Understanding the climate and environmental impacts of smallholder coffee farming in Latin and Central America

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List of acronyms

CLAC - Latin American and Caribbean Network of Fair Trade Small Producers and Workers

EUDR - European Union Regulation on Deforestation-free Products

FTF UK - Fairtrade Foundation UK

FI - Fairtrade International

GHG Emissions - Greenhouse gas emissions

GMO - Genetically Modified Organism

ICS - Internal Control System

IHCAFE - Honduran Coffee Institute

LCA - Life Cycle Assessment

MVP - Minimum Viable Product

PAR - Participatory Action Research

PoE - Panel of Experts

PoE WS - Panel of Experts Workshop

POs - Producer Organisations

SOPPEXCCA - Sociedad de pequeños productores y compradores de café [Nicaragua producer group]

SPOs - Small-scale producer organisations

VCM - Voluntary Carbon Market

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Executive summary

Background

This research study investigates the environmental sustainability of small-scale coffee production in five Latin American countries - Brazil, Colombia, Peru, Nicaragua, and Honduras - through a comparison with larger-scale production. Smallholder farmers produce approximately 60% of the global coffee supply and Fairtrade International has certified 838,116 smallholder farmers in 656 organisations across 32 countries. The study focuses on five key environmental areas: water, energy, greenhouse gas emissions (GHG), deforestation, and biodiversity. Despite the importance of smallholder coffee production, the sector faces important challenges such as high costs of production, unstable market prices, and climate change.

Key findings

1. Sustainability of smallholder coffee production compared to large-scale plantations

Despite context-specific dynamics in the countries considered, smallholders' practices are currently more environmentally sustainable than ones adopted by large-scale plantations. The latter are, however, in a better position to take risks and quickly respond to market and legislative changes. The environmental practices adopted by coffee growers are influenced by various structural conditions, including farm size, labour availability and cost, technology, economic resources, land tenure, and geographic location. Smallholders, often using family labour on small, remote, or mountainous parcels, adopt different practices compared to large-scale plantations. These differences, especially in management intensity and the use of shade, significantly impact the environment. With the exception of Brazil, smallholders often use diverse shaded agroforestry systems that employ fewer resources and inputs, while contributing to carbon sequestration, biodiversity, food security, and climate adaptation and mitigation.

2. Environmental impact comparisons

- Water: Coffee's impact on water resources mainly arises from irrigation and waste-water management. While irrigation is mainly used by plantations, especially in Brazil, water contamination from waste management is a more complex issue: smallholders in Colombia, Nicaragua, and Honduras need more technical support to reduce their environmental impact due to prevalent wet processing methods. New technologies can reduce water pollution but technical and financial assistance are needed to adopt them.

- Energy: Small-scale producers generally use less energy compared to larger producers because their farms are often less mechanised. In Brazil, both small and large farmers in certain regions employ some mechanisation. Despite small farms being less mechanised, energy use varies in the post-harvest phase.

- GHG Emissions and Carbon Stocks: Different metrics used to account for GHG emissions make comparisons difficult. Smallholder coffee production, especially when associated with agroforestry, has shown great potential for carbon stocks and emissions insetting, as measured in a recent study conducted with Fairtrade-certified cooperatives in Honduras (Lugo-Pérez, 2023; Burkey at al, 2023).

- Deforestation: Both smallholder- and plantation-driven deforestation were identified as an issue. Studies including a direct comparison suggest that larger farms have driven more deforestation. While large-scale plantations are increasing their reforestation efforts in Brazil, driven by legislation, smaller farms tend to have more on-farm forest cover, especially shaded agroecological farms in Honduras and Nicaragua.

- Biodiversity: the study findings clearly show that smallholder farms support greater biodiversity, with a higher number of pollinators, low pesticide use and a higher portion of natural vegetation in the farm. A key driver of higher biodiversity on small-scale farms are shade trees, particularly multi-species systems, which increase the number of habitats and resources for biodiversity .

3. Farmer-led data collection

There is an urgent need for participatory and farmer-led data collection methods that benefit farmers, ensure data ownership, and add relevance to local contexts. Digital tools like FairInsight can help farmers manage data, but farmers' fair engagement should be further explored. Cooperatives can play a key role in environmental data collection.

How Fairtrade supports smallholders

Fairtrade's Global Strategy 2021-2025 is based on agroecology and a sustainable agriculture approach. Fairtrade promotes sustainable practices through the Fairtrade Standard for Small-scale Producer Organizations (SPOs) (Fairtrade International, 2019), its Climate Standards (Fairtrade International, 2015) and the Fairtrade Standards for Coffee (Fairtrade International, 2021a). The latter foster organic production, with a differential for organic agriculture and agroecology. Fairtrade Standards for Coffee include criteria to: protect forests and prevent deforestation on farms; assess and mitigate deforestation risk; and prepare environmental risk assessments that identify issues that may affect the climate resilience of member organisations. One third of Fairtrade's Trader Standards include environmental aspects such as a safe use of agrochemicals, proper waste and water management, and soil fertility. A stricter criterion has been applied to deforestation since 2019, with considerable benefits also for biodiversity. Moreover, Fairtrade-certified cooperatives in the region operate to improve sustainability of the coffee sector. Examples include the SOPPEXCCA Cooperative in Nicaragua and Grupo Asociativo San Isidro in Colombia (CLAC, 2015).

Conclusions and recommendations

Coffee farming is generally more environmentally sustainable than large-scale production, especially when integrated with agroecological practices and certifications like Fairtrade. The Fairtrade system can play a major role in addressing the climate crisis and the environmental sustainability of the coffee value chain, while pursuing fairer deals for smallholders and responding to the needs of commercial partners. This can be done by means of:

1. Promoting farmer-led and owned environmental data collection to recognise and communicate smallholders' environmental sustainability. This can be done in partnership with Universities and other organisations.

2. Disseminating and systematising existing effective practices (for example in relation to agroforestry) and technologies that some Producers' Organisations are already using. This can be done through Farmer to Farmer Pedagogies and farmers' field schools.

3. Designing ad hoc arrangements with commercial partners who are interested in reducing their environmental impact, for instance, in terms of Scope 3 emissions. Paramount sustainability issues should be faced jointly in the coffee value chain, and Fairtrade can play a central coordinating role to do so.

1. Introduction

1.1 Research scope and objectives

This study investigates the environmental sustainability of small-scale coffee production in five Latin American countries, comparing its prospects for sustainability with that of larger-scale production. This research aims to shed light on the link between environmental sustainability and smallholder coffee production, showcasing some of the most promising practices already adopted by growers and existing innovations, as well as some of the most pressing challenges, observed in the sector. The study provides a comparison of smallholder and large-scale coffee production across five closely linked environmental areas: water, energy, greenhouse gas emissions, deforestation and biodiversity.

The research has a geographical focus on Brazil, Colombia, Peru, Nicaragua, and Honduras. The study also includes insights on neighbouring countries where Fairtrade operates, if relevant to the research scope. The study countries represent areas where the Fairtrade Foundation (FTF) is particularly active, and where it works closely with the Latin American and Caribbean Network of Fairtrade Small Producers and Workers (CLAC). This organisation, part of the Fairtrade International system, represents about 1,000 Fairtrade-certified organisations in 20 countries across Latin America and the Caribbean.

While the study includes some detail about coffee production in farms of different sizes and in different contexts, a few overarching considerations should be kept in mind. The first is around the inherent complexity of the coffee value chain. The natural challenges of coffee production, linked to soil quality, climate variability and extreme weather events, as well as fluctuations in the coffee price, are compounded by social challenges linked to poverty, migration and conflict, among others. At the same time, the coffee sector in Latin America is rich in interesting innovations and effective practices. Smallholders are often at the forefront of the fight against climate change, putting in place micro-innovations that can support not just their own production, but global goals.

The research paper is structured in the following sections:

- Section 1 provides an introduction to the study, its research aims and research questions;
- Section 2 outlines the methodology and limitations of the study;
- Section 3 compares smallholder and large-scale production of coffee in five countries, across five environmental dimensions, and briefly outlines social issues underlying the sector;
- Section 4 provides an overview of farmer-led data collection processes and offers some reflections on environmental data collection; and
- Sections 5 explores its potential role going forward concluding with lessons learned and recommendations for FTF to consider.

1.2 Background to the study

Smallholder farmers[1] are central to the global coffee industry, producing approximately 60% of worldwide supply (Siles et al., 2022). Fairtrade International has certified a total of 838,116 smallholder farmers in 656 Producer Organisations across 32 countries[2]. The organisation has actively engaged in promoting environmental sustainability. The organisation is dedicated to identifying the most effective methods for farmers and cooperatives to communicate their efforts and enhance the recognition of their role in biodiversity protection, the provision of environmental services, and the adaptation to and mitigation of climate change. This study on the environmental sustainability of coffee in Brazil, Colombia, Honduras, Nicaragua and Peru provides relevant insights and supports reflection on further action in this direction. In Central and Andean regions of Latin America, indeed, most coffee farmers are smallholders who cultivate small plots, frequently in combination with crops including maize and beans, fruit and timber trees. Their land often also includes small-scale livestock production and small areas allocated to forest (Harvey et al., 2021). The picture in Brazil is quite different (as further explored in **Section 3.1**), with considerable variation across geographical regions and large and medium scale plantations, mostly using sun-grown and mechanisation methods, accounting for 62% of coffee production (Sustainable Coffee Challenge, n.d.).

Smallholder coffee production generates social and environmental benefits that have a ripple effect beyond the coffee sector (Perfecto and Vandermeer, 2015). In most contexts included in our study, smallholders produce coffee in diverse, shaded agroforestry systems contributing to biodiversity, food security, and cultural conservation, as well as climate change mitigation through carbon sequestration in plants and soils (Méndez et al., 2012; Toledo and Moguel, 2012; Perfecto and Vandermeer, 2015; Guzmán-Luna et al., 2019). Farmer households also contribute to the livelihoods and economies of their regions and countries through job creation and coffee exports (Jha et al., 2011; Jezeer et al., 2017).

Despite its importance, the coffee sector faces key challenges due to economic, social and environmental factors. The coffee production system is inherently complex, with three processing stages and large distances between areas of production and consumption (ID3H). Other specific challenges include high costs of production and unstable market prices (Siles et al., 2022). While

[1] The definition of smallholder farming is debated in the literature and context-dependent, therefore we did not adopt a strict definition in terms of farm size. The Fairtrade Standards for SPOs defines family and small-scale farming as 'a means of organizing agricultural production which is managed and operated by a family and predominantly reliant on family labor' and small-scale producers as 'farmers who are not structurally dependent on permanent hired labour and who manage their production activity mainly with family workforce' (Fairtrade International, 2019). Fairtrade defines smallholders as farmers whose land is equal or below 30ha (Fairtrade International, 2019). According the calculation of the average land size per Fairtrade farmer with data available in its top 7 products dashboard, in the countries considered for this study Fairtrade certified farms are of 3.2ha on average, with an average of 9ha per farm in Brazil (Fairtrade International, n.d.). In this specific sentence, smallholders are considered as farmers cultivating less than 5 ha.

[2] https://www.fairtradeamerica.org/why-fairtrade/global-impact/reports-trends/coffee-impact-report-2021/

there is increasing consumer demand for more sustainable products, including coffee[3], interviews and a Panel of Experts' workshop included in this study pointed to this still being insufficient to encourage farmers to switch to certifications including Fairtrade. In addition, coffee production is facing important and growing challenges due to climate change (Jawo et al., 2022), compounding existing challenges due to disease, price fluctuations, living income, poverty and food security (Siles et al., 2022). Some of the changes in production techniques and location, often due to climate change, are leading to further issues with pests and a subsequent increase in the use of agrochemicals (ID1C).

While coffee demand has increased over the last two decades (ICO, 2022), some studies have estimated that its production will exceed 200 million bags by 2030 (Ralph, 2022). Recent projections point to a decrease (of up to 50%) in land suitable for Arabica cultivation by 2050 (Bunn et al., 2014), with Brazil (especially Minas Gerais) and Central America particularly affected and identified by a recent study as a climate hotspot for Fairtrade producers (Malek et al., 2021). According to this research, as shown in **Figure 1**, in a moderate (RCP 4.5) Peru and Honduras, where Fairtrade coffee production is significant in terms of volume, will be impacted by heating and drying. Peru and Nicaragua will be particularly affected in terms of the number of farmers producing coffee. In Brazil and Central America in general, according to Bunn et al. (2015), 80% of the land will indeed be unsuitable for the crop by 2050.

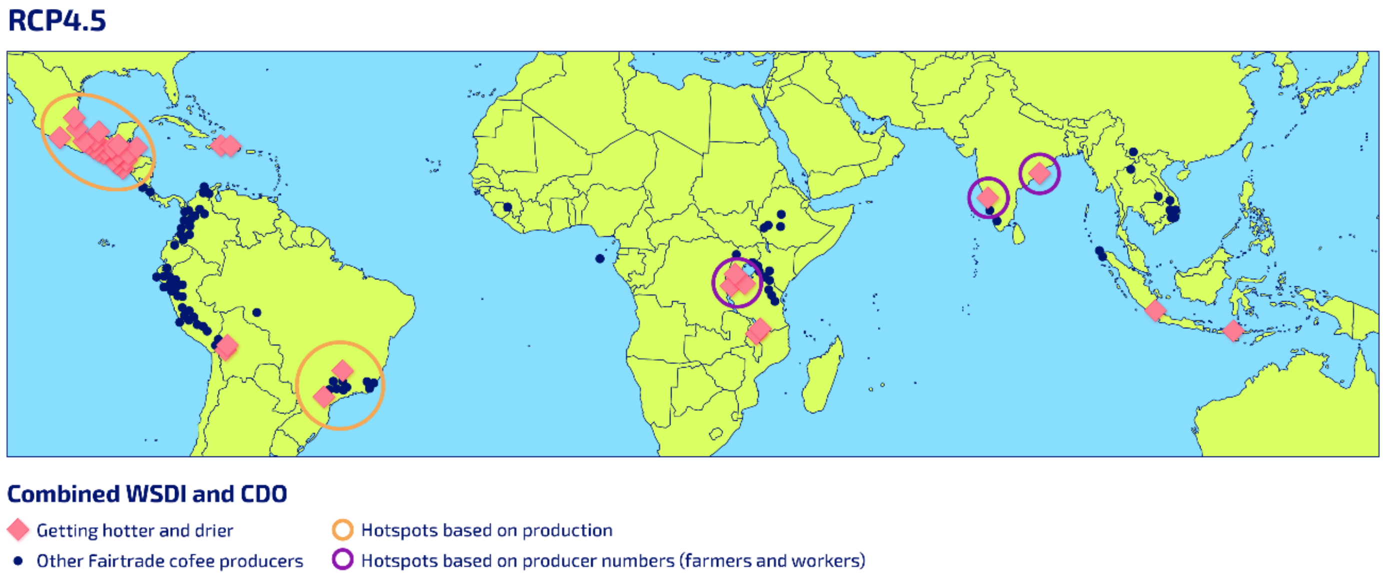

Figure 1. Hotspots of climate change impacts based on Fairtrade coffee production and producer numbers. Source (Malek et al., 2021)

Coffee is particularly affected by the rise in temperatures, unpredictable rainfalls, droughts and extreme weather events (Barreto Peixoto et al., 2023). For instance, Brazil, responsible in 2022 for

[3] For example, see a recent article from Slow Food: https://www.slowfood.com/blog-and-news/coffee-for-good-slow-food-glasgow/?INTERESSI=Coffee&DONOR=NegroniFund

40% of global coffee production, has already experienced frost and droughts in 2021, which affected the whole value chain (Millard et al., 2021). Moreover, productivity and quality are threatened by weeds and pests caused by the change in temperature. Resistance towards pesticides could further worsen the problem (Ovalle-Rivera et al., 2015). Biodiversity loss will also result in a lack of pollinators in some areas, decreasing the suitability of coffee cultivation and the quality of the yields in those locations (Imbach et al., 2017).

Greater organisation and collaboration could support farmers to address some of these growing challenges (Lerner et al., 2021), as further explored in **Section 6**. Ultimately, environmental issues are inextricably linked to social, political and structural processes. A recognition of the social conflicts surrounding land, productivity and environmental protection are necessary to support transformation of the coffee sector. As this paper will show, there is much to be learned from the practices, innovations and localised solutions that smallholders are already implementing in their contexts. With further organisation and support, smallholders can be central in the efforts to adapt to and mitigate climate change in rural areas of Latin America and beyond.

1.3 The role of Fairtrade and the rationale for the study

Coffee is particularly relevant to Fairtrade globally, as 46% of its registered farmers – all smallholders[4] – are involved in the production of this crop (Fairtrade International, 2021). The Fairtrade Global Strategy 2021-2025 and its Theory of Change call for a sustainable agriculture approach adapted to different contexts and products to enhance climate resilience and foster adaptation and mitigation (Development International & Fairtrade, 2022). This move towards more sustainable agricultural systems is detailed in the Fairtrade Sustainable Agriculture Baseline Report, which suggests that an agroecological approach[5] is the most suitable to the organisation's vision and mission, as it promotes agri-food systems transformation across social, economic and environmental pillars (Development International & Fairtrade, 2022). An agroecological approach gives clear theoretical foundation and strategic direction to the actions that Fairtrade can implement to successfully integrate environmental sustainability in the work of the organisation.

Fairtrade promotes sustainable agricultural practices through the Fairtrade Standard for Small-scale Producer Organizations (SPOs) (Fairtrade International, 2019), its Climate Standards (Fairtrade International, 2015) and the Fairtrade Standards for Coffee (Fairtrade International, 2021a). The latter

[4] The Fairtrade Standards for SPOs define family and small-scale farming as "*a means of organizing agricultural production which is managed and operated by a family and predominantly reliant on family labour*" and small scale producers as "*farmers who are not structurally dependent on permanent hired labour and who manage their production activity mainly with family workforce*". Fairtrade defines smallholders as farmers who own less than 30 hectares (ha). In the countries considered for this study Fairtrade certified farms are of 3.2ha on average, with an average of 9ha per farm in Brazil (Fairtrade International, 2019).

[5] Based on the definition of agroecology as: "*an integrated approach that simultaneously applies ecological and social concepts and principles to the design and management of food and agricultural systems. It seeks to optimize the interactions between plants, animals, humans and the environment while taking into consideration the social aspects that need to be addressed for a sustainable and fair food system*". The definition, provided by FAO, is available at: https://www.fao.org/agroecology/overview/en/.

fosters organic production, with a differential for organic agriculture and agroecology[6]. Organic coffee receives a 40 cents/pound added by Fairtrade to the Minimum Price (or the market price when higher) and Fairtrade Premium (Fairtrade International, 2018). Fairtrade Standards for coffee include criteria to protect forests and prevent deforestation on farms; assess and mitigate deforestation risk; and prepare environmental risk assessments that identify issues that may affect the performance or climate resilience of farmer members. Moreover, one third of the Fairtrade Traders Standards[7] cover environmental aspects in the development requirements. Contrary to Fairtrade core requirements, these are not necessary for producers to be certified but aim to foster their engagement in certain activities[8] such as a safe use of agrochemicals, proper waste and water management, the maintenance of soil fertility. A stricter criterion has been applied to deforestation since 2019, with considerable benefits also for biodiversity. Fairtrade provides smallholders with guidance to set up an Internal Control System (ICS) to meet the environmental requirements in the Fairtrade Standard for Small-scale Producer Organizations[9].

Fairtrade-certified cooperatives in the CLAC region already operate to improve the sustainability of coffee in the study area. For instance, the Fairtrade-certified SOPPEXCCA Cooperative in Nicaragua promotes good agricultural practices to face climate change, such as organic production with low and timely use of agricultural inputs and agroforestry. At the level of water and energy use, it promotes the use of micro-pumps for irrigation to improve water consumption and of coffee wet mill processing stations equipped to transform pulp residues into organic fertilisers. Similarly, the Fairtrade-certified Grupo Asociativo San Isidro in Colombia has purchased land to protect water and forestry and increase the interconnectivity of forests in farmed land (CLAC, 2015).

Finally, Fairtrade has undertaken in 2015 some **pilot studies on carbon** calculation and the carbon market. More recently, it commissioned a study on the different **metrics and indicators** that can be adopted by the organisation to monitor progress against its agroecological strategy. Small-grain data on deforestation, biodiversity, water, energy, greenhouse gas (GHG) emissions and carbon insetting are needed to enhance the understanding of the sustainability of the coffee value chain and to comply with new legislation, such as the recently introduced European Union Regulation on Deforestation-free Products (EUDR). In addition to this, as part of the 2021-2025 strategy, which includes a pillar on digital transformation, Fairtrade has put in place, together with the organisation

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[6] Agroecology, according to the FAO, "seeks to optimise the interactions between plants, animals, humans and the environment while taking into consideration the social aspects that need to be addressed for a sustainable and fair food system."(FAO, 2015)

[7] These are described in detail here: https://www.fairtrade.net/standard/trader#:~:text=It%20defines%20rules%20around%20the,that%20contribute%20to%20producer%20empowerment.

[8] For more information about core and developmental requirements: https://www.fairtrade.net/standard/aims

[9] For more information about Fairtrade ICS: https://files.fairtrade.net/4.0_FLO_Training_Guide_for_Small_Farmers_on_Internal_Control_Systems.pdf

AgUnity, the FairInsight data management tool[10]. This supports farmers to manage and digitally share data, for example on the use of the Fairtrade Premium, providing valuable information across the supply chain.

However, despite these new tools, data collection, particularly for environmental topics, can prove challenging in remote areas and farmers' data ownership is key to ensure fairness of the process. Although digital tools can simplify the data collection process in certain contexts, applications designed for smallholders run the risk, on the one hand, of delivering only top-down information (which can be more or less relevant to local contexts). On the other, they risk being extractive, in cases where farmers are required to give their data for traceability purposes (Hildago et al., 2023). The possibility of benefiting farmers to compensate them for time-consuming data collection should also be evaluated. To respond to this need, this study maps participatory and farmer-led techniques to collect data on carbon and GHG emissions, water, energy use, and biodiversity loss. When considering their further use, it's important to ensure these meet international accountability standards while guaranteeing that environmental data are owned by and directly benefit farmers. Both areas are explored in the report.

The analysis of the climate and environmental impact of coffee farming is particularly relevant and timely for the organisation. The primary and secondary evidence collected through this study can help to inform the Fairtrade system and external stakeholders about the current environmental sustainability of smallholders in relation to large-scale growers. Moreover, it can enable internal reflections on how to support producers to improve their environmental practices and adapt to climate change. The data collected could also foster a reflection on how smallholders can benefit from the role they are currently playing in environmental sustainability, climate mitigation and adaptation while exploring future possibilities.

[10] For more information about FairInsight: https://clac-comerciojusto.org/fairinsightuna-herramienteen a-para-difundir-el-impacto-del-comercio-justo/

2. Study design and methodology

2.1 Research aim and research questions

The present research took a multidisciplinary approach and was articulated in three steps:

1) systematic literature review: academic datasets were scanned for relevant academic literature;

2) primary data collection: primary data were collected through both interviews and two workshops: one with CLAC staff, and the other with an interdisciplinary Panel of Experts; and

3) review of farmer-led data collection tools: an online search was conducted for academic and grey literature on farmer-led sustainability data collection and data ownership.

Thematic experts were identified to provide guidance and technical inputs throughout the project. The themes covered were i) the amount of energy used by smallholder and plantation agriculture; ii) water consumption and pollution in relation to wet coffee production and the use of fertilisers in smallholder and plantation agriculture; iii) the levels of deforestation in the two systems of production; iv) GHG emissions and carbon removal associated with smallholder and large-scale farming; and v) the degree of biodiversity loss generated by smallholder and plantation farming and the efforts to conserve, restore and regenerate ecosystems. The general hypothesis explored through this study was that smallholder farming - especially when combined with agroecological practices and several types of certifications, including organic and/or Fairtrade certification - is overall more sustainable than plantation agriculture.

The study was structured to answer four main research questions:

1) What evidence exists on the environmental impacts (carbon emissions and stock, water and energy use, biodiversity, deforestation) of smallholder coffee farming compared to large-scale plantations in Latin America?
2) What are the main differences between smallholder and plantation coffee that drive sustainability differences, and where is there room for improvement?
3) What is the current evidence in terms of participatory and farmer-led practices to collect environmental data that are owned by smallholders?
4) How does FTF work align with the data collected through this study and what could be next steps?

2.2 Systematic literature review methods and evidence base characteristics

To undertake the systematic review, we followed published guidelines by the Collaboration for Environmental Evidence, an open community of stakeholders promoting and delivering evidence synthesis on environmental policy and practice issues (Collaboration for Environmental Evidence, 2018). The literature review focused on answering Research Question 1 outlined above.

The question was answered through two sub-questions comparing smallholder coffee to large-scale plantations in Latin and Central America:

1. *What is the evidence on the difference in environmental impacts between smallholders and plantations?*
2. *How does the evidence relate to sun-grown vs. shade-grown coffee?*

Annex 2 describes in detail the review protocol.

2.3 Primary data collection

Our study included interviews with 35 respondents from the five sampled countries or experts on coffee production in the Latin American region. The research sample also included an additional 10 participants to the workshop with CLAC staff members (see **Annex 5**). A high-level overview of primary data collection can be found below. Detailed lists of interviewees and of workshop participants are provided in **Annex 3** and **Annex 5** respectively.

The sample was composed as follows:

- A Panel of Experts (PoE) comprising seven academics and other professionals with extensive expertise in the coffee sector in the five sampled countries. Each participant in the PoE was interviewed individually, participated in a two-hour validation workshop (see below) and provided support in the report writing stage.
- A total of 14 interviews with academics and researchers with a focus on different areas relating to coffee production in the five countries.
- A total of nine participants directly active in coffee production or in coffee producer organisations in the five countries.
- A total of five respondents representing members of the global Fairtrade system.
- Ten CLAC staff members taking part in a workshop-based focus group discussion.

We also conducted two workshops, facilitated remotely through Miro software. The first workshop took place on March 1, 2024, and consisted of a guided focus group discussion, including small group discussions in two break-out rooms. The second workshop took place on March 15, 2024 and brought together seven members[11] of the PoE to validate, further contextualise and add to our emerging findings. **Annex 5** includes further detail on the two workshops.

2.4 Analysis

We employed a deductive coding approach using Dedoose qualitative analysis software to identify key themes emerging from the interviews and workshops, while we extracted data from published texts for the literature review. All the qualitative interviews were transcribed (and translated when needed), and securely stored.[12] While the two stages of literature review and primary data collection are distinct components of the study, they are closely connected and have informed each other. After analysing the interviews and literature review separately, we synthesised the results from both strands of the research through ongoing internal discussions, as well as the PoE workshop (see above). The synthesis of findings is reflected in all sections of the report.

2.5 Limitations and mitigations strategies

Our approach has several limitations which need to be taken into account when using the data to inform decision-making. Nonetheless, we have identified mitigation strategies to deliver robust and evidence-based findings. Limitations and mitigation strategies are outlined below.

Secondary data

When carrying out the literature review, we found few studies directly comparing large and small-scale farms for the specified environmental outcomes. Because of this, we were unable to do any further quantitative analysis on the data, such as meta-analysis. We mitigated this issue by summarising the available evidence, and triangulating the information found through the literature review with the qualitative data we collected on practices associated with farm sizes. For instance, if in certain contexts smallholders were more often associated with shaded coffee and plantations with sun, this helped us to make inferences about their environmental impacts based on literature focusing on those techniques.

A second issue we experienced in the literature review was a high degree of variability in the indicators and metrics used by different sources. Although many indicators appear to be similar, there are some differentiating factors that make it difficult to compare or aggregate data, for instance in the methodology employed in measuring GHG emissions.

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[11] Please note that, due to availability, one member of the Panel of Experts, Dr. Quiñonez-Ruiz, had to be replaced with another respondent from Colombia during the PoE workshop, Dr. Bernal. Unfortunately, no expert focusing specifically on Peru was able to participate in the PoE workshop, but we received detailed notes later on by a Peruvian expert that we included in our analysis.

[12] All data were collected in respect of UK GDPR policies and in alignment with the rules and procedures of data safety.

A third issue was the lack of longitudinal data; namely, data collected from respondents at different points in time. Longitudinal data, however, are important for deforestation, land use change and carbon accounting.

In terms of the country sample, we found a clear bias of scientific literature towards more well-researched countries (such as Brazil and Colombia) and outcomes (for instance, biodiversity). Most studies were conducted in Colombia (n=37), followed by Brazil (n=28), Nicaragua (n=11), Honduras (n=9) and Peru (n=8) (see Table 1). Of those that provided farm size, the median size for large-scale farms was 62 hectares (ha) (range from 30 to 626 ha), while the median smallholding was 6 ha (range from 0.5 to 30 ha).

Table 1. Distribution of included texts by study country

Country	Number of studies
Peru	8
Honduras	9
Nicaragua	11
Brazil	28
Colombia	37

Table 2. Number of included texts by study country and environmental outcome

	Brazil	Colombia	Honduras	Nicaragua	Peru
Water	4	10	1	3	0
GHG	5	8	2	6	5
Energy	5	2	0	0	0
Deforestation	8	2	6	0	1
Biodiversity	15	27	5	11	3

Within Brazil, a large part of the literature focused specifically on the Cerrado region and Minas Gerais, which means findings reflected in the report may not be reflective of the situation in the country as a whole. Moreover, in many instances examining large-scale farms the research tends to be biased towards more sustainable ones, perhaps because these are more likely to engage in academic partnerships and communicate their environmental sustainability. We mitigated this issue by triangulating results with the primary data, reporting on the number of studies by country and environmental outcome in the final review. Finally, we summarised the data overall by environmental outcome, and only further by country where relevant.

Lastly, interest in environmental outcomes is a recent and rapidly growing area of research with many uncertainties, a lack of evidence and coherent or standardised metrics for many aspects.

Having carried out a systematic search means that this can continue to be updated if desired, and more recent studies can be periodically added to improve the evidence base.

It's important to note that many of the challenges we experienced in our literature review were also found in other studies trying to systematise data on the environmental sustainability of coffee smallholder farmers.[13]

Primary data

In relation to qualitative data collection, the main limitation of the study is that it was conducted entirely remotely and with a limited possibility of interviewing farmers and Producers' Organisations (POs). This was due to several factors: i) the request from FTF and CLAC to not include Fairtrade-certified cooperatives in the interviewee sample to reduce the research burden on cooperatives during busy production seasons; ii) short duration of the research study and limited availability or responsiveness from farmers and producers' organisations during the research period; and iii) in some cases, limited contact information available for producer organisations found through desk-based research and snowball sampling. This resulted in a reliance on existing reporting and on experts' opinions. This is particularly relevant for our second research question, which looks at the role of farmers in environmental data collection. To further include producers' perspectives in future studies, we would recommend including country-based data collection with a larger sample of producers and POs.

A second limitation is linked to the composition of the PoE, due to their focus on specific areas and themes. It should be noted that none of the experts had previously worked specifically on the comparison between smallholder and plantation farming. To mitigate this, we relied on the combined expertise of individual panel members. It was also not possible to include an expert focusing specifically on coffee production in Peru within the PoE workshop discussions. We carried out several interviews with experts in Peru, including academics and representatives of producer organisations (see **Annex 3**).

Third, given the relatively short timeframe and small sample of respondents compared to the study's thematic and geographical areas the study aims to cover, we only provide an initial landscape mapping of the climate and environmental impacts of smallholder coffee farming. Our study includes further steps that can be taken to further develop understanding of this complex issue and potential next steps for environmental data collection (See Sections 4 and 5).

Finally, the study does not specifically assess the social and economic sustainability of coffee production. We are aware that the three are deeply interconnected and that FTF's work addresses social, economic, and environmental sustainability through the promotion of smallholder agriculture, sustainable agriculture, and agroecological practices. We included sub-questions on the theme, and cross-cutting findings are explored in **Section 3.8**.

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[13] See, for example:
https://coffeesmallholder.org/docs/State%20of%20the%20Smallholder%20Coffee%20Farmer.pdf

3. The sustainability of coffee production: a comparison between smallholder agriculture and large-scale plantations

Section 3 synthesises the main study findings. Because of the research limitations highlighted in **Section 2.5**, this section opens by presenting the significant variation across countries, acknowledging there are important context-specific factors that influence environmental sustainability (**Section 3.1**). We then present a general comparison reflecting on environmental practices in relation to farm-size and different shade systems (**Section 3.2**). The subsequent paragraphs further unpack environmental sustainability in relation to water (**3.3**), energy (**3.4**), GHG emissions and carbon stocks (**3.5**), forest (**3.6**) and biodiversity (**3.7**). The section concludes by highlighting the importance of agroforestry in relation to smallholders and the role they play for social, economic and environmental sustainability, also in relation to climate adaptation and mitigation (**3.8**).

3.1 Acknowledging diversity, regional differences and context-specific dynamics.

Our study is ambitious in its aims to compare small- and large-scale producers across a wide range of countries. There are important geographical differences within our country sample - and across regions in the same country - which determine both challenges faced in the sector, and widespread means of production. This includes soil quality, altitude of coffee production, forest cover, distance from the equator, among many other factors. The policy environment, the focus on coffee as a core export, and on different types of practices and technical support to producers also vary across countries.

Moreover, as highlighted in the study limitations, size is not the only variable influencing the environmental sustainability of coffee production. This indeed interacts with other important factors such as the management style - especially the presence and degree of shade - the fact that the producer is certified (with one or multiple certifications) and/or uses conventional or organic agriculture (IB14B). These variables are in turn driven by a range of issues including: i) farmers' individual choices, especially for large and medium farms; ii) context-specific knowledge, dynamics and attitudes towards coffee cultivation, particularly important, for instance for indigenous coffee growers; iii) national policies and legislation dealing with deforestation, price regulation, and/or land tenure.

The following paragraphs provide a brief overview of the context of coffee production in the five studied countries.

In Nicaragua, coffee production is mainly shaded and smallholders account for 96% of producers, with an average farm size of 2.1 ha. Despite being only 4% of producers, larger farmers dominate national production, with smallholders producing less than half (~40 %) of all coffee (USAID, 2017). Washed Arabica exports account for 20% of the country's GDP and half of agricultural jobs. Coffee is mainly produced in the areas of Jinotega, Matagalpa, and Las Segovias in the North Central region of the country (Valkila, 2009).

In Honduras, the majority of coffee production is shaded (HICAFE, n.d.), with 95% of producers being smallholders and an average farm size of 2.5 ha. Coffee production is categorised into traditional diverse shade systems (35%), low diversity shade systems (45%), and full-sun production (20%) (Jha et al., 2014). The country has increased its share of global Arabica production from 2.3% in the 1990s to 4% in the last decade. Coffee employs around one million people and is mainly produced in the Central American Dry Corridor at altitudes above 900 meters (Bunn et al., 2018). Smallholders diversify their income to prevent food insecurity during poor harvests (Anderzén et al., 2021).

Compared to Nicaragua, Honduras has more large-scale producers and resources for the coffee sector, including the research institution HICAFE. Migration, both rural-urban and cross-country, significantly impacts the coffee industry in both countries (Devoney, 2023). Neither government regulates coffee prices and costs (IB29H).

In Peru, coffee cultivation is relatively recent and primarily occurs on the Eastern slopes of the Andes, with an average farm size of about 2 ha. The majority of large producers are in Villa Rica and its surroundings (IA17P), while 75% of producers are smallholders (WCR, n.d.a.). Peru is a global leader in Fairtrade-certified and organic Arabica coffee. Small-scale plantations are often shaded by native or forest trees and typically do not use inputs (IA17P). Recent efforts by various organisations have aimed to improve productivity in these systems. Challenges include issues with representation, cooperative organisation, and limited negotiation power (IB38P, IB12P).

Colombia, the second largest coffee exporting country worldwide, has a long history of coffee production and, in 2022/2023, exported around 10.3 million 60-kg bags (USDA, 2023). Almost all producers (96%) cultivate coffee on landholdings of less than 5 ha (ILO, 2022; Kalmanoff, 2021). Colombian producers are well organised in cooperatives and associations. Research and rural extension services are also carried out by the National Federation of Coffee Growers (FNC) but more informal organisations are also widespread (ILO, 2022). The traditional coffee production region is the Eje Cafetero, but coffee production in other regions, such as Huila, Cauca and Nariño Departments is led almost entirely by smallholder producers (99%) l with an average of 0.97 ha. These regions are known as the Quality Coffee Axis. In the northern part of the country, such as the Sierra Nevada de Santa Marta, more environmentally-friendly coffee is produced (Quiñones Ruiz et al., 2015). Recently, the Colombian government has started incorporating agroecological practices into rural development policies, with Valle del Cauca expected to be among the first to implement these changes. Market pressures have driven producers to seek sustainable practices and alternatives to traditional fertilisers due to rising costs (Coffee Geography Magazine, 2023). Additionally, high coffee prices in recent years have led producers to prioritise harvesting over field renovation.

Finally, in **Brazil**, coffee smallholders represent 75% of growers, with a farm size of around 5 ha. Medium-sized (≥ 10 ha) and large (> 100 ha) plantations, the remaining 25%, account for 62% of total production (Sustainable Coffee Challenge , n.d.). Brazil is characterised by important differences at the regional level (I1D5B, IB14B). The state of Minas Gerais accounts for 53% of total coffee production and 70% of Arabica. In the Cerrado ecoregion, constituted by plain areas above 700 m.a.s.l., coffee cultivation is intensive, the production system is highly mechanised and full sun. It is characterised mainly by monocultural large-scale plantations that often rely on irrigation. Around 30% of Brazilian smallholders are located in Minas Gerais state. Small-scale growers can also be found in São Paulo and Espírito Santo state. In contrast, in the state of Bahia, mostly in its Western areas, coffee cultivation began in the '70 and is generally speaking, highly mechanised and irrigated with the highest productivity in the country (Martins et al, 2018). Smallholders, however, are also present in the region. The definition of smallholders and family farming is debated and different compared to other countries:

> *"[...] small in Brazil means different things depending on the region you are [in], and depending of how low or how flat this is. [...] A family farmer in Brazil can be a family farmer who owns 3 hectares, 5 hectares in the mountains, or a farmer that runs 30 hectares fully mechanised. [...]" (ID4B)*

Brazilian environmental laws are known for being stringent and advanced, although implementation remains partially challenging (Carvalhaes et al., 2019). Moreover, even if most of coffee production is conventional, organic production has increased in the past years in relation to internal and external niche markets (Santos et al., 2023). **Table 4** in **Annex 3** provides a general comparison of smallholders and large-scale plantations, challenges and recommendations for each country.

3.2 Smallholders, large-scale plantations and sustainable practices

Despite context-specific dynamics, the interaction of different variables, the use of different reporting metrics and current lack of data, especially in relation to large-scale plantations (see **Section 2.5**), our primary data collection shows that smallholders' practices are currently more environmentally sustainable compared to the ones adopted by large-scale plantations. However, it needs to be highlighted that large scale plantations have more resources in terms of social and economic capital that place them in a better position to take risks and quickly respond to market and legislative changes. They have more digital literacy and access to services that can support their transition towards more environmentally sustainable practices. Moreover, for the same reasons, they are able to effectively communicate their changes to different stakeholders of the value chain (IA1B). Especially in Brazil, therefore, due mainly to market pressures, we are witnessing an initial move towards the adoption of environmentally sustainable practices by some medium and large-scale plantations (IA2B). Some examples of these practices are the adoption of biofuels for tractors and solar powered mills to reduce large-scale plantations' carbon emission but also the adoption of agroecological practices and conservation or regenerative agriculture conducted by medium and large producers (IA2B).

Nonetheless, at present and at a systemic level, the environmental practices adopted by coffee growers are driven by structural conditions: farm size, but also labour, technology use, availability of economic resources, land tenure and finally, farm geographical location and agroecological conditions.[11] The use of family labour in small parcels of land, often located in slopes or mountainous remote areas, means that the practices adopted by smallholders differ sharply from the practices normally used in large-scale plantations. This difference is mainly driven by the intensity of management and the presence of shade and significantly influences environmental impact.

The intensity of management concerns two main practices: i) the adoption of chemical inputs, which can cause soil and water pollution, drive carbon emissions and biodiversity loss and risks, in certain cases, to be detrimental for human health (Zhang et al, 2018; FAO, 2023); and ii) the farm mechanisation, the use of technologies for field preparation, harvesting and post-harvesting treatments and, in some cases, mechanised irrigation. Both are discussed below.

Use of fertilisers, herbicides, pesticides and other chemical inputs

Smallholders use less or no fertilisers, mainly because of their high price. Many small-scale growers are indeed 'organic by default' - they cannot afford and/or access external inputs and they therefore have to practice organic production (e.g. Gibbon, 2006) - in all the studied countries, but especially in Nicaragua and Honduras. In addition to this, a highly biodiverse farm with agroforestry does not require the same quantity of chemical inputs and, in certain cases, it might not require them at all. As far as pesticides are concerned, the use of the same coffee variety grown as a monoculture can increase pest resistance in the long term, therefore creating dependence from chemical inputs in monocultures. Moreover, as emerged from interviews with producers, smallholders have an interest in protecting the health of their family and the environmental conditions of the place where they live. Finally, due to their high mechanisation, large-scale plantations can spread inputs in a planned and cost-effective manner. On the contrary, applying different kinds of inputs can be very time-consuming and labour-intensive for smallholders. As the director of a Producer Organisation (PO) put it:

> *"It would not be possible to manage a big production as our producers do, because they use family agriculture. They cultivate very well their product because it's theirs. This does not happen in a large-scale production where many people work but not with the same care. That's why we think smallholders are better placed to take care of the environment" (IB22C).*

It should be noted, however, that due to poor extension services and lack of technical knowledge on the use of inputs, smallholders and medium size farmers might also cause environmental damage by means of applying inputs incorrectly. This is one of the areas in which POs play a very important role in supporting smallholders. Cooperative strengthening and environmental training provided by regional Producer Networks including CLAC are already part of Fairtrade interventions.

Farm mechanisation

High intensity and high mechanisation farms use technologies such as tractors, mills and in some cases (20 to 30% in Brazil) irrigation systems that require energy from fossil fuels resulting in carbon emissions.

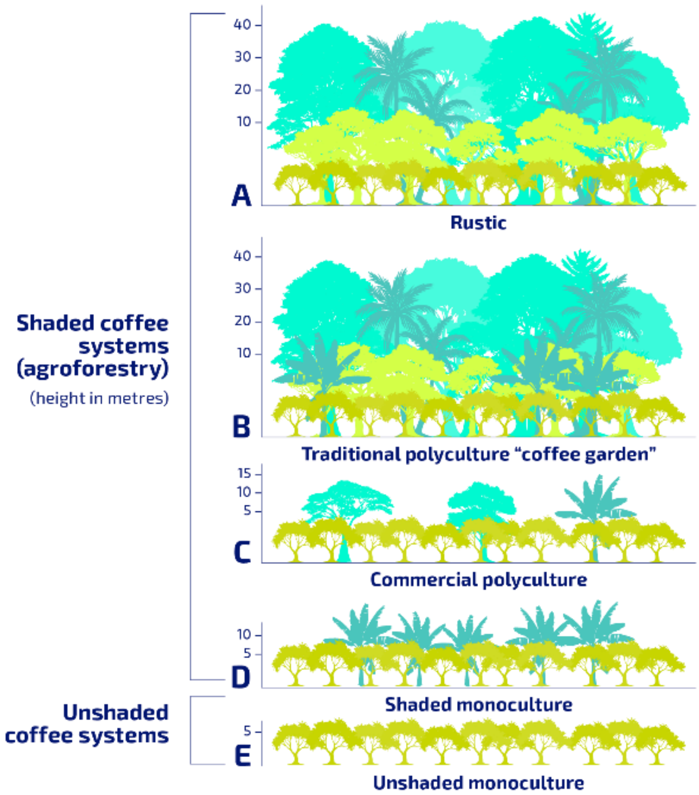

***Figure 2. Shaded Coffee Systems* (Moguel and Toledo 1999)** In addition to the difference in intensity of environmental practices and mechanisation, with the notable exception of Brazil and Colombia, small-scale growers normally practice shaded diversified coffee cultivation, which has several advantages for environmental sustainability. Trees play a crucial role in stabilizing ecosystems through water storage, soil protection, nutrient cycling, and enhancement of biodiversity (Jose, 2009; see **Section 3.8**).

Figure 2 (Moguel and Toledo, 1999) shows how farms vary in terms of shade[14] and the relative increase in biodiversity. In Honduras, Nicaragua, and Peru, smallholders work mostly in shaded diversified plantations (see **Section 3.1**). They integrate trees with complementary crops to reduce costs and input requirements while also addressing their need for food, fuel, construction materials and secondary income or cash for emergencies.

The *'rustic' system (A)* is constituted by coffee grown in thinned forest. It is the case, for instance, of coffee cultivated by Indigenous communities in Honduras or in the Peruvian Amazon. Even if this category is disappearing, several organisations are now supporting communities to grow coffee in the forest, instead of clearing the land to cultivate shaded coffee.[15] This system ensures the highest

[14] This typology was introduced in 1999 but it is now widely cited in the literature and was validated by the study PoE, with some comments on unshaded cultivation in Brazil that are explained in text.
[15] See for instance the CleanTech initiative in Peru (https://discovercleantech.com/the-eco-coffee-that-preserves-native-forest-and-improves-the-lives-of-indigenous-people/) and TechnoServe in Honduras (https://www.technoserve.org/blog/indigenous-farmers-grow-ecologically-sustainable-coffee-honduras/)

level of biodiversity and soil fertility conservation. The second and third most biodiverse types are the *traditional polyculture or 'coffee garden' (B)*, where mixed species with a complementary architecture are grown within the forest, and *commercial polyculture (C)*, with different strata of multilayered crops and trees with a commercial use. Typology B and C are the most common for smallholders in Nicaragua, Honduras, Colombia and Peru.

Types B and C are followed by *Shaded monoculture Typology (D)*, which has only one or two species of trees. In Nicaragua, for instance, while both large-scale farmers and smallholders employ agroforestry principles, smaller farmers tend to plant more diverse tree species that contribute to family incomes, such as timber and fruit trees, leading also to more biodiversity (Type B), while large scale plantation lean towards type C and D. The last category, *unshaded monoculture (E)*, is typical of the regions of Cerrado and Western Bahia in Brazil, where production is maximised via the use of full sun monoculture, chemical inputs and mechanisation. Smallholder farmers in certain regions of Brazil, such as the Zona da Mata in the State of Minas Gerais, also practice full sun agriculture due to the agroecological conditions but often have diversified farms, with home gardens and small livestock.

It is therefore clear that the different forms of agroforestry and shaded cultivation adopted by smallholders in many regions of the studied countries, together with the low intensity management of their farms and the employment of family labour, result in a considerable degree of environmental sustainability when compared to large-scale plantations with sun-grown coffee. In the next sections we will explore more in detail how environmental sustainability plays out across the dimensions of water (3.3), energy (3.4), GHG emissions and carbon stocks (3.5), forest (3.6) and biodiversity (3.7).

3.3 Water

Coffee's impact on water resources is due mainly to irrigation and waste-water management. Overall, evidence points to a lower impact of small-scale farming, compared to larger producers, in terms of water use, although water pressures are increasing due to climate change. Evidence is more mixed in terms of water contamination due to waste management. This was highlighted as an area where smallholders require further technical support, particularly in Colombia, Nicaragua and Honduras, where wet processing of coffee is strongly prevalent. New technologies have potential to enable a more environmentally friendly post-harvest process, although they remain costly and smallholder producers would require further technical assistance to implement them.

Water use and quality in cultivation

While coffee is not seen as a water-intensive crop, as it is mainly rainfed, the implications of coffee production on water use depend on the environmental characteristics of each context. Climate reliability, soil quality and management practices - including due to cultural and historical factors - all contribute to determining coffee production's water use.[16] The literature review found a total of 15 texts examining water use by coffee farming: 10 in Colombia, 4 in Brazil, 3 in Nicaragua, and 1 in Honduras. Compared to other areas like biodiversity and deforestation, this seems to be a relatively under-researched area, and it's interesting to note much of the research being focused on Colombia.

According to the literature, differences in water use are mainly driven by the use of irrigation: large-scale farms that are often irrigated tend to use more water and have a higher water scarcity impact (Winter et al., 2020; Usva et al., 2020). Winter et al. (2020) carried out expert interviews, eliciting scores to compare sustainability performance in typical conventional large-scale coffee to Fairtrade organic smallholdings in Brazil. The study found that small-scale farms scored higher (score=90/100) for water use (therefore, used less water) than large-scale ones (score = 78/100) (Winter et al., 2020). Water scarcity quantifies the potential of water deprivation to humans or ecosystems, so balances water use with water availability in the system. It is based on the water remaining per unit of surface in a watershed relative to the world average. Usva et al. (2020) found that large-scale farms in Brazil had a much higher water scarcity impact (0.26 and 0.13 m3 eq / litre coffee) than the other samples (0.01 - 0.02 m3 eq / litre coffee), driven by irrigation. This result is further supported by a regional study in Brazil (Martins et al., 2018) according to which the southeast of the country, where the majority of larger-scale plantations are located, scored higher in terms of both water and carbon footprint compared to other regions where there is a higher prevalence of small-scale producers (see **Section 3.1**). It should be noted that while most of the coffee in Brazil is rain-fed, with some exceptions, the Cerrado region is an area where most farmers are fully mechanised and irrigated (ID4B). In this area, conflicts over access to water for different uses (including agricultural uses for irrigated crops) are already happening and may be exacerbated in the near future (Salmona et al., 2023; IA2B).

Irrigation is indeed a driver for water scarcity, which results in water conflict, as highlighted for the cases of Peru (IA17P) and Brazil (Salmona et al, 2023; IA2B). In Peru, it was reported that governmental irrigation projects are being introduced to support large-scale agriculture in the coastal region, without the involvement and representation of smallholders. Also in Peru, coffee cultivation is being transferred to higher altitudes (of over 1200m) due to climate change, while cocoa and bananas are taking its place, requiring more water resources and potentially driving increased water scarcity.

While the use of irrigation is characteristic of large-scale plantations, climate change could mean that it is increasingly needed by smallholders. At the moment, however, this remains a remote possibility. Respondents in Honduras highlighted that new water threats and stressors posed by climate change have led to the adoption of irrigation by large-scale plantations in Honduras. As highlighted by one of our experts, water stress and irrigation are, in some contexts, increasing due to climate change and low reliability of rainfall:

[16] https://rutadelcafeperuano.com/2021/03/22/el-cafe-peruano-y-el-dia-mundial-del-agua-lo-que-debes-saber/

"[During data collection in Honduras], this was 2015-2016, It was the first time in my career in coffee that I heard people say that they were thinking about irrigating. So, my impression is that the higher temperatures that have resulted from climate change are stressing out plantations a lot more than they ever have before. And in areas where, especially as the elevations go lower, those plantations are struggling with water. And I have heard anecdotally that some of the larger plantations [in Honduras] are starting to use irrigation. But traditionally, coffee plantations don't use irrigation, and the water usage is mostly during processing" (ID7).

Increased frequency and quantity of chemical inputs increase water pollution from coffee farming (Winter et al., 2020; Bortolotto et al., 2013; Notaro et al., 2022). Typical Brazilian Fairtrade-certified and organic smallholders scored better (score = 72/100) than large-scale conventional farms (score = 42/100) because they apply fewer agrochemical inputs known to be toxic to bees and aquatic organisms. They maintain green cover all year round, only apply organic fertilisers and crop residues and rarely use copper fungicides thereby maintaining higher water quality (Winter et al., 2020).

When comparing smallholder sun and shade systems in Colombia, permanent shade systems scored a higher level of water care (score = 5/5) than sun systems (score = 3.8/5) (Oviedo-Celis & Castro-Escobar, 2021). Acosta-Alba et al. (2020) conducted a Life Cycle Assessment from cradle to farm gate through surveys and interviews to inventory coffee production systems and conducted an impact assessment. Permanent shade systems were found to have much lower water resource use depletion (46.4 m3 water eq /ha/yr) compared to sun (70.1 m3 water eq /ha/yr). Moreover, shaded systems had lower freshwater ecotoxicity[17] (shade = 4.2 CTU e104 / ha/ yr, sun = 5.4 CTU e104 / ha/ yr) and freshwater eutrophication[18] (shade = 3 kg P eq / ha/ yr, sun = 4.1 kg P eq / ha/ yr) (Acosta-Alba et al., 2020).

The role of post-harvest processing

The literature points to the role of chemical inputs and wastewater management as driving water-related issues. Further pollution can occur if the wastewater from coffee processing is released untreated into natural water courses. It was reported that farmers employ various methods to reduce their impact: for example, Rahn et al. (2014) found that 85% of farmers in their study in Nicaragua had infiltration pits for wastewater.

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[17] Ecotoxicity refers to the potential for biological, chemical or physical stressors to affect ecosystems. Such stressors might occur in the natural environment at densities, concentrations or levels high enough to disrupt the natural biochemistry, physiology, behaviour and interactions of the living organisms that comprise the ecosystem (see https://www.informea.org/en/terms/ecotoxicity).

[18] Eutrophication refers to excessive plant and algal growth due to water becoming filled with nutrients needed for photosynthesis, including sunlight, carbon dioxide and nutrient fertilisers. Eutrophication has been accelerated by human activities, such as the discharge of nutrients into aquatic ecosystems (see https://www.nature.com/scitable/knowledge/library/eutrophication-causes-consequences-and-controls-in-aquatic-102364466/).

Despite this, respondents mentioned important issues in terms of waste management, water pollution and residues from wet processing in relation to smallholder farmers, with regional variation. Issues related to wet processing of coffee were highlighted for producers in Colombia (ID1C), Nicaragua and Honduras (IA8). On the contrary, producers in Brazil typically employ a sun-dried (or manually dried) method, which naturally leads to fewer water contamination issues (see **Section 3.1**). Respondents highlighted that producers require more support and technical assistance to mitigate issues linked to coffee residues causing pollution. Further, it was highlighted that smallholders need more awareness of their contribution to water pollution, as they may under-estimate the impact of their residues due to their small production size. Despite this pressing need, technical assistance in this area was described as still limited. It was suggested that POs could play a role in promoting more sustainable practices (see **Section 5**). If producers focus solely on production, and work as part of cooperatives or associations for processing and commercialisation, it would be easier and more cost-effective to follow quality standards and environmental policies (ID3H).

Producers in Colombia were highlighted in interviews as facing strong challenges in post-harvest water management. This could be due to the reliance on wet processing (and de-pulping machines) in the country, as well as organisational structures where individual farmers are responsible for the management of the post-harvest process. According to one respondent, the production model traditionally promoted by government institutions was based on the use of chemicals to support productivity, with impacts on water pollution (ID1C). More recently, there has been a notable shift to more ecologically minded methods, including through the exploration of innovative practices and technologies (see **Box 1**). However, it was pointed out that these innovations come at a cost that smallholder producers are not always able to afford. As highlighted by one respondent:

> *"Colombia is more specialised with the wet processing. There are many experiments regarding sun dried coffee because people or producers started to try or test other types of coffee production. [Such as] sun dried and wet and semi-wet or honey production, where the amount of water is not [as] intense as the wet processing. There is a change, but this is only done by those [who] don't have the resources to get some water or who have a lot of knowledge to know how to do it and how to further process that coffee" (ID1C).*

According to the literature, this **low performance in residual water management is linked to lack of infrastructure to dispose of coffee residues.** For example, only 51% of farms in Santander have a septic tank system that allows the treatment of domestic sewage (Oviedo-Celis & Castro-Escobar, 2021).

Potential solutions and effective practices

Research pointed to several techniques that can help reduce smallholders' impact on water resources. First, agroecological methods can help support water conservation. Within small-scale farms in Colombia, Acosta-Alba et al. (2020) found that farms with permanent shade scored better for water conservation than sun and transitional shade systems. This was despite the use of wet processes: due to its relatively higher productivity, shaded coffee led to less impact per yield. The introduction of compost, as a replacement for mineral nitrogen fertiliser, was also found to reduce water use and increase water quality (Acosta-Alba et al., 2020). Interview respondents confirmed the potential for agroforestry to support water protection. Organic agriculture was described as leading to particularly positive results in terms of producer awareness, management processes, and maintenance of resources, including water (ID1C). Water was seen as inter-linked with other sustainability metrics; namely, tree planting and biodiversity, which reduce soil erosion and support resistance to droughts, decreasing reliance on irrigation (1B14B).

Certification - including Fairtrade's - and organisation through POs were both seen as supporting more sustainable post-harvest processes, though challenges remain. Further collaboration and organisation was advocated in particular for the post-harvest process, to support farmers to follow environmental standards (1A9). Decentralised processes, such as the one observed notably in Colombia (see above) were seen as leading to challenges in supporting environmentally friendly practices. Here, Brazil's strong cooperative structure was described as a key strength compared to other countries where the sector is less structured (1D3H), such as Peru, where only approximately 30% of producers are part of a cooperative or producer group (1A16P, IA17P).
Increased recognition of the issues linked to coffee processing has led to interesting pilots and experimentations to reduce water contamination. This includes new technologies to support de-pulping, as well as transitions towards sun-dried coffee, semi-washed or honey production (see **Box 1**). Overall, key to the future prospects of these pilots is the support offered to smallholder farmers to access, learn from and implement these types of solutions. Knowledge exchange and access to training are crucial to these endeavors.

Box 1. Smallholder Innovations to reduce post-harvest water pollution: ongoing research in Colombia

Wet coffee processing has considerable environmental impacts, both in terms of the quantity of water used, and contamination of water sources through waste discharge. Colombia is one of the countries where wet processing is most widespread, due to a combination of environmental conditions and tradition. Several pilots are exploring different processing methods, which could have both an impact on the taste profile of coffee, as well as reducing negative effects on water.

In Colombia, the Federación Nacional de Cafeteros and its research arm, Cenicafé, have been investigating the use of new technologies to transition away from the wet processing method. The organisations have been piloting and promoting the use of water-efficient coffee mills, which employ the use of 'eco-pulpers'. The first is Becolsub, developed by Cenicafé, which removes mucilage from the coffee beans without fermentation.[19] Ecomill, also developed by Cenicafé, allows coffee to be washed by a process of natural fermentation or by applying pectinolytic enzymes.[20] Both employ little or no water during the de-pulping process, removing the mucilage from the coffee bean mechanically[21], and consume much less water than the traditional method. According to an evaluation of the Intelligent Water Management System (IWM Colombia[22]), using Becolsub's ecological processing method can reduce coffee's water footprint by 45.7% and Ecomill's by an impressive 99.9%, compared to traditional wet processing technology.

These technologies are not without their challenges: first, removing the fermentation stage could impact the quality and flavour profile of the coffee, and it's important to keep in mind that, ultimately, the driving concern for consumers remains taste, not sustainability (ID1C). Second, the cost of this type of technology is not always seen as a feasible or worthwhile investment by smallholder producers (ibid.). In fact, the technology was described as most sustainable and relevant where large quantities of coffee are produced, which has resulted in relatively low take-up among smallholders (de Jong et al., 2019). For example, the IWM initiative started promoting the association of farmer groups to jointly operate community eco-mills, pointing to the potential benefits of further association and centralisation of the post-harvest process. Overall, further research and dissemination are needed, particularly to increase consumer awareness.

There are other solutions that are currently being piloted and that could improve water management, even where traditional wet processing methods continue to be used.
Recent research from the University of Surrey and University of Antioquia has pointed to the potential for Bioelectrochemical Systems as an alternative solution to conventional water treatments. Here, microbial communities have been identified as having potential to degrade organic matter present in wastewater, and co-generate electricity (Agudelo-Escobar et al., 2022).[23] Recent research has also looked at the potential of reusing water waste from coffee processing, once treated, for instance in the pharmaceutical or cosmetic industry. This could have the dual benefit of reducing environmental impacts and providing a source of extra income for producers (Campos et al., 2021). Farmers in Colombia are also exploring the processing of *aguas mieles* (coffee wastewater) to produce organic fertiliser through anaerobic digestion.[24] The potential environmental impact of these innovations and their applicability to farmers' work could be explored in future studies.

A third alternative being explored is piloting different fermentation techniques, deviating from the 'traditional' wet method. While more and more producers in Colombia are employing honey or natural processing (ID1C), other 'special' coffees are exploring various techniques, such as anaerobic fermentation, which are not only less water-intensive but have distinctive flavour profiles.[25] This remains a risky endeavour, however: not all producers have the resources or technical capacities to experiment with different techniques, and poor fermentation can affect yields and quality of coffee. Collaboration with roasters who have an interest in experimenting with new techniques was seen as a potential solution to support further innovations in this area.[26]

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[19] https://perfectdailygrind.com/2018/12/processing-101-what-is-washed-coffee-why-is-it-so-popular/

3.4 Energy

Overall, small-scale producers tend to use less energy due to lower levels of mechanisation in their farms - a key differentiator from larger producers. The reliance on hand-picking is due to both affordability and natural conditions in their environment. Brazil is partially an exception, as in some regions, both smaller and larger farmers tend to employ some level of mechanisation. While small farms tend to not be mechanised, there are still implications in terms of energy use (and carbon emissions) in the post-harvest process, depending on the technology used, drying processes, and transport links. While renewable energy could be a potential solution, access is still limited for smallholders in many cases.

Mechanisation and energy use

The literature review found a lower number of research papers focusing on energy compared to other environmental outcomes - potentially highlighting that this is an under-explored area. Seven texts evaluated the energy use of coffee farms, five of which were in Brazil and the remainder in Colombia. Only one text compared energy use between a typical conventional and organic Fairtrade smallholding in Minas Gerais, Brazil which it did through expert interviews and scoring according to sustainability categories (Winter et al., 2020). Here, energy use was found to be very similar between the two systems, both of which were found to be in the 'moderate' category (convention score = 56/100, Fairtrade organic score = 55/100). This is likely because the small-scale farm still had a level of mechanisation for harvest and weed control, and neither farm type used renewable energy sources (Winter et al., 2020), reflecting a context where production techniques are similar across farm sizes (IA9).

It is difficult to directly compare energy use for the other texts because different data and units are used between them. Instead, we examined texts more closely to understand what drives energy use in the two systems. The large-scale studies were based in Minas Gerais Brazil (n=4), and Colombia

[20] https://www.globenewswire.com/news-release/2013/06/06/1088787/0/en/Ecomill-R-a-New-Cleaner-and-More-Efficient-Technology-for-Coffee-Processing-Now-Available-to-Colombian-Coffee-Growers.html

[21] See further information at: *https://coffeelands.crs.org/2012/08/294-technologies-to-reduce-coffees-water-footprint/*

[22] IWM Colombia, active between 2014 and 2018, was implemented by the Federación Nacional de Cafeteros, in partnership with the Colombian government, Nestlé S.A., Nestlé Nespresso S.A., Cenicafé and Wageningen University. Further information available at: https://www.rwi-essen.de/en/research-advice/departments/environment-and-resources/research-projects/project/impact-evaluation-of-the-intelligent-water-management-160

[23] Further details on the research collaboration, which was awarded the UK Government's Newton Prize in 2018, can be found here: https://www.surrey.ac.uk/news/turning-wastewater-coffee-production-electricity

[24] https://perfectdailygrind.com/2020/01/agua-miel-from-pollutant-to-organic-fertiliser/

[25] For global examples of the potential environmental impact of experimental fermentation, see: https://perfectdailygrind.com/2023/11/is-washed-coffee-still-as-popular/

[26] Examples from the Colombian context can be found at: https://perfectdailygrind.com/2023/11/define-experimental-coffee-processing-fermentation/

(n=1). For these farms, energy use at the plantation level was driven by the frequent use of machinery, equipment and chemical inputs such as fertiliser, phosphate, fungicides, and pesticides. During harvest and drying phases, energy use is higher for farms that mechanise these processes, using more fuel, machinery, equipment and electricity (Giannetti et al., 2011a, 2011b; Winter et al., 2020; de Lacerda Filho et al., 2014; Méndez Rodríguez et al., 2022).

Small-scale farms tend to be less mechanised than large-scale ones (Winter et al., 2020; Muner et al., 2015; Presta-Novello et al., 2023). Their energy use is driven by the use of inputs and renewable energy sources. Small-scale organic farms in Brazil were shown to use 2.5 times less energy (MJ) than small-scale conventional farms as they have lower use of machinery, equipment and fertilisers (de Muner et al., 2015). The production and transportation of fertilisers and other agro-chemical inputs also increases the energy consumption of the farm. In the small-scale conventional systems, over 65% of their total energy use was through fertilisers, whereas for organic systems this was less than 1% (de Muner et al., 2015). Most of this energy use was due to the need to purchase and carry organic fertilisers over long distances (Muner et al., 2015) and with high costs. It should also be highlighted that producers' groups are engaging in the setting of Biofábricas to reduce their dependence on external inputs. In fact, regarding the use of organic fertilisers, the general manager Red Ecolsierra in Colombia explained that one of their goals was to create its own Biofábrica due to the high costs of buying organic fertilisers and the need to meet the associates' requirements (based on agroecological analyses and not only soil analyses) (Quiñones-Ruiz and Salcedo Montero, 2023). This shows how **on-farm production of fertilisers and energy** could reduce energy use even further. Presta-Novello et al. (2023) showed how **biodigesters used** for fertiliser production could also be used as an additional coffee-drying resource or for cooking for a family of five, an intervention that particularly benefited women in small-scale farms in Colombia.
It's interesting to note that Peru, Nicaragua and Honduras did not appear in the literature review. The three countries are characterised by small-scale production, generally, with lower implications on energy use. The lack of literature could reflect small-scale producers' more limited impacts in terms of energy or could simply reflect under-researching on the topic.

Primary data confirms the overall assessment of the literature review. Smallholders were described as employing much lower levels of mechanisation in their production. On the one hand, this is due to affordability of these types of machines (ID7). On the other hand, the geographic characteristics of forest-based, mountainous or volcanic production seen in large parts of Peru, Colombia, Nicaragua and Honduras make the use of machines unfeasible in the context and lead to a reliance on hand-picking (IA9). This was frequently contrasted with the highly mechanised plantations seen especially in some parts of Brazil, such as São Paulo state, Goias and Western Bahia (ID5B), where the use of harvesting machines is widespread (IA9, IA3H).

Energy use throughout the production, harvesting and commercialisation process

It is important to consider energy use in other parts of the coffee production chain, which remains an under-researched area. Interviews with respondents and the literature review pointed to the need for further research on:

- The use of synthetic fertilisers that are petroleum based, and their link to energy consumption of the system;

- De-pulping machines and micro-wet mills employed in wet production systems, which often have small engines running on diesel;
- Transportation for organic inputs, such as fertilisers, that are often imported from outside the region of production;
- Producing oven-dried coffee, compared to sun-dried, both of which pose advantages and challenges: while oven-dried coffee uses more energy, sun-dried coffee can be risky in terms of quality, especially with unpredictable rainfall patterns (IA9).
- Use of individual mills for processing, which often employ gasoline (ID8N).

All of these areas, closely linked to GHG emissions, were described by respondents as affected by smallholders' production techniques. Importantly, it was also pointed out that smallholders could potentially still be consuming less energy, because of their manual labour, less use of irrigation and mechanisation. However, larger producers' economies of scale and access to renewable energy sources may mean that their energy use per quantity produced may be improved. Ultimately, energy use warrants further investigation, as it's challenging to draw definitive conclusions based on available data.

Box 2. Renewable energy, coffee production and circular economy

Renewable energy holds very high potential for coffee production, which, however, remains relatively under-explored. Recent initiatives in the countries in our sample have explored coffee's potential to both benefit from, and contribute to, the renewables energy space.

While sun-dried coffee has lower direct energy use implications, it may not be possible in all contexts. For example, sun drying requires flat drying surfaces to guarantee uniform drying, while high temperatures and heavy rain can affect bean quality. The use of mechanical dryers can reduce reliance on increasingly unpredictable weather patterns and can therefore be highly suitable to certain contexts. Mechanical drying is also seen as allowing for better-quality beans and more consistency.[27] However, the use of mechanisation in coffee production can raise concerns in terms of use of fossil fuels, as well as increase farms' costs in terms of energy use.

In Nicaragua, the Fairtrade-certified SOPPEXCCA cooperative has placed economic and social sustainability at the core of all its processes. This includes the use of solar dryers to ensure coffee quality while not compromising environmental outcomes.[28] The cooperative also showcases effective practice by investing proceeds back into community efforts, including water treatment, medical services, school supplies, and a small cocoa factory to promote a source of alternative income, among many other programmes.[29] In Brazil, the use of solar energy in coffee farms was described as not only beneficial to the environment, but also to reducing farmers' production costs, given the high cost of electricity in the country.[30] This is exemplified by the case of Fazenda Três Meninas, in the South of Minas Gerais, which has been relying on solar energy as part of a long-standing commitment to regenerative farming practices.[31]

A second interesting innovation is on the use of **coffee waste as a renewable energy source.** The benefits of using coffee composting for fertiliser is well researched and a widespread practice among small farmers in Latin America (Idárraga Quintero and Sánchez Rodrigues, 2016). Recent research has been exploring the potential for coffee waste to be used for energy production. This includes both processing by-products at the farm level, as well as used coffee grounds once coffee has been consumed (Segebo, 2022). For instance, David and Lopez (2021) explored the potential for the use of coffee biomass oil as an energy source, while Setter and Oliveria (2022) recently assessed the potential for coffee husk briquettes in energy production. On the consumer side, potential for spent coffee grounds is also being explored by Johnson et al. (2022). While these technologies hold potential, supporting farmers and farmers' organisations with the know-how and required machinery, as well as providing incentives for environmental services, could support the clean energy transition both within and beyond coffee farms.

[27] https://www.idhsustainabletrade.com/news/interview-with-the-general-manager-of-aldea-global-warren-e-armstrong/
[28] https://sucafina.com/na/offerings/soppexcca-las-hermanas-regenerative-organic-certified-fw-fto-roc

Potential solutions and effective practices

Similarly to the case of water use, there is potential for improvement in smallholders' performance and reporting through organisation and technical support. First, research pointed to the potential role of POs to make post-harvesting, commercialisation and transportation processes more efficient by grouping smaller producers together. Second, there could be a role for cooperatives, associations and other actors in the coffee sector to promote, support and provide guidance on the use of renewable energy. According to the International Energy Agency (2023), despite the high potential for renewable energy, it generally remains under-explored, including in agriculture, and in particular lower income groups require more support to face the initial set-up costs of many technologies.[32] Research participants pointed to the potential to increase use of biogases, hydroelectric mini plants, efficient stoves and solar panels, for example. Interestingly, interview participants also pointed out that farmers have strong incentives to be more energy-efficient, as it would directly reduce the costs of production on their farms.

3.5 GHG emissions and carbon stocks

Different metrics used to account for GHG emissions make it difficult to make methodologically robust comparisons. Small-scale producers emit less GHG per hectare due to environmentally sustainable practices - such as lower use of fertiliser, pesticides, shaded cultivation, greater biodiversity, among others. Certified and organic producers in particular are generally carbon negative or neutral. However, larger producers' higher productivity could potentially be linked to a lower carbon footprint per kilogram. The metric adopted seems to be key to GHG emissions measurement and the lack of standardised metrics is a limit of the Voluntary Carbon Market (VCM) as it is currently conceived. Moreover, GHG emissions data collection is complex and time-consuming and often inaccessible for smallholders. Smallholder coffee production, however, especially when associated with agroforestry, has great potential on carbon stocks and emissions insetting. Available studies indeed point to smallholders' carbon neutrality or carbon positivity (Lugo-Pérez, 2023; Burkey at al, 2023). Lessons need to be learnt from VCM in the data collection associated to carbon stock and insetting (see Section 4).

[29] https://cafemoto.com/product/nicaragua-las-hermanas/
[30] https://perfectdailygrind.com/pt/2022/08/11/beneficios-e-desafios-da-energia-solar-na-fazenda/
[31] https://valorinternational.globo.com/agribusiness/news/2023/10/16/regenerative-agriculture-a-way-to-ensure-coffee-supply.ghtml
[32] https://www.iea.org/reports/latin-america-energy-outlook-2023/executive-summary

GHG emissions in the production process

The literature review found eight texts studying the greenhouse gas (GHG) emissions of coffee farms, with studies covering all countries in the sample. The reviewed studies usually included, in their analysis, any processing done on farms.

There are variations by country and by method for calculating GHG emissions, and overall evidence is patchy. A major challenge with comparing GHG emissions is linked to different metrics used, some opting to measure per litre of coffee or hectare or ton of fresh cherries. Overall, greenhouse gas emissions between large-scale and small-scale farms were estimated to be similar (Winter et al., 2020; Usva et al., 2020). In a comparative study on farms in Brazil, Colombia, Honduras and Nicaragua by Usva et al. (2020), large-scale farm emissions from coffee production and processing (not including transportation to market) ranged between 0.15 and 0.54 kg CO_2 eq/litre coffee, while small-scale farms ranged between 0.13 and 0.44 kg CO_2 eq/litre coffee. In Winter et al., 2020, Fairtrade organic farms scored lower (score=45/100) than the large-scale conventional farms (score = 54/100) for greenhouse gas emissions. Still, both farms were included in the moderate category and there was potential for improvement through areas of permanent grassland or agroforestry systems (Winter et al., 2020).

Across all studies, the common theme was that overall emissions were driven by the intensity of production (and energy consumption), mainly linked to fertiliser use in both organic and inorganic systems (Winter et al., 2020; Peixoto et al., 2008; Skevas & Martinez-Palomares, 2023). This is correlated with the country of production, linked to soil quality and agricultural policy: Brazil and Colombia tend to have a higher intensity of fertiliser use than Nicaragua, Peru and Honduras. The production and high use of fertilisers primarily drove emissions for the two most emitting farms (0.54 and 0.44 kg CO_2e /litre coffee) in Brazil and Colombia in Usva et al. (2020). Many Brazilian farms also apply lime annually due to very acidic soil conditions, which causes extra carbon dioxide emissions. On the contrary, studied farms in Nicaragua and Honduras used minimal machinery and agricultural inputs, and their emissions had a much smaller range, between 0.13 and 0.27 kg CO_2e/litre of coffee (Usva et al., 2020).

Similarly, according to interviewees, small-scale producers are overall emitting less GHG than larger-scale ones. This assessment was linked to three key features of their production:

- Larger tree cover, and resulting carbon sequestration, on their farms, particularly where shaded systems of production are employed.
- Lower use of pesticides and fertilisers in their production, often due to the inability to afford these inputs, and the transportation costs associated with bringing them to their farm.
- Lower levels of mechanisation in their production, linked to affordability and geographical conditions that render the use of machinery unfeasible in harvesting, separating and drying coffee.

As pointed out by one respondent:

> *"Obviously it's not true everywhere, but in general [for smallholders] we have a lot more tree cover and biodiversity and a lot less use of pesticides than on large farms. This tends to bring with it a much better carbon sequestration on these farms [...] there's more protection. [...] On*

plantations where you have a lot more mechanised structures and some of their large plantations, [...] The actual production of greenhouse gas emissions from all sorts of machineries is a lot higher." (1C4)

Land use change from forest to coffee was also found to be a very important emissions source, increasing emissions from Honduras, Nicaragua and Peru, which have experienced more recent deforestation due to demand for coffee (Usva et al., 2020; Burkey et al., 2023). For instance, additional greenhouse gas emissions from land use changes from samples in Nicaragua were 5.2 tCO_2e/ha/year (Usva, et al., 2020). The study estimates that 60-75% of emissions of green coffee were driven by land use change across the study period in Nicaragua and Honduras (Usva et al., 2020). Taking land use change into account is difficult, however, because it depends on the timeframe examined and attribution to a single producer is often challenging (Usva et al., 2020; Burkey et al., 2023). For instance, Burkey et al., 2023 used the Cool Farm Tool which takes any deforestation within the last 20 years into account. Across cooperatives they measured the median carbon intensity ranging from -6.80 to -1.20 kg CO_2e per green bean equivalent (GBE) excluding deforestation emissions—or from -0.15 to 67.92 kg CO_2e per GBE including deforestation emissions (Burkey et al., 2023).

GHG in the post-harvest process

*The post-harves*t process was described as crucial in GHG emission calculations. Wastewater from de-pulping and fermentation was a major source of methane emissions (Rahn et al., 2014), in addition to its water pollution effects (see **Section 3.4**). For example, in small-scale shaded, organic farms in Nicaragua, emissions were reportedly driven mainly by: i) compost production; ii) coffee de-pulping and fermentation; iii) decomposition of tree litter and prunings in the field; and iv) compost application (Rahn et al., 2014). Studies from other countries in the region also point to the link between composting and greenhouse gas emissions, affecting both climate change and air quality (Nordahl et al., 2023) due to the residue stemming from the de-pulping process (San Martin Ruiz et al., 2021).

Interviews confirmed the complexity of precise assessments on GHG emissions. One point raised by respondents is that we need greater understanding of GHG emissions throughout the whole coffee production process – including post-harvest processing, transportation, roasting and preparation. This adds complexity to GHG emission calculations and would require additional and more precise data, including on specific materials and resources used in these processes.[33] In general, however, while smallholders emit less because they adopt more sustainable cultivation practices (see **Section**

[33] Just to provide an example, sun-dried coffee was mentioned by many as requiring lower energy use. At the same time, it was highlighted that the infrastructure needed to employ this method, such as cement slabs, also generates carbon emissions (IA9). A recent study in Nicaragua surprisingly found that small-scale producers emit more GHG due to the use of organic fertiliser, due to emissions linked to both production practices and its application, two areas where smallholders would require more technical support (ID10N). While this finding contradicts the literature and most interviewee experiences, it does point to the importance of technical support for smallholders, and the potential for new technologies to further drive a reduction in GHG emissions.

3.2), they might also face high transportation costs – and associated emissions – and be less efficient in their use of wet processing and gasoline powered machines (ID10N). Finally, agroforestry is key in reducing GHG emissions and enhancing carbon stocks, as outlined in the next section (3.8).

Potential solutions and effective practices

Both the literature and primary resource pointed to areas for improvement in production processes, including for smallholders.

Research pointed to several activities that can reduce GHG emissions, such as treatment of residual waters, reducing the use of agrochemicals, herbicides and fertilisers, and improving soil management practices (IB23C). Better composting methods, such as biodigesters, were estimated to have the potential to reduce overall emissions by 38% (Rahn et al., 2014). Acosta-Alba et al. (2020) estimated that using compost as a substitute for mineral fertilisers could reduce emissions by between 22% and 41% in inorganic systems in Colombia. Others also mentioned applying concepts relating to biodynamic farming and circular economy to coffee production (IA4), which integrate many effective farming practices advocated by agronomists.[34]

Various interviewee respondents spoke about the important role of agroforestry and tree planting. Where agroforestry cannot be practiced due to agroecological conditions, as is the case in certain areas of Brazil, they spoke about the potential for zero deforestation zones, adding shade to plantations where possible, and planting trees in specific areas of their farms (IB23C, ID7). Incentivising agroforestry, greater forest cover and tree planting was described as holding potential to reduce carbon emissions and increase carbon stocks; an area where smallholders have potential for large impact. Acosta-Alba et al. (2020) found that permanently shaded farms (6.4 t $CO2e$ / ha / yr) have lower emissions than sun plantations (8.7 t $CO2e$ / ha / yr). Other studies show that above-ground carbon stocks are driven by shade cover within the system (Solis et al., 2020; Ehrenbergerová et al., 2016). For instance, in a comparison of small-scale systems in Peru, sun systems had 4 Mg above-ground C ha-1, while single-species shaded had 26 Mg above-ground C ha-1 and multi-species systems had 62 Mg above-ground C ha-1 (Solis et al., 2020). These results are echoed in Ehrenbergerová et al., (2016) where sun systems had 1 Mg above-ground C ha-1, but shaded systems ranged from 30.3 to 62.1 Mg above-ground C ha-1.

Small-scale shade systems can sequester more carbon dioxide than they produce due to the benefits of shade trees (Burkey et al., 2023), despite the increased nitrous oxide emissions from the decomposition of pruning residues (Rahn et al., 2014). Carbon sequestration potential across the data ranged from 1.8 to 7.3 Mg ha-1 year-1 into tree biomass, depending on the sequestration rates of the shade species (Lapeyre et al., 2004; Ehrenbergerová et al., 2016; Notaro et al., 2022). In Brazil, Gomes et al. (2020) found that, compared to unshaded plantations, coffee production in agroforestry

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[34] See, for example: https://perfectdailygrind.com/2022/01/exploring-biodynamic-coffee-production/ and https://www.circularinnovationlab.com/post/the-circular-economy-in-coffee-culture

systems can help mitigate the effects of climate change, and safeguard future coffee production. In Colombia, smaller farms were correlated with higher above-ground carbon stocks per hectare driven by higher shade cover than larger farms (De Leijster et al., 2021). Coffee smallholdings have, in fact, been found to have similar levels of above-ground carbon stocks (median 26 above-ground carbon Mg ha-1) to forest restoration plantings (24 above-ground carbon Mg ha-1) (Giudice Badari et al., 2020). Certification was also shown to influence on-farm carbon stocks in Nicaragua. Small-scale Fairtrade (90 above-ground t C h-1) and small-scale Fairtrade organic (110 above-ground t C h-1) had higher above-ground carbon than non-certified farms (82 above-ground t C h-1), driven by certification (Haggar et al., 2017). Some positive experiences were also mentioned for larger producers in the study, the highest carbon stocks were for large-scale Rainforest Alliance certified farms (150 above-ground t C h-1).

Despite substantial range between field sites, the average above-ground carbon in shade systems was higher for mixed-species systems (42 C Mg ha-1) than in single-species (38.18 C Mg ha-1) for our included studies (Lapeyre et al., 2004; Solis et al., 2020; Ehrenbergerová et al., 2016; Giudice Badari et al., 2020; Rahn et al., 2014; Jezeer et al., 2018). This finding points to the importance of diversified agroforestry systems within smallholder farms for social, economic and environmental sustainability, further explored in paragraph 3.8. As shown in Figures 3 and 4, traditional polyculture and commercial polyculture typical of agroforestry systems – described in detail in paragraph 3.2 – are38ecognizied with much lower total GHG emissions and higher carbon stock compared to monoculture. **Box 3** further explores the carbon benefits of organic smallholder agriculture among a small sample of six cooperatives in Central and South America.

Figure 3. Greenhouse gas emissions in coffee production systems (Source: Bunn et al., 2018)

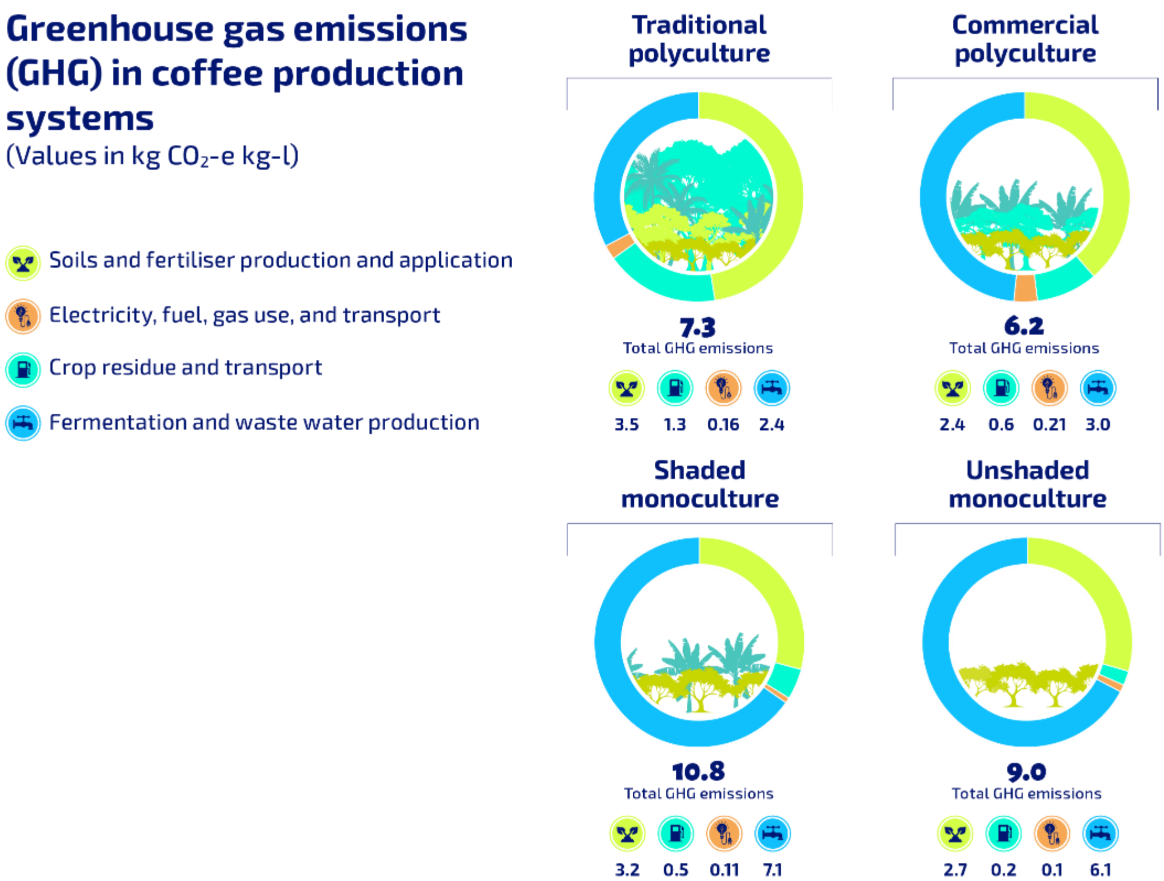
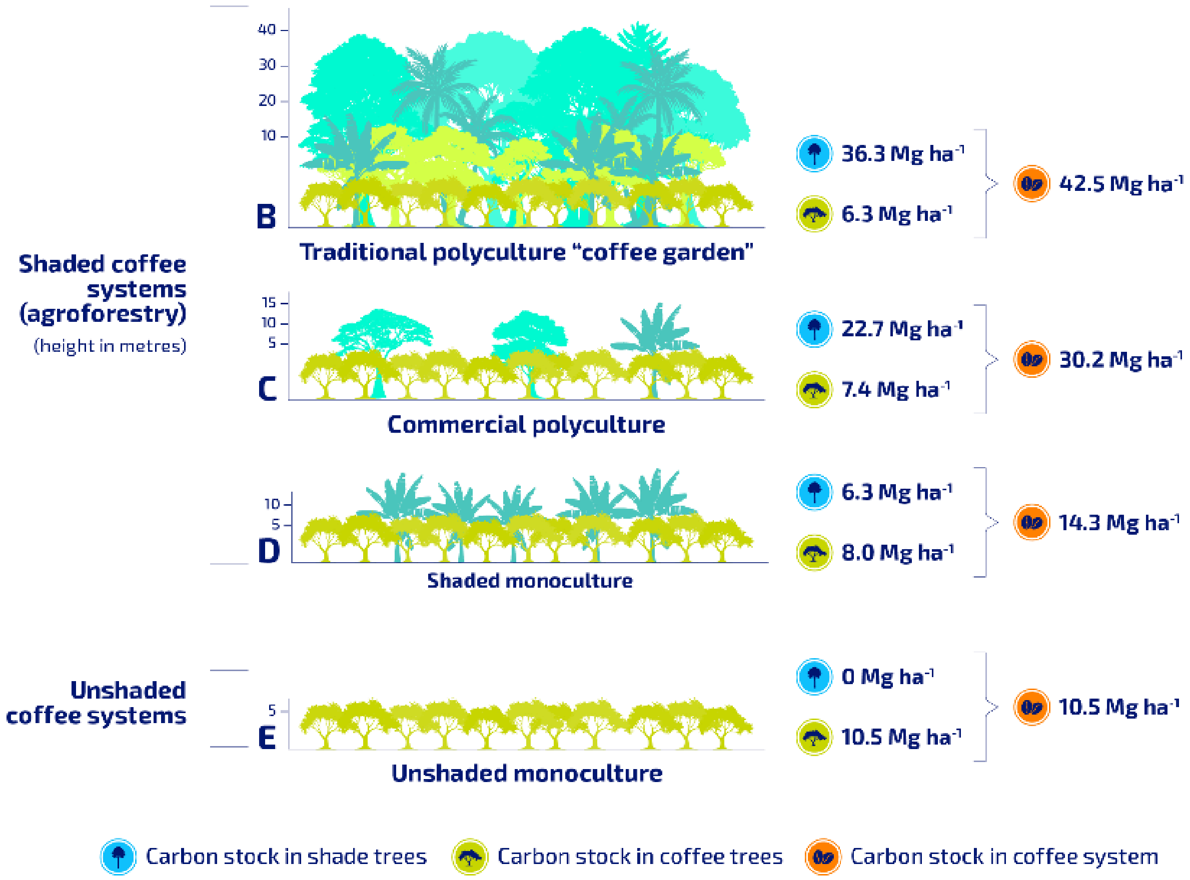


Figure 4. Carbon Stocks in coffee production systems (Bunn et al., 2018)



Small-scale producers, especially organic ones, can play a big role in relation to carbon stocks and carbon neutrality in the sector, and there is room for other stakeholders to intervene in this sense to further enhance the sustainability of the value chain. However, lessons can be learnt from the VCM and the link between economic and environmental sustainability: despite the potential of carbon credits, some participants of this study reported that many producers may still lack access to training to gain awareness and understanding needed to effectively engage in the market (IB22C). While producers may have heard about GHG and carbon stocks, this area is often perceived as being very complex. Changes in calculation guidelines adds to the perceived complexity, making it more time- and resource-intensive for farmers to change their practices (IB37N). Respondents in Brazil highlighted that farmers lack access to carbon credit, and that their share of the profit in these schemes is too low to 39ecognizing them (IB14B). Further, carbon accounting may not always capture the reality at farm level and the good practices employed by farmers (IC1). While individual producers may struggle to improve their performance and reporting in this area, cooperatives could support through 39ecognizing processes, as well as joint measurement and reporting. Research highlighted cooperatives and associations, especially the best 39ecognizi ones, reportedly making efforts to measure GHG emissions and carbon footprints (see **Box 3**). Data collection will be further explored in Section 4.

Box 3. Agroforestry as an environmental service: evidence from the Carbon, Climate and Coffee initiative

In 2023, Cooperative Coffees, in partnership with several producer organisations in Peru, Honduras and Guatemala, as well as international partners[35], published a study exploring the 'symbiotic' relationship between producer livelihoods and climate action. With a focus on the potential for regenerative agroforestry practices, it reflects the experiences of the Carbon, Climate and Coffee Initiative[36], which established a fund to compensate producers for the environmental benefits of their farming practices. It's important to note that the study sample includes only organic and Fairtrade certified producers: while the results 40ecognizin here as not representative of the smallholder sector, they can provide interesting effective practice.

Through the use of the Cool Farm tool[37], the study found 55% of coffee farms in the project sample to be carbon negative, and an additional 20% to be carbon neutral. This was largely linked to the agroforestry practices employed in the sampled farms. Practices associated with higher productivity, like organic 40ecognizing40n and regular pruning, were also found to drive carbon. While in conventional systems, the use of 40ecognizin results in about 80% of the average footprint of coffee farms, organic fertilisers reduced this considerably. Effective practices identified by the study include the use of **organic 40ecognizin, such as composted coffee pulp residue, and shade tree planting.**

After data collection, Cooperative Coffees proceed with carbon payments as a premium per pound of coffee, 40ecognizing ecosystem service payments as a normal cost in the coffee value chain that should not be paid by farmers. Different projects were financed with the premium including further investments in agroecology, agroforestry, and climate smart agriculture.

Another collaborative study from 2019, carried out by Rikolto, the Pontificia Universidad Católica del Perú (PUCP) and La Prosperidad de Chirinos, a Fairtrade-certified coffee cooperative in Northern Peru, provided similar insights on the prospects for agroforestry. The study, carried out in Cajamarca, assessed how to improve carbon capture in coffee farms, focusing on organic coffee, which did not have emissions linked to the use of agro-chemicals.[38] The study found that the cooperative was producing carbon neutral coffee, mostly due to agroforestry systems and resulting carbon capture. The main conclusion of the study was that shade-grown coffee can offer benefits to producers aiming to reduce their carbon footprint, and that producing and marketing carbon neutral or carbon negative coffee could offer an added value to producers to increase their sales – if demand remains sufficient.

These types of inclusive research processes were deemed as particularly effective in generating innovative data, and building capacity of farmer organisations for future data collection. For example, Café Organico Marcala (COMSA), a Fairtrade-certified cooperative in Honduras, which took part in the Carbon, Climate and Coffee Initiative, was mentioned by interviewees as a positive case study where farmers found both environmental and economic benefit in the project (ID8H).

3.6 Deforestation and on-farm forest cover

There was very limited evidence that compared smallholder and large-scale driven deforestation and most of it was qualitative, highlighting the difficulties of quantitatively tracking deforestation at the farm level. We identified smallholder and plantation-driven deforestation, however, for the two texts that directly compared farms of different sizes, with evidence that larger farms have driven more extensive deforestation. Large-scale plantations are increasing their reforestation efforts in Brazil, driven by legislation for a minimum percentage of on-farm forest cover. However, this may not be typical of the native forest that was cleared. Moreover, our results indicate that on-farm forest cover increased as farm size decreased, with small-scale shaded agroecological farms having the highest percentage of on-farm forest.

Deforestation and reforestation

We include 17 studies that provide evidence of coffee-driven deforestation, reforestation or forest cover metrics in the study countries: 8 in Brazil, 2 in Colombia, 1 in Peru and 6 in Honduras. Moreover, the majority of evidence regarding deforestation was qualitative and only three of eleven studies quantified any deforestation, highlighting how difficult this metric is to quantitatively track at the farm level.

Literature was very limited for a direct comparison between smallholder and plantation-grown coffee, and no studies examined Nicaragua. For the two texts that directly compared farms of different sizes, there is evidence that larger farms have driven more extensive deforestation (Achinelli & Faran, 2003; Dietz et al., 2021). Whilst Achinelli & Faran, (2003) provided qualitative evidence for Brazil, Dietz et al., (2021) showed statistically that larger farms were more likely to have deforested in Honduras.

Despite the deforestation of the Cerrado and Atlantic forests in Brazil for coffee farming large-scale plantations between 1915 and 1965 (Brannstrom, 2000), large-scale plantations in these areas are

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[35] The cooperatives were as follows: CAC Pangoa (Peru), CENFROCAFE (Peru), COMSA (Hondars), Manos Campesinas (Guatemala), Norandino (Peru) and Sol y Café (Peru). Other partners included Cool Farm Alliance, Root Capital, the Sustainable Food LAb and the Chain Collaborative.

[36] For more information, please see https://www.carbonclimateandcoffee.com/about-us

[37] The Cool Farm tool to assess current GHG footprints and run forward-looking 'what ifs' scenarios to identify opportunities for improvement. The Cool Farm Tool was created in 2010 to help agricultural actors estimate GHG emissions following calculation methods developed by the Intergovernmental Panel on Climate Change (IPCC). It consists of an online tool used by farmers, companies and consultants worldwide. For further information, please see: https://coolfarm.org/.

[38] For further information on this study, see: https://indonesia.rikolto.org/es/noticias/minimizar-huella-de-carbono-en-cafe-organico-estudio

increasing their reforestation efforts, likely driven by government legislation (Lense et al., 2022; Hardt et al., 2015). In the Atlantic Forest biome, legislation (Brazilian Forest Code) for 20% of rural properties to be reforested has driven reforestation efforts, which has reduced water erosion and loss of soil organic carbon (Lense et al., 2022). However, it is also important to note that reforestation does not always equate to regenerated native forest. For instance, in Brazil reforestation was categorised as plantations of *Eucalyptus* and *Pinus* species, which are not native and typical of the native forest that was cleared (Hardt et al., 2015). This need to have a nuanced understanding of the forms and complexity of forests and their transitions, particularly where secondary and managed forests are replacing native primary vegetation, is also echoed in Peru (Marquardt et al., 2019).

We also identified mainly qualitative evidence of smallholder-driven deforestation in the focal countries (Rivillas, 2022; Schlesinger et al., 2017; Nagendra et al., 2003; Marquardt et al., 2019) and evidence of encroachment into formally protected areas (Soares et al., 2011; Blackman & Villalobos, 2019; Southworth et al., 2004). Interviews demonstrated how complex the issue of deforestation is for smallholders due to the wide range of contexts in which they farm. For instance, one interviewee (IA17P) noted that most deforestation in Peru is caused by smallholders since they are the majority. Many also practice swidden farming[39] within forest areas, where they shift cultivation once yields decline. In addition, particularly in mountainous regions, farmers may fell a few trees from virgin forest to plant coffee shrubs, which are then grown under the canopy or there is gradual clearing of trees. This creates confusion on what constitutes deforestation and makes regulation much harder to implement (IC4).

There is mixed evidence and perspectives on how to reduce smallholder deforestation. For Honduran smallholders, higher average prices were associated with reduced deforestation (Dietz et al., 2021), and it was suggested in an interview that producers should be incentivised to maintain forests (IB23C). One interviewee (IA17P) suggested sustainable intensification such as using high-yielding varieties. However, this may fail to consider the structural drivers of deforestation such as government policy. For instance, in San Martin, Peru, intensified cash cropping has not halted deforestation and stabilised the agricultural frontier. Instead, permanent coffee fields have interrupted the traditional swidden fallow cycle but have not stopped farmers from opening up new ones or abandoning swidden farming. Moreover, increasing land competition and migration into

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[39] Swidden farming is a traditional practice similar to a rotational garden, where a small piece of forest is cleared, farmed for a few years, then left to regrow for many years before being used again. This allows the soil to stay fertile without needing fertilisers. More information at https://www.survivalinternational.org/about/swidden.

coffee growing areas has led to Indigenous groups intensifying their coffee production to secure land areas (Marquardt et al., 2019).

There is evidence, however, that smallholders are also making efforts to reforest. This kind of reforestation is much more difficult to track, as one participant described:

> *"there's also a portion of [...] smallholders, who can efficiently reforest, and they are all the time, but they're not tracking it. They're just doing it because you're on the land and putting baby trees." (IC4).*

As a mitigation for this and to better account for environmental sustainability, cooperatives are starting to ask their members to keep track of reforestation efforts.

In addition, smallholder farmers in the study areas cooperatives are currently supporting and experimenting with regenerative agriculture, agroforestry, and the 'productive forest' (ID3) or 'forest garden' - Type B described in Figure 3 (Section 3.2). In Central America, in fact, the 'productive forest' is very widespread and has several benefits. We further reflect on the role of agroforestry in Section 3.8. Moreover, in Box 4, we explore the cultural and social value of coffee grown in the forest.

On-farm forest cover

Concerning continued conservation of existing forest, there is evidence that smallholders have a larger percentage of forest cover (35.5% mean forest cover) on their holdings than large-scale farmers (19% mean forest cover) in Minas Gerais, Brazil (Pronti & Coccia, 2020). In Brazil, farmers must comply with government regulation which denotes farms must have a minimum percentage forest cover. As a region within the Cerrado biome, this is 35% for Minas Gerais, although the results of Pronti & Coccia (2020) above indicate that there is not necessarily compliance with this law for large-scale farms. However, large-scale farms have more resources to change and comply with legislation and meet market demand for more sustainability (Lense et al., 2022; Hardt et al., 2015), leading to considerable reforestation efforts in large-scale plantations. It's important to note the point made at the start of this section that these reforestation efforts may not be native forest but non-native plantations (Hardt et al., 2015). This results in a landscape of forest patches between sun-grown coffee and other farming ventures in the areas where the agroecological system is not suited to agroforestry due to the climate and altitude of the area resulting in lower yields in agroforestry systems (IA2). Similarly in Peru, well-known for its organic coffee grown with different forms of agroforestry, many smallholders only farm a proportion of their plot and the remaining area is regenerating secondary forest (IA17P).

Within smallholder systems, shaded plantations had a higher forest cover score (score = 4.8/5) on the farm than sun-grown systems (score= 3.5/5) (Oviedo-Celis & Castro-Escobar, 2021). Moreover, agroecological farms had higher forest cover (41% mean forest cover) than conventional systems (30% mean forest cover) (Pronti & Coccia, 2020, 2021). This demonstrates how shaded and agroecological systems lend themselves to increasing forest cover and the benefits that brings, such as reduced carbon emissions and benefits to biodiversity (see **Section 3.7**).

Box 4. Coffee, smallholders and the forest in southwestern Honduras

The expansion of coffee cultivation in forested tropical areas driven by market incentives typically eroded community-based governance structures and the livelihoods of indigenous populations. These communities historically grew coffee in the forest in a highly diverse system that maintained a less environmentally harmful impact on the natural surroundings compared to profit-oriented approaches (Tucker & Zelaya, 2023).

In southwestern Honduras, in the Department of La Paz, a rural area known for its Indigenous Lenca heritage, smallholder coffee farmers expanded their coffee cultivation upon discovering a potentially lucrative market. Initially, coffee was grown primarily for household consumption within highly biodiverse agroforestry systems, resembling gardens surrounding their homes. Their familiarity with coffee was rooted in its integration within these diverse ecosystems. Despite coffee becoming a primary source of livelihood for smallholders, they remained committed to shade cultivation. Attempts to remove or reduce shade, as suggested by agricultural experts aiming to boost production, proved less effective. As a researcher who has been working in the area for decades claimed: "*One of the things […] that has stood out [in my research] is that the farmers that I work with all plant trees. […] unless it's someone who's moved in and bought land and wasn't born there. […] So most of the smallholder farmers have very agrobiodiverse fields, and there's been a lot of pressure for a long time for them to […] just get one shade tree and have the same variety of coffee, but there has been a lot of resistance to tha*t". Smallholder producers' knowledge led them to practice agroforestry as the best way to cultivate coffee in the Mesoamerican Dry Corridor, where farmers figured out that without trees, especially young coffee plants would dry up. In addition to this, farmers benefit from the fruit that trees produce and firewood for their household consumption (ID2H).

3.7 Biodiversity

Small-scale farms had higher biodiversity in all texts that compared large and small-scale producers, driven by differences in management practices - a result echoed in our primary research. For instance, two studies also demonstrated that smaller farms have higher numbers of pollinators, due to practices such as beehives, low pesticide use and a higher portion of natural vegetation in the farm. A key driver of higher biodiversity on small-scale farms is the use of shade trees, particularly multi-species systems, which increases the number of habitats and resources for biodiversity such as insects and birds. For research that compared agroecological and conventional farming systems, those using agroecological methods in small-scale farms had higher biodiversity. Most scientific studies focussed on species richness metrics and the link between biodiversity and coffee production needs further research to capture all aspects of biodiversity.

Biodiversity was the most evaluated environmental outcome of coffee farming from the literature review, with 58 studies included: 15 from Brazil, 27 from Colombia, five from Honduras, 11 from Nicaragua, and three from Peru. The most commonly used biodiversity metric was species richness and texts mostly focussed on tree (n=13) and insect, particularly ants (n=12) biodiversity.

Small-scale farms had higher biodiversity in all eight texts that directly compared small and large-scale plantations, driven by differences in management practices (Hipólito et al., 2016, 2018; Haggar et al., 2015, 2017; Pronti & Coccia, 2020; Winter et al., 2020; Teixeira et al., 2021). Interview participants also agreed that smallholder practices lend themselves to maintaining higher levels of biodiversity due to lower use of inputs and more diversified systems of trees and crops that are grown for home use and consumption. There are exceptions where larger plantations may have high biodiversity, often achieved through certifications that allow them to access specialised markets.

> "*Anecdotally from being on really large farms and being on small farms [...], there's always a huge difference, [...] from even just from the anecdotes of [being] surrounded by animals and insects and critters and birds, and you hear the sounds. You're lucky if you see a bird fly over on a plantation*" (IC4).

A key driver of higher biodiversity is that smaller farms tend to have higher shade tree cover and tree diversity than larger plantations (Rahn et al., 2014; Haggar et al., 2015, 2017). This provides a larger variety of habitats and resources for insects, demonstrated by ant species richness being higher in shade plantations than sun plantations. Ant species richness in sun plantations ranged from 14-59 species but in shade systems they ranged from 16-82 species (Arenas-Clavijo & Armbrecht, 2019; Gallego Gauna & Hernández Moreno, 2021; Armbrecht et al., 2005; Urrutia-Escobar & Armbrecht, 2013; Arenas-Clavijo et al., 2018; García-Cárdenas et al., 2018). This is even more apparent for multi-species systems such as traditional coffee polyculture, where not only was species richness higher than sun plantations (shade=30, sun=26), but ant species most closely resembled forest patches (Armbrecht et al., 2005). Shade plantations scored higher for supporting faunal diversity (score = 4.8/5) compared to sun plantations (score=3/5) (Oviedo-Celis et al., 2013) and can display similar bird (coffee = 14, fragmented forest =16 bird species) and mammal (coffee = 17, fragmented forest =20 mammal species) diversity levels to fragmented forest patches (Bedoya-Durán et al., 2023).

Two studies in Brazil statistically demonstrated that pollinator richness increased as farm size decreased (Hipólito et al., 2016, 2018). This was driven by smaller farms having more pollinator-friendly practices such as beehives, low pesticide use, partial manual weeding, organic certification, presence of hedges and non coffee crops and a higher proportion of natural area in a 200m buffer around the farm (Hipólito et al., 2016). Moreover, farms where owners are actively working on the land, as is the norm in small-scale plantations, had more pollinator-friendly practices than those owned by farmers working in management (Hipólito et al., 2016). This was reiterated by an interview participant (IB8C) that discussed how monocultures that are incentivised in Colombia have a bigger impact on biodiversity due the higher use of chemical inputs, leading to important impacts on pollinators in Huila, Tolima and Antioquia and in the Eje Cafetero.

For research that compared agroecological and conventional farming systems, those using agroecological methods in small-scale farms had a higher plant species richness (18.8 plant species) than small (7.5 plant species) and large-scale conventional farms (6 plant species) (Teixeira et al., 2021). This result was echoed in Pronti & Coccia, (2021) that showed agrobiodiversity in small-scale systems was 32 species on agroecological farms and one on conventional farms. Moreover, small-scale agroecological farms were documented to have higher total species richness (Pronti & Coccia, 2021, 2020) as well as specifically for ants (Urrutia-Escobar & Armbrecht, 2013) and plants (trees, palms, shrubs, giant herbs and treelets) (Teixeira et al., 2021).

However, despite evidence for biodiversity outcomes in coffee farming, the link between biodiversity and coffee production needs further research and there is room to capture all aspects of biodiversity; not only species richness metrics, but also the connection, customs and cosmovision experienced among the producers and their nature. This could lead to the identification of environment friendly practices for the management of natural resources.

Box 5: Harnessing honeybees: A path to diversification and improved biodiversity outcomes

Coffee production is volatile to price changes from market and climactic conditions, and the coffee rust crisis of 2012-2013, spurred by climate change, highlighted the need for diversified production systems for smallholder farmers to maintain and improve their livelihoods. Beekeeping requires a relatively small investment of time and resources, and so is encouraged as a way to diversify income, improve nutrition and increase pollination of both coffee and other crops such as citrus and avocados (Fairtrade International, 2024). Pollination from bees alongside pest control from birds has been proven to increase coffee yields (Martínez-Salinas et al., 2022), thereby benefiting farmer livelihoods.

Collaborating with Food for Farmers and local cooperatives in Mexico and Guatemala, Fairtrade facilitated beekeeping training programmes and provided essential equipment and resources to coffee farmers to sustain successful commercial enterprises. Emphasising organic and environmentally-friendly practices, the initiative aims to enhance both economic viability and ecological resilience. Fairtrade coffee cooperatives where farmers are now producing honey have partnered with nearby honey cooperatives and exporters to link them to Fairtrade buyers in the European Union (Nadworny, 2016).

Participating farming communities found that combining coffee production and beekeeping has had a profound socio-economic impact. By diversifying income streams and enhancing productivity, farmers gained financial stability and resilience against market and climate uncertainties. Additionally beekeeping training programmes fostered inclusive economic development and social cohesion, particularly among women and marginalized groups (Cafe Femenino Foundation, 2024).

Aside from just beekeeping, there is evidence that coffee farmers who restore patches of forest across their properties can also improve their profits through higher pollinator numbers. Research found that coffee farms could increase their economic benefits by 98% over five years by increasing their forest area by 15%. Restoring small patches of forest throughout the farmed area maximised pollination services by allowing them to reach more coffee plants because bees can only travel short distances (up to 3km) (López-Cubillos et al., 2023; Runting & López-Cubillos, 2023). These different ways to increase pollination services support solutions for farmers with different environmental outlook, interests and capabilities.

3.8 The key role of agroforestry as a cross-cutting theme for improved climate, social and ecological outcomes

The analysis of the five environmental dimensions outlined in Sections 3.3-3.7 shows how agroforestry plays a key role in addressing environmental, social, and economic challenges faced by smallholder coffee farmers in Central and South America while also, at certain conditions, significantly contributing to climate adaptation and mitigation. By integrating (native) trees into coffee farming systems, agroforestry practices stabilise ecosystems, enhance biodiversity, and offer diversified income opportunities for farmers (Jose, 2009). Trees play a crucial role in ecosystem stability by storing water, protecting soil, and enriching biodiversity (Jose, 2009). It is also common to grow nitrogen fixing trees such as *Inga* species, that reduce reliance on fertiliser and improve soil quality (Schnabel et al., 2018; Haggar et al., 2011), therefore reducing production costs. The production of timber and fruits provides farmers with additional product sources or income streams, contributing to food security and economic resilience. Providing suitable species are planted, agroforestry embodies a holistic approach to climate action, aligning with principles of insetting and promoting ecosystem restoration essential for sustainable agricultural practices.

The scientific literature is in disagreement as to whether agroforestry affects coffee yields, likely due to the dependence on agroecological and management conditions (van Rikxoort et al., 2014; Acosta-Alba et al., 2020). There is evidence that shade trees do not negatively impact coffee yields in mountainous Peruvian systems, where higher shade levels were also associated with increased elevation and higher quality beans (Jezeer et al., 2018). In Brazil, it is reported that the benefits of agroforestry and agroecological methods are higher where farmers lack access to equipment, combined with limited cultivation areas, favouring efficient use of resources to maximise economic returns (Pronti & Coccia, 2020). This is also discussed by DaMatta and Wang (DaMatta, 2004; Wang et al., 2015) who suggest that high densities of shade trees can have adverse effects on yields in zones of optimal conditions of soil fertility, radiation and water.

Agroforestry, and, more generally, an agroecological approach, significantly reduces production costs, decreasing the need for inputs, energy and water (FAO, 2023). As seen in **Box 5**, activities such as beekeeping, can result in an economic flourishing of the farm and promote an approach that can also incentivise youth engagement in coffee agriculture, alongside other enterprises such as agrotourism (ID1C). To achieve maximum benefits, coffee agroforestry must shift from a low labour, low risk-stable return, slowly-changing matrix to more active management of species and stems that is targeted to sustain and intensify ecosystem-based benefits to coffee production, diversified income and household food security (Siles et al., 2022).

Finally, it is important to note that agroforestry can support incomes through diversification (Anderzén et al, 2021). The production of timber and fruits provides farmers with additional product sources or income streams, contributing to food security and economic resilience to price and climatic shocks. Providing suitable species are planted, agroforestry embodies a holistic approach to climate action, aligning with principles of insetting and promoting ecosystem restoration essential for sustainable agricultural practices (Lugo-Pérez et al., 2023).

Particularly as climate change alters suitability of coffee farming zones, the contribution of agroforestry to climate adaptation and mitigation is of ever growing importance. By enhancing soil health, agroforestry systems improve water retention in the soil, increasing resilience to drought and extreme weather events associated with climate change (Lin, 2007). Moreover, the shade provided by trees helps regulate microclimatic conditions, mitigating temperature extremes and reducing heat stress on coffee plants (Lin, 2007). Additionally, the integration of trees into coffee farming contributes to carbon sequestration, and therefore climate mitigation, as trees absorb and store carbon dioxide from the atmosphere - an avenue that farmers can consider as an income stream in relation to the payment for their carbon insetting. This dual benefit of climate adaptation and mitigation underscores the importance of agroforestry as a sustainable farming practice in the face of climate uncertainty. Supporting smallholder coffee farmers in adopting agroforestry techniques not only enhances their resilience to climate change but also contributes to global efforts to mitigate greenhouse gas emissions and build climate-resilient agricultural systems.

It must be noted that, while it is necessary to continue working towards the recognition of farmers' contribution to mitigation and ecosystem conservation, ensuring the success of agroforestry initiatives at the local level requires comprehensive support to adapt management to the agroecological context. Farmers should be assisted in selecting suitable shade tree species and improving tree management techniques. Additionally, training programmes on effective nutrient, pest and disease control are essential to optimise crop yield while minimising environmental impact (Jezeer et al., 2018). Support for smallholder farmers in adopting agroecological practices and accessing markets for ethical, sustainable products is crucial to ensure a more equitable and resilient agricultural sector (see **Section 6**).

4. Sustainability and farmer-led data collection: smallholders' data ownership and data collection process

The last section has shown that smallholder farmers - generally speaking, with room for improvement and context-specific dynamics - adopt more environmentally sustainable practices when compared to plantation farming. However, these are often not recognised adequately at the global level and within the coffee value chain in relation to both climate mitigation and ecosystem services. One of the reasons for this is the current lack of comparable environmental data and accountability mechanisms. In addition, recent legislative changes, such as the EUDR, and a growing market interest in the environmental sustainability of coffee, are also pushing the coffee industry towards environmental data collection, which will play a key role in the value chain in the near future. Different organisations already promote projects to collect, analyse and share environmental data, especially in relation to GHG emissions calculation, but not limited to this dimension. For instance, several Life Cycle Assessments (LCA) have been carried out in Colombia and were cited by our interviewees.

These projects, however, are rarely led by farmers and the data collection process raises questions about producers' inclusiveness and their data ownership. Illiterate farmers and producers with poor or no access to digital tools are indeed systematically marginalised by projects that rely on questionnaires delivered through digital technologies, unless dedicated staff and training are in place (IA5; IBC24; Hildalgo et al., 2023; Hidalgo et al., 2024). Moreover, data are often owned by the institution that collects them rather than by farmers (IB24C) and growers ultimately do not benefit directly from the data collected. Even when data ownership formally lies at the cooperative or association level, these don't necessarily have the technical and economic resources to perform data analysis and face several challenges in leveraging the potential value of environmental data both for fairer value distribution and for day-to-day farm management.

Through the review of grey and academic literature and our primary data collection, however, we have identified five initiatives and organisations that aim to overcome at least one of these challenges.[40] These are:

1) **The Cool Farm Alliance measuring carbon performance with Fairtrade certified POs.**

   COMSA in **Honduras,** participated with six other **Fairtrade Certified cooperatives** located in other countries, and other partners[41] in a project to assess carbon sequestration in the farms through the green gas calculator 'Cool Farm Tool'. This tool is promoted by the Cool Farm Alliance, a non-profit membership organisation of which Fairtrade is a member.[42] In the case of COMSA, the cooperative trained its technicians for data collection and Coffee Cooperative paid to the farmers a premium for their participation in the project. The study found that 50% of the farms removed more carbon than they emitted and 20% were carbon neutral. Cooperative Coffees designed environmental service payments according to the findings. The financial resources gained were used by the cooperatives to invest in further opportunities, including for climate action, such as tree planting or conservation agriculture (see also **Box 3**). In this case, data were owned by the cooperative and internal capacity was built within the organisation.

2) **Producers Direct and the Croppie App.**

The organisation CaféDirect, an NGO of which the Fairtrade Foundation is a shareholder, has partnered with the Alliance Biodiversity CIAT to develop the Croppie App with a user-centered design approach. The App requires producers to upload pictures of their crops (which should minimise literacy barriers) and means they immediately receive a crop yield prediction accompanied by tailored financial and agronomic advice, therefore directly benefiting farmers.

The App also allows to increase smallholders' traceability which is, arguably, a precondition for the recognition of sustainability across the value chain and is currently proving challenging for smallholder farmers. As new legislation such as EUDR requires advances in traceability, the private sector might turn to larger and more digitalised producers that can better manage traceability, therefore further marginalising smallholders in the market. A smooth transition to more sustainable systems, however, will require that all producers are onboarded. Fairtrade can play a role in this respect (IA5) because of its links with different stakeholders across the value chain (see **Section 4.1**).

3) **Red Ecolsierra[43] and Finca Amiga in Colombia.** The organisation Red Ecolsierra has developed a monitoring system based on digital data collection that is conducted during audits by farmers and technicians together. Farmers are then able to access the data through

[40] A considerable number of digital tools are currently being developed. For a recent global review, see Hildalgo et al. (2023).
[41] The Cool Farm Alliance, Root Capital, the Sustainable Food Lab, and The Chain Collaborative.
[42] See https://www.fairtrade.net/news/fairtrade-becomes-a-member-of-the-cool-farm-alliance
[43] More information about the organisation can be found at https://www.sustainableharvest.com/about-us

tablets. In the same country, experts identified the programme 'Finca Amiga'[44] as an example that employs digital tools and gamification to collect data on costs, harvests and rainfall. In these two cases, however, data ownership was unclear and would need further research.

4) **TAPE tool, created by FAO to monitor agroecological practices.** FAO has created this tool to harmonise evidence on agroecology (FAO, 2019), and its impact on biodiversity, resilience, and climate adaptation and mitigation. It is a multidimensional tool that measures environmental, social, and economic sustainability. At least in theory it can be also used by growers themselves to assess their situation, especially if they are transitioning to agroecology. There are other similar tools that use agroecological indicators and that might be useful in relation to Fairtrade's 2021-2025 strategy. Fairtrade has currently commissioned an outcome-based case study on coffee, cocoa, and bananas to identify a set of metrics and best cases, of which indicators from TAPE will be considered and integrated.[45]

5) The **University of Vermont has developed** several projects for **Participatory Action Research (PAR)** involving coffee cooperatives and coffee farmers. This approach was supported by Stats4SD for digital data collection. The researchers put together a youth team, composed of producers' sons and daughters, to co-design a context specific questionnaire on environmental, social and economic sustainability. The team was then trained for digital data collection and the data gathered were finally owned by the cooperative that can use them for planning and management purposes. This participatory approach offered several advantages, including a very accurate level of information, the active involvement of cooperatives and farmers, young people's training in digital data collection and the final ownership of the data. Moreover, to avoid research exhaustion and the replication of similar studies, an open access platform was created to widely share the data - together with other available data and reports. The platform therefore fosters information sharing across the value chain and aims to remove growers' barriers in accessing data about their farms.

4.1 Reflections on environmental data collection

There is great potential for the Fairtrade System to explore different pathways for environmental data collection, starting from **systematisation of and reflection on what is already happening.** The FairInsight system (**Section 1.3**) is a data collection tool through which Fairtrade can collect real time data. The system offers a repository for data that can be scanned with the aim of mapping which information already exists about sustainability in different geographic and thematic areas. Moreover, Fairtrade has partnered in important studies about the sustainability of the coffee value chain in the

[44] Luis Fernando Samper, an expert in brand management and has created the programme. More information is available at https://www.4point0brands.com/eng/experiencia-y-clientes/

[45] A full description of the tender is available here: https://www.fairtrade.net/opportunity/consultancy-for-conducting-an-outcome-based-case-studies-to-measure-agroecology-uptake-in-fairtrade-coffee-cocoa-and-banana-sectors

study area, such as The Cool Farm Alliance's study on carbon performance described in the section above (Section 4).

The main lessons that can be drawn for Fairtrade's data collection from the reviewed cases and interviews are the following:

1) There are different ways to define and **interpret environmental data collection**. The first step is therefore to identify why the data collection is needed and what are the organisational needs the data collected would be responding to. In the case of the Fairtrade system there might be several levels of complexity associated with environmental data collection. At a very basic level and at the present moment, polygons and GPS locations are required for all producers under Fairtrade Standards to respond to the EUDR legislation. At the following level of complexity, in-depth analysis of some positive experiences can be conducted through pilot projects. The latter can be oriented also in relation to the interest of commercial partners in the value chain to cover at least partially the data collection costs. At the same time, at an initial stage, environmental data collection requirements can be kept as simple as possible for the majority of the producers.
2) **Environmental data collection is costly and time consuming.** The examples of data collection for the carbon market and the payments for ecosystem services have shown that from the very early stages, all the funding was directed towards very accurate forms of measurements and data collection that quickly became too expensive and complicated for smallholders, therefore marginalising them. Lessons should be learnt from this experience.
3) Given **Fairtrade's 2021-2025 Strategy** and its orientation towards **Agroecological Principles**, a data collection tool such as TAPE, which explores sustainability **holistically and is context dependent**, might be better placed in comparison to instruments that are measuring only GHG emissions or biodiversity at a very detailed level. A pilot project to develop **agroecological indicators** is already exploring this possibility (IC9).
4) **Cooperatives and associations** play a crucial role in environmental data collection and they are well placed to improve the inclusivity of the collection process and the degree of data ownership. Moreover, partnerships with universities and or non-profit organisations can be leveraged to establish transdisciplinary participatory research and extension programmes that engage farmers as active partners in data collection design and knowledge co-creation, while reducing costs and time spent on the project by the cooperatives involved.
5) Environmental data are often kept in silos and, even when they are collected, they are **difficult to access and use** for analysis, especially for smallholder farmers. An **integrated system** of data collection and/or a **systematisation of already existing data** would allow to collect new data only when they are really needed and useful. The **FairInsight** system's potential should be explored in this sense. Moreover, in relation to the current project involving the Satelligence, environmental data collected by cooperatives and farmers in a participatory way should communicate with other data. This however, might pose challenges in terms of data ownership, which should be evaluated carefully.
6) **Digital technologies** such as mobile apps can facilitate **real-time data collection** and decision-making at the cooperative or farmer level, but it is necessary to invest in peer-to-peer learning and training programmes to support farmers with the skills and knowledge to monitor and manage their natural resources effectively. The most successful projects have taken a

participatory action research approach (PAR) and have engaged with young adults and digital technologies, offering some forms of training, peer to peer learning, and transferable skills to the young adults involved. Moreover, very importantly, participation in tool design made it possible to identify which data are more useful for end users and why.

7) It is important that environmental data collection, analysis and/or real time monitoring responds at least partially to **farmers' and/or cooperatives' immediate needs and that they add value for farmers and cooperatives**. For instance, they could offer them management instruments, such as financial forecasts or pest monitoring tools.
   Environmental data can be leveraged to **promote sectoral collaboration and knowledge sharing among stakeholders** in the value chain, including farmers, buyers, roasters, traders, and consumers, to persuade them to **jointly address shared sustainability challenges, also in financial terms**. Environmental data can be seen as a potential tool to strengthen cooperatives' position in the value chain to create **market demand for sustainably produced coffee.**

5. Conclusions and recommendations

Several contextual and conjunctural factors point towards the urgent need to enhance the environmental sustainability of the coffee value chain. Climate change represents a significant threat to coffee production as it is today and already affects the livelihood of many smallholder producers. In addition to this, the cost of fertiliser and fuel spiralled upwards as a result of the war in Ukraine, further increasing production costs for coffee growers (ID3). At the same time, legislative changes, such as the EUDR deforestation legislation, while representing an opportunity to enhance coffee's environmental sustainability, also present important challenges for its implementation, with the potential risk of creating market barriers for smallholders. Some companies are exploring the possibility of delineating a strategy based on the concentration of production, therefore privileging large-scale producers, which can ease the process of traceability and decrease its cost for buyers. This strategy is combined **with new coffee processing techniques aiming to maintain the quality of the final product (IC4). Moreover, as also highlighted in the introduction of this report, large-scale producers' economic and technical resources position them better to quickly respond to both legislative changes and market pressures. Some large-scale growers**, especially in Brazil, are already working towards achieving and effectively demonstrating their environmental sustainability (IA1B).

However, it is quite clear from this study's findings that, despite important contextual differences[46], **smallholders currently employ more environmentally sustainable practices**, if compared to large-scale plantations.[47] This is the case especially when small-scale growers are organised and supported by a favourable ecosystem and/or use agroforestry and organic farming, with advantages for social, economic and environmental sustainability that are well-documented in the literature (for example, see Siles, 2022). Agroforestry, moreover, plays a key role in climate adaptation and mitigation and in biodiversity conservation (see Section 3.8).

There is further room for improvement to enhance smallholders' environmental sustainability by means of working with them in the transition towards agroecology and agroforestry, when feasible as per farms' agroecological conditions. Further environmental sustainability can be achieved by means of **facilitating the exchange of good practices** and the **dissemination of context-specific low-cost innovative technologies**. Wastewater management, especially when coffee processing is

[46] And therefore with the need to investigate the research questions also on a case by case scenario.
[47] With a few notable exceptions, such as when large-scale producers are certified and/or when they adopt agroecological practices.

done on-farm, is an area in which this kind of project could improve the sustainability of the coffee value chain, as seen in **Section 3.3**.

Against this background, and in light of the agroecological principles adopted by Fairtrade, and its strategic position within the value chain, Fairtrade can play a major role in demonstrating and promoting smallholders' environmental sustainability, while also continuing to work with them towards social and economic wellbeing.

It is important to acknowledge that Producers Organisations are the main actor that can drive smallholders' environmental sustainability. Therefore, their capacity should be strengthened and time and resources should be allocated to their activities to support smallholders' environmental sustainability and the effort to communicate it effectively. In order to do so, cooperatives need to be commercially viable so that they have the time to genuinely focus on sustainability, instead of simply comply with environmental regulations (IC1). In fact, when roasters and international buyers get to know at first-hand the conditions of remote coffee producers, and not only those located in already touristic and well-accessed zones, they seem to be eager to increase social proximity with producers and rethink their commercial strategies (Quiñones-Ruiz, 2021). The key to a sustainable future lies in working together and acknowledging that people and nature are deeply connected, and that everyone – from scientists and everyday citizens to government officials and businesses – needs to collaborate to achieve both environmental and socioeconomic sustainability (West et al., 2020).

In some countries, such as Peru, where the lack of representation and negotiating power emerged as the main challenge for smallholders, this is particularly relevant, with an interviewee suggesting that without smallholders' representation and organisation in cooperatives (*institucionalidad)*, smallholders are at risk of disappearing (IB12P).

Another interviewee claimed:

> *"Particularly to encourage a generational renewal, to encourage young people to stay in the coffee sector, there is a need to support cooperatives and associations. The role of Fairtrade in communications and certifications is essential. They should favour certification of the processing phase: supporting organiser farmers and supporting cooperatives. Individual farmers cannot influence prices, but cooperatives can manage commercialisation better. Brazil has a lot of examples of cooperatives organised in the commercialization stage, rather than production" (ID3H).*

The role that the Fairtrade system can play is threefold:

1) **Fairtrade and CLAC can continue to work with smallholder farmers to both account for and further improve their sustainability** through producer support, trainings, and programme implementation as detailed in Section 5.1.

2) **Fairtrade can work with commercial partners on ad hoc solutions to collect data and take concrete action to enhance the sustainability of the value chain**, drawing on smallholders' current strengths such as, for instance, the insetting and biodiversity conservation potential of smallholders using agroecology and/or agroforestry (Section 5.2.) that strongly emerged from both primary and secondary data collection. For this purpose, Fairtrade can engage also with local and international universities/research centres and communities of producers.

3) In parallel, further internal reflection should be developed on coffee's environmental sustainability in relation to the Fairtrade Minimum Price, Premium, and Standards. Some considerations about the latter will be included in **Section 5.1**, before further exploring practical ways to work with farmers and commercial partners in **Sections 5.2** and **5.3**.

5.1 Fairtrade Minimum Price, Premium and Standards

As seen in **Section 1.3**, price - its fluctuation and its lack of elasticity also in relation to inflation and raising production costs - are key to coffee value chain and its sustainability (Siles, 2022). Fairtrade recognises the vital role that a fair price plays for smallholders to face the effects of climate change and the related environmental, social and economic costs. In 2023, Fairtrade indeed raised the coffee Minimum Price with considerable effects. In Colombia, for instance, in combination with the organic differential (see **Section 1.3**), the Fairtrade Minimum Price has meant farmers can receive the export-equivalent value of the Living Income Reference Price.[48]

Environmental and climate costs must be included in the Fairtrade Minimum Price and this is ultimately the principal mechanism to fairly distribute social, economic and environmental value and costs across the value chain (PoE WS). It is necessary to continue this work and engage commercial partners in this area. This work can be supported by tailored and immediate work with producers and commercial partners (further explored in this report in **Sections 5.2** and **5.3**), by means of i) raising awareness, and creating momentum across the value chain; ii) collecting information about environmental sustainability and environmental data collection; iii) creating further internal strategic alignment.

As far as the Fairtrade Premium is concerned, according to a study conducted in 2019 , only 5.44% of the Premium generated between 2014 and 2016 was invested in environmental aspects (Linne et al, 2019). With a stronger positioning of Fairtrade on climate and environmental issues and further engagement of POs this percentage should increase. It is very important to consider that interventions on drinkable water for instance or simply redistributing the Premium amongst farmers in hard times can be considered an essential climate adaptation tool, even if they are probably not strictly defined as environmental interventions. Therefore, ultimately, even though the Premium can be a precious tool, used in synergy with environmental interventions financed by commercial partners, its primary aim should continue to be producers' possibility to democratically decide about the most useful interventions. Possible areas in which the Premium can be used with environmental and socioeconomic benefits in the coffee sector are notably agroforestry, fertilisers, and plantation renewal.

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[48] For more information: https://www.fairtrade.net/news/fairtrade-increases-coffee-minimum-price-as-farmers-face-mounting-economic-and-climate-pressures.

Finally, the current Fairtrade Standards - with some environmental requirements being developmental[49] (see also **Section 1.3**) - allow Fairtrade to be inclusive while encouraging producers to become more environmentally sustainable. At the same time, particularly sustainable producers are currently rewarded by mechanisms such as the organic differential (see **Section 1.3**). In light of these considerations, Fairtrade can evaluate through time the possibility to change the Standards and make them environmentally more stringent, although this does not appear to be an organisational priority at the moment.

5.2 Working with farmers

5.2.1 Demonstrating smallholder's' environmental sustainability

An interviewed producer, very active in the agroecological movement, described their perception of environmental sustainability and current requirements by stating: ***"****there's a need to be recognised rather then facing a additional costs"* **(IB8C). In fact, research pointed to an urgent need to account for and effectively communicate to commercial partners and consumers alike smallholders' environmental sustainability.** The latter should be perceived by growers as an opportunity to leverage their position in the value chain and, in some cases, to decrease production costs.

Detailed lessons for data collection to account for environmental sustainability have been drawn in **Section 4**, after the review of existing participatory data collection tools. In general terms, however, it is necessary to bear in mind this producer's consideration while proceeding by means of:

1) **mapping what is already being done** in terms of data collection and communication at the cooperative level, especially in relation to **FairInsight[50] and simple digital tools**.

2) Explore the possibility of providing **data collection guidelines that can then be tailored to each context**, also in relation to the results of the consultancy work commissioned on agroecological metrics.

3) Investigate particularly relevant **case studies in partnership** with local and international Universities, research centres, non-profit organisations and commercial partners.

An important general consideration is that **data collection should be limited to what can be effectively used** either by cooperatives, associations or by the several actors of the Fairtrade system to further foster smallholder interests. Moreover, **storytelling of particularly exemplary cases** can be important to sensitise commercial partners and consumers and should accompany a simple framework for quantitative data collection and environmental monitoring.

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[49] See https://www.fairtrade.net/standard/aims.

[50] This report has not investigated this system in depth.

5.2.2 Dissemination of good practices: Farmer to farmer pedagogies and farmers' field schools

This study has shown that there are several positive examples of producers and cooperatives (as illustrated in Section 3) to enhance sustainability and dissemination of good practices across countries. Some examples of good practices are included in **Boxes 1, 2, 3** and **5**. Economic advantages also derive from the adoption of environmentally sound practices, such as the reduction of production costs because of the use of fewer chemical inputs and the increase in **food security.** There is a need to spread good practices and the associated advantages facilitating the exchange of knowledge amongst farmers and cooperatives. Farmer-to-farmer pedagogies across territories have proven very effective to work in this direction in the study areas (IC1) and are in line with an agroecological approach. Agroecological principles can be adapted to context so that producers do not perceive environmental sustainability as a burden but as **an investment to produce better quality coffee** that is well received in the market and to improve their own environment and quality of life.

Moreover, Fairtrade can further support producers that adopt diversification and agroforestry. Particularly, it could assess the possibility to incentivise cultivation of several certified crops, such as, in the study areas, coffee, cocoa and bananas. This would enhance farms' environmental sustainability while increasing food security and fostering economic and social sustainability and better equip growers to adapt to climate change. The advantages of agroforestry and diversification have been explored in **Section 3.8** (IB12, PoE WS).

4) Finally, apart from the differential given to organic producers, **Fairtrade could also design ad hoc projects of regenerative agriculture** during the transition period. The same could be done with farmers who aim to adopt agroecological practices.

While it is necessary to work with farmers to better account for, communicate and enhance their environmental sustainability, it is also important to work with commercial partners and further sensitise final consumers. As an interviewee put it:

> *"Farmers are trying to make a very complex calculation: essentially, while they are interested (and self-interested) in environmental sustainability, there are perceived trade-offs with productivity. Farmers also perceive challenges for meeting the standards of quality being demanded by niche buyers. […] The most important thing is for them to feel like their efforts are actually reliably being repaid by participation in Fairtrade. That's probably been the most common complaint that I have heard, that they put in all this effort and then they can't sell their coffee at Fairtrade prices" (IA4H).*

5.3 Working with commercial partners and consumers

Climate change impacts on the coffee value chain and smallholders are currently acknowledged by most stakeholders in the field. Agroforestry - currently widely practiced by small-scale growers in

Honduras, Nicaragua, Peru and Colombia[51] - is the most promising nature-based solution for climate adaptation and mitigation at the local and global level in coffee farming (see also **Section 3.8**). Smallholder coffee growers conserve the forest and biodiversity, while decreasing the need for energy and water consumption, therefore reducing GHG emissions and showing considerable potential for carbon insetting (ID4B). **The Fairtrade system can play a major role in addressing the climate crisis and the environmental sustainability of the coffee value chain, while pursuing fairer deals for smallholders and responding to the needs of commercial partners.**

It is necessary for the Fairtrade system to raise consumers' and commercial partners' awareness on the importance of agroforestry, agroecology, organic and regenerative agriculture while effectively communicating the role of smallholder farmers through environmental data collection. Effective communication would also consolidate its market positioning in relation to environmental sustainability. The Fairtrade agroecological strategy already points to this direction.

In the words of a research participant:

> *Until now they [Fairtrade] have been seen as those who sell in a small niche. But their offering is global - it's for the planet, for the world. This is changing because of climate change. They need to communicate more - Fairtrade is doing great work but they don't invest enough in communicating it. They need to 'sell' their offering as something for all farmers, for all humanity. And they can make strategic alliances to do so. There is a lot they can showcase from the Latin American experience. (IB38P)*

The global carbon and, partially, biodiversity markets have shown some shortcomings in the last few years. These are, for instance, the difficulty to clearly show that the result of a carbon project can be directly linked to the sale of a carbon credit, the different metrics, and understandings of 'value' underling the commodification of carbon emissions, and, in some cases, a lack of transparency[52]. Despite this, it is clear that **all actors involved in the value chain can play an important role in addressing paramount sustainability issues, such as the reduction of biodiversity loss, GHG emissions, and carbon insetting.** The results of a research about Nespresso coffee consumed in France, for instance, showed that around 40%-42% of the total carbon footprint is constituted by green coffee supply (Quantis, 2022).

Fairtrade can design **ad hoc arrangements with commercial partners** who are interested in reducing their Scope 3 emissions to enhance and communicate the environmental sustainability of their coffee, supporting producers to further engage in environmentally sustainable practices. Along with commercial partnerships and through the Fairtrade Premium, Fairtrade can also provide

[51] As well as other agroecological practices in Brazil, such as dedicating a part of the farm to reforestation or the *in situ* production of biofertiliser.

[52] See, for instance, https://www.compensate.com/articles/from-carbon-to-nature and https://carbonmarketwatch.org/2024/05/02/pricing-the-priceless-lessons-for-biodiversity-credits-from-carbon-markets/#:~:text=Challenges%20ahead%20for%20biodiversity%20markets,and%20the%20transparency%20of%20transactions.

financial support where it is most needed to help cooperatives in addressing sustainability challenges (some examples are projects to transition towards agroecology and organic farming, regenerative agriculture, wastewater management projects to reduce GHG emissions). Fairtrade is also well positioned to work with smallholders' cooperatives and associations to improve traceability of smallholder-produced coffee, a challenge to be overcome to address market barriers, especially in relation to the EUDR legislation. However, it is necessary to carefully evaluate trade-offs between costs and opportunities in a direct involvement of Fairtrade in enhancing coffee traceability.

There seems to be great potential to further explore, account for, showcase and improve smallholders' environmental sustainability, in close relation with social and economic sustainability. The 2021-2025 strategy and Fairtrade Policy on Sustainable Agriculture (Development International & Fairtrade International, 2022) give important theoretical and strategic orientation. Several pilot projects are exploring possibilities for environmental data collection, even if further research is needed, and good practices are already in place. These need to be further consolidated and shared across the larger network of Fairtrade producers, commercial partners and allies.

Annexes

Annex 1: Bibliography

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Annex 2: Systematic Literature Review Protocol

Research protocol

The research protocol, where possible, follows published guidelines for rapid reviews by the Collaboration for Environmental Evidence, an open community of stakeholders promoting and delivering evidence synthesis on environmental policy and practice issues (Collaboration for Environmental Evidence, 2018).

Stakeholder involvement

This rapid review aims to provide evidence to the Fairtrade Foundation on the environmental impacts of smallholder coffee farming compared to large-scale production in Latin America. FTF UK formulated the main aims of this research. The methodology and results presented in this inception report have been written by a team of independent consultants with the input of the client's point of contact throughout the inception stage.

Research objectives

This rapid review aims to provide FTF UK with a landscape understanding of the environmental impacts of smallholder coffee farming in Latin America compared to plantation-grown coffee. FTF UK formulated the project's research objectives that were then edited to fit the PICO criteria (population, intervention, comparison, outcome):

Population: Coffee farms in Brazil, Colombia, Peru, Nicaragua, and Honduras.

Intervention: Smallholder farming of coffee

Comparison: Plantation farming of coffee

Outcome of interest: Greenhouse gas emissions, water and energy use, biodiversity, deforestation

This led to the adoption of our first research question for the study (RQ1) as the primary research question for the literature review. This is formulated as follows:

What evidence exists on the environmental impacts (greenhouse gas emissions, water and energy use, biodiversity, deforestation) of smallholder coffee farming compared to large-scale plantations in Latin America?

The question will be answered through the following sub-research questions that will all compare smallholder coffee to large-scale plantations in Latin and Central America:

1. *What are the characteristics of the evidence base - location, scale, and farm management types?*
2. *What is the evidence on environmental impacts between smallholders and plantations?*
3. *How does the evidence relate to sun vs. shade management?*

4. *How does the evidence base relate to conventional vs. agroecological management?*

Methods

Deviations from the protocol

Minor deviations were made from our protocol. Firstly, we altered the study scoring from a scale of 1-4 to a scale of 1-3 to reflect the small number of studies that compared smallholders and plantations directly.

Due to time and capacity constraints, only one reviewer screened all articles. Due to the high number of Spanish and Portuguese that passed the first round of screening, we also screened articles in these languages at full-text and extracted data. This was done by the primary reviewer using online translation services for the article. If the online translation service was unclear, the study was passed onto other reviewers fluent in that language to check.

Search strategy

We created a benchmark list of articles that captured a range of relevant studies through scoping searches and the bibliographies of relevant papers. We then collated search terms through keywords extracted from the benchmark list of articles, consultation between the consultants and Fairtrade Foundation and a thesaurus. Search terms were based on the components of the research question, and the search string was developed using Web of Science and Boolean operators. Themes were combined using "AND", while synonyms within themes were combined using "OR". Combinations of different synonyms were then applied to searches and tested against the benchmark list of articles (Table 1). We removed terms for smallholder and plantations to widen the scope of the final search string because adding these terms greatly restricted search hits. We will instead categorise farm sizes within each study during screening to answer the research question. The final search string is:

Coffee OR arabica OR robusta

AND

Brazil* OR Brazil* OR Colombia* OR Peru* OR Nicaragua* OR Hondura* OR 'Latin America' OR 'Central America' OR Andes OR Ande* OR Andean

AND

deforestation OR environment* OR sustainabil* carbon OR 'greenhouse gas' OR emissions OR water OR biodivers* OR deforest* OR energy OR climate Or conservation OR forest OR diversity Or species richness OR density OR fertiliz* OR fertilis*

Bibliographic database search

We used the string described above to search in the Web of Science Core Collection (Science, Social Sciences and Arts and Humanities Citation indexes only) and SciELO Citation Index in December 2023 and January 2024. The Core Collection is the Web of Science main database, while the SciELO index specifically looks for science published in leading open-access journals in Latin America. Searches were conducted in English and bound between 2000 and the present day for the Web of Science Core Collection (n=1,803) and 2002 to the present day for the SciELO index (n=708).

Targeted peer-reviewed searching

The bibliographies and cited articles of other relevant evidence syntheses or publications on the environmental impacts of coffee for smallholder farming in Latin America were screened for relevant literature. This included already discovered literature and any found during the screening process. In addition to this, we asked the experts in the interviews to share relevant grey and academic literature for screening.

Targeted searching articles (bibliography and included studies if a review)

- De Beenhouwer, M., Aerts, R. and Honnay, O., 2013. A global meta-analysis of the biodiversity and ecosystem service benefits of coffee and cacao agroforestry. *Agriculture, ecosystems & environment*, *175*, pp.1-7.
- Harvey, C.A., Pritts, A.A., Zwetsloot, M.J., Jansen, K., Pulleman, M.M., Armbrecht, I., Avelino, J., Barrera, J.F., Bunn, C., García, J.H. and Isaza, C., 2021. Transformation of coffee-growing landscapes across Latin America. A review. *Agronomy for sustainable development*, *41*(5), p.62.
- Santos, V.P., Ribeiro, P.C.C. and Rodrigues, L.B., 2023. Sustainability assessment of coffee production in Brazil. Environmental Science and Pollution Research, 30(4), pp.11099-11118

We also conducted targeted grey literature searching of the following websites:

1. State of the Smallholder Coffee Farmer, an open access resource, connecting indicator data about smallholder coffee farmers for Nicaragua, Honduras and Guatemala (*https://coffeesmallholder.org/en/indicators*). Here, we downloaded the relevant data and screened the original source to ensure it met the inclusion criteria.
2. Lavazza (https://www.lavazzagroup.com/en.html)
3. Starbucks (https://www.starbucks.com/responsibility/planet/)
4. Nespresso (https://www.sustainability.nespresso.com/reports)

Table A1. Benchmark list of articles

Reference	Short description	Keywords from title and abstract	Pilot testing inclusion criteria for stage 1 screening
Arendt, W.J., Tuckfield, R.C., Martínez-Sánchez, J.C., Reidy, J.L., Thompson III, F.R., Wunderle Jr, J.M. and Zolotoff, J.M., 2019. Avian community density and distribution patterns among Nicaraguan conventional and organic shade-coffee	Bird density in shade-coffee plantations in Nicaragua	density **species richness** **conventional**	Country: Nicaragua Coffee system: yes Environmental outcome: Biodiversity Farm type: plantations, size

plantations. *Agricultural Sciences*, *11*(1), pp.27-53.			unclear
Armbrecht, I., Rivera, L. and Perfecto, I., 2005. Reduced diversity and complexity in the leaf-litter ant assemblage of Colombian coffee plantations. *Conservation biology*, *19*(3), pp.897-907.	Ant biodiversity comparing sun and shade coffee in Colombia	**Diversity** complexity **Colombian**	Country: Colombia Coffee system: yes Environmental outcome: Farm type: plantations, size unclear
Ehrenbergerova, L., Cienciala, E., Kučera, A., Guy, L. and Habrová, H., 2016. Carbon stock in agroforestry coffee plantations with different shade trees in Villa Rica, Peru. *Agroforestry systems*, *90*, pp.433-445.	Peruvian Andes Compares carbon storage between different shade coffee plantations and sun coffee	**carbon** stock agroforestry **coffee** plantation **shade** **Peru** biomass soil coffea arabica	Country: Peru Coffee system: yes Environmental outcome: GHG Farm type: plantation, size unclear
Haggar, J., Asigbaase, M., Bonilla, G., Pico, J. and Quilo, A., 2015. Tree diversity on sustainably certified and conventional coffee farms in Central America. *Biodiversity and Conservation*, *24*, pp.1175-1194.	Includes Nicaragua Nicaragua includes large-scale conventional and Rainforest Alliance. Tree species diversity focus.	**diversity** conventional certified **Central America** **species richness** agroforestry **biodiversity** **smallholder** **species** composition **large-scale**	Country: Nicaragua Coffee system: yes. certification Environmental outcome: Biodiversity Farm type: unclear
Haggar, J., Soto, G., Casanoves, F. and de Melo Virginio, E., 2017. Environmental-economic benefits and trade-offs on sustainably certified coffee	Compares environmental impacts between different	**environmental** **coffee** **carbon** stocks	Country: Nicaragua Coffee system: yes. certification Environmental

farms. *Ecological indicators*, *79*, pp.330-337.	certification schemes in Nicaragua: habitat quality, tree carbon stocks, soil conservation	tree **diversity** shade **coffee**	outcome: Biodiversity, GHG Farm type: unclear
Hardt, E., Borgomeo, E., dos Santos, R.F., Pinto, L.F.G., Metzger, J.P. and Sparovek, G., 2015. Does certification improve biodiversity conservation in Brazilian coffee farms?. *Forest Ecology and Management*, *357*, pp.181-194.	compares deforestation between certified and non-certified farms for large-scale coffee in Brazil	**biodiversity** **coffee** **forest conservation** land use change	Country: Brazil Coffee system: yes Environmental outcome: Deforestation Farm type: unclear
Méndez, V.E., Bacon, C.M., Olson, M., Morris, K.S. and Shattuck, A., 2010. Agrobiodiversity and shade coffee smallholder livelihoods: a review and synthesis of ten years of research in Central America. *The Professional Geographer*, *62*(3), pp.357-376.	Looks at the agrobiodiversit y of smallholder shade coffee farms in Nicaragua.	agrobiodiversit y coffee smallholder	Country: Nicaragua Coffee system: yes, smallholder Environmental outcome: Biodiversity Farm type: smallholder
Pronti, A., & Coccia, M. (2021). Multicriteria analysis of the sustainability performance between agroecological and conventional coffee farms in the East Region of Minas Gerais (Brazil). Renewable Agriculture and Food Systems, 36(3), 299-306.	Minas Gerais - Brazil Comparative analysis of agroecological and conventional small coffee farms.	agroecology, agro-**biodiversity** and **forest** cover **sustainability** multicriteria analysis **coffee** **Brazil**	Country: Brazil Coffee system: yes, agroecology Environmental outcome: Biodiversity, Deforestation Farm type: unclear
Usva, K., Sinkko, T., Silvenius, F., Riipi, I. and Heusala, H., 2020. Carbon and water footprint of coffee consumed in Finland—life cycle assessment. *The*	Gives farm-level data on water use, irrigation/ha, carbon at the farm level in Brazil,	**carbon** **water** footprint **coffee**	Country: Brazil, Colombia, Honduras and Nicaragua Coffee system: yes

International Journal of Life Cycle Assessment, *25*, pp.1976-1990.	Colombia, Honduras and Nicaragua	life cycle assessment LCA water footprint **carbon** footprint **water** scarcity	Environmental outcome: GHG, water Farm type: unclear

Table A2. Search term building as entered into Web of Science Core Collection, no date range on 28/11/2023

Search	Hits	Test list	Notes
((TS=(coffee) AND TS=(Brazil* OR Colombia* OR Peru* OR Nicaragua* OR Honduras* OR 'Latin America' OR 'Central America') AND TS=(smallholder) AND TS=(plantation OR large-scale OR commercial OR conventional) AND TS=(deforestation OR environment* OR sustainabil* carbon OR 'greenhouse gas' OR emissions OR water OR biodivers* OR deforest* OR energy OR climate Or conservation OR forest OR diversity Or species richness OR density)))	34	1/9	Very difficult to find studies that have compared smallholders and large-scale plantations in one study. Strategy to expand the search to smallholder OR large-scale to see if this increases hits.
((TS=(coffee) AND TS=(Brazil* OR Colombia* OR Peru* OR Nicaragua* OR Hondura* OR 'Latin America' OR 'Central America') AND TS=(smallhold* OR small-hold* OR plantation OR large-scale OR commercial OR conventional) AND TS=(deforestation OR environment* OR sustainabil* carbon OR 'greenhouse gas' OR emissions OR water OR biodivers* OR deforest* OR energy OR climate Or conservation OR forest OR diversity Or species richness OR density)))	656	6/9	Missing - Haggar et al., 2017 - Usva et al., 2020 Due to lack of hits, combined smallholder and plantation synonyms. However, this still did not capture test-list of articles. Search could be widened.
((TS=(coffee) AND TS=(Brazil* OR Colombia* OR Peru* OR Nicaragua* OR Hondura* OR 'Latin America' OR 'Central America') AND TS=(smallhold* OR small-hold* OR plantation OR large-scale OR commercial OR conventional OR sun OR shade) AND TS=(deforestation OR environment* OR sustainabil* carbon OR 'greenhouse gas' OR emissions OR water OR biodivers* OR deforest* OR energy OR climate Or conservation OR forest OR diversity Or species richness OR density)))	769	7/9	Missing - Usva et al., 2020 Add sun or shade - still did not capture test list.

((TS=(coffee) AND TS=(Brazil* OR Colombia* OR Peru* OR Nicaragua* OR Hondura* OR 'Latin America' OR 'Central America') AND TS=(deforestation OR environment* OR sustainabil* carbon OR 'greenhouse gas' OR emissions OR water OR biodivers* OR deforest* OR energy OR climate Or conservation OR forest OR diversity Or species richness OR density)))	1873	8/9	Search not including for smallholder/plantation + synonyms to see results compared to the test list. This search captures the test list available on Web of Science. With this strategy farm size will need to be classified during screening and data collection. Missing - Arendt - but not in Web of Science so this search hits all of the test list
((TS=(coffee) AND TS=(Brazil* OR Brazil* OR Colombia* OR Peru* OR Nicaragua* OR Hondura* OR 'Latin America' OR 'Central America') AND TS=(deforestation OR environment* OR sustainabil* carbon OR 'greenhouse gas' OR emissions OR water OR biodivers* OR deforest* OR energy OR climate Or conservation OR forest OR diversity Or species richness OR density)))	1898	8/9	Add Brazil to expand synonyms.
((TS=(coffee OR arabica OR robusta) AND TS=(Brazil* OR Brazil* OR Colombia* OR Peru* OR Nicaragua* OR Hondura* OR 'Latin America' OR 'Central America') AND TS=(deforestation OR environment* OR sustainabil* carbon OR 'greenhouse gas' OR emissions OR water OR biodivers* OR deforest* OR energy OR climate Or conservation OR forest OR diversity Or species richness OR density)))	2030	8/9	Add arabica or robusta to expand synonyms.
((TS=(coffee OR arabica OR robusta) AND TS=(Brazil* OR Brazil* OR Colombia* OR Peru* OR Nicaragua* OR Hondura* OR 'Latin America' OR 'Central America' OR Andes OR Ande* OR Andean) AND TS=(deforestation OR environment* OR sustainabil* carbon OR 'greenhouse gas' OR emissions OR water OR biodivers* OR deforest* OR energy OR climate Or conservation OR forest OR diversity Or species richness OR density)))	2075	8/9	Add Andres Ande* or Andean to expand synonyms.
((TS=(coffee) AND TS=(Brazil* OR Colombia* OR Peru* OR Nicaragua* OR Hondura* OR 'Latin America' OR 'Central America') AND TS=(smallhold* OR small-hold*) AND TS=(plantation OR large-scale OR commercial	17		Quick test to see if adding comparison would help search string.

OR conventional OR sun OR shade) AND TS=(compar*) AND TS=(deforestation OR environment* OR sustainabil* carbon OR 'greenhouse gas' OR emissions OR water OR biodivers* OR deforest* OR energy OR climate Or conservation OR forest OR diversity Or species richness OR density)))			
((TS=(coffee OR arabica OR robusta) AND TS=(Brazil* OR Brazil* OR Colombia* OR Peru* OR Nicaragua* OR Hondura* OR 'Latin America' OR 'Central America' OR Andes OR Ande* OR Andean) AND TS=(deforestation OR environment* OR sustainabil* carbon OR 'greenhouse gas' OR emissions OR water OR biodivers* OR deforest* OR energy OR climate Or conservation OR forest OR diversity Or species richness OR density OR fertiliz* OR fertilis*)))	2153	8/9	Add in fertiliser to expand synonyms because this is linked to GHG emissions Final chosen search string - widest possible search string that captures the benchmark list and is still a manageable amount of articles to do within the timeframe allotted.

Article screening and study eligibility

Pilot testing

The eligibility criteria were pilot-tested by one research team member on the benchmark list of articles. First, the reviewer screened the titles and abstracts. Screening decisions were discussed with the review team, and criteria were adjusted. This process was then repeated for full-text screening of the benchmark list. Once the eligibility criteria were set, the data extraction codebook was also pilot-tested, discussed and adjusted accordingly.

Study eligibility:

Each publication was screened according to the eligibility criteria in **Table 2**. All publications must also be online. We include a list of all excluded articles that made it to full-text screening and the reason for exclusion here.

Table A3. Eligibility criteria

Question component	Criteria
Coffee farms in Brazil, Colombia, Peru, Nicaragua, Honduras	Inclusion: The text must study coffee systems in at least one of the following countries: Brazil, Colombia, Peru, Nicaragua, and Honduras. Texts that span multiple countries with some outside the focal countries will be included if the countries are all in Latin America.
Farming system	Inclusion: the text must state the farm size. All farming systems will be included and then classified into smallholder or plantation upon data extraction under the following definitions provided by FTF (Fairtrade International 2019):

	Smallholder farming of coffee Inclusion: Smallholder farming systems are defined according to Fairtrade foundation standards based on labour management: ● 'members do not hire workers on a continuous basis and they work on their own-account ● farm work is mostly done by members and their families'. If the study does not give any labour information, we will use a maximum farm area of 30 hectares. Plantation farming of coffee Inclusion: Plantation farming systems are defined according to Fairtrade foundation standards based on labour management: ● Farms that hire permanent labour external to the family. If the study gives no labour information, we will use a minimum farm area of 30 hectares.
Greenhouse gas emissions, water use, energy use, biodiversity, deforestation	Inclusion: Studies that examine greenhouse gas emissions, water and energy use, biodiversity or deforestation at the farm level. Exclude: Studies that examine greenhouse gas emissions, water use, energy use, biodiversity or deforestation at levels higher than the farm, e.g., coffee processing emissions and landscape-level biodiversity metrics not directly attributable to coffee farms. Greenhouse gas emissions includes studies that examine greenhouse gas emissions, carbon stocks or sequestration (above and/or below ground). Greenhouse gases refer to carbon dioxide, methane and nitrous oxide. Water use includes any evidence of water use (the total amount of water withdrawn from its source to be used), consumption (the portion of water use that is not returned to the original water source after being withdrawn), or studies examining water pollution. We may also include studies that use other metrics to provide evidence on water use or consumption, such as scarcity impact (the potential of water deprivation to humans or ecosystems). Biodiversity includes any study that examines species richness, abundance, composition, and density. Deforestation is the purposeful clearing of forested land, in this instance, for coffee farming. We will include measurements of on-farm tree cover / forested area, deforestation measurements, reforestation measurements or other evidence of forest clearing.

	Energy use refers to studies on energy use at the farm level when producing coffee, efficiency projects such as improved cookstoves, water filtration/purification systems, energy energy-saving lamps/fluorescent lamps.
Study types	
Qualitative, quantitative, mixed-methods	Inclusion: Methods used may be qualitative, quantitative, or mixed methods.
Format of the results	Inclusion: Book chapters, reports, grey literature publications, scientific publications, and evidence syntheses. Inclusion: Online formats and in English only. Exclusion: Results will be excluded if the format 1. does not provide sufficient information, I.e. there are no associated publications with results, faulty links, presentations, conference proceedings 2. is journalism, i.e. news and magazine articles, 3. is a proposal, i.e. manuals and grant proposals. 4. is a student thesis (BSc, MSc, PhD) 5. is that of a book because book chapters will be found in the search strategy

Screening process

Screening was first conducted for titles and abstracts using the web program Rayyan, and then articles that passed the first round were screened at full text. At both stages, inclusion was determined through the eligibility criteria (outlined in **Table 2**). If the reviewer was unsure of inclusion at the title and abstract stage, the study was automatically screened for full-text screening. Doubts of inclusion at the full-text stage were discussed and determined by the review team.

Data coding and extraction

Studies that have met the eligibility criteria at full-text screening underwent data coding and extraction. Each publication was assessed using a codebook to capture the relevant data—the final codebook alongside data extracted from the benchmark articles is here. The data extracted was grouped under the following categories:

- Bibliographic information
- Study country
- Study details (farm type, size, management)
- Environmental outcomes (biodiversity, water, energy, deforestation, GHG emissions)

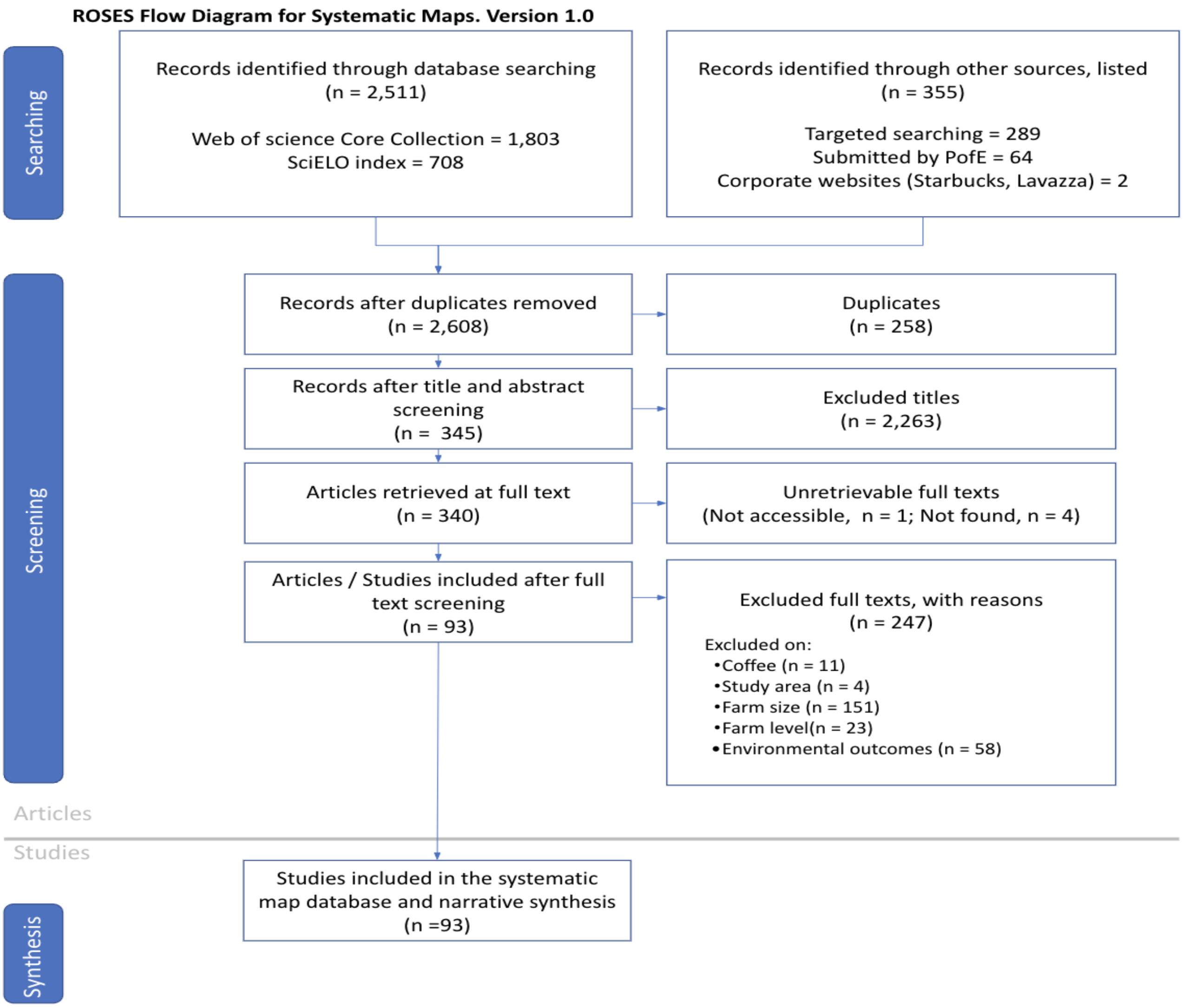
During data coding, each study was scored according to relevance to answer the research questions according to the criteria below:

1. The study details information on smallholder and plantation coffee for the environmental outcomes
2. The study details information on smallholders only for environmental outcomes
3. The study details information on plantations only for environmental outcomes

Study mapping and presentation

2,822 records were identified through bibliographic databases (n=2,511) and other searches (n=355). After removing duplicates, 2,608 unique publications underwent title and abstract screening under inclusion criteria developed from the search terms. 345 articles passed to the full-text stage, however, 5 articles were unretrievable so 340 were screened: 255 English, 57 Spanish and 31 Portuguese. 247 texts were excluded at the full-text stage due to not being about coffee (n=11), not being in the focal countries (n=4), not studying the environmental outcomes of focus (n=58), not providing farm size (n=151) or not being at the farm level (n= 23). 93 studies passed full-text screening to be included in the final rapid review: 72 English, 2 Portuguese and 19 Spanish. A full list of texts at the full-text screening stage and the reason for exclusion can be found here, including those not found or not accessible. Included texts were also scored on their relevance to answer the research questions. We then extracted data from these studies to answer the research objective based on a pre-defined data codebook. The data extracted from studies was quantitative where possible. Microsoft Excel and R was used to systematise data from the literature review and support visualization. 95.7% of the texts included were scientific journal articles (n=89), with two reports and two MSc theses. Texts were published between 2003 and 2023, the most texts were published in 2021 (n=12).

Figure A1. ROSES diagram of the flow and number of studies from searches to the final included set.



Annex 3 Country synopsis

Table A4. Country synopsis

	General Comparison	Main Challenges	Recommendations
Brazil	Legislation and policy environment stronger than other contexts but little incentive to showcase certification. Also many farmers do not qualify due to farm size. Cooperative system and technical services quite strong but influenced by the private sector.	Lower soil quality, need for fertiliser, climate variability, irrigation. What is considered a smallholder in Brazil may be 'too large' by Fairtrade standards (IB14B), but they face similar challenges (eg linked to family farming). Rural extension services for smallholders may 'push' their product, leading to overuse of chemicals.	Definition of smallholders by size may not be most relevant for Brazil - should focus more on practices and family farming. Potential to achieve more impact at scale if shifting also to medium producers? There is potential to provide **rural extension promoting more sustainable practices.**
Colombia	Policy focusing more and more sustainability with recent change in government. POs system relatively strong. Innovation in quality, specialty coffee and investment in new technologies.	A lot of innovation in sustainable practices happening in more isolated areas, affected by conflict. Federación de Cafeteros historically more focused on productivity rather than sustainability.	There is room for general switch to agroecology and networks of farmers interested in it.
Honduras	Smallholders traditionally committed to shade production and diversification (cultural, economic, nutritional reasons) - Bosque Productivo	Political and climate insecurity, high levels of migration outside of the country. Deforestation among larger producers who want to clear out trees to produce more.	There is great potential for pilots/demonstration farms on GHG emissions, carbon insetting, biodiversity conservation.
Nicaragua	Very small-scale producers in general, with concentration of very large farms among a small percentage (as a result of the coffee	The main issue is the use of fertiliser - damaging soil and water quality. This is more frequent among larger-producers who have more knowledge	Need for more technical support to small-scale farmers as part of the certification process, for instance on sustainable practices

	crisis in 90s- 2000s). Most producers (of all sizes) employing agroforestry processes/ systems. Many 'organic by default' producers	and resources to invest in inputs. However small producers use of water and energy can also become more efficient.	and on communicating those already implemented. There is great potential for pilots/demonstration farms on GHG emissions, carbon insetting, biodiversity conservation.
Peru	Lack of representation and limited ability to influence public policy (for instance on irrigation)- IB12. Cooperative system relatively weak. Diversification & Agroforestry enhance food security, while contributing to adaptation (eg water retention in the soil, resilience to price and weather shocks) and mitigation (carbon sequestration IB12)	Particularly challenging Andean terrain. Historically less support to the coffee sector compared to neighbouring countries, less organisation in cooperatives.	Strengthening smallholders' representation

Annex 4 Expert and Fairtrade contributors

Table A5. Panel of Experts members

	Name	Role and Institution	Country/ies
1	Prof. Ricardo Silva Santos	Professor - Federal University of Viçosa	Brazil
2	Prof. Ernesto Mendez	University of Vermont	Central America and Peru
3	Prof. Xiomara F. Quinones Ruiz	Senior Scientist - University of Natural Resources and Life Sciences, Vienna (BOKU)	Colombia
4	Prof. Catherine Tucker	Professor - Center for Latin American Studies, University of Florida	Honduras
5	Prof. Massimo Battaglia	Research Leader - Marzocco Coffee Academy & The Slow Food Coffee Coalition	Nicaragua, Honduras and

			Central America region
6	Prof. Salazar Centeno	University of Managua	Nicaragua
7	Prof. Norvin Sepulveda	CATIE	Nicaragua

Table A6. List of Fairtrade and CLAC participants[53]

Name	Role and Institution	Country/Region
Monika Firl	Senior Advisor, Coffee Programme - Fairtrade International	Central and Latin America
Julie Francoeur	CEO - Fairtrade Canada	Global
Juan Pablo Solís Víquez	Senior Advisor, Climate and Environment - Fairtrade International	Global
Martin Schuller	Development and Environmental Policies Manager - Fairtrade Germany	Global
Nicolas Dutois	Programme Coordinator, Climate and Environment - Fairtrade International	Global
Maria Asunción Meza	Country Manager Nicaragua	Nicaragua
João Mattos	Commercial Director, Brazil	Brazil
Paulo Ferreira Junior	Coffee Commercial Liaison, Brazil	Brazil
Leonardo Perlata	- Coffee Commercial Liaison Andean Region	Peru
Mireya Levy	MEL Officer in Climate Change Unit	Ecuador

[53] In addition, please see list of participants to the validation workshops, provided in Annex 5.

Rosa Nila Alfaro	MEL Officer	El Salvador
Walter López Peña	Country Manager, Honduras	Honduras
Jaquelina Vivanco	Regional Director	Central America and Mexico
Gonzalo David Rueda	Country Manager	Colombia
Catalina Jaramillo	Regional Director	Conor Sur

Annex 4: Interview topic guides

Please note that interviews are ***anonymous or after.*** *Interviews will also be* ***confidential*** *as only the study team will have access to the data. We will request* ***permission to record,*** *purely for note-taking purposes. All interviews will be transcribed and kept internal to the evaluation team. Participants are free to not answer any question they do not feel comfortable with, and to stop the interview at any point. We have broadly divided the interviewees in FTF UK staff, CLAC staff, Cooperatives and Farmers but we will further tailor research questions to the specific interviewee, based on their role and area of expertise.*

Interview Guide: Panel of Experts

At the start of the interview, we will ***introduce respondents to the study aims and design****. We will then illustrate the modality of the interview, including how findings will be used and reported back to FTF UK. We will inform participants that interviews are* ***anonymous****, in that findings will not be linked back to any specific individual in our report. Interviews will be also* ***confidential*** *as only the study team will have access to the data We will request permission to record, purely for note-taking purposes. All interviews will be transcribed and kept internal to the evaluation team. We will also remind participants they are free to not answer any question they do not feel comfortable with, and to stop the interview at any point. We will tailor research questions to the specific interviewee to broadly cover the themes below.*

1. Brief Introduction to their experience and expertise. Given the description of the study what they believe they can contribute.
2. Examples of good agricultural practices that enhance the sustainability of smallholder farming when compared to large-scale agriculture in relation to greenhouse gas emissions, deforestation, biodiversity loss, water and energy use.
3. Aspects in which smallholder producers can improve their sustainability, and potential methods to do so.

4. Interconnection of social and environmental sustainability for smallholders, compared to large-scale producers.
5. Their understanding of the role FTF UK/ CLAC/ Fairtrade International/other Fairtrade organisations are currently playing and/or should play in the future. Literature and datasets relevant to the comparison between the sustainability of smallholder farmers and large-scale agriculture in Brazil, Colombia, Honduras, Nicaragua, Perù.
6. Suggested Approaches for sustainability data comparison, as there are no shared metrics.

Snowball sampling for Cooperatives and farmers, researchers, academics, and governmental officers we can interview for the project in their country of reference.

Interview Guide: Academics and consultants[54]

1) What do you think are the main differences between smallholder farming agriculture and large-scale plantations in relation to the sustainability of coffee production? In what ways are sustainability considerations linked with small-scale coffee production, and to what extent do they form part of the debate in this sector?

2) In your experience, what are the most important issues that should be tackled to enhance the sustainability of coffee production in terms of:

- greenhouse gas emissions
- deforestation
- biodiversity loss
- water and energy use

Please refer to concrete examples and case-studies where possible.

4) In your view, to what extent are smallholders well-placed and prepared to tackle these issues? What are some of the main issues they face in order to do so? How can they be supported to further enhance the sustainability of their production?

4) What role are FTF UK/CLAC/Fairtrade International currently playing and/or should play in the future to enhance the sustainability of the coffee value chain? Who are some of the other important actors in this space, and how does their approach differ? What are some of the strengths and weaknesses of each approach?

5) Do you know about any projects that piloted field data collection on sustainability outcomes in which farmers are actively involved and owners of their data? These could be about all the four dimensions previously mentioned or just one/some of them.

a) If yes, what have been some of the most important results of these initiatives, and what have been some of the challenges? What could be improved or further explored going forward?

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[54] Interviews were conducted in Spanish when preferred by respondents.

b) If no, what do you think are the main opportunities and areas to explore to support farmer-led data collection on environmental outcomes?

5) Do you know any relevant literature data-set, case-study comparing smallholder agriculture and small-scale farming in relation to deforestation, biodiversity loss, GHG emissions, water and energy use?

6) Snowball sampling - Is there someone you would recommend us to interview so as not to miss important information about the topics we have just discussed?

Interview Guide: Producers and producers' organisations[55]

1) What do you think are the main differences between smallholder farming agriculture and large-scale plantations in relation to the environmental sustainability of coffee production? What are some of the advantages and disadvantages of small-scale farming when it comes to environmental outcomes?
2) What are the main challenges and opportunities smallholder farmers in your context face in relation to increasing environmental sustainability of production? More specifically, what are the main challenges and opportunities in the areas of:
    - greenhouse gas emissions
    - deforestation
    - biodiversity loss
    - water and energy use

    How does this apply to your work, or other cases you have seen in your context? Are there any specific case studies or lessons learned you would like to mention? Please refer to concrete examples where possible.

3) In your view, to what extent are sustainability considerations driving decision-making for large- and small-scale producers in your country? What are some of the other important considerations at play?
4) What do you think are the issues that should be prioritised to support smallholders to have sustainable production methods? What further support would smallholders need to increase the sustainability of their production? Which are most important in your view, and why?
5) In your line of work, what type of data is useful to drive production decisions? Where do you normally access this data? Have you ever collected or do you intend to directly collect data about farm management and deforestation, GHG emissions, water, energy?
6) If yes, what were the methods for collecting this data, and in what format do you think it should be stored? In what ways did it support your work, and what have been some of the challenges you faced in collecting and using the data?

[55] Interviews were carried out in Spanish and Portuguese, as needed. We only carried out interviews with cooperatives and producers following discussion with and approval by FTF UK.

7) Do you think these data and data collection processes would be of interest for cooperatives and /or other small-scale producers? Do you think anything could be improved to make the processes easier and more useful in the future?
8) Snowball sampling - Is there someone you would recommend us to interview so as not to miss important information about the topics we have just discussed?

Interview Guide: FTF UK and CLAC staff

1) Could you please introduce yourself and your role in the Fairtrade system? What do you think are the main differences between smallholder farming agriculture and large-scale plantations in relation to the environmental sustainability of coffee production?
2) How do you think Fairtrade is currently enhancing the environmental sustainability of smallholder farmers, if possible in the coffee value chain in Brazil, Colombia, Honduras, Nicaragua, Perù)?
3) Are there any particularly important examples or lessons learned worth mentioning from the Latin America region and/ or the countries mentioned?
4) What have been some of the main challenges for Fairtrade to support farmers in the region to enhance their sustainability? Why has that been the case, and how has Fairtrade addressed this challenge?
5) What do you think could be future directions to explore to further enhance sustainability for farmers in the region? What do you expect might be some challenges going forward?
6) What are the main challenges and opportunities for the Fairtrade MEL system in measuring and reporting on environmental sustainability (if possible in the coffee value chain in Brazil, Colombia, Honduras, Nicaragua, Perù)? What data would be most useful for Fairtrade and its partners? What about for smallholder farmers and producer organizations, and why?
7) How is Fairtrade currently supporting farm-level sustainability data collection? Have there been any particularly promising initiatives led by Fairtrade or other actors in this space? What have been some of the main challenges faced, and what do you think could be next steps to further improve farmer-level data collection?
8) Snowball sampling - Is there someone you would recommend us to interview so as not to miss important information about the topics we have just discussed?

Annex 5: Workshop structures and Miro board

5.1 Workshop with CLAC respondents

Structure

1. Duration: 1.5 hours

2. Attendees:

1. Maria Asunción Meza - Country Manager Nicaragua
2. João Mattos - Commercial Director, Brazil
3. Paulo Ferreira Junior - Coffee Commercial Liaison, Brazil
4. Leonardo Perlata - Coffee Commercial Liaison Andean Region, Peru
5. Mireya Levy - MEL Officer in Climate Change Unit, Ecuador
6. Rosa Nila Alfaro - MEL Officer, El Salvador
7. Walter López Peña - Country Manager, Honduras
8. Jaquelina Vivanco - Regional Director, Central America and Mexico
9. Gonzalo David Rueda - Country Manager, Colombia
10. Catalina Jaramillo - Regional Director, Conor Sur

Aim of the workshop

- Guided focus group discussion through three break-out sessions in small groups, focusing on: i) differences between smallholders' and larger producers' environmental impact; ii) effective practices emerging from CLAC's experience; iii) further areas to explore going forward.
- Discussion was facilitates through a Miro board, which can be found here: https://drive.google.com/file/d/1jSyRSBtDfQOjodNlblufh2Uz2npCdDv0/view?usp=sharing

5.2 Panel of Experts' Workshop

Structure

1. Duration: 2 hours
2. Attendees: Dr Battaglia, Dr Bernal, Prof. Mendez, Prof. Santos, Dr Sepulveda, Prof Tucker[56]

Aim of the workshop

Gather experts' views on emerging findings and identify useful directions to support further analysis. Collect further insights on and examples of the sustainable practices of smallholder

[56] Please note that, due to her availability, Dr. Quiñonez-Ruízc could not take part in the PoE workshop and was replaced by Dr. Bernal representing Colombia.

farmers in relation to greenhouse gas emissions, deforestation, biodiversity loss, water and energy use. Explore the comparison between smallholder and large-scale farming.

Approach to workshop:

- Structured workshop with pre-filled contents on the different sustainability metrics, using a Miro board. The completed Miro board can be found here: https://drive.google.com/file/d/1sydU0syyy_SOxlVtBhBU5BZlW_jRLJlG/view?usp=sharing

- Mix of plenary discussion and small group discussions to maximise time and topics discussed

- A suggested approach may be to split up groups based on experts' knowledge of themes (to greenhouse gas emissions, deforestation, biodiversity loss, water and energy use) and ask them about a feasible (also socially and economically) holistic approach that can be applied across countries and encompasses all these variable in the plenary sessions

The workshop was structured as follows:

- Session 1 – Introductions

- Session 2 – Presentation of preliminary findings, including Q&A and comments

- Session 3 – Activity 1. Brainstorming on farms typology and farm size
  – Activity 2. Discussion about Fairtrade's potential role in supporting smallholders and their sustainability

- Session 4 – Closing and final remark