushtaq, S., Cockfield, G., 2019. The impact of climate change and variability on coffee production: a systematic review. Clim. Change 156, 609–630. https://doi.org/10.1007/s10584-019-02538-y.
Pohl, C., 2010. From transdisciplinarity to transdisciplinary research. Transdiscipl. J. Eng. Sci. 1 https://doi.org/10.22545/2010/0006.
Reed, M., Graves, A., Dandy, N., Posthumus, H., Hubacek, K., Morris, J., Prell, C., Quinn, C., Stringer, L., 2009. Who's in and why? A typology of stakeholder analysis methods for natural resource management. J. Environ. Manag. 90 (5), 1933–1949. https://doi.org/10.1016/j.jenvman.2009.01.001.
Reed, M.S., 2008. Stakeholder participation for environmental management: a literature review. Biol. Conserv 141, 2417–2431. https://doi.org/10.1016/j.biocon.2008.07.014.
Ricart, S., Olcina, J., Rico, A., 2018. Evaluating Public Attitudes and Farmers' Beliefs towards Climate Change Adaptation: Awareness, Perception, and Populism at European Level. Land (Basel) 8, 4. https://doi.org/10.3390/land8010004.
Richards, M.B., Méndez, V.E., 2014. Interactions between carbon sequestration and shade tree diversity in a smallholder coffee cooperative in El Salvador. Conserv. Biol. 28 (2), 489–497.
de Sousa, K., van Zonneveld, M., Holmgren, M., Kindt, R., Ordoñez, J.C., 2019. The future of coffee and cocoa agroforestry in a warmer Mesoamerica. Sci. Rep. 9 (1), 8828.
Stewart, I.T., Maurer, E.P., Stahl, K., Joseph, K., 2022. Recent evidence for warmer and drier growing seasons in climate sensitive regions of Central America from multiple global datasets. Int. J. Climatol. 42, 1399–1417. https://doi.org/10.1002/joc.7310.
Stokols, D., Fuqua, J., Gress, J., Harvey, R., Phillips, K., Baezconde-Garbanati, L., Unger, J., Palmer, P., Clark, M., Colby, S., Morgan, G., Trochim, W., 2003. Evaluating transdisciplinary science. Nicotine Tob. Res. 5, 21–39. https://doi.org/10.1080/1462220031000162555.
Tucker, C.M., Eakin, H., Castellanos, E.J., 2010. Perceptions of risk and adaptation: Coffee producers, market shocks, and extreme weather in Central America and Mexico. Glob. Environ. Change 20 (1), 23–32.
Turnhout, E., Metze, T., Wyborn, C., Klenk, N., Louder, E., 2020. The politics of co-production: participation, power, and transformation. Current Opinion in Environmental. Sustainability 42, 15–21.
Valencia, D.H., Riera, E.M., Boada i Juncà, M., 2012. Participatory action research applied to the management of natural areas: the case study of Cinquera in El Salvador. J. Lat. Am. Geogr. 45–65.
Villarreyna, R., Barrios, M., Vílchez, S., Cerda, R., Vignola, R., Avelino, J., 2020. Economic constraints as drivers of coffee rust epidemics in Nicaragua. Crop Prot. 127, 104980 https://doi.org/10.1016/j.cropro.2019.104980.
Viterna, J., 2013. Women in War. Oxford University Press. https://doi.org/10.1093/acprof:oso/9780199843633.001.0001.
Wiltberger, J., 2014. Beyond remittances: contesting El Salvador's developmentalist migration politics. J. Lat. Am. Caribb. Anthr. 19, 41–62. https://doi.org/10.1111/jlca.12065.
World Bank, 2020. The Global Economy: El Salvador: Remittances, percent of GDP [WWW Document]. URL ⟨https://www.theglobaleconomy.com/El-Salvador/remittances_percent_GDP/⟩.
World Bank, T. 2017. El Salvador [data].