Evaluating strategies for equitable co-design of sustainability interventions with smallholder farmers

Abstract

Purpose

Global food and agricultural systems face mounting climate, biodiversity and livelihood crises. Co-design - where stakeholders with different experiences and views work together to develop sustainable solutions - has gained attention as an approach to agricultural innovation that can help address these crises. Focusing on smallholder *Kichwa*-manged agroforestry cocoa systems in Napo, Ecuador, we conceptualise a co-design framework that embeds procedural equity to enhance the legitimacy and relevance of agricultural innovations bridging different knowledge systems.

Approach

Through a literature review and PESTLE (Political, Economic, Social, Technological, Legal, Environmental) analysis, informed by a series of focus groups with cocoa producers, we identify principles, mechanisms and processes that make co-design more equitable. These are combined into a framework incorporating equity considerations into all key co-design stages.

Findings

Our analysis reveals that co-design potential in driving transformation in agriculture depends not only on recognising equity as a goal but also relies on embedding procedural equity principles and mechanisms from the start and throughout all phases of the process. Early integration of fairness, inclusivity, and shared decision-making helps establish trust and legitimacy; prerequisites for sustained collaboration. In Napo, *Kichwa* farmer cooperatives' tradition as spaces for discussion and collective decision-making offer favourable conditions to initiate equitable co-design processes.

Our framework also redefines the role of extensionists and researchers as facilitators of knowledge exchange in co-design.

Practical implications

The co-design framework we configured offers a structured but flexible approach for integrating equity within co-design processes, providing guidance for moving from top-down knowledge transfer to knowledge co-production.

Theoretical implications

This study contributes to rethinking agricultural extension practices by demonstrating how embedding equity principles early in co-design can bridge diverse scientific traditions and enhance the legitimacy of agricultural innovations.

Originality

This framework is among the first to explicitly operationalise equity-based co-design in Indigenous smallholder settings.

1. Introduction

The escalating global environmental crises, including climate change, biodiversity loss, and land degradation, pose an unprecedented threat to livelihoods and ecosystems, demanding transformative changes to the food system, a primary driver of environmental degradation (Bommarco, 2012; IPBES, 2019a; van Bers et al., 2019). The scale of transformation extends beyond technical solutions and requires fundamental shifts in societal values, governance structures, and economic systems (Marin et al., 2016; Mauser et al., 2013; O'Brien et al., 2025; Page et al., 2016; Pascual et al., 2023). Central to this food system transformation is also a reconsideration of how knowledge is generated and applied in innovation processes, as knowledge systems fundamentally shape the design and implementation of agricultural practices and policies (Busse et al., 2024; Page et al., 2016).

However, conventional approaches to agricultural innovation, dominated by linear technology transfer within extension systems, top-down information sharing, and research-driven development, show limitations in facilitating such changes (Fleischer et al., 2002). These models continue to privilege Western scientific paradigms over local practical knowledge, often failing to respond to place-specific challenges in farming landscapes (Klerkx et al., 2023; Marin et al., 2016; Scoones et al., 2020).

These limitations are further exacerbated by the complexity of agricultural landscapes themselves, given their multi-scale dynamics, diverse stakeholders involved, and the complex socio-ecological interactions that underpin them (Busse et al., 2024; Chaplin-Kramer et al., 2024; Marin et al., 2016; Prost, 2021). In these environments, stakeholders with different priorities and interests co-exist, often leading to disagreements over which issues to prioritise and how to address them (Cooke et al., 2021; Marin et al., 2016).

In Indigenous contexts, these challenges are compounded by the colonial legacies that have long influenced innovation processes: traditional knowledge systems are often marginalised in favour of externally-designed solutions that fail to account for cultural values and local ecological understanding (IPBES et al., 2019; Klerkx et al., 2023; Tengö et al., 2021). These legacies reflect and reinforce knowledge hierarchies and what de Sousa Santos defines the ‘abyssal line’, a divide that systematically positions Western scientific tradition as superior to Indigenous science, peasant and local ways of knowing (Santos, 2016; R. C. Smith et al., 2024; Yanou et al., 2023). This ultimately leads to poor adoption rates and the limited effectiveness of innovations in addressing the specific environmental and livelihood challenges facing farming communities (Scoones et al., 2020)

Conversely, collaborative approaches that value local knowledge holders as co-creators, from problem framing to innovation design, rather than as passive recipients (Cartagena et al., 2025; Page et al., 2016), have greater potential to initiate and guide long-lasting transformations (McGuire et al., 2024). Moving beyond the token participation of knowledge holders in innovation processes requires adopting a decolonisation stance to knowledge production that aims to challenge knowledge hierarchies and build on different knowledge systems to facilitate more inclusive and adaptive forms of agricultural innovation (Cooke et al., 2021; Norström et al., 2020; Page et al., 2016).

However, while the need for more inclusive and equitable innovation processes is widely recognised, there remains a lack of clarity on how to operationalise these principles in practice. In particular, few frameworks explicitly address how to embed equity within co-design processes so that diverse knowledge systems can engage on genuinely equal terms.

To address these challenges, we first examine the limitations of conventional top-down knowledge transfer models and their implications for sustainable agriculture. We then explore how participatory approaches that value Indigenous and local knowledge (ILK) systems, such as co-design, can address these limitations. Finally, we outline the research questions and present the case study context of *Kichwa*-managed *chakra* agroforestry systems in Napo, Ecuador.

1.1. Top-down knowledge transfer as a barrier to sustainable agricultural innovations

Agricultural extension services have traditionally operated through linear approaches to knowledge transfer to farmers, often prioritising agricultural industry- and productivity-oriented solutions (Mauser et al., 2013). In these models, ‘pre-packaged’ technologies and recommendations are developed by agricultural researchers and industry experts with limited farmers’ engagement (Conti et al., 2025; Haug, 1999). In some instances, this approach to knowledge transfer has exacerbated socio-ecological vulnerabilities by promoting practices unsuited to local contexts and ultimately led to farmers' disengagement (de Snoo et al., 2013; Ronner et al., 2019).

Although extension models have nominally shifted towards more participatory approaches, such as Farmer Field Schools, knowledge hierarchies persist through institutional structures and funding mechanisms that keep privileging Western scientific tradition over farmers' experiential knowledge (Klerkx et al., 2023; Roué & Nakashima, 2018). As a result, farmers' agency is often limited to choosing between externally-developed solutions. This generates a disconnect between innovations and farmers' everyday realities but also raises the critical question about the level and nature of farmers' engagement required to achieve sustainable innovations (Carmenta et al., 2025; Haug, 1999).

1.2.The role of ILK as a foundation for contextualised agricultural innovations

The limitations of conventional extension practices highlight the importance and need of recognising, and bridging different knowledge systems, such as ILK, within agricultural innovation processes. ILK emerges and evolves from close observation and practical experimentation within specific socio-ecological contexts over generations (Berkes et al., 2000; Roué & Nakashima, 2018). It also reflects a holistic worldview integrated into daily practices and interactions with the landscape, from resource monitoring to management approaches (Berkes et al., 2000; Roué & Nakashima, 2018). These knowledge systems are primarily transmitted through peers and geographical proximity (Cámara-Leret et al., 2019).

Despite its demonstrated value in informing innovations, ILK has been systematically excluded from many formal agricultural innovation processes, raising practical and ethical challenges (IPBES, 2019b). Movements such as agroecology resist this marginalisation by advocating for the legitimisation of diverse knowledge systems and peer-to-peer learning to effectively address complex socio-ecological challenges (Conti et al., 2025; Cooke et al., 2021; Klerkx et al., 2023; Liberloo et al., 2022; Marin et al., 2016; Martin et al., 2018; Prost et al., 2018). Within this framework, ILK becomes a catalyst for agricultural transformations (Hill et al., 2020; Tengö et al., 2021; Utter et al., 2021a).

1.3. Co-design to bridge knowledge systems and enable participatory innovation processes in agriculture

Co-design has emerged as a participatory approach that draws on diverse knowledge systems to develop contextually-appropriate solutions. Originating in design studies, co-design has been described as a process where stakeholders ‘come together to conceptually develop and create’, despite ‘their different agendas, needs, knowledge and skills’ (Zamenopoulos et al., 2021). In agricultural contexts, co-design often involves researchers and farmers engaged in various cycles of ‘action, reflection, and inquiry’ to address real-world challenges (Lang et al., 2012; Utter et al., 2021).

Farmer-led and farmer-focussed extension approaches have emerged within this discourse. These approaches position farmers as primary stakeholders who define what constitutes ‘value’ or ‘improvement’ for their specific context (Haug, 1999; Villaseñor et al., 2020). Farmers’ knowledge is regarded as equivalent to scientific knowledge in generating innovations (Hill et al., 2020; McElwee & Harrison, 2024).

1.4. Equity and power considerations in co-designing agricultural innovations

Despite their potential for more inclusive and contextually-relevant agricultural innovations, co-design methodologies can inadvertently reproduce or reinforce existing power imbalances between stakeholders even within collaborative research processes (McGuire et al., 2024; Urquhart et al., 2023). Such risk is particularly significant in contexts shaped by colonial legacies, where historical patterns of knowledge extraction in conducting research can continue to influence how stakeholders interact, and how knowledge is negotiated, validated and applied within these collaborative spaces (Carmenta et al., 2025; O'Connor et al., 2019).

Integrating equity considerations within co-design processes therefore becomes integral to broader efforts to decolonise agricultural research and development (McGuire et al., 2024; Reynolds-Cuéllar & Ming, 2020). This requires recognising the legacies of knowledge extraction and reshaping how interactions between participants occur throughout research practices (McGuire et al., 2024).

1.5. Knowledge-action gap in operationalising equity within co-design for agricultural innovation

To date, the application of co-design approaches in smallholder agriculture and with historically marginalised groups remains limited and largely experimental (Hakkarainen et al., 2022; Utter et al., 2021a). Additionally, equity considerations are often inadequately integrated into co-design processes or remain loosely defined, thus undermining their effectiveness as well as that of the resulting co-designed solutions (Adeyeye et al., 2019; Yua et al., 2022).

Moreover, while theoretical approaches for addressing power asymmetries between researchers, farmers and other value chain stakeholders in co-design have emerged (Cooke et al., 2021; Farr, 2018; Weaver, 2023), whether they genuinely transform power relations within research practice is still largely untested (McGuire et al., 2024; Reynolds-Cuéllar & Ming, 2020).

Insights about what constitutes successful co-design are usually derived *a posteriori* (Busse et al., 2024; Hölting et al., 2022; Parsons et al., 2016). While this has generated a relevant body of knowledge and valuable evidence, practitioners and researchers still lack actionable frameworks to integrate equity considerations in co-design from the start. This reactive rather than proactive approach to equity risks reproducing the very knowledge hierarchies that co-design aims to dismantle.

Achieving ‘procedural effectiveness’ - the extent to which a co-design process generates outputs that are both legitimate and actionable – is central to the success of participatory approaches (Raymond et al., 2010; Tengö et al., 2021). ‘Legitimacy’ refers to users’ acceptance of and trust in both processes and outputs (de Boon et al. 2022); while ‘actionability’ concerns users’ capacity to apply outputs independently to generate data that can inform their decisions (Jagannathan et al., 2023).

Procedural effectiveness depends fundamentally on ‘procedural equity’, understood here as the degree to which co-design processes ensure inclusive, fair, and meaningful participation in decision-making, particularly for historically marginalised or underrepresented groups (Brown & Corbera, 2003; McDermott et al., 2013). This involves actively addressing power asymmetries throughout the co-design process by ensuring participants have equal opportunities to shape outputs (Adeyeye et al., 2019), legitimising diverse knowledge systems, applying transparent procedures in the knowledge bridging process, and establishing processes to prevent dominant voices from silencing others (Hill et al., 2020; Norström et al., 2020). Procedural equity thus operates both as normative goal and a practical mechanism to ensure that agricultural innovations are accessible to and benefit traditionally marginalised farmers / groups[1].

[1] While we focus on procedural equity, we recognise that equity in participatory processes is multi-dimensional. Various scholars distinguish between *distributive equity,* the fair allocation of costs and benefits, and *access equity,* which considered pre-existing differences in opportunities to participate (Brown & Corbera, 2003; McDermott et al., 2013; Grabs et al., 2021). In focusing on procedural equity, we focus on a foundational dimension through which other forms of equity can be advanced in co-design processes.

1.6.Research objectives

This study aims to respond to these gaps by conceptualising an equity-based co-design framework for sustainable agricultural innovations in smallholder farming systems. We will test and co-develop this in cocoa agroforestry systems (known as *chakras*) in Napo, in the Ecuadorian Amazon region, managed by *Kichwa* farmers. This context provides an ideal cases study because: (i) it is a biodiversity-rich system under increasing pressures from agricultural expansion, market demands, and local knowledge erosion, creating a need for locally-grounded innovations that can inform management decisions reconciling apparently diverging conservation and productivity objectives (Bredero zur Lage et al., 2023; FAO, 2023; Torres et al., 2024; Vasco et al., 2024); (ii) offers opportunities to bridge *Kichwa* experiential and place-based traditional ecological knowledge with Western scientific knowledge to enhance the relevance and usability of co-designed solutions (Hölting et al., 2022; Ruck et al., 2024); (iii) provides a strong basis for testing frameworks designed to redress knowledge hierarchies and power imbalances in *chakra*-related decision-making, considering the historical marginalisation of ILK from agricultural innovation processes.

Our specific research questions are:

1. What principles and processes contribute to equitable co-design in agriculture, enabling the bridging of multiple knowledge systems, including ILK, while avoiding the reproduction of existing knowledge hierarchies?
2. How can equity-oriented principles and processes be integrated into and operationalised in a co-design framework to support the emergence of legitimate, relevant innovations for sustainable *chakra* management in Napo?

The following section introduces the *chakra* agroforestry systems of Napo, Ecuador, which serve as the empirical setting for testing and refining the proposed equity-based co-design framework.

1.7. Case study context: **chakra** *agroforestry systems in Napo*

The *chakra* agroforestry systems of Napo, Ecuador, are polycultures, combining fruit and timber trees, which are primarily chosen for their utilitarian value (e.g., food, timber, and cash crops) (Bredero zur Lage et al., 2023). *Chakras* are recognised as a Globally Important Agricultural Heritage System (GIAHS) by the Food and Agriculture Organization, being a model of agrobiodiversity conservation and integrated land management grounded in local ecological knowledge. Among the *Kichwa*, the *chakra* is understood not only as a space for food production and gathering but also as a 'form of language', functioning as a locus for the intergenerational transmission of knowledge. This also reflects what Escobar (2014) describes as a 'relational ontology', where human and natural worlds form a continuum rather than separate entities.

However, these systems face mounting pressures from the expansion of cash crops, land scarcity, and increasing market pressures pushing farmers towards more intensive production practices (Salazar et al., 2023; Torres et al., 2024). These pressures also risk displacing *chakras* traditional management approaches, resulting in culture and knowledge erosion.

The *Kichwa* people of Napo, locally referred to as *Runa Kichwa*[2], have participated in numerous research projects and development initiatives analysing *chakras* as potential models for sustainable rural development and biodiversity conservation. This focus has created both opportunities for participatory approaches, but has also exposed the limited effectiveness of top-down research models that fail to let farmers define their own needs and aspirations (Salazar et al., 2023).

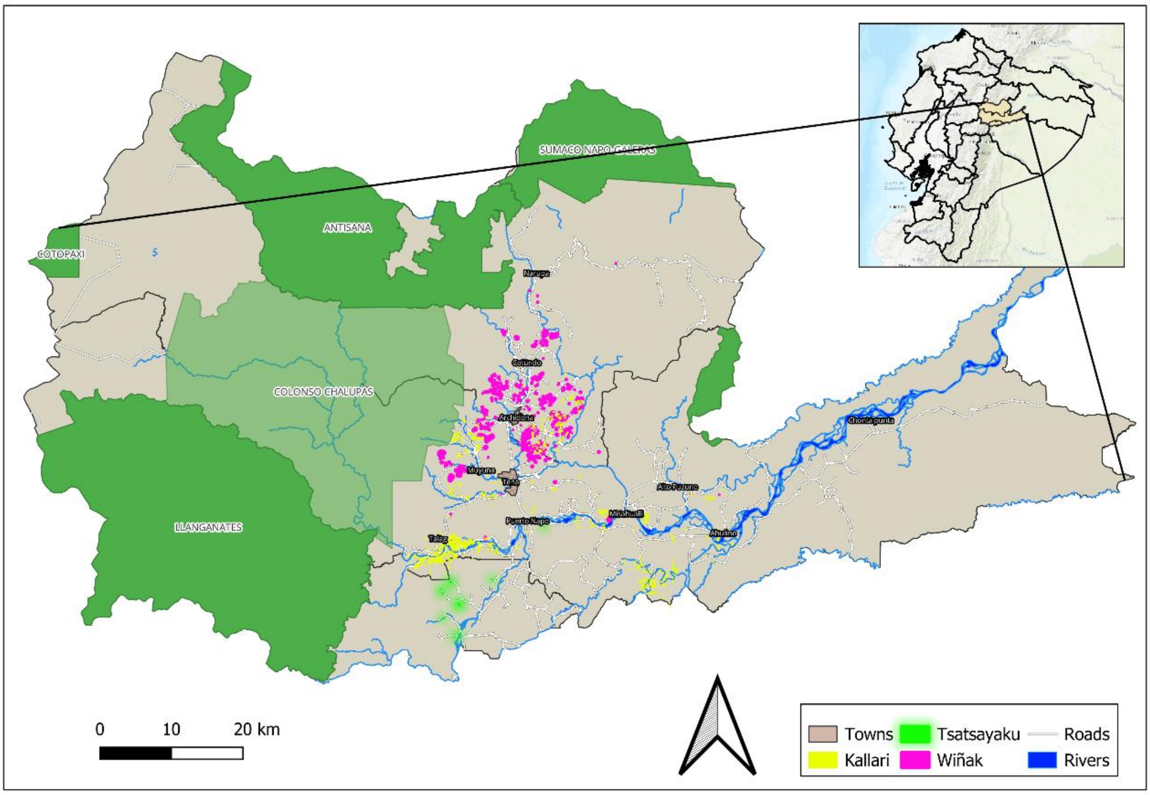

Figure 11: Napo province and cocoa cooperatives by colour.

Over the past decade, *Kichwa*-led cooperatives have emerged as important spaces for farmer-driven innovation. In 2016, local government, international cooperation agencies, and three cocoa cooperatives, Kallari, Wiñak, and Tsatsayacu, established a Participatory Guarantee System (PGS), called *Sello Chakra*, which certifies production compliance with a series of ecological and cultural standards. What began as a top-down

[2] *Runa* means ‘people’ and *Kichwa* denotes their language, but they are currently identified by the broader ethnonym *Kichwa.*

initiative, over time, evolved into a process increasingly shaped by bottom-up contributions and trust-based relationships via the local agricultural cooperatives. This scheme has also influenced local policies around agroforestry and has further strengthened the cooperatives' role as spaces for farmer-led decision-making.

This context provides a practical entry point to explore how equity-oriented co-design principles can be operationalised to guide agricultural innovations for *chakra* management that align with the knowledge, interests, and constraints of smallholder farmers.

2. Methods

We developed our equity-based co-design framework through four sequential phases, as sketched below: (i) a rapid literature review to identify dominant co-design principles, processes and challenges in agricultural contexts, (ii) thematic analysis to extract core equity-oriented co-design features and potential mitigation measures to recurring implementation challenges, (iii) a contextual analysis of the Napo *chakra* systems using a Political, Economic, Social, Technological, Legal, Environmental (PESTLE) framework to understand key factors influencing farmer decision-making, and (iv) the development of a theoretical co-design framework applicable to our case study building on the findings of the mentioned analyses.

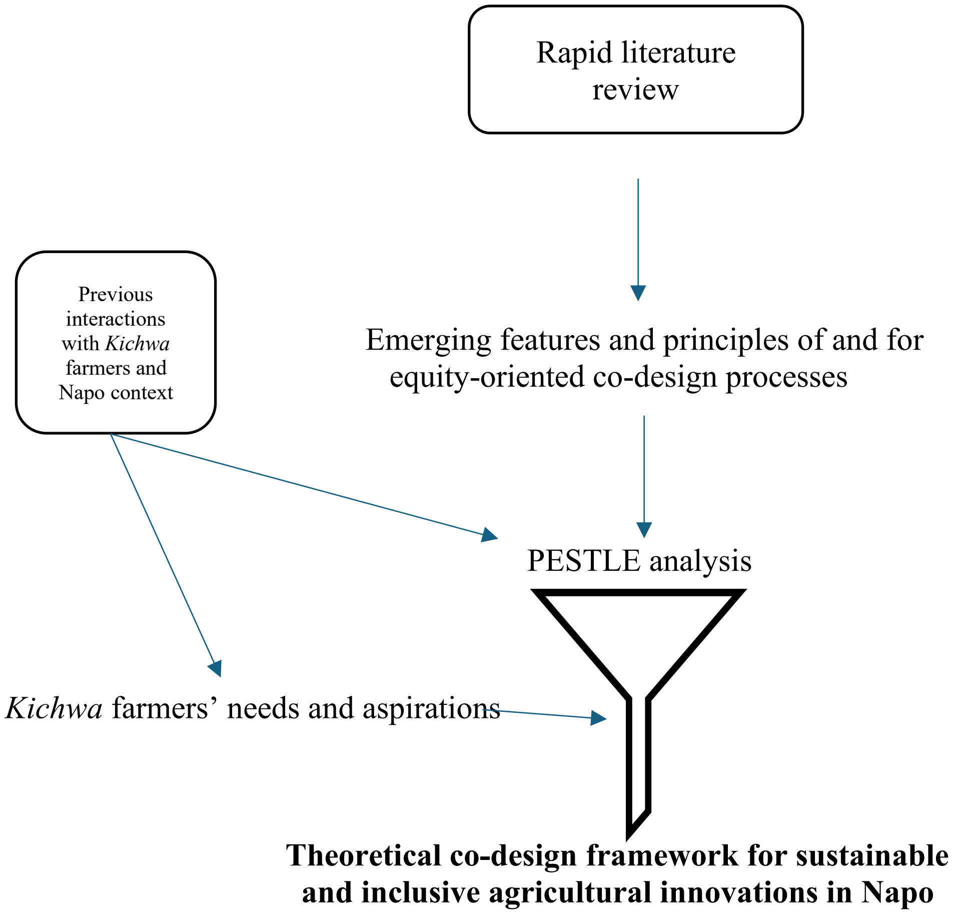

Figure 2: Schematic representation of methodological approach

2.1.Rapid literature review and interpretative synthesis

We conducted a rapid literature review to identify key principles, processes and challenges in co-design for agricultural innovation, particularly around equity and power dynamics. Given the emerging and evolving nature of the topic, but the still limited evidence base, we prioritised relevance over exhaustive coverage, consistent with rapid review methodologies in emerging fields (Khangura et al., 2012; Robinson et al., 2022; Wollscheid & Tripney, 2021).

We searched Scopus and Web of Science using two main search strings: *("co-design*" OR codesign* OR co-creat* OR co-produc* OR "knowledge integration" OR " living labs") AND equit* AND (agric* OR farm*)* and *("co-design*" OR codesign*) AND (farm* OR agric*) AND (biodiv* OR "bio-div*").* The search was intentionally broad to capture the diverse terminology used across different disciplines.

Following the initial database searches, we used backward and forward citation tracking to identify additional relevant sources until saturation was reached. This is the point when further searching is unlikely to yield additional relevant information to answer the research questions (Saunders et al., 2018).

Papers were considered if they addressed co-design and knowledge co-creation approaches in agricultural contexts with smallholder farmers and / or traditionally marginalised groups, focussed on co-designing solutions balancing productivity and conservation or discussed power dynamics and equity considerations in co-design and co-creation innovation processes. Given the limited evidence base meeting all criteria, we also analysed studies of co-design processes involving traditionally-marginalised groups in natural resource management or conservation where relevant, aligning with recommendations for scoping reviews in emerging research areas (Arksey & O'Malley, 2005).

We then conducted an interpretive synthesis of the reviewed papers to identify the features, principles, and mechanisms most relevant to enhancing procedural equity and procedural effectiveness in co-design. The synthesis compared findings from the literature with our conceptual definitions of equity, highlighting elements that contributed most directly to these dimensions (Dixon-Woods et al., 2005; Thomas & Harden, 2008). The resulting themes informed the design of our equity-based co-design framework.

Given the very specific nature of the topic and the relatively small pool of directly relevant studies, all potentially relevant papers were manually screened, rather than using a formal coding procedure, following practices adopted in similar rapid evidence syntheses (Haby et al., 2016; Khangura et al., 2012; Pham et al., 2014).

2.2. Contextual analysis (PESTLE)

We complemented the literature review with a PESTLE analysis to understand the factors influencing *chakra* management and the feasibility of implementing equity-based co-design approaches to generate innovations to guide it.

Originating in management theory (Aguilar, 1967) and later adapted to guide strategic decision-making in complex systems (Archer, 2013; Farr, 2018), PESTLE helps systematically assess the different factors that influence the risks, mitigation measures and enabling conditions for innovation design and implementation, including in agricultural contexts (Uztürk & Büyüközkan, 2023).

In our case study, a PESTLE analysis also served to understand how previous interactions between *Kichwa* farmers and researchers could influence knowledge generation and application to address key issues in *chakra* cocoa production (O'Connor et al., 2019).

2.3. Engagement with **Kichwa** *farmers*

Our framework development built on our established collaboration with *Kichwa* cocoa farmers from Napo. In late 2024, we conducted preliminary discussions with 55 *Kichwa* cocoa farmers to explore their needs and priorities for *chakra* management. These discussions were followed by semi-structured interviews with leaders of cocoa cooperatives and key farmers in January 2025.

Insights from these interactions were examined in relation to our conceptual definitions of procedural equity and procedural effectiveness. We identified features of co-design that contributed to them from farmers' perspectives.

2.4. Development of an equity-based co-design framework to support decision-making in **chakra** *systems*

We drew on insights from interactions with *Kichwa* farmers, the literature review, and contextual analyses to conceptualise an equity-based co-design framework specifically adapted for developing decision support tools.

Following similar approaches in co-design research (Eastwood et al., 2022; Hölting et al., 2022; Pohl, 2008), such framework also serves to guide our prospective collaboration with *Kichwa* farmers and facilitate engagement, rather than as a blueprint. This approach is consistent with the need for co-design to be flexible and responsive to stakeholders' needs and input to generate credible and actionable solutions .

To address unconscious biases and avoid replicating potential colonial practices during this phase, we, as researchers, employed reflexive methods, including autoethnography, that can serve as a valuable tool to critically interrogate our own positionality and assumptions, contributing to more ethical and transparent engagement (Blanco, 2012). This ethnographic approach has also been adopted by natural scientists (Kline, 2025), designers, artists (Moreira et al., 2018), and practitioners in adjacent fields to establish an objective perspective on human-environment interactions while contributing to ethical and transparent engagement.

3. Results and discussion

Our analysis shows that achieving equity in agricultural co-design requires a redistribution of decision-making power among stakeholders and the legitimisation of multiple knowledge systems. We identify five core principles that must be operationalised across co-design phases for this to happen. The analysis of Napo's *chakra* systems shows how existing cooperative structures, Indigenous governance norms, and dominant knowledge transmission practices create both opportunities and requirements for equitycentred approaches to innovation. Building on these findings, we propose a four-phased equity-based co-design framework that progressively builds legitimacy, horizontal knowledge exchange, farmer agency, and adaptive learning toward the co-evolution of solutions through peer-to-peer communication.

3.1. Moving towards equity-based knowledge bridging as a strategy for sustainable agricultural innovation

Key guiding principles for equitable participatory processes in agricultural innovation

Our thematic analysis identified five core principles crucial to achieving procedural equity and effectiveness in co-design and inclusive innovation processes in agriculture, more broadly speaking: (i) transparency, (ii) fairness and inclusivity, (iii) empowerment, (iv) co-ownership, and (v) reflexivity.

Transparency (i) emerges as the foundation to (re-)build trust between farmers, researchers, extensionists and other value chain stakeholders in innovation processes - relationships often compromised by historical patterns of knowledge extraction and the systematic marginalisation of knowledge systems, including ILK, in decision-making processes in agriculture (Buffa et al., 2023; Howlett et al., 2025; Roué & Nakashima, 2018). This principle directly addresses the ‘colonial’ legacies that continue to influence interactions between researchers, extension services, and farming communities (Buffa et al., 2023; Howlett et al., 2025; Roué & Nakashima, 2018). In practice, in participative agricultural research, transparency requires openly discussing research objectives through dialogue with farmers, as well as collaboratively defining decision-making processes and validation criteria for knowledge ‘selection’ (Cooke et al., 2021; Norström et al., 2020; Piczak et al., 2022). When working with Indigenous communities, this transparency extends to acknowledging different ways of producing and transmitting knowledge, such as oral knowledge transmission (Berkes et al., 2000; Ho-Tassone et al., 2023; Roué & Nakashima, 2018).

Fairness and inclusivity (ii) address structural and procedural barriers that have historically excluded knowledge systems, such as ILK, from agricultural innovation processes (Thirschler et al., 2019). These barriers often manifest as a dominance of technical jargon in the research process, meeting formats that privilege formal presentations, and the timing of key events conflicting with agronomic calendars (Barnaud & Van Paassen, 2013; Jakku & Thorburn, 2010). Equitable co-design involves actively removing these barriers and facilitating access, particularly for historically marginalised groups, to discussions accommodating diverse communication approaches, such as storytelling, and language style (Conti et al., 2025; Sadovska et al., 2023), as well as co-defining engagement modalities (Barnaud & Van Paassen, 2013; Cooke et al., 2021).

Linked to these two concepts is that of empowerment (iii), which extends beyond inclusion to address historical limitations of farmers' agency. Farmer empowerment requires farmers to frame the problem, define what counts as ‘innovation’ and challenge imposed definitions of agricultural success (Cullen-Unsworth et al., 2012; Villaseñor et al., 2020), as well as addressing institutional practices that have historically subordinated their knowledge, such as technology transfer programmes (McGuire et al., 2024).

Co-ownership and shared responsibility (iv) challenge the historical approach to innovation where solutions are ‘transferred’ to implementers, instead identifying farmers as co-designers with equal stakes in both the process and the outcomes (Le Gal et al., 2011; Utter et al., 2021a). In this reframed approach, extensionists and researchers primarily act as facilitators, supporting the co-design of locally-grounded solutions that bridge Western scientific tradition with farmers' knowledge to develop context-appropriate farming practices, technologies, and management strategies (Haug, 1999; Sadovska et al., 2023; Villaseñor et al., 2020). In equity-oriented co-design, co-ownership and shared responsibility imply that farmers retain intellectual property rights over innovations incorporating their knowledge, share in any benefits, and exercise agency over how innovations are adapted and disseminated. This principle contributes not only to legitimacy but also to the effectiveness of co-designed solutions, favouring their embeddedness in existing social and institutional fabrics (Dolinska & d'Aquino, 2016; Lang et al., 2012a).

Finally, reflexivity (v) sustains procedural equity by embedding mechanisms for critical self-assessment and adaptive learning in co-design. It requires all participants, including researchers, to examine positionality, assumptions, and power relations throughout the process (Archer, 2013; S. Cornell et al., 2013; Liberloo et al., 2022).

Co-design configurations and equity-enhancing levers

While the previous section identified the normative principles that shape equitable co-design, here we examine how these principles are translated into practice across different co-design approaches in agricultural innovation.

Our analysis shows that co-design processes usually comprise five interrelated steps, each offering entry points to enhance procedural equity. There exist considerable variations in how these stages are configured, especially in terms of who participates, when, and with what level of influence, with implications on both the procedural equity and outcomes of co-design (Moll et al., 2020; O'Connor et al., 2019; O'Donnell et al., 2025).

Table 1: Typical steps in co-design processes and equity-enhancing levers

Step	**Conventional approach**	**Equity-enhancing approach**	**References**
Problem framing	Researchers or external agencies define the problem and prescribe solutions; industry- or productivity-oriented approaches over farmer-generated innovations.	Farmers co-define problems, values, and priorities; clarity on process and objectives provided early but remains adaptable.	Busse et al., 2024; Cooke et al., 2021; Haug, 1999; Parsons et al., 2016
Relationship building	Engagement through established institutions and “easy-to-reach” farmers.	Mapping power dynamics; building trust with marginalised groups (women, smallholders, Indigenous); using cooperatives for inclusive participation; using non-dominant forms of communication.	Dolinska & d’Aquino, 2016; Hurley et al., 2022; Marin et al., 2016; Murgue et al., 2015; Neef & Neubert, 2011; O’Connor et al., 2009; Sadovska et al., 2023
Needs assessment and diagnosis	Technical experts conduct standardised assessments and give recommendations.	Farmers’ experiential knowledge is valued alongside science; participatory diagnosis is used to stimulate peer learning and context-specific solutions; findings are interpretated jointly.	Baloch & Thapa, 2018; Cerf et al., 2012; Dogliotti et al., 2014; Lang et al., 2012; Meynard et al., 2023; Smith et al., 2024; Utter et al., 2021

Step	Conventional approach	Equity-enhancing approach	References
Innovation development and testing	Predetermined solutions are trialled by farmers mainly as end-users.	Farmers and researchers co-desig, prototype, and iterate; mutual learning reframes knowledge hierarchies.	Berthet et al., 2018; Blazy et al., 2009; Conti et al., 2025; Fleischer et al., 2002; Hill et al., 2020; Jakku & Thorburn, 2010; Marin et al., 2016; Prost et al., 2018
Innovation validation and adaptation	Success measured by adoption rates and productivity-focussed metrics via extension networks.	Solutions validated through legitimacy, ownership, and adaptability; farmer-to-farmer exchange and cooperative governance to support ongoing evolution.	Blazy et al., 2009; Blockeel et al., 2023; Bonilla et al., 2024; Busse et al., 2024; S. Cornell et al., 2013; Dolinska & d'Aquino, 2016; Neef & Neubert, 2011

Challenges in ensuring procedural equity and effectiveness in agricultural innovation

From our review, it also emerges that several challenges can limit co-design effectiveness in creating equitable agricultural innovation processes and solutions (Berthet et al., 2018). These challenges are often rooted and / or the result of institutional structures and funding mechanisms that can inadvertently privilege certain knowledge systems over others, even within participatory approaches (Carmenta et al., 2025).

A central issue concerns the persistence of knowledge hierarchies and power imbalances - between donors and implementers, researchers and farmers, or state and community actors - which can perpetuate the privileging of Western scientific knowledge over the experiential knowledge from farmers and field-based practitioners (Adeyeye et al., 2019; Buffa et al., 2023; Howlett et al., 2025). These asymmetries manifest primarily through a bias towards quantitative over qualitative metrics, continued requirements for peer validation of knowledge and knowledge legitimacy issues (Adeyeye et al., 2019; Buffa et al., 2023). Tackling these asymmetries requires transparent governance and clear roles within co-design, alongside agreed criteria for knowledge validation (Reyes-García et al., 2023; Tengö et al., 2021; Villaseñor et al., 2020).

Closely related to power asymmetries, we identified the underrepresentation or exclusion of participants facing resource limitations as an additional risk, which can reproduce traditional social hierarchies, particularly in terms of age, gender and land tenure (Haug, 1999; Hurley et al., 2022). This finding indicates that meaningful inclusion requires targeted strategies addressing context-specific participation barriers, diversified engagement formats and consensus around engagement modalities (Haug, 1999; Hurley et al., 2022; Newing et al., 2024).

Another challenge is represented by the directionality of knowledge flows within co-design processes. Unidirectional knowledge transfer from researchers and extension agents to farmers is a risk of participatory processes in the absence of specific mitigation measures, undermining the principle of mutual learning and failing to create genuine dialogue between knowledge systems (Cooke et al., 2021; Sadovska et al., 2023). Preventing and addressing such shortcomings requires farmer-led diagnostic and knowledge-sharing sessions, engagement of farmers in both problem identification and solution co-design, and the adoption of different communication formats accessible to farmers, among others (Cooke et al., 2021; Liberloo et al., 2022; Marin et al., 2016; Sadovska et al., 2023).

The absence of clear equity-sensitive metrics for evaluating co-design success presents another challenge, with many initiatives focussing on technical or output-oriented assessments (O’Connor et al., 2019; Utter et al., 2021a). Effective evaluation benefits from the participatory definition of 'success', across multiple scales and time horizons, and sensitivity to contextually-relevant socio-cultural values and ecological aspects, to capture how different groups might be impacted differently by both the co-designed process and resulting solutions. This includes assessing changes in value chain stakeholder relationships and decision-making in farm management, complementing productivity-focussed indicators common in conventional agricultural innovation processes (O'Connor et al., 2019; Utter et al., 2021; Villaseñor et al., 2020).

3.2. Contextualising equity-based co-design in **chakra** *agroforestry systems*

Our PESTLE analysis of the Napo *chakra* systems serves to situate and inform our co-design framework and understand how contextual factors could reinforce or hinder the operationalisation of equity-enhancing principles and processes identified in our literature review.

Table 2: Key PESTLE factors anticipated to influence co-design equity-enhancing principles and processes in *chakra* agroforestry systems in Napo, Ecuador

Factor	**Key considerations for co-design**
Political	Local governance structures, particularly farmers' cooperatives, offer a space for collective decision-making as an alternative to the individual farmer-focused approaches typical of conventional agricultural extension services (Salazar et al. 2023). The political context also reveals tensions between Indigenous governance norms and broader agricultural development policies that emphasise standardised, productivity-focused approaches to problem-solving in *chakra* system management. These characteristics require co-design processes able to align with Indigenous decision-making traditions and policy frameworks, such as the PGS, supporting

	participatory and agroecological transitions respectful of socio-ecological traditions.
Economic	Market dependencies on cocoa exports and price fluctuation vulnerabilities have often motivated agricultural and rural development interventions that prioritise short-term productivity over long-term sustainability and cultural preservation (Castañeda-Ccori et al., 2020). This focus has often failed to secure higher profits, which demotivated farmers (Vasco et al. 2023). Cooperative-mediated market access represents an alternative model that helps stabilise income for small-scale cocoa producers and reinforces empowerment by positioning farmers as collective market actors. Equity-based co-design must address how different economic models can either perpetuate or transform the interactions and power asymmetries along the value chain and ensure that benefits derived from co-designed innovations are equitably shared.
Social	The *Kichwa* culture emphasises collective decision-making, reciprocity, and oral knowledge transmission, (Berkes et al., 2000; Roué & Nakashima, 2018). The *chakra* remains a central space for maintaining and facilitating intergenerational (agricultural) knowledge transmission. However, language barriers are threatening this transmission: the more knowledgeable members of the community, the elders, often prefer to articulate their knowledge in culturally specific terms, even when they speak Spanish, while younger generation are increasingly abandoning the *Kichwa* language. Equity-based co-design therefore requires engagement approaches different from the oftentimes individualistic, literacy-dependent methodologies that characterise conventional agricultural extension services. Such

	approaches should legitimise different communication formats and accommodate traditional knowledge transmission practices to ensure accessibility and legitimacy - ultimately contributing to the operationalisation of transparency, inclusivity, and empowerment principles identified in our literature review.
Technological	*Chakra* system management primarily relies on traditional knowledge with limited integration of formal agricultural technologies and recommendations. This reflects both the inadequacy of standardised technological solutions and the ability of ILK in responding to context-specific challenges (Sadovska et al., 2023). This finding reinforces the need for co-design approaches that position extensionists and researchers as facilitators of knowledge bridging (Haug, 1999; Villaseñor et al., 2020), encouraging innovations for *chakra* management that integrate rather than replace existing knowledge systems.
Legal	*Chakra* systems operate within a complex framework of Indigenous and community-managed resource governance, and evolving national and international policies that increasingly recognise both the urgency of biodiversity conservation and Indigenous Peoples' rights and participation in the process (Borras & Franco, 2018; Newing et al., 2024). Recent developments in international law, such as the EU Deforestation Regulation and evolving certification standards, show how the recognition of Indigenous Peoples' role in biodiversity conservation can co-exist with compliance demands (Corbera & Schroeder, 2011).

	In *Kichwa* communities, innovations and traditional knowledge systems operate under the principles of collective rather than individual ownership. When external systems fail to recognise these collective intellectual property rights, the absence of 'ownership' of innovations has at times been perceived as a form of violation of their collective rights. Co-design initiatives must therefore navigate between Indigenous legal traditions and formal regulations to protect collective intellectual property rights and avoid reproducing external dependencies or rights violations.
Environmental	*Chakra* systems face growing environment pressures, particularly from climate variability, pest pressure and the need for enhanced productivity. Standardised interventions have proven unable to evolve and mutate under these rapidly changing conditions (Busse et al., 2024). However, the environmental pressures facing *chakra* systems also create opportunities for co-design processes to demonstrate how ILK and Western scientific knowledge can be bridged to develop more robust, culturally-appropriate adaptive management strategies that reinforce resilience and sustain agrobiodiversity (Lehmann & Rodríguez, 2013; Torres et al., 2024). This requires moving towards collaborative knowledge production processes that stimulate co-ownership of the emerging solutions, enabling farmers to adapt them based on changing environmental conditions and cumulated experience.

3.3. Four-phased equity-based co-design framework for **chakra** *management*

Building on the findings from the thematic literature analysis and the PESTLE analysis, in this section, we conceptualise a co-design framework with *Kichwa* farmers as co-designers of innovation alongside extension agents and researchers.

Our co-design framework comprises four key phases that progressively build trust and stimulate horizontal dialogue between stakeholders, while bridging different knowledge systems. To that end, each phase incorporates specific mechanisms aimed at addressing the knowledge hierarchies and procedural inequities that have historically marginalised ILK in agricultural innovation processes in Napo. Each phase is further detailed in the following sections.

Phase 1 - Planning: Identification of key issues and initial research conceptualisation

The initial phase of the co-design processes addresses the dilemma of how to provide clear research frameworks and boundaries to facilitate stakeholder engagement without reinforcing extractive researcher-defined agendas that could undermine the process legitimacy and effectiveness (Piczak et al., 2022; Weaver, 2023). Our co-design framework explicitly acknowledges the 'colonial legacy' of much academic research in Napo by leaving processes and outcomes open to negotiation with stakeholders from the outset. However, we also recognise the need for clarity about the research objectives to (re-)build trust with farmers, extension agents and community leaders during the initial phases of engagement (Urquhart et al., 2023; Yua et al., 2022).

Rather than impose a fixed research approach, we propose a gradual trust-building process with farmers grounded on prior collaborations between the lead researcher and *Kichwa* farmers on food systems initiatives. These interactions provided valuable insights into the contemporary issues faced by farmers in *chakra* management and pointed to the need for transparency in conducting research, aligning with local needs and can counteract the extractive research patterns that have historically characterised academic-farmer interactions.

This phase provides an alternative to the 'pre-packaged solution' model typical of conventional innovation processes in Napo, laying the foundations for a more equitable interaction with farmers to discuss and validate issues and solutions in *chakra* management.

Phase 2 - Preparatory phase: Building the foundations for horizontal knowledge flows

In this phase, the focus shifts to establishing process legitimacy and equity in the research-practice interface, by addressing historical patterns of knowledge extraction and the systematic marginalisation of ILK in agricultural innovation processes. The cooperative structures identified in our PESTLE analysis provide the institutional foundation for this engagement, as they operate on the *Kichwa* norms of reciprocity and collective agency (Salazar et al., 2023).

Establishing engagement through cooperatives offer practical mechanisms to establish an equitable relationship between researchers, farmers and other stakeholders while facilitating horizontal knowledge exchanges. This phase lays the groundwork for transparency, inclusivity, and mutual learning, producing a shared diagnostic baseline of issues and opportunities for *chakra* management.

Phase 3 - Ideation and design: From technology transfer to farmer-centred innovation

This phase builds upon participatory extension practices by positioning farmers as co-designers rather than just recipients of innovation. This phase serves to operationalise the empowerment and co-ownership principles by ensuring that farmers participate not only in solution development but also in the definition of ‘effectiveness’ and ‘actionability’ of the co-designed solutions within their specific contexts (Cullen-Unsworth et al., 2012; Villaseñor et al., 2020).

Approaches that encourage dialogue between researchers, and farmers, such as workshops, field demonstrations or collaborative design sessions, are meant to facilitate knowledge exchange and social learning, particularly in a context, such as the *Kichwa*'s, with a strong dialogical tradition for knowledge transmission (Sadovska et al., 2023; Salas et al., 2010). An emphasis on field-based, and practice-based solution development also responds to the technological considerations identified in our PESTLE analysis.

The farmer-centred approach to innovation development also manifests in innovation pathways defined collaboratively and design options assessed against criteria established by farmers, integrating both ILK validation methods and feasibility considerations (Linan et al., 2022; Salas et al., 2010).

The products of this phase include co-developed prototypes and knowledge artefacts that are legitimate, technically actionable, and collectively owned.

Phase 4 - Deployment: From adoption to co-evolution of co-designed solutions

This final phase reframes implementation and dissemination of the co-designed solution as a dynamic and farmer-led process. Moving beyond standardised scaling approaches focussed on adoption rates, in our proposed framework, this phase recognises and leverages farmers' prevailing knowledge adaptation and transmission practices as the primary vehicles for co-designed knowledge dissemination (Hurley et al., 2022; Neef & Neubert, 2011).

The deployment strategy builds directly on the social and technological insights from the PESTLE analysis, recognising that, in *Kichwa* communities, knowledge dissemination takes place primarily via informal peer interactions and the cooperatives' dialogical space, rather than formal extension channels (Cámara-Leret et al., 2019;

Dolinska & d’Aquino, 2016). Therefore, the focus shifts from external dissemination mechanisms to strengthening existing peer-to-peer learning and farmer-led knowledge dissemination pathways for ensuring continued co-ownership and facilitating the natural evolution of co-designed solutions. This approach recognises that the wider validation of co-designed solutions emerges through trusted social networks rather than external verification processes (Dolinska & d’Aquino, 2016; Rose et al., 2016).

This phase also addresses the evaluation challenges identified in our literature review by incorporating a participatory definition of success metrics that extend beyond productivity-focused indicators to include contextually-relevant socio-cultural values, ecological integrity and governance shifts. This approach ensures that assessment processes remain aligned with *Kichwa* priorities and values rather than external development objectives.

The culmination of this phase is ‘living innovations’ embedded in cooperative governance structures that maintain co-ownership, accountability, and capacity for adaptation.

Together, these four phases form a continuous and iterative process for embedding equity in agricultural innovation co-design. To support the practical application of this framework, we developed a complementary set of reflective prompts and guiding questions designed to help researchers and practitioners apply and monitor progress towards more equitable co-design innovation processes. These materials are provided in the *Supplementary Materials* (Section S1).

4. Limitations of this study

Our theoretical framework for enhancing extension practice through equity-based co-design remains at the conceptual stage without empirical implementation or testing, primarily due to the early-stage nature of our research. We also acknowledge that this is a theoretical framework developed without the direct involvement of *Kichwa* farmers in its conceptualisation. While some researchers argue that a ‘pure’ co-design process also requires the involvement of stakeholders in the conceptualisation phase (Yua et al., 2022), others emphasise the importance of a flexible research approach with co-design evolving iteratively and stakeholder engagement deepening as the research progresses (Francis et al., 2024). Our approach aligns with the latter perspective, with mechanisms in place to engage *Kichwa* farmers meaningfully during the implementation phase.

A further limitation concerns the limited empirical evidence about co-design processes for agricultural innovations, particularly regarding their effectiveness in achieving equitable outcomes. While a growing number of studies documents co-design processes, few offer insights into to what extent specific mechanisms actually dismantle the power asymmetries and knowledge hierarchies that can limit their effectiveness. This makes it difficult to validate which elements of our framework will prove most effective in achieving procedural equity.

Additionally, while our study is not confined to a specific environment or region, the majority of the studies reviewed primarily engaged relatively ‘privileged’ producers, with access to technology and resources not hindering their participation in the co-design process. Therefore, we recognise that some of the processes or factors identified as critical components of our equity-based and equity-oriented approach to co-designing may have limited applicability in contexts characterised by marked resource constraints or significant social marginalisation.

Finally, as O’Connor et al. (2019) argue, we are aware that research does not happen in a vacuum and, irrespective of arguments of neutrality and objectivity, researchers are bearers of values that can influence research ideas and interactions between researchers and other stakeholders. Understanding our positionality as predominantly non-Indigenous researchers developing frameworks for Indigenous contexts is crucial for acknowledging the power imbalances inherent in this work - specifically between university-based researchers and *Kichwa* farmers, and between formally educated extension agents and Indigenous knowledge holders (Moll et al., 2020; Yua et al., 2022). While not eliminating these power imbalances, our work can be useful to initiate processes that can help make space for traditionally-marginalised groups and knowledge systems to lead innovation processes, thus challenging extractive practices that have characterised much agricultural extension work with Indigenous communities.

5. Conclusion

This study responds to and supports the ongoing debate in agricultural extension practice, which, since the 1980s, has promoted a shift away from top-down approaches and a revision of how professionals engage with farmers, produce knowledge, and provide technical support (Conti et al., 2025; Haug, 1999)(Freire, 1984;. Our equity-based co-design framework seeks to addresses the power asymmetries and knowledge hierarchies that have historically marginalised ILK systems in agricultural innovation processes.

Our analysis demonstrates that achieving the transformative potential of co-design requires explicit attention to procedural equity from the outset, rather than assuming that participatory approaches automatically generate equitable outcomes. The shift from 'pre-packaged solutions' to knowledge bridging requires extensionists and researchers to adopt a role as facilitators and ‘knowledge bridge-builders’ rather than exclusive ‘innovators’. This presupposes acknowledging that different forms of knowing, including ILK, are equally valid in generating effective innovations, especially when they provide a sophisticated understanding of context-specific challenges that cannot be effectively addressed through standardised technological solutions (Sadovska et al., 2023; Villaseñor et al., 2020)

Our conceptual framework specifically addresses the unique challenges of implementing equity-based co-design in Indigenous farming contexts, where agricultural system management is deeply interconnected with cultural practices and traditional knowledge systems (Berkes et al., 2000; Reyes-García et al., 2023; Roué & Nakashima, 2018). Our framework aims at operationalising what Latulippe & Klenk (2020) define as an epistemological process of 'moving over' by giving space to ILK to address local issues while contributing to self-determination. This approach is consistent with the promotion of the agroecological transition, which requires empowering grassroots farming communities to move beyond the dominant conventional agricultural model. Revitalising grassroots socio-political organisations can support transformations both in production practices and in the way agricultural development is conceived.

In our study of *Kichwa* farmers in Napo, we found that specific aspects of co-design can contribute to procedural equity. More specifically, we argue that, building on the traditional and collective decision-making, knowledge creation and dissemination processes predominant among *Kichwa* farmers, co-design can find an enabling environment for the emergence of equitable discussions and interactions between researchers, extensionists and farmers. Cocoa farmers, in particular, are engaged in a process of empowerment, strengthened by the support of external stakeholders and local leaders during the establishment of the PGS *Sello Chakra*, creating the conditions for deeper engagement in shaping their own development and innovation trajectories. This finding suggests that the evolution of agricultural extension approaches and innovation processes can benefit from working with rather than against existing social and institutional arrangements, such as farmer-led cooperatives, that rely on collaborative decision-making practices to address common issues.

However, our analysis also highlights the necessity of implementing mechanisms that can prevent the reproduction of power asymmetries between participants in contexts where hegemonic values and Western scientific authority have been internalised by all stakeholders, including farmers. This stresses the need for critical reflection and explicit strategies on how to recognise and value different forms of agricultural knowledge in generating actionable and long-lasting innovations.

Despite its theoretical nature, our work provides the foundations for future empirical research to test how specific co-design features can ensure procedural equity in practice, particularly in agricultural contexts historically characterised by power asymmetries, and can lead to solutions respectful of cultural values while maintaining scientific rigour. Future research should also explore how co-designed solutions evolve over time and space to assess their long-term impact and reveal the conditions under which co-design successfully leads to behavioural and, ultimately, socio-ecological change. This analysis is key for understanding whether equity-based approaches can enhance the sustainability and effectiveness of agricultural innovations within extension programming.

Finally, more broadly speaking, this research points to a need for critical reflection on the practice of agricultural research and extension practice and the role of researchers in perpetuating and / or addressing existing power dynamics in these spaces. To address complex challenges that exceed the capacities of both ILK and conventional science paradigms, it is essential to implement participatory strategies that engage farmers meaningfully in knowledge co-design, particularly in critical decision-making phases, such as solution design, while encouraging researchers to think critically about the way knowledge is valued, shared and implemented.

The authors report there are no competing interests to declare.

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Supplementary materials (S1)

S1. Assessing equity-based co-design

While the four-phase framework identifies mechanisms for embedding equity, assessing whether these mechanisms actually produce equitable outcomes remains an unresolved challenge, as also emerges from the co-design literature.

To address this, we propose a concise evaluation tool, offering a set of prompts and guiding questions that translate our framework's principles into practical reflection points. This enables researchers, practitioners, and community partners to assess whether procedural equity (and, ultimately, effectiveness) are being achieved and sustained across co-design stages.

Table S1: Reflective prompts for assessing procedural equity in agricultural innovation co-design

Dimension	**Observable signals / guiding questions**
Process legitimacy	Were research aims, engagement rules, and decision criteria co-defined and accessible to all participants? Were these revisited collectively as the process evolved?
Voice parity and inclusivity	Did traditionally manrginalised groups actively contribute to discussions? Were culturally appropriate methods (e.g., storytelling, translation, visual tools) used to ensure parity?
Horizontal knowledge exchange	Were both ILK and Western scientific knowledge treated as legitimate and used jointly to inform decisions?

	Were criteria for knowledge validation co-defined?
Co-ownership and shared responsibility	Were intellectual-property, authorship, and data-use agreements transparently discussed and agreed upon?
	Were roles for maintaining, updating, and disseminating co-designed outputs jointly defined?
	Are accountability mechanisms (e.g., monitoring, reporting, stewardship) distributed equitably?
Actionability and uptake	Are co-designed outputs perceived as relevant, usable, and applied by intended users?
	Were participants involved in defining and testing their practical usefulness?
	Is the co-designed solution adaptable to different users' needs for them to be successful?
Reflexivity and adaptability	Were feedback and learning sessions built into the process?
	Were approaches adjusted as understanding or conditions evolved?

Source: Synthesised from the literature on evaluation of equity-based co-design and other participatory processes (Cockbill et al., 2019; S. Cornell et al., 2013; O'Connor et al., 2019; Villaseñor et al., 2020).