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Just transition in the livestock sector under the frameworks of the Paris agreement and environmental, social, and governance: a review

Abstract

Countries are committed to reduce their greenhouse gas (GHG) emissions under the Paris agreement (PA); yet, the livestock sector (LS) continues to encounter challenges in fully achieving PA goals. Key challenges include inconsistent governance, limited GHG emissions reporting, limited access to climate mitigation technology, and social and economic transition barriers. Current approaches often discuss mitigation, adaptation, and transparency in isolation rather than through integrated strategies. Therefore, this review examined how the LS can achieve a just transition (JT) toward climate sustainability by aligning these elements with the PA and environmental, social, and governance (ESG) frameworks. Existing literature, industry standards, and policy documents were synthesized to investigate how PA and ESG frameworks support JT in the LS, focusing on alignment of transparency systems, mitigation, and adaptation strategies to achieve nationally determined contributions (NDCs). This review followed a narrative approach. Key policy and technical documents were identified from major institutional sources, including the United Nations framework convention on climate change (UNFCCC), food and agriculture organization (FAO), and intergovernmental panel on climate change (IPCC) with citation chaining to identify related peer-reviewed literature. The review covers material published between 2015 and 2026. It also traces the institutional evolution of LS within the UNFCCC, from the Koronivia joint work on agriculture at the conference of parties (COP) 23 through the Sharm el-Sheikh joint work (SJWA) at COP 27 and the COP 28 UAE declaration, showing gradual but limited progress. ESG principles are increasingly aligned with national climate objectives and may offer indirect support for PA goals. Within LS, however, their integration remains limited, with persistent challenges including fragmented supply chains, animal welfare gaps, weak traceability, and smallholder vulnerability. Improved transparency systems place additional pressure on national reporting capacity, which may affect trust in collective climate action. JT in agriculture further requires addressing behavioral and socio-cultural dimensions, including dietary shifts and their implications for rural livelihoods and food system equity. In conclusion, merging the ESG frameworks and PA objectives may facilitate more transparent, socially equitable, and climate resilient LS, while supporting the transition toward a long-term sustainable future.

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Keywords: Agriculture, Climate change, Climate policy, Enhanced transparency framework, Nationally determined contributions

1. Introduction

Climate change is one of the most complex and serious global challenges of this century, with direct impacts on economic development, social equity, and ecological stability. Agriculture, particularly the livestock sector (LS), is both a contributor to and affected by climate change. On one hand, the LS is among the largest sources of greenhouse gas (GHG) emissions and releases methane (CH_4), nitrous oxide (N_2O), and carbon dioxide (CO_2) through enteric fermentation, manure management, and land-use change [1,2]. On the other hand, LS remains essential to human nutrition, rural livelihoods, cultural identity, and economic development worldwide [1,3]. At the same time, LS is highly vulnerable to the impacts of climate change, such as extreme heat, drought, feed and water scarcity, and the emergence of new disease agents [1,2]. This dual role creates a fundamental climate policy challenge, as efforts to reduce GHG emissions from LS must be balanced against the sector's social, nutritional, and economic importance. Consequently, simple sectoral restrictions or elimination strategies are neither practical nor socially acceptable, thus, effective climate action requires integrated and adaptive governance approaches.

The Paris agreement (PA), adopted in 2015, represents a significant transformation in global climate governance through the establishment of a universal framework aimed at limiting global warming and enhancing resilience [4]. The Agreement established a collective goal to limit the rise in global average temperature to well below 2°C above pre-industrial levels, while pursuing efforts to limit warming to 1.5°C [4]. To support this objective, global GHG emissions are expected to peak rapidly and decline substantially over the coming decades. The agreement emphasizes three central pillars including transparency, mitigation, and adaptation, which are very important to livestock policies. Transparency provides a means of accountability through improved monitoring and reporting mechanisms; mitigation seeks to reduce and remove GHG emissions; and adaptation increases resilience to the impacts of climate change that we will be unable to avoid.

Following the adoption of the PA, the global climate community increasingly recognized agriculture and livestock as key sectors for achieving climate objectives. Several important milestones reflect this evolution. The Koronivia joint work on agriculture (KJWA), established at conference of the parties (COP), COP 23 in 2017, represented the first formal process under the United Nations framework convention on climate change (UNFCCC)

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dedicated specifically to agriculture [5,6]. Following this initiative, the Sharm el-Sheikh joint work on implementation of climate action on agriculture and food security (SJWA), established at COP 27, expanded the operational focus toward implementation and food system resilience [7]. More recently, the COP 28 UAE, declaration on sustainable agriculture, resilient food systems, and climate action demonstrated the increasing political recognition of the need to transform agri-food systems as part of the global climate response. At COP 29, hosted by Azerbaijan, attention also turned to the nation's expanded involvement in the global transition toward sustainable energy, driven by its strategic focus on renewable resources such as wind, solar, and hydropower. Together, these milestones demonstrate gradual progress, although agriculture and livestock remain insufficiently integrated into international climate governance. The private sector has increasingly adopted environmental, social and governance (ESG) frameworks to evaluate, manage, and disclose climate-related risks and opportunities [8,9]. First introduced through a United Nations initiative in 2004, ESG has become a widely recognized framework for sustainable finance and corporate governance. ESG frameworks offer practical mechanisms for the assessment of climate-related risks, sustainability performance, and corporate accountability and influence investment decisions, supply chain practices, and institutional strategies [10].

Despite the growing convergence between PA objectives and ESG frameworks, substantial gaps remain. The LS continues to be underrepresented in many nationally determined contributions (NDCs), while agricultural mitigation targets often remain less ambitious than scientific recommendations. In addition, inconsistencies in emissions accounting methodologies, limited technological accessibility, inadequate financial support, and governance fragmentation continue to hinder effective climate action in the LS. Furthermore, critical social dimensions such as food security, rural employment, consumer behavior, animal welfare, and a just economic transition, receive limited attention within both climate policies and ESG frameworks.

The concept of a just transition (JT) has therefore gained importance within climate governance. A JT recognizes that the climate transition must minimize social and economic disruption and protect fairness, inclusivity, and resilience for affected communities [11]. In the LS, this requires a balance between emission reduction objectives and livelihood protection, food system stability, and rural development needs. However, the practical integration of JT principles into livestock-related climate policies and ESG frameworks remains limited. This practical gap also appears in the review literature. Existing reviews usually treat these three topics separately. Climate policy reviews focus on NDCs and mitigation targets without considering private-sector ESG mechanisms. ESG analyses examine corporate ratings and finance but rarely link them to national climate commitments or rural livelihood impacts. JT

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literature discusses social equity in energy and agriculture but does not connect it to livestock-specific ESG accountability or PA transparency requirements. This review contributes an integrated analytical framework that shows how these three governance layers, the PA, ESG, and JT, interact, where they disconnect, and what this means for livestock climate action. It offers a conceptual foundation for researchers, policymakers, and industry stakeholders working to align national climate targets, corporate sustainability practices, and social equity measures in the LS.

The remainder of this review is structured as follows. Section 2 examines the PA's core mechanisms, including transparency, mitigation, and adaptation, and traces livestock's evolving representation within UNFCCC negotiations and NDCs. Section 3 evaluates ESG frameworks and their current application in the LS. Section 4 examines JT principles, implementation challenges, and behavioral dimensions in agriculture. Section 5 maps the linkages and disconnects between PA and ESG frameworks in supporting a livestock JT. Section 6 discusses the major challenges limiting their alignment. Section 7 presents future perspectives and concluding recommendations.

This review followed a narrative rather than systematic approach. Key policy and technical documents were identified from major institutional sources, including the UNFCCC, food and agriculture organization (FAO), intergovernmental panel on climate change (IPCC), and the GHG protocol, and citation chaining from these sources was used to identify related peer-reviewed literature. The review covers material published between 2015, the year the PA was adopted, and 2026. Sources were included if they directly addressed the PA, ESG frameworks, JT, or LS climate policy; sources limited to non-livestock agricultural sub-sectors, or lacking a clear connection to climate governance, mitigation, or adaptation, were excluded.

2. The Paris agreement and livestock

2.1. Key goals and structure of the Paris agreement

The PA sets out a series of core provisions that frame and guide international climate action [4]. Article 4 constitutes the foundation of the mitigation framework and obliges parties to develop, communicate, and periodically update successive NDCs that reflect their highest feasible level of ambition [4]. Article 7 establishes the global goal of adaptation, with the objectives of strengthening adaptive capacity, enhancing climate resilience, and reducing vulnerability to the adverse impacts of climate change [4]. Critically, Article 13 establishes an enhanced transparency

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framework (ETF) to build mutual trust and confidence by requiring countries to regularly report their emissions, progress toward NDCs, and the support provided or received [4].

2.2. Transparency

Transparency is a foundational component of the PA, referring to both the reporting of climate-related actions and circumstances, such as national GHG inventories, policies, and climate finance, and expert review of this information to ensure that countries comply with international rules [12].An effective transparency framework builds mutual trust among parties and strengthens confidence in the accuracy and reliability of the reported GHG data, which is essential for coordinated global efforts to avert dangerous climate change [12]. For the system to function, countries must trust that others fulfill their commitments, and the international community must ensure the quality of the information submitted. Because accurate measurement depends on adequate reporting, it is important to understand the core reporting obligations under the PA and the types of information subject to review. These include national GHG inventories, information used to track progress toward NDC implementation, reports on support provided by developed countries, and assistance requested by developing countries that need capacity-building support. A clear understanding of these requirements and how they differ from existing reporting practices, clarifies the new challenges that countries face in the biennial transparency report review process.

2.3. Mitigation

Mitigation includes actions that reduce the impacts of climate change, mainly through lower GHG emissions and greater removal from the atmosphere. Mitigation is a central priority in developed countries because of their large contribution to global emissions. Efforts have typically focused on sectors and regions that have the greatest influence on global emission levels. Although the removal of emission sources can be an effective mitigation strategy, this approach is not feasible for the LS, as it would require the removal of animals, an option that is neither practical nor socially acceptable. Livestock remains essential for nutrition, rural livelihood, food security, and community resilience [2]. Globally, animal-sourced foods account for about 34% of total protein intake by humans [3]. Moreover, ruminants can convert non-edible or indigestible feedstuffs into nutrient-rich foods. For example, research from North America has shown that dairy cattle fed leftovers or non-edible human food can produce a net gain of human-edible nutrients through milk [13].

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Improved productivity of natural resources is essential to meet food production demands and support environmental objectives. Dietary interventions are widely recognized as the most effective way to reduce CH_4 emissions from enteric fermentation. These strategies include better forage quality, optimized forage-to-concentrate ratios, targeted supplementation, and changes to carbohydrate composition [14]. Such approaches have consistently reduced CH_4 emissions in various regions, especially when more digestible grain-based diets have replaced conventional low-digestibility forage [15]. Additionally, certain feed additives reduce CH_4 formation through suppression of the growth of methanogenic microbes. This can be achieved through anti-methanogenic compounds, such as antibiotics, which diminish methanogen populations, or through electron acceptors such as nitrate salts [16]. Housing design, manure management systems, and post-collection treatment practices also significantly influence emissions of ammonia and GHGs from LS [17]. Mitigation options for stored manure typically involve reduced storage duration, enhanced aeration and pile management, and limitation of the time available for microbial decomposition before the manure is applied to agricultural land [17]. The improvement of animal nutrition via grazing management may also be infeasible in regions with poor pasture quality, which necessitates the use of preserved forage or concentrate [18,19].

2.4. Adaptation

Adaptation in this context refers to the process by which ecological, social, and economic systems are adjusted to cope with the observed or expected climate variability and its related effects [20]. These adjustments involve changes to processes, practices, and structures to reduce harmful effects or take advantage of potential opportunities that arise from climate change. Although climate impacts are global, adaptation is often prioritized by developing countries because they experience significant vulnerability despite their minimal contribution to global GHG emissions. Adaptation measures are typically implemented at the local or regional levels, as they respond to specific conditions and risks faced by communities or ecosystems.

Effective adaptation requires the development and implementation of context-specific strategies to address current and future climate-related risks [20]. As climate impacts vary widely, there is no universal solution; successful adaptation depends on the circumstances of each community, sector, or region. It also requires coordinated efforts across multiple entities, including governments, local communities, civil society, and national, regional, and international organizations. Robust knowledge generation, sharing, and management are essential components of

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successful planning and implementation [20]. More broadly, adaptation means countries anticipate and prepare for the adverse effects of climate change and maximize the benefits that may emerge [21]. In contrast, mitigation aims to reduce the severity of climate change through lower GHG emissions or greater removal of these gases from the atmosphere through sequestration [21].

Adaptation to climate change requires a dual response including management of long-term effects on infrastructure and resilience to acute and extreme weather events [22]. The key goals of infrastructure adaptation include reduced exposure and vulnerability, continued functionality of critical systems, and greater resilience of cities and communities, particularly marginalized populations. Climate-resilient infrastructure helps protect lives and livelihoods and reduces direct losses from extreme weather [23].

Precision livestock farming tools including AI-driven heat stress monitoring systems, automated disease surveillance, and automated feeding systems allow producers to detect and respond to environmental and health challenges in real time, improving both animal welfare and production efficiency [24,25]. The World Economic Forum reported that digital technologies can automate and greatly improve the efficiency of industrial, manufacturing, and agricultural processes. AI-based systems could cut global emissions by 4% by 2030 [26]. The main mitigation and adaptation strategies discussed are summarized in Table 1.

2.5. The progress of agriculture in the UNFCCC negotiation

In 2017, at the 23rd session, the COP adopted the KJWA, which called for the joint consideration of agricultural issues through workshops, expert dialogues, and technical exchanges [5] (Fig. 1). The decision recognized the interconnected nature of climate change, agriculture, and food security and identified several thematic areas for further research: (a) methods for assessing adaptation, adaptation co-benefits, and resilience; (b) soil carbon enhancement, soil health, and soil fertility in grasslands, croplands, and integrated systems, including water management; (c) improved nutrient use and manure management; (d) enhanced livestock management sectors; and (e) socioeconomic and food security dimensions of climate change in the agricultural sector [6]. A Koronivia roadmap was established to guide the in-session workshops held between 2018 and 2020 [39]. These workshops provided valuable insights into the latest agricultural research, national circumstances, realities of farmers, and emerging challenges and opportunities for climate action in agriculture and food security. The roadmap also created a practical foundation for using these technical findings [40].

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At COP 27, parties adopted the SJWA, which advanced the outcomes of the KJWA. The SJWA aims to operationalize these outcomes while reaffirming the central importance of food security, the need to end hunger, and the vulnerability of global food production systems to climate impacts [7]. Importantly, SJWA recognizes that sustainably managed LS contribute significantly to adaptation and resilience, offering benefits such as food security, livelihood support, nutrient cycling, and carbon management. It further emphasizes the role of improved animal health, sustainable production, emission reduction from livestock, and enhanced carbon sequestration in grazing systems as pathways for aligning livestock with long-term climate goals. The SJWA includes a new roadmap outlining in-session workshops. The first workshop, held during the 62nd subsidiary body meetings in June 2025, focused on systemic and holistic approaches for integrating climate action into agriculture, food systems, and food security planning.

2.6. Current status of livestock in NDCs

Recent iterations of NDCs have shown a shift from the early practice of subsuming livestock, within the broad categories of agriculture or LULUCF (the land use, land use change, and forest), toward a more explicit recognition of the dual role of the sector in climate action. Many countries now acknowledge livestock as both a major source of GHG emissions especially CH_4 from enteric fermentation and a sector highly vulnerable to climate impacts. Notably, 53% of parties include livestock-related transformational adaptation measures, which signal growing awareness of its importance for food security and rural livelihoods [41]. Adaptation strategies commonly cited in the NDCs include the development of drought and heat tolerant breeds, improved water use efficiency in feed production, stronger veterinary services to address shifting disease vectors, and integrating climate-risk management tools. Frequent reference to sustainable and regenerative LS also reflects the ambition to enhance resilience and deliver environmental co-benefits, such as soil carbon sequestration and biodiversity protection [42]. However, these measures are often presented as priorities rather than as quantified or binding commitments, which makes progress hard to assess.

In contrast to adaptation planning, mitigation ambitions in the LS remain limited, which reveals a persistent gap between scientific recommendations for rapid reductions in non-CO_2 emissions and the commitments proposed in NDCs. Historically, livestock emission mitigation has largely been captured indirectly through economy-wide targets or bundled with broader LULUCF actions, particularly through efforts to curb the deforestation linked to

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pasture expansion [43]. Consequently, few countries have established standalone, measurable targets to reduce CH_4 or N_2O emissions from LS. Even in the updated NDCs, mitigation commitments tend to remain general and reflect concerns about food security, development priorities, and political feasibility.

A smaller but expanding group of countries has begun to articulate more direct livestock mitigation strategies. These include the promotion of improved feed formulations and dietary additives such as inhibitors that reduce enteric CH_4, the expansion of anaerobic digestion to capture CH_4 from manure and higher productivity per animal to reduce emissions intensity [43,44]. Despite these advances, overall ambition remains conservative, and most NDCs lack quantified livestock-specific GHG reduction targets or clear pathways for implementation. This livestock mitigation commitment gap suggests that, although countries now recognize the importance of this sector, they have yet to fully use its mitigation potential within the current NDC frameworks [41]. Table 2 illustrates this variation in ambition across five major livestock-producing countries, comparing whether livestock is explicitly named in the NDC, whether mitigation actions are quantified, whether livestock-relevant adaptation measures are present, and whether a standalone livestock-specific CH_4/N_2O target exists.

Several factors help explain why countries avoid setting explicit livestock mitigation targets in their NDCs. Livestock's importance for food security and rural employment makes explicit targets politically sensitive, governments are often concerned about the economic and social impacts of constraining the sector, and measuring livestock emissions accurately remains technically difficult given variation in breed, feed, and climate [48]. Agriculture and livestock mitigation also continue to receive comparatively limited attention within policy-linked research and NDC design, reinforcing a pattern in which most countries rely on broad, economy-wide targets rather than sector-specific ones [49]. Addressing this gap may require linking quantified sectoral mitigation estimates, such as those demonstrated in Kenya's dairy sector, more directly to national targets and reporting systems [50].

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3. Environmental, social, and governance frameworks and the livestock sector

3.1. The concept of environmental, social, and governance

The concept of ESG criteria emerged as a formalized framework in the 2004 United Nations (UN)-led initiative (the *Who Cares Wins* Report). This initiative was a collaborative effort among financial institutions that encouraged stakeholders to integrate ESG factors into investment analyses and corporate strategies [8]. This marked a shift from niche, value-based investment to a mainstream approach, driven by greater awareness of global challenges,

such as climate change and inequality. Over time, ESG has evolved from a niche investor concern to a central feature of sustainable finance and corporate governance driven by pressure from regulators, stakeholders, and climate risk awareness. Furthermore, ESG has become integral to investment strategies, with a focus on measurable impacts in areas such as diversity, emissions reduction, and ethical leadership. Although ESG is now widely recognized, it has never been defined using a single, universally binding standard. This definitional openness enables its application across diverse sectors and regulatory contexts; however, it has also drawn criticism. Critics point to inconsistencies across ESG rating methodologies, concerns about greenwashing, and a persistent weak link between ESG performance and financial outcomes [9]. This ambiguity is both a strength (adaptability) and weakness (comparability) of the ESG framework.

Despite the rapid growth of ESG-aligned investment, evidence that ESG frameworks have delivered measurable emission reductions in the LS remains limited. Most ESG ratings rely on self-reported corporate data with weak independent verification at the farm level. Because livestock supply chains are highly fragmented and CH_4 measurement is technically demanding, companies can achieve high ESG scores without demonstrating actual reductions in enteric or manure CH_4. This creates a credibility gap: ESG may function as a disclosure tool rather than a driver of decarbonization. Unless rating methodologies incorporate livestock-specific CH_4 metrics and third-party verification of farm-level data, ESG risks becoming a form of greenwashing in the LS.

3.2. Environmental, social, and governance performance in the livestock sector

The LS poses major environmental risks, primarily because of its contribution to global GHG emissions and extensive land and water use. Ruminant livestock emit large quantities of CH_4 through enteric fermentation, which makes the sector one of the largest agricultural sources of CH_4 emissions [2]. Feed production particularly soy and pasture expansion, is a well-documented driver of deforestation and biodiversity loss in regions such as the Amazon and Cerrado [51,52]. In addition, livestock and feed systems require large freshwater inputs and generate nutrient-rich waste, which can lead to water pollution and eutrophication when poorly managed [53]. These broad and systemic environmental pressures make it difficult for the sector to demonstrate credible mitigation and responsible land-use practices.

Social and governance concerns stem largely from animal welfare issues, labor conditions, and weak oversight across fragmented supply chains. Animal welfare remains a persistent public concern and many companies

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struggle to ensure consistent welfare standards across geographically dispersed suppliers [54]. Social risks also include labor safety, low-wage conditions, and community impacts linked to feed production and large-scale LS [55]. Governance challenges arise because livestock supply chains from feed cultivation to final processing are highly complex and opaque, which makes it hard to trace inputs or confirm that production practices comply with environmental and ethical norms, including the avoidance of feed sourced from illegally deforested areas [56]. Across the ESG pillars, the core constraints are insufficient supply chain transparency and inconsistent data reporting. The global LS includes millions of small producers, multiple intermediaries, and heterogeneous production systems, resulting in a lack of standardized, reliable, and farm-level information on emissions, land-use practices, and animal welfare conditions [57]. This fragmentation limits comparability and undermines the ability of investors to differentiate between high performing and poorly performing producers [54]. Consequently, financial institutions face heightened uncertainty and often hesitate to invest in sustainable LS, thereby slowing the transition toward lower-emissions, deforestation, and socially responsible production systems [56].

4. Just transition and social equity in the livestock sector

4.1. Conceptual framework of just transition

The concept of a JT is frequently described using justice theory ("why") and governance theory ("how"). Transition theory focuses on understanding how and when systems undergo significant changes and emphasizes the mechanisms that mobilize these transformations. Scholars now consider justice as a necessary condition for transformative change to occur [58].

Fundamentally, a transition recognizes that achieving timely reductions in climate emissions inevitably results in losses that must be accounted for and prevented, alleviated, or compensated when sufficiently severe [59]. This approach often focuses on issues related to labor, energy, and climate justice [60]. Transformative solutions to climate change require transforming the way the problem is defined and conceptualized, emphasizing humility in valuing science and technology as solutions to global inequity.

4.2. Policy implementation challenges in just transition

The adoption of the PA necessitates a JT as it generates new opportunities while mitigating the losses associated with breaking the "carbon lock-in" and transforming all economic sectors [11]. To support this, several

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298 countries have adopted national JT initiatives that incorporate a range of policy instruments, including governance,
299 social support, workforce development, and financing [61].

300 However, the pursuit of justice is complicated by gaps in implementation. Despite these national initiatives,
301 global economic stimulus remains dominated by fossil fuel investments [62]. The political tendency to invest in the
302 fossil fuel economy accelerates future environmental injustice. This financial misalignment confirms that the failure
303 to align capital allocation with institutional justice mandates, such as those articulated in the PA, guarantees increased
304 future social injustice, leading to stranded assets, economic losses, inequality, and continued growth in emissions.

305 ## 4.3. Enabling just transition

306 The agricultural sector presents unique challenges and opportunities for a JT, with the potential for high job
307 multipliers and social benefits [63]. In agriculture, JT must aim to build a resilient and sustainable food system that
308 supports all communities and ecosystems, so that it can cope with future climate impacts [64]. This requires a shift
309 from the intensive industrial-agricultural system, which both fuels the climate crisis and leaves food systems
310 vulnerable, to one that supports farmers, local knowledge, and sustainable practices [65].

311 Supporting smallholders through this transition requires concrete policy instruments rather than principles
312 alone. These include social protection measures, support for climate-resilient farming practices, water infrastructure,
313 climate information services, concessional finance, and targeted income support, since evidence from smallholder
314 systems indicates that adaptive capacity rises as financing gaps close [66]. The JT frameworks in agriculture
315 increasingly draw on social-law approaches to formalize protections for farmers and farmworkers during the transition
316 [67], and recent livestock-specific analyses argue that current transition frameworks still under develop the position
317 of smallholders relative to large commercial producers [68].

318 ### 4.3.1. Behavioral nexus and socio-cultural impacts

319 Most climate adaptation plans require stakeholders to change their behavior as part of efforts to build
320 resilience [69]. A key element of low-carbon transitions in industrial food systems is the shift toward plant-based diets
321 [70]. This shift requires major changes in supply chains and cultivated crops, which in turn affects employment and
322 work within the agriculture and food industries [71]. The implications extend to the consumer level, where changes
323 in dietary habits are interlinked with socio-cultural valuations, conceptions of eating well, and the capacity of
324 individuals to change their practices and still maintain good nutrition [72]. For instance, significant sex disparities in

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the consumption of and attitudes toward red and processed meat imply that dietary shifts affect different consumer groups differently.

Beyond individual dietary choice, the climate relevance of this shift is substantial: unabated livestock production alone could consume an estimated 37–49% of the remaining global GHG budget compatible with 2 °C and 1.5 °C pathways by 2030, underscoring why dietary change is a matter of climate policy rather than consumer preference alone [73].

4.3.2. Stakeholder engagement

Effective stakeholder engagement and partnerships are closely linked to successful transitions and reflect a gradual increase in engagement through information, consultation, and involvement. For the food supply chain to become more environmentally sustainable and potentially slightly more expensive, consumers must perceive the multiple positive changes this brings, rather than remaining unaware of the industrial-scale mass production driving 'cheap' food [74]. Nurturing relationships and communicating policy initiatives using appropriate language are vital because food has a deep cultural resonance, and superficial conversations focusing solely on affordability can discount the connection people have to places where food is grown and reared [59]. Increased scholarly attention should focus on merging the priorities of downsizing unsustainable consumption and production practices with a core focus on labor and community rights [75].

Implementation of these shifts also faces socio-political resistance, including farmer protests and pressure to roll back environmental policy where it lacks a credible social dimension, reinforcing the need for transition frameworks that combine environmental ambition with formal protections for farmers and farmworkers [76].

5. Linkages between Paris agreement and ESG

ESG frameworks provide a vital bridge between corporate and financial activities and Paris goals by translating climate and social objectives into operational metrics upon which investors and firms can act (Table 3). Figure 2 presents a conceptual linkage framework that maps how the PA, ESG, and JT intersect within LS. The framework shows three operational pathways: (i) the PA provides the regulatory architecture (NDCs, ETF, Article 6); (ii) ESG translates these into private-sector mechanisms (disclosure, finance, governance); and (iii) JT ensures that mitigation and adaptation do not disproportionately harm smallholders and rural workers. These pathways are not yet fully connected in practice, which is the central challenge addressed in this review. ESG has become a tool for

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internalizing parts of the Paris framework into corporate strategies. First, the "E" component of ESG explicitly captures climate-related risks and opportunities, emissions, carbon footprint, transition pathways, and physical climate exposure. ESG assessments that align with the 1.5 °C or below 2 °C thresholds help capital flow toward decarbonizing sectors and away from "high-carbon stranded assets." For example, in Kenya's dairy sector, improved forage quality has been shown to reduce emission intensity by 26–31%, while covered manure management reduced manure emissions by 68%, illustrating how a quantified farm-level mitigation gain can, in principle, be reported through ESG channels and linked to national NDC accounting [50].

Embedding ESG considerations into financial decision-making and corporate operations enables the mobilization of substantial private sector capital required to meet the climate finance objectives of the PA. The PA emphasizes that developed countries should provide resources (financial, technical, and capacity-building) and encourage the mobilization of private investment alongside public funding. Through ESG-informed investment decisions, private investors direct funding toward clean energy, low-emission infrastructure, climate resilience initiatives, and transition activities that align with NDCs [9] (Fig. 2). In this way, ESG helps operationalize the financial and investment logic of the PA at the micro (firm or fund) level.

Concrete cases illustrate how these pathways can operate in the LS. In Korea, the transition to updated IPCC inventory guidelines for livestock GHG accounting illustrates a disclosure pathway linking national ETF reporting to sector-specific data [76]. In Scotland, adoption of precision livestock farming technologies in beef production illustrates a measurable emissions-reduction pathway that can generate verifiable ESG-relevant data [25]. Proposed LS climate finance mechanisms in Africa illustrate a capital-allocation pathway connecting international climate finance to smallholder-relevant investment [77]. Silvopastoral systems integrated into REDD+ activities under PA Article 6 illustrate a land-use integration pathway linking carbon markets to livestock landscapes [78].

ESG encourages accountability, transparency, and long-term orientation, which are central to the iterative ratcheting mechanism of the PA. The cycles of enhanced ambition and global stocktaking of the agreement rely on tracking, reporting, and peer review. Climate-related ESG reporting frameworks reinforce transparency through greater visibility, quantification, and accountability of corporate climate actions [10]. This overlap allows the principles of the PA to be put into practice within corporate governance systems and financial markets.

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From an investor perspective, the mitigation options summarized in Table 1 can be recast as measurable ESG indicators: institutional investors weight GHG emissions, pollution and waste management, and risk-and-opportunity management heavily in ESG assessment, while lenders increasingly require clearly defined KPIs for financing decisions [79]. Sustainability reporting mandates similarly shape how such indicators are disclosed and verified [80]. However, most ESG frameworks still lack livestock-specific CH_4 metrics, so the link between technical mitigation options and ESG-informed investment decisions remains only partially operationalized in practice.

5.1. Achieving just transition in the livestock sector through Paris agreement and ESG

The environmental, social, and governance risks affecting the LS, including supply-chain traceability and data-reporting limitations, are discussed in detail in Section 3.2. The present section focuses specifically on how the three ESG pillars align with the corresponding objectives of the PA. The environmental component of ESG is directly aligned with the core targets of the PA, which focuses on mitigation and adaptation. However, this alignment remains incomplete in the LS because most ESG frameworks do not yet require livestock-specific CH_4 disclosure or independent verification of farm-level data [81]. Therefore, corporate ESG information cannot yet be reliably aggregated into national ETF reporting. Organizations committed to environmental sustainability aim to reduce GHG emissions, enhance energy efficiency, and promote the deployment of renewable energy sources, which are fundamental to the achievement of NDCs. Investors who prioritize environmental criteria tend to favor companies with low-carbon strategies that directly support climate goals [79,82].

The social dimension ensures that the transition to a low-carbon economy is inclusive and addresses concerns such as fair labor practices, community engagement, and stakeholder inclusion. The PA emphasizes that climate policies must not adversely affect vulnerable communities and that social equity must be embedded within sustainable development strategies. Companies that integrate social responsibility foster stakeholder trust and resilience, which are key to long-term climate resilience and attainment of the PA objectives [60].

Governance provides a central link between ESG and the PA by supporting transparent reporting, accountability, and climate-related decision-making. Robust governance helps organizations incorporate climate risks and opportunities into corporate strategies, risk assessments, and disclosures [10,76]. However, inconsistent ESG methodologies and the absence of livestock-specific standards limit the comparability of corporate performance with

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national climate commitments [81,83,84]. Stronger governance and reporting systems are therefore needed to connect corporate ESG actions with national transparency and accountability requirements. Table 4 summarizes the alignment of the environmental, social, and governance dimensions with the PA and just-transition objectives.

6. Challenges

The main challenge is to connect the PA and ESG, especially in the LS, because they work at different levels. The PA sets national goals, while ESG works at the company level. Since the LS is rarely included in NDCs, there is a gap between what science recommends and what national policy requires. ESG frameworks therefore need to be flexible enough to fit local conditions but must also help cut emissions globally. Effective plans for mitigation or adaptation also depend on reliable data, but companies often find it hard to get accurate and consistent data from their supply chains. Differences in how companies report ESG add to this problem. A closer match between ESG reporting and the PA's transparency framework (ETF) could make national reports easier to compare. These challenges and proposed directions are summarized in Table 5.

Despite growing policy attention, three critical gaps limit climate action in the LS. First, the PA and ESG frameworks operate in parallel but not together. The PA asks countries for national targets, yet most NDCs lack livestock-specific mitigation commitments. At the same time, ESG relies on voluntary corporate reporting with no standard CH_4 metrics, making it impossible to compare company data with national inventories. This creates a gap between national promises and private-sector action. Second, ESG credibility in livestock remains weak. Rating methods differ across agencies, supply chain traceability is poor, and there is little proof that higher ESG scores have reduced actual livestock emissions. Without reliable farm-level data, ESG may become greenwashing rather than real progress. Third, JT is discussed widely but applied narrowly. Current frameworks focus on large commercial farms and offer little practical support for smallholders, who risk being left behind. To close these gaps, future work must harmonize ESG reporting with the PA's enhanced transparency framework, build standard livestock emission factors, and design transition policies that protect rural livelihoods while cutting emissions. Without these steps, the LS cannot make a fair or effective contribution to the 1.5 °C goal.

A major barrier to the alignment of corporate ESG reporting with national climate goals is the absence of enforceable mitigation obligations for the LS in NDCs of most countries. Although the PA sets a collective objective

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to limit global warming and requires countries to outline their contributions, it does not prescribe sector-specific mandates for CH_4 or livestock emissions [4]. Consequently, although livestock is a dominant emitter of agricultural CH_4 globally [2], many national policies still lack binding requirements for producers and meat or dairy companies. This creates a disconnect, in which companies rely on voluntary ESG targets that rarely match the ambition or methodological rigor required to make a meaningful contribution to national or global climate goals [81,83,84].

Serious gaps in data and traceability across livestock supply chains further hinder close alignment. Emissions from cattle, feed production, manure management, and land-use change often occur in dispersed and loosely connected production systems, which makes it difficult for companies to obtain accurate, farm-level activity data [85]. Livestock supply chains are among the most complex to monitor, because companies often have little visibility over upstream suppliers, especially smallholders [81]. As a result, methodologies are inconsistent and ESG disclosures incompatible, so governments cannot readily aggregate them into the standardized formats required under the ETF of the PA [81,83,92,94].

To address these challenges, harmonized metrics and reporting systems are needed that directly link corporate disclosures to national inventory accounting under the PA. Standardized measurement approaches such as CH_4 quantification methodologies, emission factors, and activity data can ensure that company-level reporting becomes comparable, verifiable, and compatible with the intergovernmental panel on climate change (IPCC) inventory guidelines [2,76]. Furthermore, if ESG reporting was aligned with the structure and requirements of the ETF, corporate mitigation actions could be integrated transparently into national progress tracking, and ESG reporting would shift from a voluntary exercise to a real contribution to national and global climate targets [92,94].

Operational harmonization between climate and ESG reporting requires a common taxonomy, shared definitions, and interoperable indicators across systems, since sustainability-reporting legislation increasingly spans corporate reporting, taxonomy alignment, financial-product disclosure, and bank ESG-risk disclosure in ways that are difficult to navigate without coordination [94]. In the LS, this means aligning CH_4/N_2O accounting methods so that company-level data can feed into national inventories, improving farm-level data collection to close the traceability gap described above, and adopting standard livestock indicators such as CH_4 per kilogram of protein. Government inventory audits and voluntary corporate ESG assessments currently operate under different rules and assumptions, which remains a structural barrier to harmonization in its own right.

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Accountability under the ETF faces major implementation pressures, because heavy reporting demands strain national capacities and can undermine the trust needed for collective global action. Mitigation efforts in the LS are also constrained by social imperatives, including food security and livelihoods, and require strategies that enhance productivity rather than impose trade-offs. These efforts are further challenged by non-technical factors such as economic volatility and animal welfare considerations. Persistent misalignment in financial policy can reinforce environmental injustice and create long-term economic vulnerability [62].

7. Conclusions

The PA and ESG frameworks are very similar even though they have different implementation strategies. The PA represents a global political framework that defines nation's collective ambitions and long-term targets to limit global warming. In contrast, ESG provides mechanisms for the private and financial sectors to assess, manage, and transparently report their contributions toward these global goals. Although these frameworks are designed for different goals (state-level policies versus investment and corporate disclosure), they are focused on the same fundamental goals of reducing climate risk and accelerating transition to a low-carbon economy. This relationship between PA and ESG is complementary, where the PA provides the overall 'why' and global target, and ESG provides the practical 'how' for corporate and investor entities to translate the high-level climate objectives into measurable actions. Standardized ESG frameworks help companies assess and report their contributions to climate goals. As a result, achieving the PA goals increasingly depends on the widespread and transparent use of ESG frameworks across global economies. In the LS, stronger alignment between global climate commitments and ESG frameworks is needed support progress toward PA goals. Although UNFCCC initiatives, such as KJWA, SJWA, have contributed to this effort, several challenges remain. These include limited data traceability, inconsistent emissions reporting, and the absence of livestock-specific mitigation targets in many countries' NDCs. To address these challenges requires better monitoring and reporting systems, stronger coordination between policy and corporate action, and integrated mitigation, adaptation, and transparency measures. These efforts should be implemented within a JT framework that protects food security and supports rural livelihoods. Most NDCs still lack clear, measurable targets for reducing CH_4 from LS, and future NDCs should set stronger, more specific goals. Standardizing how CH_4 is measured and reported would also help make ESG disclosures comparable across companies and countries. Together, these steps would help

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ESG reporting move from a voluntary practice to a real contribution to climate goals. Overall, meeting the 1.5 °C goal depends on reinforcing synergies between transparency, social equity, and robust corporate governance across sectors. Three priorities should guide future action. Policymakers should integrate livestock-specific CH_4 reduction targets into NDCs, incorporate JT measures to support affected workers and smallholders, and adopt harmonized measurement, reporting, and verification protocols that link national ETF reporting to corporate ESG disclosures. Industry should move beyond generic sustainability ratings and adopt sector-specific metrics such as kilograms of CH_4 per kilogram of protein while investing in supply-chain traceability to avoid greenwashing. Researchers should develop region-specific emission factors for IPCC Tier 2/3 inventories, evaluate whether current ESG frameworks actually reduce livestock emissions, and assess which JT policy instruments most effectively include smallholders.

References

1. FAO. Five practical actions towards low-carbon livestock [Internet]. Rome; 2019 [cited 2022 Oct 12]. Available from: https://www.fao.org/policy-support/tools-and-publications/resources-details/en/c/1257346/
2. IPCC. 2019 Refinement to the 2006 IPCC guidelines for national greenhouse gas inventories. 2019.
3. FAO. Livestock solutions for climate change [Internet]. 2010. Available from: https://www.fao.org/gleam/results/en/
4. UNFCCC. The Paris Agreement [Internet]. 2025 [cited 2025 May 9]. Available from: https://unfccc.int/process-and-meetings/the-paris-agreement
5. Ramifehiarivo N, Chevallier T, Defrance D, Brossard M, Chotte JL. Framing the future of the Koronivia joint work on agriculture from science-based evidence. A review. Agron Sustain Dev. 2022;42(5). https://doi.org/10.1007/s13593-022-00835-y
6. UNFCCC. Koronivia joint work on agriculture [Internet]. 2025 [cited 2025 Jun 29]. Available from: https://unfccc.int/topics/land-use/workstreams/agriculture/KJWA
7. FAO. Sharm el-Sheikh joint work on implementation of climate action on agriculture and food security [Internet]. 2025 [cited 2025 Jun 29]. Available from: https://www.fao.org/climate-change/action-areas/climate-negotiations/sharm-el-sheikh-joint-work/en

ACCEPTED

8. IFC Advisory Services in Environmental and Social Sustainability. Who cares wins, 2004–08 [Internet]. Washington (DC): World Bank Group; [cited 2026 Sep 2]. Available from: http://documents.worldbank.org/curated/en/444801491483640669

9. BIAC. The risks of divergence between global ESG reporting standards. Paris, France; 2025 Jul. Report.

10. Sahu AK, Debata B. Firm-level climate risk exposure, ESG disclosure and stock liquidity: evidence from textual analysis. China Account Finance Rev. 2025 ;27(2):181–209. https://doi.org/10.1108/cafr-05-2024-0055

11. Emden J, Ahmad H, Murphy L, Cameron C. Lessons learned: Just transitions from around the world [Internet]. 2020. Report. Available from: www.ippr.org

12. Hanle L, Gillenwater MW. Challenges and proposed reforms to the UNFCCC expert review process for the enhanced transparency framework [Internet]. 2019. Report. Available from: http://www.ghginstitute.org

13. Takiya CS, Ylioja CM, Bennett A, Davidson MJ, Sudbeck M, Wickersham TA, et al. Feeding dairy cows with "Leftovers" and the variation in recovery of human-edible nutrients in milk. Front Sustain Food Syst. 2019 ;3. https://doi.org/10.3389/fsufs.2019.00114

14. Haque MN. Dietary manipulation: a sustainable way to mitigate methane emissions from ruminants. J Anim Sci Technol. 2018. p. 1–10. https://doi.org/10.1186/s40781-018-0175-7

15. Caro D, Kebreab E, Mitloehner FM. Mitigation of enteric methane emissions from global livestock systems through nutrition strategies. Clim Change. 2016;137(3–4):467–80. https://doi.org/10.1007/s10584-016-1686-1

16. Llonch P, Haskell MJ, Dewhurst RJ, Turner SP. Current available strategies to mitigate greenhouse gas emissions in livestock systems: An animal welfare perspective. Animal. 2017;11(2):274–84. https://doi.org/10.1017/S1751731116001440

17. Hristov AN, Oh J, Lee C, Meinen R, Montes F, Ott T, et al. Nutritional and management strategies to mitigate animal greenhouse gas emissions. In: Rumen Nutrition Conference. 2013. p. 90–7.

18. Benoit M, Mottet A. Energy scarcity and rising cost: Towards a paradigm shift for livestock. Agric Syst. 2023. https://doi.org/10.1016/j.agsy.2022.103585

19. Mottet A, de Haan C, Falcucci A, Tempio G, Opio C, Gerber P. Livestock: On our plates or eating at our table? A new analysis of the feed/food debate. Global Food Secur. 2017. p. 1–8. https://doi.org/10.1016/j.gfs.2017.01.001

ACCEPTED

20. UNFCCC. Introduction to adaptation and resilience/loss and damage [Internet]. 2024 [cited 2024 Feb 14]. Available from: https://unfccc.int/topics/adaptation-and-resilience/the-big-picture/introduction

21. EEA. What is the difference between adaptation and mitigation [Internet]. 2024 [cited 2024 Feb 14]. Available from: https://www.eea.europa.eu/help/faq/what-is-the-difference-between

22. Engineer the Future. Infrastructure, engineering and climate change adaptation: ensuring services in an uncertain future. Royal Academy of Engineering; 2011. 107 p.

23. UNDP. Climate resilient infrastructure [Internet]. 2025 [cited 2025 May 19]. Available from: https://www.adaptation-undp.org/climate-resilient-infrastructure

24. Neethirajan S. Digital livestock farming. Sens Bio-Sens Res. 2021;32:100408. https://doi.org/10.1016/j.sbsr.2021.100408

25. McNicol, L., Bowen, J. M., Ferguson, H. J., Bell, J., Dewhurst, R. J., and Duthie, C.-A. (2024). Adoption of precision livestock farming technologies has the potential to mitigate greenhouse gas emissions from beef production. Front Sustain Food Syst. https://doi.org/10.3389/fsufs.2024.1414858

26. World Economic Forum. Harnessing technology for the global goals: a framework for government action. 2021. Report.

27. Hristov AN, Oh J, Firkins JL, Dijkstra J, Kebreab E, Waghorn G, Makkar HP, Adesogan AT, Yang W, Lee C, Gerber PJ. Special topics—Mitigation of methane and nitrous oxide emissions from animal operations: I. A review of enteric methane mitigation options. J Anim Sci. 2013;91(11):5045-69. https://doi.org/10.2527/jas.2013-6583

28. Honan M, Feng X, Tricarico JM, Kebreab E. Feed additives as a strategic approach to reduce enteric methane production in cattle: Modes of action, effectiveness and safety. Anim Prod Sci. 2021;62(14):1303-17. https://doi.org/10.1071/AN20295

29. Olijhoek DW, Hellwing AL, Noel SJ, Lund P, Larsen M, Weisbjerg MR, Børsting CF. Feeding up to 91% concentrate to Holstein and Jersey dairy cows: Effects on enteric methane emission, rumen fermentation and bacterial community, digestibility, production, and feeding behavior. J Dairy Sci. 2022 ;105(12):9523-41. https://doi.org/10.3168/jds.2021-21676

ACCEPTED

30. Xie X, Cao Y, Li Q, Li Q, Yang X, Wang R, Zhang X, Tan Z, Lin B, Wang M. Mitigating enteric methane emissions: An overview of methanogenesis, inhibitors and future prospects. Anim Nutr. 2025;21:84-96. https://doi.org/10.1016/j.aninu.2025.02.001

31. Hou Y, Velthof GL, Oenema O. Mitigation of ammonia, nitrous oxide and methane emissions from manure management chains: a meta-analysis and integrated assessment. Glob Change Biol. 2015;21(3):1293-312. https://doi.org/10.1111/gcb.12767

32. Montes F, Meinen R, Dell C, Rotz A, Hristov AN, Oh J, Waghorn G, Gerber PJ, Henderson B, Makkar HP, Dijkstra J. SPECIAL TOPICS—Mitigation of methane and nitrous oxide emissions from animal operations: II. A review of manure management mitigation options. J Anim Sci. 2013 ;91(11):5070-94. https://doi.org/10.2527/jas.2013-6584

33. Bashiru HA, Oseni SO. Simplified climate change adaptation strategies for livestock development in low-and middle-income countries. Front Sustin Food Syst 2025;9:1566194. https://doi.org/10.3389/fsufs.2025.1566194

34. Taye T, Vithalrao US, Borah S, Kumar M, Singh AK, MT M, Kanwar BP, Chincholikar M. Scientific advances in climate-resilient livestock production with emphasis on sustainability: a review. J Exp Agric Int. 2025;47(8):744-57. https://doi.org/10.9734/jeai/2025/v47i83716

35. Manyike JZ, Taruvinga A, Akinyemi BE. Mapping the research landscape of livestock adaptation to climate change: a bibliometric review using scopus database (1994–2023). Front Clim. 2025;7:1567674. https://doi.org/10.3389/fclim.2025.1567674

36. Matere J, Simpkin P, Angerer J, Olesambu E, Ramasamy S, Fasina F. Predictive Livestock Early Warning System (PLEWS): Monitoring forage condition and implications for animal production in Kenya. Weather Clim Extrem. 2020;27:100209. https://doi.org/10.1016/j.wace.2019.100209

37. Alemayehu S, Tegegne G, Dejene SW, Tesfaye L, Abdulhamid N, Girvetz E. Harnessing livestock water and pasture monitoring and early warning systems for anticipatory action to strengthen resilience of pastoral communities in Ethiopia: A qualitative multi-stakeholder analysis. Sustainability. 2025 ;17(10):4350. https://doi.org/10.3390/su17104350

ACCEPTED

38. Tua UR, Al Zakir MA, Ghosh PR. Mapping solutions for livestock climate challenges: satellite tech innovations steer through environmental risks. Sci Technol Public Policy. 2025;9(2):117-26. https://doi.org/10.11648/j.stpp.20250902.15

39. Rioux J, Vasileiou I, Burgos S, Wolf J, Drieux E, Kagure L, Bernoux M. Outcomes and lessons learned from the Koronivia UNFCCC negotiations on agriculture and food security, and the way forward after COP 27: brief note [Internet]. Rome: FAO; 2023 [cited 2026 Oct 8]. p. 4. Available from: https://doi.org/10.4060/cc5739en

40. FAO. Outcomes and lessons learned from the Koronivia UNFCCC negotiations on agriculture and food security and the way forward after COP27 [Internet]. 2025 [cited 2025 Jun 29]. Available from: https://openknowledge.fao.org/server/api/core/bitstreams/17f2404f-5c4f-4f33-93fd-7e864850e37d/content

41. UNFCCC. Nationally determined contributions under the Paris Agreement: synthesis report by the secretariat. 2022. Report.

42. FAO. The State of Food and Agriculture 2023: Revealing the true cost of food to transform agrifood systems. The state of food and agriculture 2023. Rome: FAO; 2023. https://doi.org/10.4060/cc7724en

43. Griscom BW, Adams J, Ellis PW, Houghton RA, Lomax G, Miteva DA, et al. Natural climate solutions. Proc Natl Acad Sci U S A. 2017;114(44):11645–50. https://doi.org/10.1073/pnas.1710465114

44. Coalition UNEP and C and CA. Global methane assessment: Benefits and costs of mitigating methane emissions [Internet]. Nairoby: United Nations Environment Programme; 2021. 173 p. Available from: https://www.unep.org/resources/report/global-methane-assessment-benefits-and-costs-mitigating-methane-emissions

45. Rose S, Khatri-Chhetri A, Dittmer K, Stier M, Wilkes A, Shelton SW, Arndt C, Wollenberg EK. Livestock management ambition in the new and updated nationally determined contributions: 2020-2021: Analysis of agricultural sub-sectors in national climate change strategies. https://cgspace.cgiar.org/server/api/core/bitstreams/95318160-38dd-4b4d-92f3-9decd0e08533/content

46. Dittmer, K.M., Khatri-Chhetri, A., Rose, S., Stier, M. and Wollenberg, L., 2024. Agriculture sub-sectors in the NDCs: 2020-2024 Data & Maps. CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS). Available at: https://ccafs.cgiar.org/resources/tools/agriculture-in-the-ndcs-data-maps-2021 [Accessed 1 June 2026].

ACCEPTED

47. Trung ND, Thang NT, Anh LH, Babu TA, Sebastian L. Analysing the challenges in implementing Vietnam's Nationally-Determined Contribution (NDC) in the agriculture sector under the current legal, regulatory and policy environment. Cogent Environ Sci. 2020 ;6(1):1792670. https://doi.org/10.1080/23311843.2020.1792670

48. Hood, C., and Soo, C. (2017). Accounting for mitigation targets in Nationally Determined Contributions under the Paris Agreement. https://doi.org/10.1787/63937a2b-en

49. Kilemo, D. (2025). Linking climate change research to the Paris agreement and NDCs: evidence from agriculture and livestock sectors in East Africa. Int J Environ Prot Policy. https://doi.org/10.11648/j.ijepp.20251305.13

50. Brandt P, Herold M, Rufino MC. The contribution of sectoral climate change mitigation options to national targets: a quantitative assessment of dairy production in Kenya. Environ Res Lett. 2018;13(3):034016. https://doi.org/10.1088/1748-9326/aaac84

51. FAO and UNEP. The State of the world's forests 2020: Forest, biodiversity and people. FAO and UNEP; 2020. https://doi.org/10.4060/ca8642en

52. Pacheco P, Mo K, Dudley N, Shapiro A, Aguilar-Amuchastegui N, Ling PY, et al. Deforestation fronts: Drivers and responses in a changing world. 2021. Report.

53. FAO. FAO Livestock environmental assessment and performance partnership. 2024. Report.

54. OECD-FAO Business handbook on deforestation and due diligence in agricultural supply chains [Internet]. Paris: OECD Publiaher; 2023. https://doi.org/10.1787/c0d4bca7-en

55. ILO. Safety and health in agriculture: ILO code of practice. International Labour Office; 2011. 327 p.

56. WRI. Creating a sustainable food future: a menu of solutions to feed nearly 10 billion people by 2050 [Internet]. 2019. Report. Available from: www.sustainablefoodfuture.org.

57. UNEP FU. Rethinking our food systems: a guide for multi-stakeholder collaboration. Rethinking our food systems: a guide for multi-stakeholder collaboration. Nairobi, Rome, and New York: FAO; UNEP; UNDP; 2023. https://doi.org/10.4060/cc6325en

58. Huttunen S, Tykkyläinen R, Kaljonen M, Kortetmäki T, Paloviita A. Framing just transition: the case of sustainable food system transition in Finland. Environ Policy Gov. 2024 ;34(5):463–75. https://doi.org/10.1002/eet.2096

59. Ciplet D, Harrison JL. Transition tensions: mapping conflicts in movements for a just and sustainable transition. Env Polit. 2020 ;29(3):435–56. https://doi.org/10.1080/09644016.2019.1595883

ACCEPTED

60. Jasanoff S. Just transitions: A humble approach to global energy futures. Energy Res Soc Sci. 2018;35:11–4. https://doi.org/10.1016/j.erss.2017.11.025

61. Tian J, Yu L, Xue R, Zhuang S, Shan Y. Global low-carbon energy transition in the post-COVID-19 era. Appl Energy. 2022 Feb 1;307. https://doi.org/10.1016/j.apenergy.2021.118205

62. De La Peña L, Guo R, Cao X, Ni X, Zhang W. Accelerating the energy transition to achieve carbon neutrality. Resour Conserv Recycl. 2022 Feb 1;177. https://doi.org/10.1016/j.resconrec.2021.105957

63. Climate Justice Alliance. Just transition: a framework for change [Internet]. 2024 [cited 2024 Aug 5]. Available from: https://climatejusticealliance.org/just-transition/

64. Allen S, Smith S, De Wel B, Rosemberg A, Ojo G, Tripathi R, et al. Principles for a just transition in agriculture [Internet]. 2019. Report. Available from: www.NickPurserDesign.com

65. Walawalkar TP, Hermans LM, Evers J. Evaluating behavioural changes for climate adaptation planning. J Environ Plan Manag. 2023;66(7):1453–71. https://doi.org/10.1080/09640568.2022.2028610

66. Ojo, M., Ayanwale, A., Adelegan, O., Ojogho, O., Awoyelu, D. E. F., & Famodimu, J. (2024). Climate change vulnerability and adaptive capacity of smallholder Farmers: A Financing Gap Perspective. Environ Sustain Indic. https://doi.org/10.1016/j.indic.2024.100476

67. Cunniffe E. A just transition for agriculture in the EU? Applying a social law lens to farming. Eur Labour Law J. 2026(1):88-104. https://doi.org/10.1177/20319525251390406

68. Thornton P, Wollenberg E, Cramer L, Flintan F. Options for a just transition for livestock under climate change. Outlook Agric. 2025;54(3):222-33. https://doi.org/10.1177/00307270251365668

69. Springmann M, Clark M, Mason-D'Croz D, Wiebe K, Bodirsky BL, Lassaletta L, et al. Options for keeping the food system within environmental limits. Nature. 2018 ;562(7728):519–25. https://doi.org/10.1038/s41586-018-0594-0

70. Kaljonen M, Kortetmäki T, Tribaldos T, Huttunen S, Karttunen K, Maluf RS, et al. Justice in transitions: Widening considerations of justice in dietary transition. Environ Innov Soc Transit. 2021; 40:474–85. https://doi.org/10.1016/j.eist.2021.10.007

71. Valsta LM, Tapanainen H, Kortetmäki T, Sares-Jäske L, Paalanen L, Kaartinen NE, et al. Disparities in nutritional adequacy of diets between different socioeconomic groups of finnish adults. Nutrients. 2022 ;14(7). https://doi.org/10.3390/nu14071347

ACCEPTED

672 72. Sares-Jäske L, Valsta L, Haario P, Martelin T. Population group differences in subjective importance of meat in
673 diet and red and processed meat consumption. Appetite. 2022;169:105836 https://doi.org/
674 10.1016/j.appet.2021.105836
675 73. Harwatt H. Including animal to plant protein shifts in climate change mitigation policy: a proposed three-step
676 strategy. Clim Policy. 2019;19(5):533-41. https://doi.org/10.1080/14693062.2018.1528965
677 74. Stark A, Gale F, Murphy-Gregory H. Just transitions' meanings: a systematic review. society and natural resources.
678 Routledge; 2023. p. 1277–97. https://doi.org/10.1080/08941920.2023.2207166
679 75. Masud MAK, Sahara J, Maola M, Rahman M. Enhancing ESG performance through corporate governance:
680 insights from emerging markets. Int J Energy Econ Policy. 2025;15(1):47–58.
681 https://doi.org/10.32479/ijeep.17717
682 76. Nugrahaeningtyas E, Lee JS, Lee DJ, Kim JK, Park KH. Impacts of guidelines transition on greenhouse gas
683 inventory in the livestock sector: a study case of Korea. J Anim Sci Technol. 2025;67(2):453-467.
684 https://doi.org/10.5187/jast.2024.e7
685 77. Ndue, K., and Pál, G. (2022). European green transition implications on Africa's livestock sector development and
686 resilience to climate change. Sustainability. https://doi.org/10.3390/su142114401
687 78. Nugrahaeningtyas E, Chun J, Song M, Prasojo YS. Beyond carbon credits: integrating silvopastoral systems into
688 REDD+ activities for Article 6 of the Paris Agreement. Forests. 2026;17:70.
689 https://doi.org/10.3390/f17010070
690 79. Park, S., and Jang, J. (2021). The Impact of ESG Management on investment decision: institutional investors'
691 perceptions of country-specific ESG criteria. Int J Financ Stud. https://doi.org/10.3390/ijfs9030048
692 80. Hummel, K., and Bauernhofer, K. (2024). Consequences of sustainability reporting mandates: evidence from the
693 EU taxonomy regulation. Accounting Forum, 48, 374–400. https://doi.org/10.1080/01559982.2024.2301854
694 81. Gerber R, Smit A, Botha M. An evaluation of environmental, social, and governance reporting in the agricultural
695 sector. Bus Strategy Dev. 2024 ;7(1):e316. https://doi.org/10.1002/bsd2.316
696 82. Krueger P, Sautner Z, Starks LT. The importance of climate risks for institutional investors. Rev Financ Stud.
697 2020;33(3):1067–1111. https://doi.org/10.1093/rfs/hhz137
698 83.Berg F, Kölbel JF, Rigobon R. Aggregate confusion: The divergence of ESG ratings. Rev Financ. 2022;26(6):1315-
699 44. https://doi.org/10.1093/rof/rfac033

ACCEPTED

84. Leffel B, Lyon TP, Newell JP. Filling the climate governance gap: Do corporate decarbonization initiatives matter as much as state and local government policy?. Energy Res Soc Sci. 2024 109:103376. https://doi.org/10.1016/j.erss.2023.103376

85. Dewilde E, Coglan L, Mitchell E, Tucker D, Rowlings DW. Farm-level environmental sustainability in Australia's beef industry: systemic and practical challenges in data collection and reporting. Clean Food Syst. 2026:100038. https://doi.org/10.1016/j.clfs.2026.100038

86. Leahy S, Clark H, Reisinger A. Challenges and prospects for agricultural greenhouse gas mitigation pathways consistent with the Paris Agreement. Front Sustain Food Syst. 2020;4:69. https://doi.org/10.3389/fsufs.2020.00069

87. Hussein J, Bilotto F, Mbui D, Omondi P, Harrison MT, Crane TA, Sircely J. Exploring smallholder farm resilience to climate change: intended and actual adaptation. Pastoralism: Research, Policy and Practice. 2024;14:13424. https://doi.org/10.3389/past.2024.13424

88. Clay N, King B. Smallholders' uneven capacities to adapt to climate change amid Africa's 'green revolution': Case study of Rwanda's crop intensification program. World Dev. 2019;116:1-4. https://doi.org/10.1016/j.worlddev.2018.11.022

89. FAIRR Initiative. Just Transition in Animal Agriculture: Implications, Risks and Opportunities. FAIRR, 2022, https://www.fairr.org/resources/reports/just-transition. Accessed 1 June 2026.

90. Onwezen MC, Nassar G, Bouma JA. Change meat resistance: systematic literature review on consumer resistance to the alternative protein transition. Annual Rev Food Sci Technol. 2025 ;16(1):127-46. https://doi.org/10.1146/annurev-food-111523-121744

91. Wiesli TX. Meat consumption among different social groups and specific options for reducing it: a literature review of empirical research. Front Soc. 2025;10:1547663. https://doi.org/10.3389/fsoc.2025.1547663

92. Dittmer KM, Wollenberg E, Cohen M, Egler C. How good is the data for tracking countries' agricultural greenhouse gas emissions? Making use of multiple national greenhouse gas inventories. Front Sustain Food Syst. 2023;7:1156822. https://doi.org/10.3389/fsufs.2023.1156822

93. Nugrahaeningtyas E, Lee JS, Park KH. Greenhouse gas emissions from livestock: sources, estimation, and mitigation. J Anim Sci Technol. 2024;66(6):1083. https://doi.org/ 10.5187/jast.2024.e86

ACCEPTED

94. Global Environment Facility. 2024. Progress Report on the Capacity-Building Initiative for Transparency. GEF/C.68/Inf.13. November 18, 2024. https://www.thegef.org/sites/default/files/documents/2024-11/EN_GEF_C68_Inf.13_Progress%20Report%20on%20the%20Capacity-building%20Initiative%20for%20Transparency_final%20%281%29.pdf

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Figures

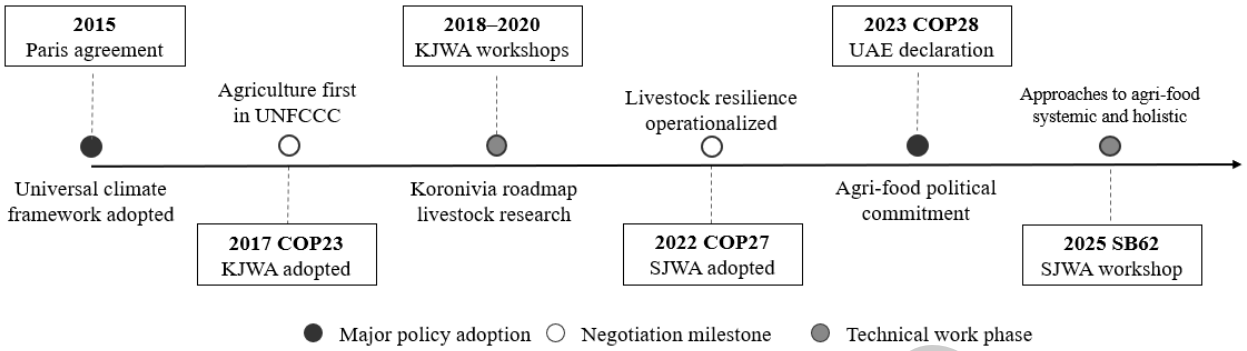


Fig. 1. UNFCCC milestones for agriculture and livestock (2015–present). UNFCCC, United nations framework convention on climate change; COP, Conference of the parties; KJWA, Koronivia joint work on agriculture; SJWA, Sharm el-Sheikh joint work; UAE, United Arab Emirates; SB 62, the 62nd session of the subsidiary bodies.

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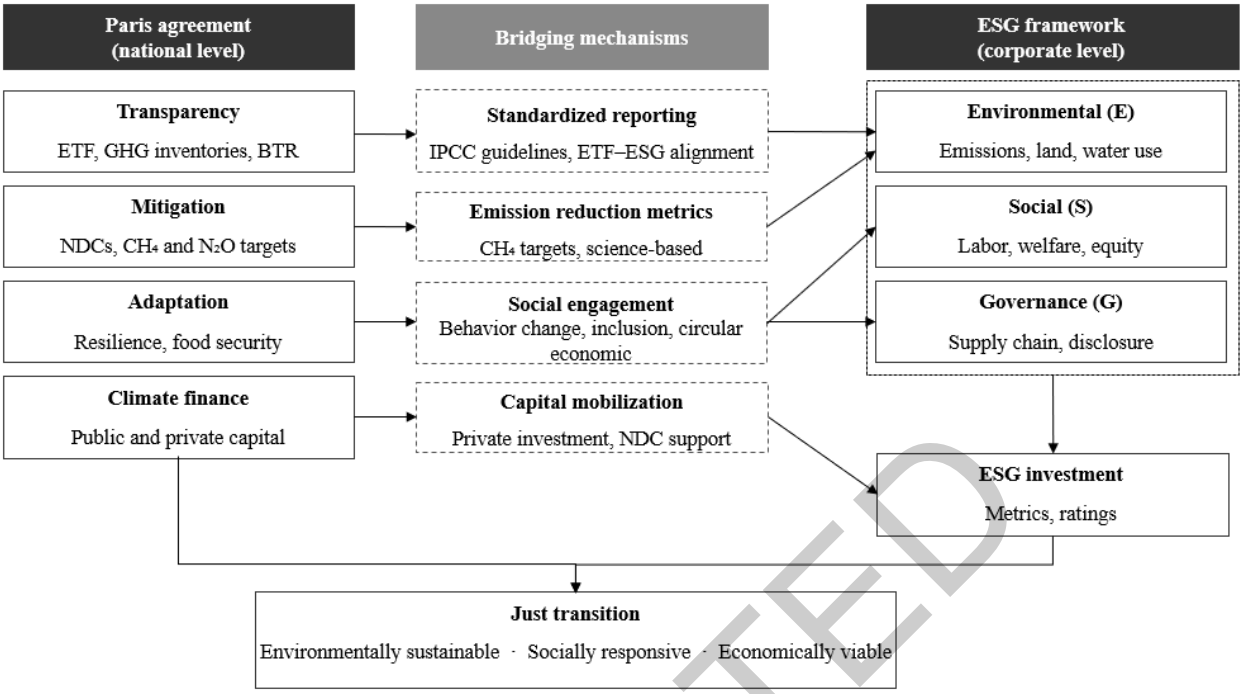


Fig. 2. Conceptual linkage framework between the PA and ESG principles for the just transition pathway. BTR, biennial transparency report; ESG, environmental, social, and governance; ETF, enhanced transparency framework; NDCs, nationally determined contribution; CH_4, methane; N_2O, nitrous oxide; IPCC, intergovernmental panel on climate change.

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Tables

Table 1. Livestock mitigation and adaptation strategies under the Paris agreement framework

Strategy	Category	Main objective	Livestock application	Potential benefits	References
Improving forage quality	Mitigation	Reduce enteric methane emissions	Ruminant feeding	Improved digestibility and lower methane emissions	[14,15,27]
Optimizing forage-to-concentrate ratio	Mitigation	Improve rumen efficiency	Dairy and beef cattle	Reduced methane emissions intensity	[15,27--29]
Dietary supplementation	Mitigation	Modify rumen fermentation	Livestock diets	Improved productivity and methane reduction	[14,27,28]
Methane inhibitors and feed additives	Mitigation	Suppress methanogenic microbes	Intensive livestock sectors	Lower enteric methane production	[16,28,30]
Manure management improvement	Mitigation	Reduce methane and ammonia emissions	Stored manure systems	Lower emissions from decomposition	[17,31]
Anaerobic digestion	Mitigation	Capture methane from manure	Large livestock sectors	Renewable energy generation	[32]
Heat- and drought-tolerant breeds	Adaptation	Increase climate resilience	Vulnerable production systems	Improved adaptation to heat stress	[33,34]
Water-use efficiency in feed production	Adaptation	Improve drought resilience	Feed production systems	Reduced water demand	[29,33]
Livestock sectors strengthening	Adaptation	Address shifting disease vectors	Livestock health management	Improved disease resilience	[33,35]
Climate-risk management tools	Adaptation	Improve preparedness	Livestock production planning	Reduced climate vulnerability	[36,37]
Artificial intelligence-based monitoring and digital technologies	Adaptation and mitigation	Improve efficiency and resilience	Precision livestock sectors	Emission reduction and operational efficiency	[26,34,38]

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Table 2. Comparative assessment of livestock-relevant commitments in selected major livestock-producing countries' NDCs

Country	Livestock explicitly mentioned	Quantified livestock/agriculture mitigation	Livestock-relevant adaptation	Standalone livestock CH_4/N_2O target
Brazil	Explicitly mentioned	Crop–livestock–forestry integration and associated investment [45]	Livestock-relevant measures identified	No explicit target identified
India	Mentioned within the broader agriculture context	No clearly livestock-specific mitigation action identified [45,46]	Livestock-relevant measures identified	No explicit target identified
China	Mentioned within the broader agriculture context	Livestock and poultry manure management [45]	Livestock-relevant measures identified	No explicit target identified
Pakistan	Agriculture mentioned	No clearly quantified livestock-specific action identified [45,46]	Livestock-relevant measures identified	No explicit target identified
Vietnam	Explicitly mentioned	Feed improvement; estimated mitigation potential of 7.90 Mt CO_2-eq [47]	Livestock-relevant measures identified	No explicit target identified

Note: "No explicit target identified" indicates that a standalone livestock-specific CH4 or N2O target was not identified in the NDC reviewed; it does not imply that CH_4 or N_2O is excluded from the country's economy-wide GHG targets. Comparisons are based on the NDC versions reviewed and supporting literature and should not be interpreted as a direct ranking of national climate ambition. Source: NDC content adapted from Rose et al. [45] and Dittmer et al. [46]; methane target analysis based on Trung et al. [47].

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759 **Table 3.** Alignment between ESG framework and the PA in global climate goals

Elements	ESG framework	PA	Cross-cutting or overlap concept
Primary objective	Promote sustainable and ethical corporate performance	Limit global warming below 2°C	Paris-aligned ESG strategies support both corporate sustainability and global climate goals
Scope and focus	Broad issues including ESG	Primarily on climate adaptation, mitigation, and finance	ESG environmental goals align with Paris climate action, while social and governance dimensions support resilience and accountability
Legal nature	Voluntary and no universal binding requirements	Legally binding on signatory countries with flexibility (no enforced target)	Paris-related regulations increasingly influence ESG reporting and corporate accountability
Measurability	ESG ratings	Emission reduction, NDC-progress	ESG metrics increasingly incorporate Paris-aligned to measure corporate contributions to global emission reduction goals.
Impacts	Investment and risk management decisions	Climate policy and regulatory change	PA shapes regulatory and market trends that reinforce ESG's focus on climate risk and opportunities
JT pathway	Focus on inclusion, labor rights, and stakeholder engagement	Supports equitable transition to low-carbon economies	Social responsibility strengthens resilience and supports climate transition goals

760 ESG, environmental, social, and governance; NDCs, nationally determined contributions; PA, Paris agreement; JT: just transition

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762 **Table 4**. Alignment between the Paris agreement (PA), environmental, social, and governance (ESG) frameworks, and

763 just transition (JT) principles in livestock sector (LS)

Dimensions		Context in the Livestock sector
Transparency		
PA	Enhanced transparency framework and biennial transparency reports	Farm-level emissions and supply chain reporting
ESG Framework	ESG disclosure and reporting systems	
JT Principle	Participatory accountability	
Mitigation		
PA	NDCs and GHG reduction	Reduction in GHG emissions from the sources (enteric fermentation and manure management)
ESG Framework	Carbon footprint and climate-risk assessment	
JT Principle	Fair distribution of transition burdens	
Adaptation		
PA	Climate resilience and adaptive capacity	Heat stress and disease management in all practices (rural, small-farming, mid-to-big scale)
ESG Framework	Climate-risk management	
JT Principle	Protection of vulnerable communities	
Finance		
PA	Climate finance mobilization	Support for sustainable LS
ESG Framework	Sustainable investment and ESG financing	
JT Principle	Equitable access to transition support	
Governance		
PA	International reporting and compliance	Enabling decision-making for all types of management practices, supply chain traceability and oversight
ESG Framework	Corporate governance and accountability	
JT Principle	Inclusive decision-making	
Social dimension		
PA	Sustainable development and food security	Rural employment and food system stability
ESG Framework	Labor practices and stakeholder engagement	
JT Principle	Livelihood and rural community protection	

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765 NDCs, nationally determined contributions; GHG, greenhouse gas

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767 **Table 5.** Major challenges and future directions for alignment of PA and ESG in JT of LS

Challenge	Main issue identified in literature	Impact on LS	Potential direction	References
Underrepresentation of LS in NDCs	Limited LS-specific mitigation commitments	Weak mitigation ambition	Development of measurable LS targets	[45-47]
Inconsistent ESG reporting	Lack of harmonized methodologies	Limited comparability and transparency	Alignment with ETF and IPCC guidelines	[76,83]
Weak supply chain traceability	Fragmented production systems	Difficulty obtaining reliable farm-level data	Improved traceability systems	[85,86]
Limited access to mitigation technologies	Financial and technological barriers	Slow adoption of mitigation practices	Climate finance and technology transfer	[87]
Smallholder vulnerability	Unequal adaptive capacity	Risk of exclusion during transition	Inclusive JT	[68,88]
Consumer behavioral barriers	Socio-cultural dietary preferences	Resistance to dietary transition	Stakeholder engagement and education	[89,90]
Governance fragmentation	Weak coordination between national and corporate systems	Reduced policy effectiveness	Harmonized governance frameworks	[91-93]
Capacity constraints in reporting	High reporting burden under ETF	Reduced transparency quality	Capacity building and institutional support	[25,94]

768 PA, Paris agreement; ESG, environmental, social, and governance NDCs, nationally determined contributions; JT, just transition; LS, livestock
769 sector; ETF, enhanced transparency framework. IPCC, intergovernmental panel on climate change.

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