Brewing resilience

Insights on ecosystem-based adaptation from Indonesia's coffee sector

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Petronella, a CFS participant, harvests coffee beans off a coffee plant on her farm in Bajawa, Flores in September 2023. Photo credit: Cynthia Crouse

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1. Ecosystem-based adaptation for climate-resilient rural livelihoods: An introduction to the volume

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Climate change poses significant threats to agricultural producers around the world. Rising temperatures, shifting precipitation patterns, and increasingly intense extreme weather events have slowed productivity growth in many countries, caused crop losses, and strained rural livelihoods and food security (Bezner Kerr et al. 2022). Going forward, the impacts are only expected to worsen.

For Indonesia, where agriculture employs almost 30% of all workers,[1] building resilience to climate change is thus an urgent priority. The stakes are particularly high for smallholders, most of whom lack the resources to adapt effectively – even if they produce valuable crops.

Coffee producers are a prime example. Indonesia is one of the world's top coffee growers, accounting for about 4.9% of global production in 2023–2024 – and 6.5% in 2022–2023, when growing conditions in the country were more favourable.[2] Smallholders grew virtually all of that coffee, 99.56% in 2023 (BPS 2024).

Coffee is a climate-sensitive crop. *Coffea arabica* (Arabica coffee), the source of the beans valued most highly on global markets, can grow at temperatures of about 15–24°C, but performs best within a narrower range of 18–22°C (Magrach and Ghazoul 2015). *Coffea canephora* (Robusta coffee) is far more heat-tolerant, able to withstand temperatures up to 30°C, but recent research has shown that Robusta is also heat-sensitive: yields drop by about 14% for every 1°C increase in mean temperatures beyond the 16.2–24.1°C range (Kath et al. 2020). Erratic rainfall, pests and diseases can also severely affect coffee production (Bilen et al. 2023).

Coffee growers in Indonesia already face serious climatic impacts. From 2022 to 2023 alone, national statistics show coffee yields per hectare dropped by almost 3% (BPS 2024), and Indonesia's coffee exports shrank by 36% by volume and 19% by value.[3] Behind those numbers are thousands of individual smallholders whose crops were damaged or lost entirely, and whose livelihoods are increasingly precarious amid climate change.

1 See World Bank data for employment in agriculture (% of total employment), using modelled estimates from the International Labour Organization (ILO): https://data.worldbank.org/indicator/SL.AGR.EMPL.ZS?locations=ID. The share was 29% in 2022.

2 See commodities data from the Foreign Agriculture Service of the U.S. Department of Agriculture: https://www.fas.usda.gov/data/production/commodity/0711100 [accessed 22 January 2025].

3 The reason for the smaller drop in value vs. volume is that it was only the lower-value Robusta exports that declined, by more than 40%; Arabica exports actually rose slightly in 2023.

This report distils insights from a collaboration between Indonesia's Meteorological, Climatological and Geophysical Agency (BMKG), su-re.co (Sustainability and Resilience Ltd.), Stockholm Environment Institute, and other civil society actors to help coffee growers manage climate risks through ecosystem-based adaptation (EbA). This approach integrates biodiversity and ecosystem conservation with sustainable socio-economic development as part of a broader effort to build resilience to climate change (FEBA 2018).

The EbA Enhanced Climate Field Schools for Climate Resilience (EECCLiRe) project, funded by the Global EbA Fund, focused on coffee producers in Flores (East Nusa Tenggara) and Bali who face significant climate risks. Building on BMKG's existing approach to supporting farmers through "climate field schools", EECCLiRe delivered knowledge about EbA principles, agroforestry and climate-smart technologies, connecting them with local and traditional knowledge. It also explored other ways to enhance farmers' livelihoods sustainably and assisted BMKG in developing policies to improve climate field schools and bring them to more farmers.

The rest of this introductory chapter provides an overview of coffee cultivation in Indonesia, how climate change affects it, and how EbA can make a difference. Chapter 2 focuses on climate field schools, how EECCLiRe used them to introduce coffee farmers to EbA, and the potential for taking a similar approach with other crops in Indonesia.

Chapter 3 focuses on agroforestry – the integration of trees with crops and livestock – and its potential for enhancing the climate resilience of coffee farms in line with EbA principles, as well as challenges that still need to be addressed. Chapter 4 describes how EECCLiRe introduced biodigesters – which turn farm waste into biogas as well as organic fertilizer – as an element of EbA on several farms, key lessons learned and next steps. Lastly, Chapter 5 explores how ecolabelling and international sustainability standards could support farmers' adoption of EbA while enhancing their income, and what it may take to realize this potential.

CFS participants study coffee plants during the first round of CFS in Sukawana, Bali, in June 2023.
Photo credit: Cynthia Crouse

It is important to stress that while this report is based on a specific project in specific contexts, the approaches it describes and the challenges it raises are of broad relevance to agriculture and other crops or commodities across Indonesia and beyond. Indeed, we hope that the experiences and lessons presented here will inspire and encourage the wider promotion of EbA to build climate resilience and strengthen rural livelihoods.

Coffee cultivation in Indonesia

Agriculture, fisheries and forestry contribute about one-eighth of Indonesia's gross domestic product (GDP).[4] Palm oil and rice are the top crops by far, but the archipelago's fertile soils and diverse geography have enabled the cultivation of a broad range of crops for domestic consumption and export markets. Among them are beverage crops such as coffee, tea and cocoa, with a combined export value of about USD 2.7 billion in 2022.[5]

Indonesia has a long history of coffee cultivation, dating back to Dutch colonists' introduction of Arabica coffee in Java in the late 17th century (Breman 2015). Colonial-era coffee production was highly exploitative, but it established Indonesia's reputation as a source of high-quality coffee. Over time, farmers across the country developed their own varieties with distinct flavour profiles, such as Gayo coffee from Sumatra, Java Preanger, Bali coffee, and Toraja from Sulawesi (Indonesia Specialty Coffee 2023).

Indonesia has been the fourth-largest coffee producer in the world for several years, after Brazil, Vietnam and Colombia – though reduced outputs in 2023 brought it down to the fifth largest, after Ethiopia.[6] With very little land suitable for Arabica coffee, Vietnam grows about 96% Robusta (USDA Foreign Agricultural Service 2024b), and so do many Indonesian farmers; in 2019–2022, about 88% of the coffee produced nationwide was Robusta (USDA Foreign Agricultural Service 2024a). However, the most prized Indonesian coffees are Arabica varieties grown in the highlands.[7]

Coffee production across Indonesia supports about 1.8 million smallholder farmers working across 1.27 million hectares (BPS 2024). The top coffee-producing provinces are South Sumatra, Lampung, North Sumatra and Aceh, but coffee is also widely cultivated in Bali (almost 34 000 hectares) and East Nusa Tenggara (over 75 000 hectares), including the island of Flores, a key source of top-quality Arabica beans. As noted above, Bali and Flores are where the EECCLiRe project was carried out.

Altogether, Indonesia produced about 775 000 tonnes of coffee in 2022 and exported about 437 500 tonnes (BPS 2024). The top export destinations were the United States, Egypt, Malaysia, India and Italy. As a globally traded commodity, coffee is a challenging crop for smallholders to grow, as prices can fluctuate significantly, and they must keep

4 See World Bank data for agriculture, forestry and fishing, value added (% of GDP): https://data.worldbank.org/indicator/NV.AGR.TOTL.ZS?locations=ID. The share in 2023 was 12.5%. After declining sharply in the 1990s and 2000s, the sector's contribution to GDP has held relatively steady since 2010, fluctuating within the range of 12.4% to 13.7% of GDP. See also BPS (2024).

5 See Indonesia exports data from the Observatory of Economic Complexity: https://oec.world/en/visualize/tree_map/hs92/export/idn/all/show/2022. Exports of cocoa beans and cocoa products were valued at about USD 1.35 billion; coffee exports, at USD 1.27 billion, and tea exports, at about USD 101 million.

6 See commodities data from the Foreign Agriculture Service of the U.S. Department of Agriculture: https://www.fas.usda.gov/data/production/commodity/0711100 [accessed 22 January 2025].

7 Indeed, the value per tonne of Arabica exports in 2023 was about 2.8 times that of Robusta exports, about USD 6.98 vs. USD 2.47 per kg. See BPS (2024).

up with mandates from key importers, such as the European Union's Regulation on Deforestation-free Products (EUDR).[8] Moreover, most revenue goes to actors farther down the supply chain, such as roasters and retailers. A study found that of the average EUR 8.06 per kg paid by German consumers for ground coffee in 2021, for example, only about EUR 1.97 went to farmers (BASIC et al. 2024). After covering non-labour production costs averaging EUR 1.56, this left just EUR 0.41 for labour and net profit.

Coffee and climate change

Climate change has been described as an "existential threat" to coffee farmers today (McCook 2024). Smallholders contribute only minimally to global greenhouse gas emissions but are highly exposed to climate hazards, and inadequate infrastructure and socio-economic factors exacerbate their vulnerabilities (Rahn et al. 2025).

As climate change intensifies, coffee growers face a wide range of challenges, including more frequent and severe extreme weather events such as heatwaves, droughts, torrential rains and floods, as well as an increase in pests and diseases (Richardson et al. 2023).[9] Heat and drought are of particular concern to coffee farmers in Indonesia, who overwhelmingly rely on rain to irrigate their crops and have faced multiple extreme events involving heat and drought in recent years. Such events affect crop yields during the dry years and may have lasting effects on coffee plants (Bracken et al. 2023).

The impacts of climate change on individual farmers will depend not only on the severity of the climate hazards, but also on their unique circumstances and capacity to adapt. Farmers struggling to support themselves may be unable to make the investments needed to avoid significant reductions in crop yields. Women and members of marginalized groups, such as ethnic minorities, can be particularly vulnerable.

Arabica production, which is already constrained to areas with cooler climates, is particularly imperilled. Timely and substantial investments in adaptation measures such as shade trees, irrigation, and resilient varieties are needed for long-term viability (Rahn et al. 2025). There are also concerns that farmers will shift production to higher elevations, encroaching on natural forests, degrading ecosystems and leading to biodiversity loss.

As noted above, however, even Robusta coffee is increasingly recognized as susceptible to rising temperatures (Kath et al. 2020). Large fluctuations in rainfall are also affecting production, as in 2023 when heavy rains in Sumatra and Java sharply reduced crop yields. In southern Sumatra, farmers in Lampung reported declines of 25–70% (Kurniawati and Thukral 2023). In 2024, El Niño brought hot, dry weather instead, affecting two-thirds of the country. Both kinds of extreme weather put particular pressure on farms that are already struggling. About 9.4% of Indonesia's coffee crops in 2023 were classified as damaged, meaning they were old or in bad condition and no longer provided adequate yields (BPS 2024). The share was lower in Bali, about 6.9%, but higher in East Nusa Tenggara (12.5%).

8 See https://environment.ec.europa.eu/topics/forests/deforestation/regulation-deforestation-free-products_en.
9 See also Rahn et al. (2025).

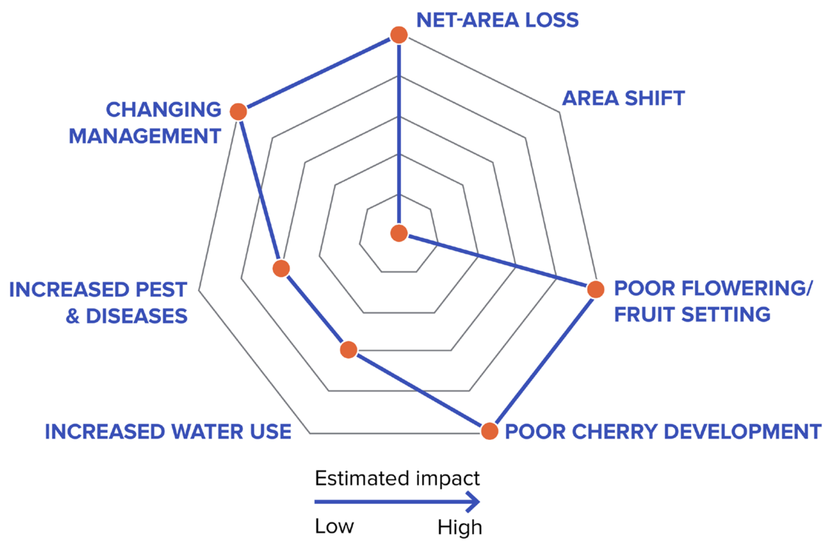
A study published in 2015 found that by 2050, rising temperatures and changes in rainfall would "drastically reduce" the total area of land suited climatically for coffee production across Indonesia (Schroth et al. 2015). Major Arabica-growing regions, particularly North Sumatra, Aceh, Flores, Sulawesi and Bali, will be seriously affected by climate change. Without timely adaptation, the study projected that 84% of current Arabica production zones will be affected, impacting yields and the quality of the coffee produced. The study found that 59% of the current Arabica-growing area in Bali and 98% in Flores is at risk.

Studies focused on coffee pests and diseases offer a similarly dire outlook. An analysis focused on Toba, a coffee-growing region in North Sumatra, projected that yields could decrease by 25–75% due to the combination of climatic changes and increased infestations by coffee berry borers (*Hypothenemus hampei*) (Boer et al. 2020). During a major coffee berry borer outbreak in 2017, 65% of farmers in Toba suffered crop damage. Infestation of this pest increases with frequent rainfall.

The study also identified several other coffee pests and diseases likely to become more prevalent with rising humidity due to climate change, including the coffee twig borer (*Xylosandrus morigerus* and *Xylosandrus compactus*), striped mealybug (*Ferrisia virgate*), coffee leaf rust (*Hemileia vastatrix*), brown eye spot (*Mycosphaerella coffeicola* or *Cercospora coffeicola*), pink diseases (*Corticium salmonicolor*), and root diseases (*Phellinus noxius*, *Rosellinia bunodes* and *Rigidoporus microporus*) (Boer et al. 2020). However, certain Arabica genotypes in Indonesia might resist coffee leaf rust and are worth exploring as a potential intervention to address climate impacts (Malau and Sihotang 2024).

Figure 1 shows a synthesis of likely climate change impacts on Indonesian Arabica coffee, produced by the Sustainable Coffee Challenge.

Figure 1. Illustration of the likely impacts of climate change on Indonesian Arabica coffee. Based on (Sustainable Coffee Challenge 2020).



- Stress caused by heat and drought increases the susceptibility of coffee trees to pests and diseases.
- Large areas will require investments into shade trees and irrigation to cope with the higher evapotranspiration and decreasing rainfall.

Ecosystem-based adaptation on coffee farms

Coffee systems are complex social-ecological systems linking individual farmers and households with the land, the region, the country, and the global supply chain (Rahn et al. 2025). This means the farmer–consumer chain is long and extensive. Interventions to make coffee production more climate-resilient and/or sustainable must account for numerous factors, from ecological systems to global markets. Failure to see the whole context may lead to ineffectual actions or shift risks to other vulnerable actors (Dzebo and Adams 2022).

Adaptation in Arabica coffee production may mean anything from shifting cultivation to higher elevations, to introducing new cultivars that can withstand higher temperatures, adding agrochemical inputs and installing irrigation, finding ways to increase farmers' incomes from coffee and other sources, working with nature by increasing the organic content of soils to retain moisture, and planting shade trees (Bracken et al. 2023).

With any of these strategies, there are financial, environmental and technical constraints to address. To support resilience-building in the coffee sector, an international consortium focused on sustainable coffee production (Solymosi and Techel 2019) has proposed:

- Further research on the impacts of climate change on coffee;
- Site-specific farm and processing investments;
- Designing and implementing financial mechanisms to facilitate investment;
- Investing in adaptation and in developing more climate-resilient coffee varieties;
- Strengthening national development and environmental policies; and
- Strengthening farmer organizations.

The EECCLiRE project incorporates several of those measures, including promoting and building capacity for adaptation, on-farm investments, strengthening farmer organizations, and rigorous analysis to keep building the knowledge base and inform government efforts to enhance climate resilience and support farmers.

The project grew out of the recognition that adapting coffee production to a fast-changing climate requires an integrated approach that looks at human activities and needs within the context of the ecosystems that support them. That is the value added by EbA, as it explicitly incorporates biodiversity and ecosystem services in adaptation strategies. EbA can help coffee farms become more sustainable, but this is just one of the expected outcomes, rather than the main objective. Instead, EbA seeks to manage, conserve and restore ecosystems so their services help enhance people's livelihoods and make them more resilient to climate change.

The difference between EbA and business-as-usual approaches is thus that it links biodiversity and ecosystem conservation with sustainable socio-economic development as part of an overall adaptation strategy (FEBA 2018). In practice, EbA can entail many different approaches, tailored to the specific context. Table 1 provides an overview of key EbA measures introduced through EECCLiRe via climate field schools, direct engagement with farmers and cooperatives, and demonstration projects. As discussed further in Chapters 2 and 3, activities were tailored to each village, responding to the interests and concerns of participating farmers. The project team also shared ideas and practices across villages, further enriching the curriculum.

Table 1. Ecosystem-based adaptation (EbA) measures introduced by EECCLiRe in coffee-growing communities in Bali and Flores

Using climate information
• Accessing and understanding 10-day climate forecasts from BMKG • Using 3-month climate forecasts to plan farm activities and preventive measures
Agroforestry
• Planting fruit trees for shade and additional income • Planting native trees with high pollinator value • Planting trees, shrubs and legumes with nutrient-fixing properties • Using trees and shrubs to stabilize slopes, reducing flood and landslide risks
Other beneficial farming practices
• Revitalizing coffee plants through pruning • Rorak (an Indonesian technique of digging holes next to plants to deliver organic nutrients and water and control flooding) • Biopores for aerating the soil
Biogas and bio-slurry production
• Recycling farm waste in biodigesters to produce biogas for household cooking as well as bio-slurry • Applying bioslurry as an organic fertilizer
Ecolabels and sustainability standards
• Exploring the viability of ecolabels and sustainability standards as mechanisms for enhancing farmers' income, and incentivizing and supporting the adoption of EbA approaches

Evaluating the outcomes of EECCLiRe

To monitor the experiences of farmers over the implementation of EECCLiRe, a project team visited two participating communities in Flores – Ruteng, Manggarai Regency, and Bajawa, Ngada Regency – in June 2024. They conducted focus group discussions with 22 farmers (12 men and 10 women) and 10 extension workers (four men and six women) who had participated in the project and volunteered to contribute to monitoring and evaluation. They also interviewed two representatives of a local non-profit organization in Bajawa (a man and a woman) and two men from a coffee farmers' cooperative in Ruteng. The project activities were carried out in Bahasa Indonesia. The results were published in a project brief (Tran 2025).

Coffee producers in the two communities face numerous climate-related challenges, including changing rainfall patterns, increased pests and diseases, and increased damage from extreme weather events. Farmers' vulnerability is exacerbated by several factors, such as soil degradation, reduction of agricultural land due to urban expansion and infrastructure projects, and demographic change as young people aspire to non-farming livelihoods.

A key outcome of EECCLiRe highlighted by the focus groups was that it enabled the integration of diverse knowledge systems for EbA. Some new farmers reported that participating in a climate field school through the project (see Chapter 2) had helped them to appreciate the value of both traditional and modern perspectives. They learned that many farming practices that have passed down through the generations are supported by scientific research and learned more about why they are effective. They also gained a new understanding of climate and weather patterns, pest and disease management, and sustainable farming techniques.

However, the focus groups also highlighted some challenges or tensions in integrating traditional and scientific knowledge into EbA approaches such as agroforestry. For instance, farmers in Flores were distressed by the need to prune mature coffee trees inherited from their grandparents to rejuvenate them, as this felt like "harming the spirit of the tree, which has been with us since our ancestors' time" (see also Chapter 3). At the same time, farmers were drawn to modern, chemical-based practices because they produce results and pay off quickly, while coffee agroforestry and traditional practices can take time.

Another challenge discussed during evaluation activities is that farmers lack access to crucial information and the resources needed to adopt climate-resilient practices. Access to timely, reliable weather information is important for EbA, but farmers often do not have tools or handsets they can use to access it.

A final insight drawn from the evaluation activities is that, as discussed further in Chapters 2, 3 and 4, gender and social inclusion are crucial to realizing the full potential of EbA in these communities. Women participated in several EECCLiRe activities, and the team noted that women were typically more open to new knowledge and tended to stay longer during training activities than men did. It was also noted that women increasingly stay behind while men migrate to find work outside Flores. Youth are also getting more educated and using modern technology, and many are uninterested in farming. Future activities would benefit from an upfront analysis of gender, generational and other dynamics within communities to inform the design of even more inclusive programming that fully engages and benefits all.

The next chapter delves deeper into the climate field schools and their central role in promoting EbA among coffee farmers in Flores and Bali and supporting them on the path towards social, environmental and economic resilience.

2. Using climate field schools to promote ecosystem-based adaptation

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Climate field schools (CFS), which are based on an established practice for delivering training to farmers in Indonesia, have become an essential part of Indonesia's agriculture adaptation strategy. CFS are run jointly by the Indonesian Meteorological, Climatological and Geophysical Agency (BMKG), which provides climate information, and the Ministry of Agriculture, which brings expertise in farmer extension, agronomy and farm husbandry to respond to deepening climate impacts. This chapter describes the history of CFS; how they were adapted to support ecosystem-based adaptation (EbA) among coffee farmers; and key lessons learned, including potential ways to deepen the integration of EbA principles into the design and implementation of CFS.

In 2009, the Indonesian Meteorological, Climatological and Geophysical Agency (BMKG) introduced "climate field schools" (CFS) as a strategic initiative to deliver climate information and support for adaptation to vulnerable groups, including smallholder farmers. The name CFS reflects their unique focus on climate information and adaptation support, led by BMKG, in contrast to the established practice in Indonesia of running farmer field schools overseen by other government entities.

The effort, led by BMKG's climatology division, became part of a broader collaboration with the Ministry of Agriculture (MoA). Focused initially on rice farmers, it has grown over time and is driven by several national policies. Presidential Instruction No. 5/2011 mandated BMKG to monitor extreme climatic conditions and provide early warnings to rice growers to enable them to prepare for extreme weather. Presidential Decree No. 2/2015, in turn, laid out a vision for strengthening key economic sectors, including agriculture. Within BMKG, specific goals were set to develop early warning systems, improve climate literacy and access to climate information among vulnerable groups, and create an integrated crop calendar in partnership with the MoA.

Climate field schools operate through a partnership in which BMKG works closely with agricultural extension workers and farmers to translate technical climate information and data into useful knowledge tailored to the farmers' needs. This includes actionable recommendations for coping with climate shocks and adapting to changing conditions. Over time, BMKG has also engaged other government agencies, development partners, researchers and the private sector to improve the field schools and deliver specialized content. As of 2023, CFS had been implemented in more than 600 locations in 33 provinces in Indonesia, reaching over 18 600 participants.

The CFS curriculum is flexible, with a simplified format for creating action plans, and has been tailored to address the needs and vulnerabilities of different crops and regions. For instance, in 2018, BMKG teamed up with su-re.co and Stockholm Environment Institute (SEI) to create CFS for cacao and coffee growers, working out of the Jembrana climatology station in western Bali (Biskupska and Salamanca 2020). The curriculum was informed by vulnerability assessments to understand the farmers' specific needs, and it integrated cutting-edge science with traditional knowledge and practices.

The next phase in the evolution of CFS in Indonesia has been to introduce the principles of ecosystem-based adaptation (EbA) as a way to sustainably increase productivity and climate resilience, enhance biodiversity and strengthen farmers' livelihoods. This is the purpose of the EbA-Enhanced Climate Field Schools for Climate Resilience (EECCLiRe) project.

Promoting ecosystem-based adaptation through climate field schools

Integrating EbA principles into CFS for coffee farmers required adapting the curriculum to incorporate new modules. The EbA materials were developed collaboratively through an inception workshop in February 2023 that included staff from BMKG headquarters and two climatology stations, su-re.co, SEI, and local farmers.

The curriculum was tailored to the specific needs of farmers in the four project sites in Flores and Bali. At each site, the EECCLiRe team conducted a "training of trainers" session for agricultural extension workers to prepare them to deliver the EbA-enhanced curriculum. They also conducted two CFS sessions per site to present the content and dive deeper into the local context and the concerns and needs expressed by coffee farmers.

The curriculum for the EbA-enhanced CFS was built on the standard CFS curriculum developed by the Bali Climatology Station, which focused on understanding climate information and creating action plans based on it, often incorporating field activities to study existing crops. The modified curriculum began with an introduction to EbA concepts before diving into the technical aspects of climate information. Simple and relevant examples of EbA were provided to the farmers, such as using organic fertilizers derived from bio-slurry and incorporating shade trees into coffee farms. This foundational knowledge helped farmers appreciate the benefits of EbA in enhancing the resilience and productivity of their farms.

During field visits, the focus was on the crop itself – coffee – and surrounding shade trees and shrubs to build an understanding of agroforestry. This holistic approach emphasized the importance of maintaining a diverse ecosystem for the overall health and productivity of the farm. In addition, biodigesters were introduced to show how recycling organic waste could provide both clean energy for households and fertilizer for coffee farms, in line with EbA principles (see Chapter 4). The process of creating action plans was also modified to include activities for shade trees and the entire farm ecosystem, not just coffee (see Chapter 3).

The discussions with farmers explicitly acknowledged the roles and contributions of different participants, including men and women, to ensure that the modules were inclusive and relevant to all. Traditional ecological knowledge was also integrated into the modules by engaging local farmers in discussions about their practices and experiences. In Bali, BMKG's forecasts were presented as complementing existing *sasih* and *saka* calendars that the Balinese have used for centuries. In Flores, traditional rituals and ceremonies were taken into account in planning key CFS activities, especially for demonstrations in the farm. This approach helped incorporate valuable local insights into the curriculum, making the modules more relevant and effective.

In the first round of CFS, farmers were asked what they wanted to learn more about. Their input was crucial in refining the curriculum to better meet participants' needs. In the second round of CFS, the program was tailored to the interests and needs of farmers in each location. For instance, in Bali, there was a focus on creating *rorak* – an Indonesian technique of digging holes next to plants to deliver nutrients and channel water (Astuti et al. 2022), biopores to aerate the soil,[10] and organic fertilizer, while in Flores, the emphasis was on plant pruning and rejuvenation as well as new plantings. The flexibility of the CFS curriculum thus enabled the trainers to connect climate information with day-to-day farming practices, ensuring that farmers could implement effective adaptation strategies tailored to their unique contexts.

Altogether, a total of eight CFS sessions were held in four locations: Wanagiri and Sukawana, Bali, and Manggarai and Bajawa, Flores (East Nusa Tenggara). The Bali sessions were held in June and November 2023, and the Flores CFS were held in September 2023 and February 2024. A total of 234 people participated in the CFS, including 133 farmers (37 of whom attended both sessions in their community). Table 2 provides an overview of participants and the contexts in which the CFS were held.

Table 2. Facts and figures on the climate field schools (CFS) held in several locations in Bali and Flores

Indicator	Figures
Total number of participants in CFS	101 extension workers in training of trainers 86 farmers participated in 1st round of CFS (17 Wanagiri, 22 Sukawana, 22 Manggarai, 23 Bajawa) 84 farmers participated in 2nd round of CFS (16 Wanagiri, 26 Sukawana, 29 Manggarai, 23 Bajawa)
Average farm size for farmers in the CFS	1.05 hectares
Total area of ecosystems covered by CFS	139.65 hectares
Coffee cooperatives and village-owned enterprises involved	Arabica Flores Bajawa Cooperative (Bajawa, Flores) Badan Usaha Milik Desa (BUMDes) Eka Giri Wanagiri (Wanagiri, Bali) Koperasi Serba Usaha Asosiasi Petani Kopi Manggarai Raya (KSU ASNIKOM) (East Manggarai, Flores)

10 This is a technique recommended by the Indonesian Coffee and Cocoa Research Institute (ICCRI) to improve and aerate the soil based on natural principles. Biopores are small voids in the soil formed by living things, such as channels created by earthworms and gaps left by the decay of organic material (Kautz 2015).

Key lessons

Integrating EbA principles into the coffee CFS is crucial for enhancing climate resilience among farmers, conserving ecosystems, and strengthening livelihoods. The CFS has evolved into a medium for disseminating climate information and introducing a range of practices essential for the resilience of farming communities. This comprehensive approach includes appropriate agroforestry techniques, hands-on learning through site visits and demonstration plots, biogas to recycle wastes, and integration of Indigenous knowledge and practices.

The CFS proved effective in promoting crop-appropriate agroforestry practices and maintaining the biodiversity of surrounding ecosystems. In coffee farming, shade tree management is vital and closely linked to seasonal climate patterns. For instance, pruning is recommended during the rainy season to promote growth. Still, sufficient shade must be maintained during the dry season to protect coffee plants from excessive heat and water stress. This practice is particularly relevant in regions like Bali and Flores, where farmers rely predominantly on rainwater for irrigation. By promoting these agroforestry practices through CFS, farmers can better manage their crops in response to climate variability, ensuring both the health of their coffee plants and the conservation of the surrounding ecosystem. The CFS framework provides an ideal platform for integrating EbA practices, as it facilitates the transfer of knowledge and skills necessary for sustainable farming in a changing climate.

One of the most critical components of CFS is the emphasis on hands-on learning, with site visits and demonstration plots. This practical approach is deliberate, aimed at engaging farmers and creating more effective learning environments than formal classroom settings could offer. Field visits and direct hands-on activities should thus be prioritized in the CFS curriculum, as they enable farmers to apply what they have learned, observe the outcomes, and refine their techniques based on direct feedback and experience.

Demonstration plots are also crucial for increasing farmers' understanding of theoretical concepts by allowing them to see and participate in implementing EbA practices in real-life settings. Instead of passively receiving information, they become active participants and can practice techniques to adapt to their farms. For example, farmers can observe different species of trees, learn about their specific benefits, and practice planting and maintaining these trees.

Farmers' active and meaningful participation in the CFS program is essential to its success. However, climate science is complex, and so are some of the techniques being taught. Thus, it is crucial to tailor the curriculum to match farmers' existing knowledge, the specific challenges they face, and local climatic conditions.

For example, farmers in Sukawana are relatively new to coffee farming, while those in Bajawa have decades-old coffee trees that require different management practices. Understanding these differences enabled the CFS teams to tailor the curriculum for each group. During the inception workshop, a farmer from Bajawa highlighted the need for strategies to maintain old coffee trees by pruning them to enable rejuvenation – an issue that the project team had not thought to cover in the CFS. The farmer's input helped shape a curriculum that better reflected local needs. This demonstrates the importance of incorporating local insights and experiences into the curriculum.

Acknowledging and integrating traditional ecological knowledge is also crucial for the success of CFS. In Bali, traditional calendars like *sasih* and *saka*, which have guided agricultural practices for centuries, must be a topic on their own during the CFS. In Flores, different regions have traditional rituals that hold significant cultural importance. Farmers in Bajawa sometimes could not attend CFS sessions due to planned rituals, and the same was true in Bali. Recognizing the importance of these rituals, the CFS program incorporated them into the training schedule. In Bajawa, a traditional ritual was practiced as part of the second round of CFS, helping to anchor the program within the community's traditional ecological knowledge.

Next steps

To ensure the continued success and expansion of CFS that integrate EbA principles, it is essential to **enhance the practical components of CFS**. Allocating more time and resources to hands-on learning, site visits and demonstration plots will ensure farmers can directly apply and refine their skills. Demonstration plots are crucial for increasing farmers' understanding of theoretical concepts by allowing them to see and test them in real-life settings. They can observe different species of trees, learn about their specific benefits, and practice planting and maintaining these trees. This hands-on approach reinforces the theoretical knowledge provided in the classroom and helps farmers to internalize and apply these practices more effectively.

It is vital to **tailor the curriculum to local contexts**. Conducting regular needs assessments in different regions will help understand the specific challenges and requirements of local farming communities. Developing region-specific modules that address each region's unique climatic conditions, crop types, and existing agricultural knowledge will ensure that the training is applicable and beneficial to all participants. It is equally crucial to acknowledge and integrate traditional ecological knowledge.

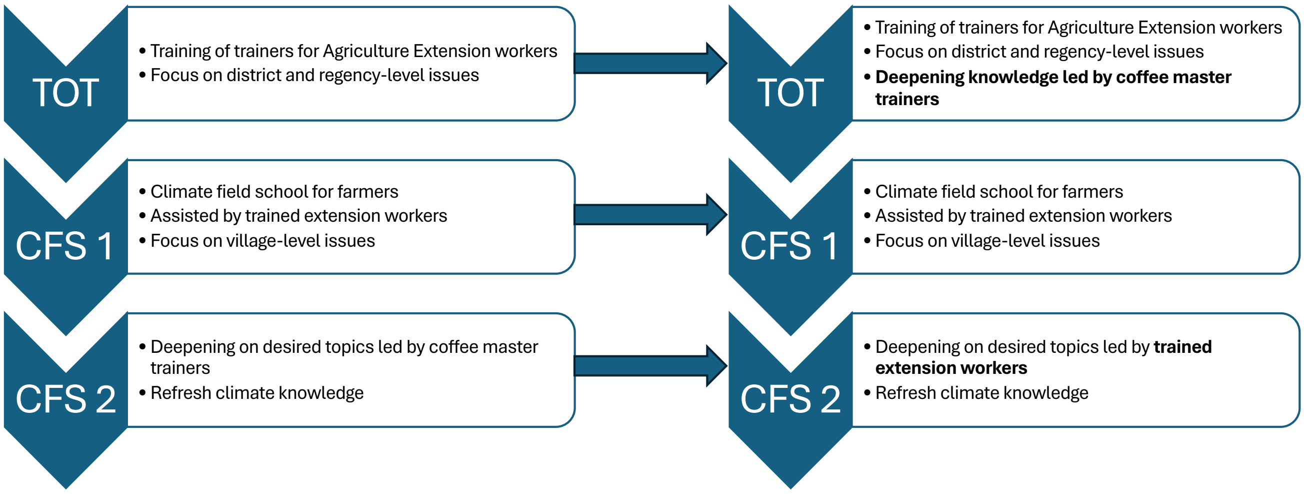
Continuous learning and feedback are also important. Establishing mechanisms for ongoing support and feedback for farmers after the initial training will help ensure that the knowledge and skills imparted are retained and applied effectively. This could include follow-up visits, additional workshops, and the formation of farmer networks. Establishing farmer groups and networks will encourage peer learning and knowledge-sharing among farmers, helping disseminate best practices and fostering a supportive community.

Establishing reliable and predictable funding – particularly through subnational government programs – is essential to broadening CFS coverage and integrating EbA principles into local development strategies. This will also strengthen community ownership while contributing to the long-term sustainability of CFS programs.

To improve future programs

To promote the EbA-enhanced modules for other crops, we suggest an initial "train the trainers" workshop to deepen the extension workers' knowledge before engaging directly with the farmers. In the EECCLiRe project, the extension workers' training did not extend to specialized content on EbA for coffee farms; instead, coffee master trainers delivered specialized content to the farmers during the second round of CFS. Figure 2 compares the EECCLiRe approach with what is recommended for future CFS.

Figure 2. EECCLiRe approach to training of trainers (ToT) for extension workers (left) and recommended approach for future climate field schools (CFS) (right)



In EECCLiRe, the specialized coffee training was only provided to local extension workers at one site, Bajawa, and farmers were more engaged when they received the information from them rather than from master trainers. Prioritizing the capacity building of local extension workers is crucial, as they have the power and responsibility to work with multiple regions and ensure consistent and effective dissemination of knowledge. Moreover, local extension workers are better at connecting and communicating with local farmers in their language and with sensitivity to their culture.

Incorporating advanced technologies can also play a significant role. Integrating digital tools and platforms for climate information dissemination and training can complement traditional field-based training and reach a wider audience. Promoting data-driven decision-making by encouraging the use of climate data and advanced technologies in agricultural planning and decision-making will further enhance the resilience of farming communities.

In addition, it would be good to explore further how information from climate projections and crop models can be integrated into the modules. Continual monitoring and evaluation of their use will help track insights from their application and refine the modules accordingly. However, the costs of these devices need to be factored in, as these might be unaffordable to farmers.

Lastly, gender equality and social inclusion (GESI) are vital components that require more attention. If gender norms and disparities are not understood and deliberately addressed in the design of the CFS, the program will not meet the needs of all participants and may even deepen inequality. As part of the initial assessment of the local context, a gender analysis should thus be conducted, taking an intersectional perspective to shed light on any additional factors that may disadvantage or marginalize people, such as age, marital status, disability or ethnicity.

Grounded in this knowledge, the CFS design should be, at the very least, gender-responsive – that is, deliberately structured to promote gender equality, ensuring that women's voices are heard, their knowledge and skills are recognized, and their needs are met.[11] While EECCLiRe included women in some activities and sought to identify and promote benefits to women as well as men (e.g. biogas reducing women's time gathering firewood), no gender analysis was conducted, and more can be done to make the CFS more inclusive. In some communities, the best approach may be to conduct separate CFS for men and women. More broadly, future CFS must ensure that no groups within a community are left behind, and all can benefit.

With these enhancements, future climate field schools can build on the successes of EECCLiRe and previous efforts and help ensure that farmers are well-equipped to adapt to climate change, strengthen their livelihoods, and contribute to conservation efforts.

CFS participants develop climate action plans together during the first rounds of CFS in Bajawa, Flores, in September 2023. Photo credit: Cynthia Crouse

11 For insights on how such considerations may be taken into account, see, e.g., Huyer (2021); Dazé and Terton (2021).

3. Agroforestry as an ecosystem-based adaptation strategy for coffee growers

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Agroforestry is the age-old practice of integrating trees and shrubs with crops and livestock, emulating natural ecosystems to make farms more productive and resilient. It is thus a key strategy for ecosystem-based adaptation (EbA), an approach that harnesses nature-based solutions and ecosystem services to reduce vulnerability to climate change. It is highly relevant to coffee producers and especially for Arabica growers, as trees provide crucial shade to protect crops.

The EECCLiRe project introduced agroforestry techniques through the climate field schools (CFS) for coffee growers in Bali and Flores. The work highlighted the importance of tailoring solutions to each context, from species selection to tree placement and spacing. It is also crucial to set up demonstration plots where farmers can see agroforestry techniques in the real world, integrate traditional ecological knowledge, and ensure the full inclusion of women. However, agroforestry has challenges, such as higher costs and the complexities of managing shade, especially in areas with land tenure problems and weak community support. Thus, monitoring progress and providing sustained support to farmers is important, as well as applying lessons from experience to improve adaptation strategies.

Agroforestry entails deliberately growing or retaining trees and shrubs alongside crops or livestock to achieve multiple benefits (Nair et al. 2021, p.21). It has existed since ancient times but became recognized as a formal practice grounded in science in the 1970s. There is now a vast evidence base on agroforestry techniques suited to different contexts and best practices.

Trees and shrubs can be planted among croplands or on pastures and cast shade over crops, reducing their exposure to the hot sun. They also provide shelter for livestock; act as windbreaks; enrich the soil by adding essential nutrients and organic matter; promote biodiversity; and regulate water flows and improve soil water storage (Uthappa et al. 2017; Vinodhini et al. 2023).

These benefits make agroforestry valuable for both climate change mitigation and adaptation (Shi et al. 2018). Agroforestry systems can increase soil carbon storage, enhance soil fertility, reduce net greenhouse gas emissions, and store carbon in trees and shrubs. By regulating water flows and enabling soils to store more water, they can protect crops from extreme weather events such as floods and droughts.

Moreover, with the right selection of tree and/or shrub species, farmers can produce sustainable timber, fruits, nuts and other valuable items for sale or household use. Agroforestry can thus enable farmers to earn additional income and diversify their livelihoods, thus becoming more resilient to climate shocks that affect their crops (Muthuri et al. 2023).

Agroforestry can be a key strategy for ecosystem-based adaptation (EbA), which harnesses ecosystem services to enhance climate resilience. EbA starts by recognizing that healthy ecosystems are crucial to people's livelihoods and well-being, and works with nature to deliver solutions tailored to each context. Not all tree planting on farms aligns with EbA principles, but the holistic approaches favoured in agroforestry hold significant promise.

Agroforestry in coffee production

As noted in the introduction, coffee is a very climate-sensitive crop. *Coffea arabica*, the species cultivated by the farmers involved in the EECCLiRe project, can grow at about 15–24°C, but does best at 18–22°C (Magrach and Ghazoul 2015). *Coffea canephora* (Robusta coffee) is much more heat-tolerant but performs better at temperatures below about 24°C (Kath et al. 2020). In addition to heat, coffee is also vulnerable to droughts, torrential rains, floods, pests and diseases, which can damage coffee plants and lead to crop losses (Bilen et al. 2023).

Agroforestry is particularly relevant to Arabica coffee production to reduce crops' exposure to heat and excessive sunshine, a growing concern with climate change (Merga and Alemayehu 2019). Arabica coffee was traditionally grown in at least partial shade under the canopies of large native trees (Jha et al. 2014). However, in recent decades, many farmers worldwide – including in Indonesia – have reduced or eliminated shade trees due to intensification.

Proper shade management and reduction of heat stress can mitigate the risk of diseases such as coffee leaf rust (Wienhold and Goulao 2023). The litter from shade trees adds nutrients to the soil and creates mulch that retains moisture during dry spells (Martini et al. 2017). Moreover, adding trees and shrubs can enable coffee farmers to diversify their livelihoods and earn income from selling fruits such as durian and jackfruit (Chemeda et al. 2024).

Agroforestry approaches need to be tailored to coffee farmers' needs and contexts. Drawing on insights from work with coffee agroforestry in Indonesia, the World Agroforestry Centre (ICRAF) identified six principles for establishing successful systems (Martini et al. 2017):

1. Provide appropriate shade tree species. Ideally, shade trees should be planted a year before the coffee plants, and tree species should be selected to provide the optimal temperature for the coffee variety being grown.
2. Select species to achieve the desired benefits. Along with shade, considerations may include suitability to the specific site, market potential and good windbreak characteristics in areas frequently affected by strong winds.
3. Use high-quality planting materials that are healthy and disease resistant.
4. Carefully manage the spacing of coffee plants and shade trees horizontally and vertically to prevent them from competing for sunlight, water and nutrients.

5. Prepare the land well and carefully time plantings to ensure they grow well.
6. Monitor and maintain plants and trees regularly to keep them healthy, ensure they have the necessary nutrients, and check for and address any diseases or pests.

It is also crucial to recognize that, like any development or adaptation interventions, any effort to promote agroforestry must be inclusive, incorporating all community members' needs, priorities and differentiated roles (Martini et al. 2017) – which aligns with EbA principles. Due to prevailing gender norms, women often lack decision-making power on family farms and are less likely than men to participate in training programs.

Gender-responsive design can help ensure that women are actively involved in learning about agroforestry, making plans for their farms, and then successfully planting, maintaining and harvesting. Women's perspectives and knowledge can help enhance agroforestry strategies, making them more likely to result in improvements to households' overall well-being beyond simply improving crop yields.

Agroforestry as an adaptation strategy

Indonesian coffee production faces many challenges, including ageing plants, inadequate plant husbandry, inferior seeds, outdated farming practices, and a lack of modern technology and information (Nurhapsa et al. 2020; Padjung et al. 2021). Unfavourable climatic conditions and extreme weather events can significantly reduce yields from one year to the next (BPS 2024), and climate change exacerbates those problems (Djufry et al. 2022).[12]

Agroforestry has been recommended for many years in Indonesia to make coffee farms more climate-resilient and productive. However, farmers are also aware of known trade-offs (Martini et al. 2017). There are costs associated with planting shade trees and additional costs for shade management. Agroforestry requires skilled labour and has limited potential for mechanization, and crop yields can be lower due to slower plant metabolism, particularly if the wrong shade tree species are used.

Conservation International, the Smithsonian Migratory Bird Center, and World Coffee Research have produced a catalogue of suitable shade trees for coffee in Indonesia,[13] with 45 species selected through case studies in Indonesia (see Annex 1). The catalogue is searchable by desired use on the farm (e.g. shade, windbreak, erosion control), by desired tree products (e.g. for food, medicine, fuelwood), by coffee system (Arabica or Robusta) and by elevation range. The tool highlights the broad range of options available to farmers, who can select species to fit their needs and preferences.

For example, a farmer growing Arabica coffee at an elevation of 1200 meters, looking for suitable shade trees that would also provide food and have biodiversity benefits, might want to plant jengkol (*Archidendron pauciflorum*), a native tree that grows to just 10–20 meters, provides shade and nitrogen fixation, and produces edible seeds

12 See also Sujatmiko and Ihsaniyati (2018); Sustainable Coffee Challenge (2020); Sarvina, June, et al. (2021); Sarvina, Natural, et al. (2021).
13 See https://www.shadecoffee.org/en/catalog/indonesia.

and fruit, as well as lumber. Another option is jackfruit (*Artocarpus heterophyllus*), which grows up to 20–35 meters, provides windbreak as well as shade, can help stabilize slopes, and not only produces a valued fruit, but can also provide fuelwood, a high-quality wood for furniture, natural dyes, and forage for livestock. A third option is water apple (*Syzygium aqueum*), which grows no taller than 10 meters, is native, helps regulate water flows, and produces an edible fruit and leaves that are used to wrap sticky rice snacks. It is also medicinal, and the wood is used in construction.

Several institutions are well positioned to support the adoption of agroforestry among coffee farmers in Indonesia, as they already provide guidance, research and resources to enhance coffee production. These include the Project Management Office (PMO Kopi Nusantara), the Indonesian Coffee and Cocoa Research Institute, BMKG, and the Ministry of Agriculture.

Agroforestry practices already exist in several locations across Indonesia, such as South Sulawesi (Lisnawati et al. 2017), South Banten (Budiwati et al. 2019), Sumatra (Arifin 2022) and West Java (Sanudin et al. 2024), offering valuable lessons and models for expansion. These practices can be enhanced and tailored to the specific needs of coffee farmers to maximize their benefits and address local challenges effectively.

For example, farmers in Atu Lintang District, Central Aceh, Sumatra, have grown coffee alongside avocado, banana and chili plants (Huhasna et al. 2021). This practice maximized agricultural land use while avoiding decreased land fertility and erosion. According to research from the University of Shah Kuala, this agroforestry method resulted in a 352% increase in annual income for farmers, from an initial average of IDR 19 824,772 per hectare (USD 1288.61/ha) from coffee planting alone to IDR 89 598 278 (USD 5823.89/ha), with the addition of other agricultural activities in the area. These crops help sustain soil fertility, resulting in fewer failed harvests due to soil issues.

In Mekarjaya village in West Tanjung Jabung Regency, Sumatra, significant coffee development occurred in the late 1980s after a hybrid coconut planting program failed, driving the community to plant Liberica coffee and areca nuts instead among dead coconut trees (Waluyo and Nurlia 2017). They discovered that areca nuts act as boundaries and protect the soil from landslides, while coffee plants thrive under the shade of areca nuts and coconut trees. With this agroforestry, the average production potential of Liberica coffee in West Tanjung Jabung reached 950 kg of coffee beans per hectare with 900–1000 trees. In 2016 alone, the regency produced about 1200 tonnes of coffee, bolstering the local economy and community resilience. This method offers stable yields and higher incomes compared to non-coffee crops.

Agroforestry in the EECCLiRe project

Before incorporating agroforestry into the suite of adaptation options promoted through EECCLiRe, the project team consulted with stakeholders in Indonesia in 2023 to hear their perspectives on how agroforestry could advance the principles of EbA. These stakeholders include PMO Kopi Nusantara, ICCRI, DKLH (Department of Environment and Forestry), BPSIP (Agricultural Instrument and Standardization

Agency), and LAPMAS, an NGO from Bajawa. Based on this input, the agroforestry curriculum and hands-on activities for farmers were tailored for coffee farms with plants needing rejuvenation.

The agroforestry training was incorporated into the climate field schools (CFS) offered to coffee farmers as part of EECCLiRe (see Chapter 2). In the first round of field schools, farmers were asked about their needs, including knowledge gaps. Farmers did not understand proper agroforestry techniques in all four sites – Wanagiri and Sukawana in Bali, and East Manggarai and Bajawa in Flores. In the second round of field schools, the training provided reflected the farmers' expressed needs and interests. Overall, best practices and pruning were discussed at all four sites; for instance, in Sukawana, the material on biopores[14] was presented at the farmers' request.

Traditionally, field schools focus on a single crop – such as rice, cacao, or coffee – without considering the surrounding species. However, in these CFS, farmers were encouraged to plan for other aspects of agroforestry, including properly managing shrubs and canopy trees, to ensure that all components of the agroforestry system would be managed effectively. This approach also helped farmers understand the interdependencies between different plant species and how they contribute to the overall health and productivity of the farm.

Coffee trees planted alongside shade trees in Wanagiri, Bali. Photo credit: su-re.co

To hasten the transfer of agroforestry technologies and approaches, demonstration plots in the field schools were established in Bajawa and Wanagiri. The demonstration plots directly engage farmers in agroforestry practices and showcase these practices to other farmers.

14 Biopores are small voids in the soil formed by living things, such as channels created by earthworms and gaps left by the decay of organic material (Kautz 2015).

In Bajawa, the plot was set up during the second round of CFS, which included a traditional ceremony before the coffee plants were pruned. The plot also showed the best methods for planting coffee and shade trees, considering plant spacing and species selection. A similar demonstration plot was set up in Wanagiri, though not during the field school.

To sustain the knowledge-sharing, we developed and tested a manual on agroforestry in Bahasa Indonesia that includes EbA principles (Figure 3). Rather than reinventing agroforestry practices existing in Indonesia, this synthesizes coffee-appropriate practices based on existing manuals from the Indonesian Coffee and Cocoa Research Institute (ICCRI) and the Center for International Forestry Research and World Agroforestry (CIFOR-ICRAF). It is also informed by extensive field discussions with experts from these organizations and farmers. By working closely with these institutions and other experts, we ensured that the manual reflects the latest research and best practices in coffee agroforestry.

A farmer holds the coffee agroforestry manual produced by the EECCLiRe project in the village of Rakateda II in the Ngada Regency of East Nusa Tenggara. Photo credit: su-re.co

In addition, to address specific concerns raised by farmers about the challenges of implementing agroforestry, we conducted soil analyses in some locations to show which agroforestry practice is appropriate for certain types of soils. These analyses provided valuable insights into soil health and nutrient availability, alerting farmers to the need for specific inputs (e.g. potassium-rich fertilizer, or lime to raise soil pH).

They can also help farmers select tree species that will thrive on their land and/or help remedy any deficiencies.

Table 3 shows the results for different coffee sites in Wanagiri. Location 2, for example, is very low (SR) in sulphur, but very high (ST) in potassium and boron. Location 4 is very low in sulphur and diphosphorus pentoxide, but high in carbon, potassium and boron.

Table 3. Soil analysis conducted by ICCRI in Wanagiri, Bali, as requested by farmers

Locations	C	N	K	Ca	Mg	KTK	KB	S	P_2O_5	Cu	Fe	Zn	Mn	B	pH
1	T	S	ST	S	T	T	S	R	R	R	S	S	S	ST	S
2	T	S	ST	S	S	S	S	SR	S	R	S	S	S	ST	S
3	S	R	ST	S	S	T	S	R	ST	R	S	R	S	ST	S
4	ST	S	ST	T	T	T	S	SR	SR	R	S	S	S	ST	S
5	T	S	R	R	R	R	R	R	SR	R	S	R	R	ST	S
Mahoni Loc 2	ST	S	ST	T	T	T	S	R	R	R	R	S	R	ST	S

Notes:
SR – Sangat Rendah (**Very Low**)
R – Rendah (**Low**)
S – Sedang (**Medium**)
T – Tinggi (**High**)
ST – Sangat Tinggi (**Very High**)
C – Carbon **N** – Nitrogen **K** – Potassium **Ca** – Calcium **Mg** – Magnesium **S** – Sulphur **Cu** – Copper **Fe** – Iron **Zn** – Zinc **Mn** – Manganese **B** – Boron
KTK – "Kapasitas Tukar Kation" (Cation Exchange Capacity, in soil science; a measure of a soil's ability to hold positively charged ions)
KB – "Kapasitas Basa" (Base Saturation, in soil science; the proportion of soil's cation exchange capacity occupied by base cations like Ca^{2+}, Mg^{2+}, K^+, and Na^+)
P_2O_5 – Diphosphorus Pentoxide (used to indicate the amount of phosphorus in fertilizers)

Key lessons

The EECCLiRe project highlighted some challenges of incorporating agroforestry into existing coffee farms with mature plants. For example, as noted above, proper spacing of shade trees and shrubs is crucial. Yet it is not common to find a farmer with an empty landscape that allows for a perfect design scheme.

Although many shade tree species have been found to work well in Indonesia, the suitability of a given species will depend on the specific context. For example, trees with extensive root systems, such as mahogany, must be at least 10 meters away from coffee plants and are best placed along the farm's borders to prevent competing for nutrients and water with coffee plants. In Wanagiri, farmers struggled to manage their coffee plants within an existing mahogany forest. Issues may arise with other shade tree species as well. For instance, bitter beans (*Parkia speciosa*) and other legumes are suitable for nitrogen fixation, but they do not grow very tall in Wanagiri and Kintamani.

The forest farmers in Wanagiri and Bajawa also struggled to manage shade properly, as not all shade trees can be trimmed or pruned. While some recommended shade tree species can be managed independently, it takes time before newly planted trees provide the necessary shade. In the interim, coffee plants may suffer from excessive sunlight or inadequate protection, impacting their health and yield.

Soil health is another critical factor influencing the success of agroforestry practices. The soil analysis in Wanagiri revealed significant nutrient deficiencies (see Table 3). Without adequate soil nutrients and chemistry, coffee plants cannot achieve optimal growth or bean production. Conducting a soil analysis in conjunction with promoting agroforestry can help farmers identify and address soil deficiencies through chemical inputs, organic inputs (e.g. mulch or biochar), and/or trees and companion plants.

Incorporating traditional ecological knowledge (TEK) and EbA principles in managing shade trees and landscapes is also crucial. Working closely with farmers to integrate their TEK can enhance the relevance and acceptance of agroforestry practices. For example, in Flores, farmers hesitate to prune or rejuvenate old trees because they are considered ancestral property. This belief can impede necessary agricultural practices. Engaging with farmers to find culturally acceptable methods of tree management can help overcome such barriers and improve the overall effectiveness of agroforestry systems.[15]

Another challenge is ensuring gender and social inclusion. As noted above, gender norms and gendered responsibilities on farms can influence who participates in – and benefits from – agroforestry practices. Expert guidance is available on how to design gender-responsive EbA interventions (Dazé and Terton 2021). There is also extensive and growing knowledge on effective gender integration in agroforestry, including in Indonesia in particular.[16] Gender cannot be an afterthought; it must be integrated from the outset to ensure an effective and inclusive project design. Post-harvesting processes should also be included in agroforestry training programs to ensure that both men and women can benefit from the entire value chain of coffee production.

Next steps

Our experiences in the EECCLiRe project have shown that implementing crop-specific agroforestry practices aligned with EbA principles is not a one-size-fits-all solution. While agroforestry is a valuable strategy for EbA, practical challenges and the unique needs of different crops require tailored approaches.

One critical next step is establishing more demonstration plots featuring local native shade trees. These demonstration plots will serve as practical examples for farmers, showcasing

15 This tension is also discussed in Tran (2025).
16 See, e.g., Catacutan et al. (2014); Mulyoutami et al. (2016); Huyer (2021); Cordon (2025). See also the CIFOR-ICRAF gender knowledge hub: https://www.cifor-icraf.org/research/topic/gender/ and the CGIAR Gender Impact Platform: https://gender.cgiar.org/.

different agroforestry models tailored to specific local conditions. Coffee agroforestry can be implemented in multiple ways, for example, and a general species recommendation is insufficient. As seen in the Wanagiri and East Manggarai cases, placing recommended species must follow spacing guidelines, and extensive studies and guidance are needed to determine the suitability of different regions based on agroclimatic conditions and soil health. Once the tangible benefits of the demonstration plots are seen, adoption in the larger community can be done. Thus, by evaluating and demonstrating the effectiveness of various native shade trees, we can provide farmers with a broader range of options and the knowledge to choose the best practices for their specific contexts.

Integrating and honouring local traditional agricultural practices is another essential step. Farmers' traditional ecological knowledge and cultural practices play a significant role in accepting and implementing new methods. By respecting and incorporating these traditional practices, we can increase the relevance and acceptance of agroforestry systems. Involving local communities as early as the inception of the workshop period is critical to introducing such practices in the project design. For instance, in regions such as Flores, where ancestral beliefs influence tree management practices, working with farmers to develop culturally acceptable methods that do not conflict with their traditions is crucial.

Similarly, as noted above, gender issues must be addressed from the start. Including women farmers in the inception workshop is critical to ensuring that agroforestry interventions address women's needs and priorities as well as men's. It is also crucial to evaluate the supply chain holistically to ensure the benefits of agroforestry reach downstream processes. This means looking beyond the farm level to understand how agroforestry practices affect post-harvest handling, processing and marketing.[17] By doing so, we can identify any bottlenecks or challenges hindering the full realization of agroforestry benefits. This process involves working with various stakeholders, including processors, marketers and consumers, even during the inception workshop.

While our focus has primarily been on coffee, the principles and lessons learned from coffee agroforestry can be applied to tree crops and others. Tailoring strategies for different crops involves understanding their specific needs and how they interact with shade trees and other components of the agroforestry system. This requires research and experimentation to develop crop-specific guidelines optimizing growth and resilience. By creating a framework for agroforestry, we can extend the benefits of agroforestry to a wider range of agricultural systems, enhancing overall sustainability and biodiversity benefits.

Finally, continuous monitoring and evaluation are essential to tracking the effectiveness of agroforestry practices and making necessary adjustments. This involves regularly assessing soil health, plant growth and overall farm productivity. Feedback from farmers must be incorporated into research and development. A data management system would be ideal for further analysis and project design improvement to recalibrate agroforestry practices to address evolving needs. Curating which agroforestry system works for a specific community will ultimately aid in wider adoption in the area.

17 A potentially useful analytical framework for doing this is the 13 principles laid out in Wezel et al. (2020).

4. Biogas production: Turning waste into affordable clean energy and fertilizer

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Biogas, a renewable energy alternative derived from agricultural and livestock wastes, is a viable energy source for remote households and communities in Indonesian islands. EECCLiRe introduced biogas systems to smallholder coffee farmers as a component of climate field schools in Bali and Flores, linking these efforts with ecosystem-based adaptation (EbA) principles. The goal was to reduce deforestation and recycle farm wastes while improving health outcomes and enhancing adaptive capacities. By involving local communities, particularly women, and tailoring training and technology to specific contexts, EECCLiRe has enabled farmers to reduce reliance on firewood and improve soil fertility with bio-slurry. Moving forward, scaling up these projects, improving technology, and cooperating with local governments and NGOs will ensure that biogas plays an important role in Indonesia's sustainable energy transition and climate change adaptation.

For generations, Indonesians have cooked with traditional biomass, mainly firewood. The fuel is free but takes time to collect, and its daily use puts pressure on forests and exposes people, especially women and children, to toxic smoke that causes illness and many premature deaths (World Bank 2013). According to the World Health Organization, an estimated 3.2 million people worldwide die prematurely each year from diseases related with household air pollution[18] – exceeding the combined number of deaths from HIV/AIDS[19] and malaria (WHO 2022).

This is why Indonesia has prioritized bringing clean cooking technologies and fuels to all, increasing access from just 6.7% in 2000 to 89.1% as of 2022.[20] Nationwide, liquefied petroleum gas (LPG) was the most common cooking fuel as of 2021.[21] LPG was also the main cooking fuel for 82% of households in Bali, followed by firewood at 14%. Meanwhile, in East Nusa Tenggara province, which includes Flores, 69% of households cooked mainly with firewood and 28% with kerosene, while just 1% used LPG.[22]

Biogas offers farmers a more affordable and sustainable option, turning farm waste into clean energy. As piles of organic matter decompose, they release methane. Biogas technology harnesses that natural process, putting farm residues, animal manure, food waste and other organic materials into airtight "digesters" where anaerobic microorganisms break them down. The output is a methane-rich gas that can be used

18 See WHO online fact sheet on household air pollution and health: https://www.who.int/news-room/fact-sheets/detail/household-air-pollution-and-health [accessed 27 May 2025].
19 See global HIV and AIDS statistics from UNAIDS: https://www.unaids.org/en/resources/fact-sheet [accessed 27 May 2025].
20 See Tracking SDG 7 country page for Indonesia: https://trackingsdg7.esmap.org/country/indonesia [accessed 27 May 2025].
21 See national statistics for "Percentage of Households by Province and Main Fuel for Cooking (2) (Percent), 2021" (in Indonesian): https://www.bps.go.id/id/statistics-table/2/ODQzIzI=/persentase-rumah-tangga-menurut-provinsi-dan-bahan-bakar-utama-untuk-memasak--2-.html.
22 See https://www.bps.go.id/id/statistics-table/2/ODQzIzI=/persentase-rumah-tangga-menurut-provinsi-dan-bahan-bakar-utama-untuk-memasak--2-.html.

for household cooking and lighting,[23] and a nutrient-rich bio-slurry or solid digestate that can be used as fertilizer.

Biogas has been used in Indonesia for decades (Situmeang et al. 2022) and has grown rapidly in recent years. The Indonesia Domestic Biogas Program (BIRU), launched with international partners in 2009, had installed nearly 28 000 digesters as of June 2022, benefiting nearly 130 000 people.[24] Biogas and biomethane, its purified form, are seen as key elements of Indonesia's transition to clean energy (IRENA 2022), and palm oil producers are now investing in massive biogas plants to extract additional value from the large volumes of waste they generate (GAPKI 2024).

From a climate perspective, biogas production is often discussed as a mitigation strategy, but it also fits well with ecosystem-based adaptation (EbA). To the extent that biogas replaces firewood as a cooking fuel, it reduces pressures on forests and protects the ecosystem services they provide while also reducing harmful air pollution from smoke, which improves health. If used instead of LPG, biogas also cuts fuel costs, freeing up resources for other household needs.

Biogas production also efficiently turns farm waste, especially animal manure, into high-quality organic fertilizer (Mukhtiar et al. 2024).[25] Farmers can apply bio-slurry to add nutrients, improve soil structure and water retention, and increase crop yields – all while reducing their reliance on chemical fertilizers, which are often costly and environmentally harmful.

The rest of this chapter describes how the EECCLiRe project introduced biogas production as an element of EbA in small-scale farms, the key lessons learned, and next steps.[26]

Bringing biogas within farmers' reach

Small, fixed-dome biodigesters are common but costly to build and complex to operate, so the resulting biogas is more expensive than other fuels, such as kerosene (Roubík and Mazancová 2020). To address these challenges, su-re.co, through the IKI Small Grants-funded "Biogas Initiative for Agriculture in Bali and Flores Funded by Carbon Offset,"[27] has piloted the installation of 40 plastic biodigesters for smallholder farmers, using readily available materials. These digesters are placed above ground and are thus easier to maintain and troubleshoot, though they may be less efficient in colder weather. The EECCLiRe project further improved this design by increasing the volume of the biodigesters, enhancing their capacity and efficiency. Overall, this is a practical, low-cost solution for biogas production on small farms.

23 For an overview, see the first chapter of IEA (2020).
24 See http://www.biru.or.id. As of 2023, the biodigesters had also avoided an estimated 528 781 tonnes of carbon dioxide (CO_2), and the program has generated revenue by selling carbon credits through the voluntary Gold Standard mechanism: https://marketplace.goldstandard.org/products/fairclimatefund-indonesia-biogas-programme.
25 For a brief overview of the benefits of bio-slurry, see: https://www.biru.or.id/en/about-bioslurry.
26 For additional materials, including photos and a farmer's perspective, see su.re.co (2023).
27 More information on the project can be found at https://iki-small-grants.de/k1project/biogas-initiative-for-agriculture-in-bali-and-flores-funded-by-carbon-offset/.

The EECCLiRe project introduced this biogas technology to four new locations: Wanagiri and Sukawana in Bali, and East Manggarai and Bajawa in Flores. A baseline survey found the four sites differed in their energy use patterns and local climate systems. In Bali, farmers used mainly LPG for cooking, supplemented by firewood, while in Flores, farmers used mainly firewood or kerosene for cooking, as LPG was scarce and typically only affordable to wealthier households. Wanagiri, Sukawana, and Manggarai have a cooler climate, while Bajawa is warmer during the day and has the most sunlight. Bajawa also has more adopters of small-scale biodigesters, making it an ideal demonstration site. In total, 27 biogas units were installed in Bali and Flores. With an average flow rate per biodigester of 0.5 litre/minute and an average usage per day of 60 minutes, the estimated emission reduction is 0.56 tonnes CO_2e per m^3 per year, a meaningful fraction of these households' already small carbon footprint.

We introduced biogas and its alignment with EbA principles during the training of trainers (ToT) and climate field schools (CFS). We conducted one ToT and two CFS sessions for each location, with the second CFS session incorporating some new farmers. In each training session, we included a section on the biogas system, its benefits and its integration with EbA principles. We also assessed farmers' knowledge of biogas before and after the training.

During the CFS and ToT sessions, we identified farmers interested in adopting biogas technology, which was key for building trust and demonstrating its benefits. We collected their contact information and assessed their readiness, considering factors such as sunlight availability, space for the digester, and proximity to the stove. In Wanagiri, Sukawana and Ruteng, su-re.co directly reached out to potential farmers, while in Bajawa, we worked with LAPMAS, a local NGO, to select suitable candidates.

Monitoring was crucial for ensuring that the digesters and biogas were being used as expected. We established a WhatsApp group with the biogas recipients and maintained continuous contact with the farmers to gather updates on the condition of the biodigesters and gas meters. In Bajawa, we partnered with LAPMAS to monitor and check the biogas systems, as they had experience with su.re.co's biodigesters.

We installed gas meters for each biogas unit as part of the monitoring. These gas meters detect biogas flow to the stove, the pressure, and the total biogas consumption. Powered by solar panels and equipped with SIM cards, each gas meter sends data to an online server, enabling us to monitor remotely. The data enable us to calculate the avoided greenhouse gas emissions. The gas meters also have a feature to detect leaks.

Given that women are disproportionately affected by indoor air pollution and typically manage household energy needs, we deliberately sought their involvement in this project, especially in Flores. The su-re.co biodigester program is also led by a woman (the author of this chapter). Women play vital roles in farmers' groups and cooperatives – particularly in coffee post-harvesting – while caring for livestock, preparing family meals and collecting firewood. Introducing biogas provides a ready supply of energy and frees up time they would otherwise spend gathering firewood. This allows them to spend more time with their children, tend to other household chores, engage with the community, or focus on coffee farming.

Successes, challenges and adjustments

We found that farmers benefited substantially from the biogas systems, particularly in Bajawa. They used the bio-slurry not only to fertilize coffee plants, but also for other crops, such as maize, bananas and other horticultural produce. Monitoring data indicated that the average production of bio-slurry was about 15 litres per day, enough for use in small-scale farms.

The farmers said bio-slurry significantly enhanced plant growth. They had previously used chemical fertilizers, and the bio-slurry improved soil health, leading to greener and healthier crops. The first reports of benefits came shortly after the first application, and farmers mentioned it again in surveys at the end of the project. Yields improved for both coffee and horticultural plants such as eggplants and maize. Our monitoring also showed that farmers in Bajawa had reduced their firewood consumption by 56%, highlighting the system's potential to address deforestation and greenhouse gas emissions.

Initially, the biogas systems had a volume of 0.7 m^3, but the project showed that farmers needed more capacity. In response, we made larger 1 m^3 digesters which we tested in Wanagiri and Bajawa with positive results. In Bajawa, some households reported that they could use biogas to cook most of their daily dinners, preparing meals sufficient to feed a family of five with staples such as 3 kg of rice, fried fish and stir-fried vegetables. While biogas did not entirely replace their LPG or firewood usage, it significantly reduced their reliance on these fuels, leading to greater satisfaction and cost savings.

Due to space constraints, however, installing larger digesters was only feasible for some farmers. Larger biodigesters also require more feedstock, and we found that coffee farmers produced different amounts of feedstock. In the future, we aim to develop a digester with a larger capacity that fits in the same area as smaller units. Having digesters available in different sizes will also allow us to tailor the systems to each farm's capacity.

Another challenge is that our biogas system is above ground and thus sensitive to cold weather. This can affect biogas production, particularly during the rainy season. Anaerobic digestion in commonly used systems such as su-re.co's works optimally at 30°C or more and declines significantly at temperatures below 20°C (Nie et al. 2021). This is especially relevant for our target group of coffee farmers at elevations of 800–1600 meters above sea level, where the cooler climate is conducive to growing Arabica coffee.

We observed this effect in Manggarai and Sukawana. During the rainy season, reduced sunlight can extend the time needed for biodigesters to reach optimal functionality. While this presents a challenge, it also offers an opportunity for improvement. We are exploring using greenhouses to create a warmer environment for the biodigesters during the rainy season. This could enhance the systems' efficiency and improve farmer satisfaction.

Another key lesson we learned is that providing appropriate support and training to local implementing partners is crucial, particularly when introducing new technologies to communities. These partners offer valuable expertise, facilitate installations, and support ongoing monitoring, especially in remote areas with limited connectivity. Building effective partnerships requires substantial time and effort, and continuous training is necessary to ensure that local partners are proficient with the technology and can effectively assist farmers.

For example, our partnership with LAPMAS Bajawa in this project required extensive training. In order to create a robust support system for farmers, however, this was a worthwhile investment. By providing training and ongoing education, we can ensure that local partners like LAPMAS Bajawa can provide consistent, reliable support, enhancing the sustainability and success of biogas technology in these communities.

The experience also highlighted the importance of a well-designed manual. We provided a manual with clear instructions, supported by visuals and diagrams, which helped guide farmers in the daily operation and maintenance of the biogas system and use of bio-slurry. Such a resource ensures that farmers have a dependable reference when project personnel are not present, thus supporting proper usage and system sustainability.

Community engagement is pivotal to our goal for farmers to keep using their systems independently and sustain the benefits of the biogas technology even after the project's conclusion. As we introduced the digesters to new villages, we found that installing biogas systems on several neighbouring farms was highly beneficial. This approach allows farmers to learn from one another, seek advice, and provide mutual encouragement, fostering a supportive environment that enhances the sustainability of the biogas systems.

A biogas digester is being assembled and installed on a farm in Bajawa, Flores. September 2023.
Photo credit: Cynthia Crouse

Next steps: Making the most of biogas for ecosystem-based adaptation

This project highlighted the many potential benefits of biogas technology as part of broader EbA interventions and raised awareness among farmers. It also enabled us to identify further ways to improve our technology, including tailoring it to different farmers' needs.

An ongoing challenge is improving performance in cooler climates. We have proven that biogas functions well in lowland farms throughout the year. However, performance decreases at higher elevations with lower temperatures and less sunlight. Similar challenges would also arise with farms growing crops other than coffee. As noted above, we are testing potential solutions such as the use of a greenhouse or a plastic dome, but more research and experimentation are still required.

One key area for future development is to make larger digesters, going beyond the 1 m^3 units. For example, with a volume of 1.5 m^3, we could meet a larger portion of households' energy needs and further reduce their reliance on firewood or LPG. A larger biogas system would produce more bio-slurry, potentially providing more fertilizer to support this project's typical farm, which is around one hectare in size.

We also see potential for expanding the types of feedstock used to produce biogas. The farmers in this project all had livestock, but as the large-scale projects on oil palm plantations show, farm residues and waste from processing crops can be valuable feedstock.[28] Making similar use of waste on coffee farms can provide added value to the supply chain and make biogas technology accessible to more farmers, including those without livestock.

This potential is evident in Wanagiri and other coffee-producing areas such as Bajawa and Manggarai. In these regions, coffee pulp is typically discarded on the ground, which can damage the soil if not properly treated. Furthermore, the water used for fermenting coffee during wet processing has significant potential as a biogas booster due to its rich bacterial colony. We learned from a cacao group that fermented cacao water greatly enhances biogas production. This insight suggests that experimenting with fermented coffee water could similarly boost biogas output. Targeting coffee production houses in Bajawa, Manggarai and Wanagiri in the future could close the loop even more, turning waste into valuable energy and further promoting sustainable agricultural practices across multiple regions.

We also aim to reduce costs by establishing a local production facility in Bajawa. We faced logistical challenges and high expenses because we shipped prefabricated biogas systems from our main facility in Bali to Flores. A facility in Bajawa can help us better meet the high demand in Flores, reduce shipping costs, and streamline our operation. LAPMAS Bajawa can already install, monitor and troubleshoot biogas systems. With more training, LAPMAS Bajawa could also manufacture the digesters, and Bajawa could even serve as a production hub for the local area and neighbouring

28 See, e.g., Keerthana Devi et al. (2022); Sodri and Septriana (2022).

regions such as Manggarai. A local production initiative would also create jobs and stimulate the local economy.

Our next priority is to work with local governments to scale up our biogas initiatives. By sharing our successes and the potential benefits, we aim to open more opportunities for collaboration and support. Government involvement can provide farmers with additional resources, funding and technical assistance, making adopting and sustaining biogas technology easier. Such a collaboration could also contribute to national sustainability goals.

Additionally, scaling up biogas adoption requires adequate funding to implement each digester at scale. Carbon credit mechanisms and other climate finance instruments offer potential opportunities to monetize emission reductions from biodigesters, creating new revenue streams that could incentivize farmers. In the future, we aim to explore these financial tools to accelerate biogas technology's widespread adoption and support broader climate action efforts.

5. Can ecolabels and sustainability standards support ecosystem-based adaptation and enhance farmers' livelihoods?

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Ecolabels and sustainability standards – such as Rainforest Alliance, Fairtrade, USDA Organic – and government-issued geographical labels are being used by farmers and cooperatives throughout Indonesia's coffee sector to secure premium selling prices and guarantee buyers. The requirements set out by these labelling schemes often overlap and support ecosystem-based adaptation efforts, therefore enhancing climate resilience in smallholder farmers and coffee production. While this may seem like a clear "win-win" situation, with labelling schemes addressing both climate resilience and market security, the experiences of farmers and cooperatives involved in these agreements reveal challenges and barriers that should be acknowledged and understood.

Ecosystem-based adaptation (EbA) has many long-term benefits, but it requires upfront efforts and investments that can be challenging for farmers. Knowing that "ecolabels" are widely used in Indonesia's coffee sector,(Wahyudi et al. 2020) we set out to learn whether sustainability certification could facilitate EbA adoption by enabling growers to boost their income.

Ecolabels and sustainability standards can take different forms, but all aim to convey to consumers that a product is "environmentally friendly" and, often, that it also meets certain social and economic criteria, such as fair payment to growers (Dillon 2023). Participation is voluntary but can require significant efforts throughout the supply chain (Barreto Peixoto et al. 2023). The reward for coffee growers is the ability to command higher prices for their beans. For Indonesia's coffee sector, ecolabels have also helped enhance global competitiveness.

Ecolabels first appeared in the Indonesian coffee sector in 1993 through the Rainforest Alliance; Fairtrade followed in 1997 (Ibnu 2017). Organic certifications were also introduced around that time (Wahyudi and Jati 2012). Today, according to the Ecolabel Index, there are 26 different ecolabels in Indonesia; the most widely used are Rainforest Alliance, Fairtrade, UTZ, 4C, and USDA Organic (Ibnu 2017). Some coffee growers have also sought geographical indication (GI) labels denoting a product's location-specific characteristics (Adnan et al. 2022).

The intention of ecolabels aligns with EbA. For example, farmers seeking Rainforest Alliance certification may not convert natural forests into agricultural land. They are encouraged to adopt agroforestry with optimal shade coverage and species diversification, and they must also protect wildlife to preserve biodiversity (Rainforest Alliance 2023).

Fairtrade standards not only aim to ensure that farmers earn enough to support themselves and produce their crops sustainably, but also incorporate environmental principles, focusing on forest protection and deforestation prevention; climate risk assessment and adaptation; minimized and safe use of agrochemicals; proper waste management; biodiversity; soil health; and water protection and efficient water use. These practices help protect ecosystems and the services they provide to farmers (Rodríguez 2019).

Organic certification not only entails forgoing synthetic pesticides and fertilizers, but also adopting measures that promote soil health and biodiversity, such as crop rotation, organic nutrient management, and working with nature to control pests (Baier and Ahramjian 2012).[29] These measures are highly compatible with EbA. Meanwhile, the GI label for Flores Bajawa Arabica coffee contributes to EbA by requiring shade trees and terraces for water retention, erosion prevention, and post-harvest wet processing, which enhance climate resilience and reduce environmental impacts (MPIG 2011).[30]

These labels and standards thus align significantly with EbA, promoting sustainable practices that make coffee farms more climate-resilient and foster healthy ecosystems essential for agriculture and the broader environment. Combined with the extra income associated with ecolabels, this suggests a strong synergy. But is it delivering on the ground? This is what we set out to find out.

The MPIG label is displayed on the upper right-hand corner of a bag of coffee in Bajawa, Flores in September 2023. Photo credit: su-re.co

29 See also https://www.ams.usda.gov/about-ams/programs-offices/national-organic-program and https://attra.ncat.org/topics/organic-certification/.
30 See also https://mpigkafm.com/en/arabica-flores-manggarai-coffee/.

Coffee growers' experiences with ecolabels

Many farmers in Bali and Flores who participated in the EECCLiRe project already had either Rainforest or GI certification. Some also had experience with Fairtrade and USDA Organic certification.

Fairtrade in Flores

In Flores, members of cooperatives in Manggarai and Bajawa had previously sought Fairtrade certification but ultimately decided not to continue with the label. They said a buyer had approached the cooperatives, urging them to get certified with Fairtrade and promising to purchase their coffee once it had the label. Both cooperatives went through the certification process and paid the required fees, but they never communicated directly with Fairtrade; the buyer was their main point of contact.

In Manggarai, the cooperative delivered three containers of coffee beans to be sold under the Fairtrade label at an elevated price. However, the farmers said they had been told that only one container would be bought at the premium price. The other two did not meet the standards, so the farmers were paid the usual price. When they questioned this decision and asked to see the beans, they were denied access.

In Bajawa, cooperative members said the buyer had claimed that none of their beans met the standards, so they could never receive the premium. They were also denied access when they asked to see the beans that were not selling. In both situations, the cooperatives decided, based on their experiences, that the cost of certification and renewal was not worthwhile, as they had not actually benefited financially.

Notably, the problem in the Flores case was that the farmers needed access to the certification bodies themselves. All their communication was done via the buyer. Fairtrade has mechanisms for farmers to connect directly with the organization and other producers who can support them, such as Regional Producer Networks.[31] However, if cooperatives and farmer groups are unaware of these mechanisms, they cannot use them or access information that could benefit them. It is crucial that before getting into an official agreement with a buyer or a certification body, farmers and cooperatives are aware of their options and rights.

Rainforest Alliance and organic certification in Bali

In Wanagiri, Bali, several farmers had obtained Rainforest Alliance and/or USDA Organic certification through their local cooperative for many years and said they planned to continue to do so. The cooperative handles most of the logistics around certification.

31 See https://www.fairtrade.net/about/producer-networks.

In an interview, a Rainforest Alliance-certified farmer reported receiving the premium price as expected and said the requirements were relatively easy to comply with. An auditor had come to the farm, and they were certified once everything was agreed upon. The cooperative handled the documentation. The farmer reported having received training on tending to seedlings and plant maintenance, including pruning.

The farmers interviewed in Bali said they felt that the knowledge and information they had received from the two programs had helped them adapt to the changing climate to a point, but that, ultimately, productivity was determined by the environment.

The Flores Bajawa Arabica GI label

The Flores Bajawa Arabica coffee GI label was launched in 2012 when the national government asked LAPMAS, a local NGO, to administer the label for the Ngada Regency.[32] In an interview, the LAPMAS director said the label had 1080 participating farmers, and the NGO was working to include more. However, the certification process is time-consuming, and farmers are spread out across a large region, so many may not even know about the opportunity, he noted. He estimated that another 7000–8000 farmers in the region could potentially participate.

The LAPMAS director noted that coffee sold with the label commands twice the price of non-labelled coffee from the same region. Some cooperatives in Manggarai and Bajawa that participated in the EECCLiRe project said they used the GI label to enhance the value of their coffee. These are the same cooperatives with previous commercial label experiences.

LAPMAS helps farmers comply with the requirements and provides training and valuable information that aligns with EbA principles. The director said many farmers in the area would uproot and replace their coffee plants if their main crop was not doing well in the market. By using the GI label, which requires the adoption of agroforestry, among other things, farmers can have a more stable connection to the market and diversify their income by growing additional cash crops, he said.

GI labels are also available in other parts of Indonesia, including Bali. In some parts of the island, such as Kintamani, coffee farmers used a GI label to strengthen their position in international markets. However, many farmers in Sukawana and Wanagiri who participated in the EECCLiRe project said they were unaware of any GI label. Conversations with village heads and representatives made it clear that the success of GI labels depends on the structure of cooperatives in the area and the performance of the designated administering body, such as LAPMAS in Flores.

32 LAPMAS stands for Lembaga Advokasi dan Penguatan Masyarakat Sipil, or Civil Society Advocacy and Strengthening Institution.

Key lessons and ways forward

The EECCLiRe project did not actively promote sustainability or GI certification among participants – the research team only spoke with different stakeholders to begin exploring the potential for these labelling schemes to contribute to EbA. The insights drawn from our analysis are thus only preliminary, though some clear themes still emerged.

First, there is a significant overlap between the requirements for specific labels and effective EbA measures, from using shade trees, to water conservation and various measures that support soil and ecosystem health. Agroforestry systems help protect crops from heavy rainfall and extreme heat, for instance, while also boosting productivity. Working with nature and promoting biodiversity enhances ecosystem services, another key element of EbA (IUCN 2017). Annex 2 provides an overview of how ecolabelling schemes in Indonesia align with EbA principles.

Moreover, by enhancing their market competitiveness and enabling them to command higher prices for their coffee, these labelling schemes also improve farmers' livelihoods, further strengthening their climate resilience. Several labels can also be applied to other crops, supporting income diversification.

That said, there are limitations. First, none of these eco-labels was specifically designed to support EbA. Moreover, EbA requires context-specific solutions, including incorporating Indigenous and traditional knowledge (Global EbA Fund 2023). International standards designed to be applied in a wide range of contexts cannot provide that level of tailoring.

One option is for ecolabelling initiatives to **integrate more context-specific solutions to support EbA efforts**. Within the framework of broader international standards, they could incorporate traditional knowledge and local practices to enhance the relevance and effectiveness of their initiatives. For example, training on agroforestry practices and management of shade trees can be tailored to each region's specific social, climatic and ecological conditions, thereby improving coffee farms' resilience to climate change. Requirements can have specific sections dedicated to each region's geographical and cultural characteristics. Gender equality and social inclusion principles should be explored in ecolabels to ensure that the needs of various groups and communities are met.

The GI label in Flores presents another promising approach. By definition, the GI label highlights the unique characteristics of the region. Moreover, LAPMAS, the administering body, is an NGO that works with local farmers and understands their challenges and strengths. As a result, it can provide context-specific training and solutions that better meet local communities' specific needs.

Developing local administrative bodies or partnering with local civil society organizations is beneficial for labelling. Like LAPMAS, such bodies can provide localized support, ensuring that certification requirements are met in a manner that fits the local ecological and socio-economic context. This could help bridge the gap between global certification standards and local practices, making the certification process more efficient and less burdensome for farmers. It would also help connect farmers more directly with the certification scheme. The Ministry of Cooperatives also already supports farmers in obtaining organic certification. There is potential for multi-stakeholder collaborations, including cooperatives, local NGOs and certification bodies, to make it easier and more affordable for farms to get certified.

The latter would help address one of the biggest challenges identified in our analysis: When farmers rely on intermediaries with little knowledge, agency or connections, the power imbalance can set them up for failure. Certification bodies should **work to ensure that farmers are well-informed about their rights, options and available resources**. For example, if the farmers in Flores who sought Fairtrade certification had been made aware of the regional producer networks and other support systems, they would have had much better chances of success. Certification bodies can sponsor targeted training sessions and informational workshops and distribute clear, accessible materials to farmers directly or through local and regional partners.

Even if reliable intermediaries are available, it is essential to **establish direct lines of communication between farmers and certification bodies to mitigate the risk of misinformation and exploitation**. Beyond training opportunities and workshops, this could involve creating digital platforms or mobile applications that allow farmers to track their certification status, access resources, and communicate directly with certifying organizations. That said, it is important to recognize that remote farmers may have difficulties accessing materials online, as they may not have digital devices or reliable internet connections.

Another important challenge is that certification can require considerable resources, including time and money. Each label has its process, but they all require an application, an audit, time for correcting non-compliance, and then determination. This can take close to a year to complete, and many labels require periodic renewal processes as well. On top of that, there are certification costs, audits and potential export fees. It is normal for farmers to join these agreements through cooperatives to lessen the financial burden, but it is still important that before starting the process, farmers know all that will be expected of them.

One option that could help is **participatory guarantee systems** (PGS), which are already used in Indonesia and worldwide to reduce barriers to smallholders' participation in certification schemes. IFOAM – Organics International, which coined the term, describes PGS as "locally focused quality assurance systems" aimed at reducing barriers to participation, fostering trust, building local ownership and promoting mutual learning.[33] While no PGS existed at the EECCLiRE project sites,

33 See IFOAM's resource hub on PGS: https://www.ifoam.bio/our-work/how/standards-certification/participatory-guarantee-systems.

PAMOR (Penjaminan Mutu Organik) Indonesia[34] is an example of a PGS being used to help small-scale coffee producers to achieve certification more affordably.

Governments and other partners can help address this by **providing financial and logistical support to farmers to cover the initial costs of certification and compliance**. NGOs and international development organizations can also play a pivotal role in offering grants, low-interest loans, or subsidies to help farmers bear these costs. Supporting cooperative structures and governance systems to help distribute the costs and resources needed for certification could also help farmers with the financial burden. Training programs focused on sustainable farming practices, financial management, and certification procedures can empower farmers to navigate the certification process better and maximize the benefits of ecolabels.

Raising awareness about the different types of labels available, including the benefits of a GI label, can help more farmers leverage this certification to improve their market positioning. This can be achieved through community meetings, farmer field schools, and collaboration with local agricultural extension services.

By building a robust support system and ensuring that farmers are well informed and equipped to meet certification standards, ecolabelling could thus significantly enhance their livelihoods and climate resilience – all while making coffee production more environmentally sustainable.

34 See https://aoi.ngo/pamor-penjaminan-mutu-organik-komunitas-di-indonesia/.

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Annex 1. Tree species identified as suitable for use as coffee shade trees in Indonesia

Scientific name	Common and local names
Albizia chinensis	The Sau Tree, *Sengon*
Aleurites moluccanus	Candlenut, *Kemiri, Miri* (Javanese), *Kemintan, Muncang* (W. Javanese/ Sundanese)
Alstonia scholaris	Devil's Tree, *Pulai, Pule* (Javanese), *Rite* (Ambon), *Pulai gading*
Archidendron microcarpum	*Kabau, Balinag, Girik, Jaring burung, Jaring hutan, Jering, Langir Hantu, Piling, Tionggong* (Borneo)
Archidendron pauciflorum	*Jengkol, Jering*
Arenga pinnata	Sugar Palm, *Aren, Enau, Kawung*
Artocarpus altilis	Breadfruit, *Sukun, Kelur, Timbul*
Artocarpus heterophyllus	Jackfruit, *Nangka, Nongko* (Javanese)
Averrhoa bilimbi	Bilimbi, *Belimbing, Belimbing wuluh, Belimbing sayur*
Bambusa vulgaris	Common bamboo, *Bambu ampel, Bambu kuning, Domar* (Ambonese)
Carica papaya	Papaya, *Pepaya, Telo Gantung, Kates* (Javanese), *Gedang* (Sundanese)
Cinnamomum burmanii	Cinnamon, *Kulit manis, Kayu manis*
Cinnamomum parthenoxylon	*Kayu lada, Ki sereh* (Sundanese), *Selasihan* (Javanese), *Rawali* (Borneo)
Citrus aurantium	Tangor, Bitter Orange, *Jeruk siam, Jeruk manis*
Citrus hystrix	Kaffir Lime, *Jeruk Purut*
Citrus medica	Citron, *Jeruk sukade, Sitrun*
Cordyline fruticosa	Ti plant, *Jeluang, Hanjuang, Puding merah*
Dalbergia latifolia	Black Rosewood, *Sonokeling, Sonosungu*
Dendrocalamus asper	Giant bamboo, *Bambu petung, Awi bitung* (Sundanese), *Buluh batung* (Batak), *Pring Petung* (Javanese)
Erythrina subumbrans	Erythrina, *Dadap*
Erythrina variegata	Indian Coral Tree, *Dadap, Dadap Blendung* (Sundanese), *Dadap Ayam* (Javanese), *Dede Bineh* (Madurese)
Falcataria falcata	White albizia, *Sengon putih, Jeungjing* (Sundanese), *Sengon Laut* (Javanese), *Sikat* (Banda)
Gigantochloa apus	*Bambu apus, Bambu tali, Pring tali, Pring apus* (Javanese), *Awi tali* (Sundanese)

Scientific name	Common and local names
Gigantochloa atter	The black bamboo, *Bambu ater, Pring legi* (Javanese), *Awi temen* (Sundanese)
Gigantochloa verticillata	Whorled bamboo, *Bambu gombong*
Gliricidia sepium	Johar Kandang, *Gliricidia, Gamal, Ki Hujan*
Gmelina arborea	White Teak, *Jati putih*
Gnetum gnemon	*Buko,* Melinjo
Leucaena cultivars	*Leucaena cultivars* – diversifolia, leucocephala, and hybrids
Tamarindus indica	River Tamarind, *Lamtoro, Lamtoro PG 79, Mlanding* (Javanese), *Pelending* (Sundanese), *Pete selong* (Sundanese)
Maesopsis eminii	Umbrella Tree, *Kayu afrika, Trembelu* (Javanese)
Magnolia champaca	Champak, *Cempaka, Semulun*
Mangifera indica	Mango, *Mangga, Pelem* (Javanese), *Buah* (Sundanese)
Morinda citrifolia	Noni, *Mengkudu, Bengkudu* (Minahasa, Gorontalo), *Cangkudu* (Sundanese), *Mengkudu besar, Mengkudu jantan* (Malaysia)
Palaquium obovatum	Gutta-percha Tree, *Nyatoh*
Parkia speciosa	Bitter bean, *Petai, Pete* (Javanese)
Persea americana	Avocado, *Alpukat*
Pinus merkusii	Merkus Pine, *Pinus*
Psidium guajava	Guava, *Jambu Biji, Jambu Kluthuk* (Javanese)
Shorea platyclados	*Meranti bukit, Banio* (Sumatra), *Ketir* (South Kalimantan), *Meranti cingham* (Eastern Sumatra)
Swietenia macrophylla	Mahogany, *Mahoni*
Syzygium aqueum	Water apple, *Jambu air*
Syzygium malaccense	Malay Apple, *Jambu bol*
Tectona grandis	Teak, *Jati*
Toona sinensis	Red Cedar, *Surian, Ingul* (Sumatra)
Toona sureni	Red Cedar, *Surian, Surian amba* (Sumatra), *Suren*

Source: Conservation International, Smithsonian Migratory Bird Center and World Coffee Research database.[35]

35 See https://www.shadecoffee.org/en/catalog/indonesia.

Annex 2. How selected ecolabelling schemes align with ecosystem-based adaptation principles

Ecosystem-based adaptation principles	Rainforest Alliance (2023)	Fairtrade[36]	USDA Organic (Baier and Ahramjian 2012)[37]	Geographical Indication (MPIG 2011)[38]
People-centred	Farmers sell coffee at a premium price. Sustainable farming practices support farmers' livelihoods. Requires sustainable livelihoods and fair working conditions for farm workers, ensuring social sustainability.	Farmers sell coffee at a premium price. Sustainable farming practices support farmers' livelihoods. Promotes fair wages and labour conditions. Strengthens farmer organizations, ensuring democratic decision-making and equitable distribution of benefits.	Farmers sell coffee at a premium price. Sustainable farming practices support farmers' livelihoods.	Farmers sell coffee at a premium price. Sustainable farming practices support farmers' livelihoods. Participation is structured through community-based resource management, such as cooperatives that bolster farmers' resources and capacities.
Enhancing biodiversity	Includes criteria that support or require maintaining natural vegetation, natural pollination and pest control, conservation of riparian buffers and forest areas, protect native species, and use of organic inputs.	Include criteria that support or require agroforestry practices, conservation, reforestation, restoration, and soil conservation through mulching or cover cropping, and prohibits deforestation.	Includes criteria that supports or require use of organic inputs, soil and crop nutrient management, water conservation, crop rotation, natural pest management, and agro-ecological practices.	Includes criteria that support or require agroforestry practices, organic farming practices, pollination and pest control, and soil and water conservation.
Supporting overall adaptation strategy	Encourages adaptive farm management, risk assessments, and tracking improvement with specific indicators.	Supports adaptation through training programs on soil and water conservation, promotes community-driven decision-making, encourages investment in sustainability and long-term environmental improvements through Fairtrade Premium funds.	Requires long-term land management plans, supports a transition period for farms converting to organic practices, reduces carbon footprints through organic and regenerative farming practices.	The scheme is integrated into local and national government initiatives. Allows for exchange of traditional and modern knowledge.

36 See https://www.fairtrade.net/en/why-fairtrade/how-we-do-it/standards.html.
37 See also https://www.ams.usda.gov/about-ams/programs-offices/national-organic-program and https://attra.ncat.org/topics/organic-certification/.
38 See also https://mpigkafm.com/en/arabica-flores-manggarai-coffee/.

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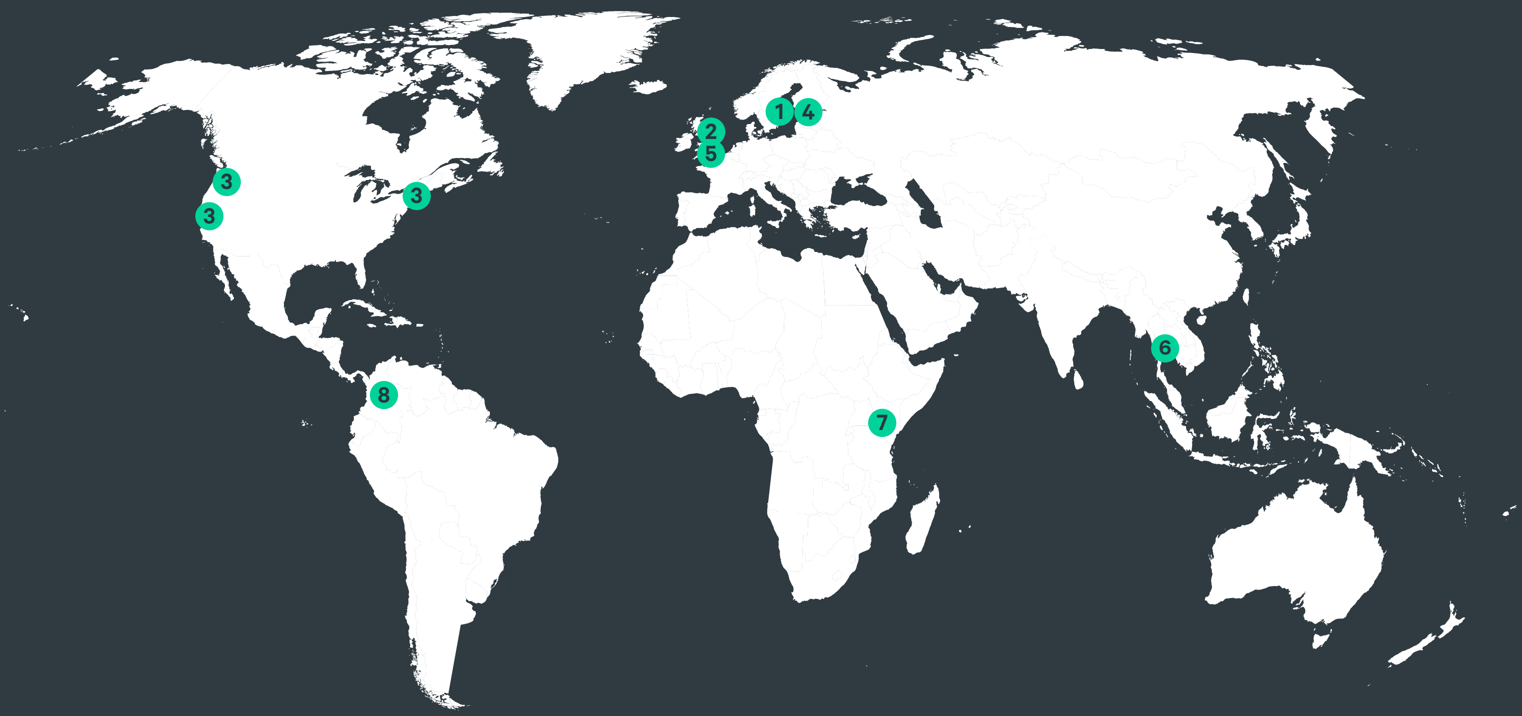

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