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Assessing Environmental and Social Burdens in Agrifood Systems

Insights from Colombia and Peru

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ABSTRACT

Agrifood systems (AFS) in Colombia and Peru generate substantial economic value but also impose significant environmental and social externalities that remain unpriced and largely invisible in policy and market decisions. Using the Global Impact Database (GID) and a True Cost Accounting (TCA) framework, this paper quantifies the hidden costs embedded in 19 AFS sectors, with a focus on seven major crop sectors. As one of the first cross-country applications of GID data in Latin America, the analysis offers a harmonized and comprehensive assessment of the true costs of food production, processing, and distribution. Results show that externalities are equivalent to 12 percent of AFS output in Colombia and 13 percent in Peru—a substantial burden that is not captured by conventional economic indicators. Environmental externalities dominate in both countries, driven primarily by land occupation, climate change, air pollution, and use of scarce water. Social externalities—especially underpayment, child labor, and gender wage gaps—are smaller in aggregate but become markedly more significant within crop sectors, as labor intensity and informality characterize production systems. Livestock, dairy, and bovine meat products consistently emerge as the most externality-intensive sectors, while cereals, rice, sugarcane, oilseeds, and fruits and vegetables exhibit comparatively lower externality costs. Value-chain decomposition shows that most externalities originate at the production stage (at farm level). These findings highlight several clear leverage points for targeted policy and investment: reducing environmental pressures in livestock systems, improving labor conditions in crop sectors, and integrating TCA metrics into national planning and sustainability strategies. Making the hidden costs visible is essential for advancing more sustainable, equitable, inclusive, and resilient food systems in Colombia and Peru.

Keywords: True cost accounting, externalities, agrifood systems, Colombia, Peru, environmental impacts, social impacts, value chains.

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ACRONYMS

AFS	agrifood systems
ESG	environment, social, and governance
FAO	Food and Agriculture Organization of the United Nations
GDP	gross domestic product
GHG	greenhouse gases
GID	Global Impact Database
ILO	International Labour Organization of the United Nations
ISO	International Organization for Standardization
LCA	life cycle assessment
MRIO	multi-regional input–output
NMVOCs	non-methane volatile organic compounds
PCI	procurement chain impact
TCA	True Cost Accounting
TEEB	The Economics of Ecosystems and Biodiversity
UN	United Nations
UNEP	United Nations Environmental Program
VCI	value chain impact

1. Introduction

Agrifood systems (AFS) are central to economic development, employment creation, and food security across Latin America (TEEB, 2018). In Colombia and Peru, these systems form the backbone of rural economies and play a decisive role in national growth trajectories. Agriculture and food processing together account for a substantial share of GDP, provide livelihoods for millions of rural households, and contribute significantly to export earnings through commodities such as coffee, fruits, vegetables, and fisheries products (UN, 2021). Beyond their economic footprint, AFS shape territorial development, influence dietary patterns, and underpin national strategies for poverty reduction and climate resilience (Wiedmann & Lenzen, 2018). Yet these systems also generate a wide range of environmental and social externalities that remain largely invisible in market transactions and policy debates, despite their importance.

These hidden costs—spanning greenhouse gas (GHG) emissions, land degradation, water scarcity, air pollution, child labor, and wage inequities—undermine long-term sustainability, equity, and productivity (Gemmill-Herren et al., 2021). Because these externality costs are not incorporated into prices or standard economic indicators, producers, consumers, and policymakers often underestimate the true resource use or degradation and social impacts[1] embedded in food production and processing (van den Bergh, 2010). This invisibility leads to systematic underinvestment in sustainable practices, weak incentives for technological upgrading, and persistent overuse of natural and human capital. As a result, AFS may appear more competitive or profitable than they truly are once environmental degradation and social harms are accounted for (Tol, 2018).

A major challenge for policymakers is the lack of robust, comparable tools to quantify the magnitude and distribution of these externalities. Without clear metrics, it becomes difficult to design interventions that internalize external costs—such as targeted subsidies, regulatory reforms, or sustainability standards—

[1] The term *impact* in the True Cost Accounting (TCA) framework should not be interpreted as *causal* impact as it is in economics, since experimental or non-experimental methods are not used to calculate it. In TCA impact must be understood as cost.

without jeopardizing productivity, rural incomes, or export competitiveness (Peters et al., 2011). True Cost Accounting (TCA) has emerged as a promising framework to address this gap by systematically valuing environmental and social impacts in monetary terms and integrating them into economic assessments (TEEB, 2018).

This paper applies the TCA approach to quantify the environmental and social externalities embedded in the AFS of Colombia and Peru. Using the Global Impact Database (GID), one of the most comprehensive datasets available for environmental and social impact valuation to date (Impact Institute, 2025), we estimate monetized externalities (12 external impacts) across 19 AFS sectors, including seven major primary crop sectors. Our analysis provides an estimate of the true costs associated with food production, processing, and distribution in both countries. By doing so, it offers evidence-based insights for policy design, investment prioritization, and broader food systems transformation.

We address five research questions: (1) What is the weight of externalities relative to AFS output? (2) How do environmental costs compare to social externalities? (3) Which sectors generate the highest marginal (per unit) and total external costs? (4) Which cost categories dominate externalities? and (5) How are externalities distributed across value-chain stages? By answering these questions, the paper contributes to the growing literature on TCA and provides one of the first cross-country applications of GID data in Latin America.[2]

The outline for this paper is as follows. The next section presents the conceptual foundations of TCA and its relevance for food systems analysis. This is followed by a detailed description of the data sources and methodological approach, including the structure of the GID in Section 3. Section 4 presents the empirical results for Colombia and Peru, comparing the magnitude and composition of externalities across sectors and value-chain stages. Section 5 concludes the study by summarizing the results and outlining key policy implications, investment opportunities, and areas for future research.

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[2] Prior similar and comparable analysis includes applications to Kenya and Viet Nam (Benfica et al., 2024a; Benfica et al., 2024b).

2. Analytical framework

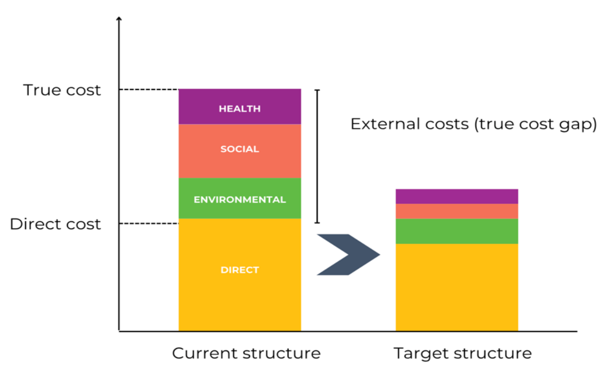
2.1. True Cost Accounting

TCA provides a systems-based approach for evaluating the full range of environmental, social, health, and economic externalities generated by AFS. Rather than limiting analysis to market transactions or conventional measures of productivity, TCA seeks to capture the broader set of impacts—both positive and negative—that food systems impose on society and the environment. By monetizing these externalities through standardized impact-monetization factors, TCA enables comprehensive comparison of different types of external costs across sectors, production systems, and policy options, ultimately supporting more informed decision-making. **Figure 1** illustrates a hypothetical food system structure, showing the addition of external costs atop direct production costs.

The TCA framework applied in this study is grounded in the TEEB Agrifood Evaluation approach (**Figure 2**), which emphasizes the interconnected roles of natural, human, and social capital in shaping food systems performance (TEEB, 2018).

This perspective recognizes that agricultural production depends on ecosystem services such as soil fertility, water availability, and climate regulation, while also relying on labor conditions, community well-being, and institutional structures. When these forms of capital are degraded or undervalued, food systems may appear economically efficient in the short term but generate long-term costs that undermine sustainability and resilience.

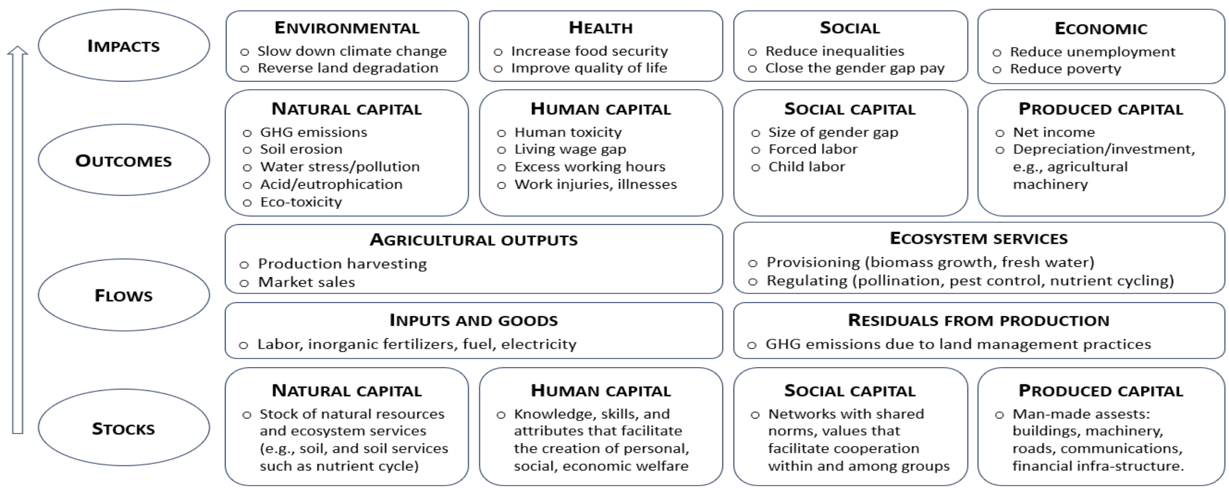
Figure 1. The true costs of food



Source: Adapted from True Price (2021).

TCA aims to reveal these *hidden costs* by quantifying impacts that are not reflected in market prices. In the context of AFS, these externalities include environmental degradation, such as soil erosion and biodiversity loss; GHG emissions contributing to climate change; water pollution and depletion of scarce water resources; labor exploitation and unsafe working conditions; wage inequities and gender-based disparities; and occupational hazards and long-term health risks for workers.

Figure 2. Elements of the TCA methodology



Source: Adapted from Muller and Sukhdev (2018) and True Cost Initiative (2022).

By assigning monetary values to these impacts, TCA provides a common metric that allows policymakers, investors, and researchers to compare externalities across sectors and identify where interventions may yield the greatest societal benefits.

Because our data do not include health-related externalities (such as dietary risks, foodborne illnesses, or noncommunicable diseases), this analysis focuses exclusively on environmental and social impacts. While this represents a partial application of the TCA framework, it nonetheless captures a substantial share of the external costs associated with AFS in Colombia and Peru. The exclusion of health impacts underscores the need for future research to integrate additional dimensions of food systems externalities as data availability improves.

2.2. External impact categories

In this analysis, external impacts are organized into two overarching domains—environmental and social—each comprising multiple impact categories that together capture a broad spectrum of externalities (**Table 1**).

Social impacts capture the human-centered externalities embedded in production, processing, and trading activities. These include: (a) workplace health and safety risks; (b) forced labor; (c) child labor; (d) gender wage gaps; and (e) underpayment relative to living-wage benchmarks. These indicators reflect violations of labor rights, inequities in compensation, and risks to worker well-being. Monetizing these impacts allows for a clearer understanding of how labor conditions vary across sectors and where policy interventions may be most urgently needed. See **Box 1** for definitions of social impacts.

Box 1. Definition of individual social costs

Child labor. Child labor is work that deprives children of their childhood, their potential, and their dignity, and is harmful to physical and mental development. Whether participation of children in work is deemed child labor depends on age, local regulation on minimum working age and minimum age for light work, nature of the work and the work relation, as specified by international institutions such as the International Labour Organization (ILO) and UNICEF. Hazardous child labor includes enslavement, family separation, dangerous tasks, and illness exposure.

Forced labor. Forced labor refers to physical or psychological harm from work imposed under threat and without autonomous consent. It includes performing unwanted tasks, exposure to hostile or violent employer communication, and threats or acts of violence. Severity is classified into "least severe forced work", "medium severe forced work", and "high severe forced work".

Gender wage gap. The gender wage gap refers to the difference between average wages earned by female workers and those earned by male workers performing comparable work. It captures systematic disparities in pay that persist even when job tasks, skill requirements, and working conditions are similar, highlighting structural inequalities in labor markets and employment practices. This gap is widely documented in international labor statistics and policy analyses.

Underpayment. Underpayment refers to the shortfall between the legally mandated daily minimum wage and the actual wages received by hired labor, as documented in labor-market assessments. It also includes farmers earning returns below subsistence levels, reflecting structural inequities and inadequate remuneration within agricultural and rural economies.

Workplace health and safety risks. Workplace health and safety risks refer to conditions or practices that expose workers to physical injury, illness, or psychological harm. These risks include hazardous equipment, unsafe environments, chemical or ergonomic hazards, excessive workloads, and inadequate protective measures. They reflect structural gaps in compliance, monitoring, and employer responsibility, as emphasized in international labor standards.

Source: Definitions based on True Price (2021).

Environmental impacts encompass pressures on natural capital and ecosystem services. The database includes (a) climate change (measured through GHG emissions); (b) air pollution; (c) water pollution; (d) use of scarce water; (e) fossil fuel depletion; (f) material depletion; and (g) land occupation. These categories capture both resource use and environmental degradation, enabling a comprehensive assessment of how AFS contribute to ecological stress. Monetized values allow for aggregation across impact types, which facilitates comparisons between environmental and social externalities and highlights trade-offs across sectors. For detailed definitions of environmental impacts see **Box 2**.

Box 2. Definition of individual environmental costs

Land occupation. Land occupation is an environmental externality that captures the opportunity cost of allocating land to agriculture, including the associated biodiversity loss and the foregone ecosystem services that arise when land is converted to, or maintained in, agricultural production. It reflects the pressure that agricultural systems place on landscapes by occupying land that could otherwise support natural ecosystems and therefore serves as a key indicator of land-use intensity and its broader ecological consequences.

Contributions to climate change. Contribution to climate change from emissions of GHG (carbon dioxide, methane, nitrous oxide, and others) that increase atmospheric concentrations and radiative forcing, raising global temperatures. Resulting warming heightens climate-related risks, including extreme heat, heavy precipitation, drought, and ocean acidification. These impacts generate economic losses, political instability, health burdens, and ecosystem damage.

Air pollution. Air pollution encompasses impacts on air from non-GHG emissions, including ozone-layer depletion, acidification, photochemical oxidant formation, particulate matter formation, nitrogen deposition, and terrestrial or aquatic ecotoxicity and human toxicity from airborne pollutants, as characterized in life-cycle assessment methodologies.

Water pollution. Water pollution refers to emissions to water that contribute to ecotoxicity, human toxicity, and marine or freshwater eutrophication. Eutrophication results from nutrient runoff and discharge—particularly phosphorus and nitrogen—from leaching into soils and water bodies, which elevates nutrient levels and degrading ecosystems.

Scarce water use. Concerns the use of blue water in such a way that the water is evaporated, incorporated into products, transferred to other watersheds, or disposed into the sea, in areas where water is scarce, meaning it is no longer available in the watershed of origin for humans or ecosystems. Scarcity of water depends on the watershed of origin and the geographical context.

Fossil fuel depletion. The consequence of the primary extraction of fossil fuels linked to fuel use, energy use, and to produce other inputs, such as mineral fertilizer. Extraction of crude oil, hard coal, and natural gas carries external societal costs because the stock of these materials is reduced for present and future generations. In this method, fossil fuel depletion is considered separately from the depletion of other non-renewable materials in line with life-cycle assessment (LCA) methodologies.

Material depletion. Material depletion refers to the consequences of extracting scarce, non-renewable resources—such as metals and minerals—whose removal reduces remaining stocks for present and future generations. This depletion generates external societal costs linked to long-term resource scarcity and reduced availability. In LCA methods, material depletion is assessed using characterization models that quantify resource extraction impacts.

Source: Definitions based on True Price (2021).

2.3. Agrifood systems sectors

The analysis covers 19 AFS sectors, reflecting the breadth of activities that contribute to food production, processing, and distribution. These sectors span primary production (e.g., crop cultivation, livestock, dairy), processing industries (e.g., meat processing, oils and fats, sugar, beverages and tobacco), and other food-related manufacturing activities (**Table 1**). This broad coverage ensures that the assessment captures externalities not only at the farm level but also along upstream and downstream value chain segments where environmental and social impacts are also present.

In addition to the full set of AFS sectors, the study highlights seven major crop sectors as reported for all countries in the GID database. These are paddy rice, cereals/grains, oilseeds, wheat, sugarcane/sugar beet, vegetables/fruits/nuts, and other crops. Focusing on these sectors allows for a more granular understanding of how externalities vary across key commodities and provides insights that can inform targeted interventions.

3. Data and methods

3.1. The Global Impact Database

This analysis draws on the GID, a harmonized dataset that provides monetized estimates of environmental and social externalities across global value chains. Developed by the Impact Institute, the GID integrates multiple evidence streams, including scientific impact-assessment models, environmental footprint databases, labor and social-risk indicators, global input–output and trade tables, and corporate environment, social, and governance (ESG) disclosures (Impact Institute, 2025). The database builds on established methodologies in life-cycle assessment (ISO, 2006), environmental-economic accounting (UN, 2021), and social life-cycle assessment (Benoît-Norris et al., 2011), enabling consistent valuation of impacts across countries and sectors. Its integration of upstream and downstream linkages aligns with multi-regional input–output (MRIO) modeling approaches widely used to trace environmental footprints in global supply chains (Wiedmann & Lenzen, 2018). The GID's harmonized structure makes it particularly suitable for TCA applications, where comparability and completeness are essential for assessing the full external cost of AFS.

Table 1. Global impact database: Impacts, sectors, and measurement indicators

Impact categories			Sector categories	
Externality (capital) type	**Impact groups**	**Impact types (12)**	**Sector groups**	**Sector types (19)**
Social (human and social)	Labor rights	Workplace health/safety	Rice	Paddy/rice ***
		Forced labour		Processed rice
		Child labour	Cereals/grains	Wheat ***
	Labor remuneration	Gender wage gap		Cereal/grains ***
		Underpayment	Other crops	Vegetables, fruit, nuts ***
				Other crops ***
			Cattle	Cattle, sheep, goats, horses
Environmental (natural)	Climate	Climate change	Meat / dairy products	Raw milk
	Air	Air pollution		Animal products
				Bovine meat products
	Water	Water pollution		Meat products
		Use of scarce water		Dairy products
			Fish	Fishing
	Fossil fuels	Fossil fuel depletion	Oil	Oilseeds ***
				Vegetable oils and fats
			Sugar	Sugar
	Material	Material depletion		Sugarcane, sugar beet ***
			Food products	Food products
	Land	Land occupation	Beverages & tobacco	Beverages and tobacco

Impact Measurement Indicators	
Indicator	**Definition**
PCI (procurement chain impact) (Int. $PPP impact/$ output) **	The PCI * reflects the impact of the entire production process of a final (or intermediate) product of a sector. Therefore, the PCI includes impacts occurring throughout the entire production chain. The data are expressed as monetized impact per dollar output of the sector. This means that it is the impact occurring during the production process of products with a value of 1 dollar.
VCI (value chain impact) (Int. $PPP impact/$ added value) **	The VCI reflects the impact on the global economy of adding value in a sector. As economic activity in a sector stimulates both the supplying sectors and the clients, adding value in a sector not only leads to external costs in that sector, but also to additional externalities in the value chain. The VCI reflects this by providing impact data that aggregate the *direct* and value chain impact, both *upstream* and *downstream*.
VCI Direct	Portion of VCI due to a sector's *own impact*. This is the part of the impact intensity of a sector that can be attributed to it rather than its value chain partners, based on added value.
VCI Upstream	Portion of VCI due to a sector's *upstream impact*.
VCI Downstream	Portion of VCI due to a sector's *downstream impact*.
Sector output	Value added (in 2016 US dollars)

Source: Compiled from Global Impact Database documentation (Impact Institute 2025).

Note: * The production chain is estimated based on input–output analysis and therefore reflects the economically weighted average production chain of all goods and services produced by the sector. ** Purchasing power parity (PPP) is a metric used to compare economic productivity and standards of living between countries. PPP compares different countries/ currencies through a "basket of goods" approach. PPP is the exchange rate at which one country's currency is converted into another to purchase the same amounts of a large group of products. ***seven primary crop sectors in GID.

3.2. Analytical approach

The analytical strategy follows a structured, five-step process designed to quantify, compare, and decompose externalities across AFS sectors in Colombia and Peru. First, we extract sector-level procurement chain impact (PCI) and value-chain impact (VCI) values from the GID. PCI captures total externalities generated by a sector's own production activities, while VCI reflects the full value-chain footprint, including upstream suppliers and downstream processing (Impact Institute, 2025). This distinction mirrors established approaches in footprint accounting that differentiate territorial from consumption-based impacts (Peters et al., 2011).

Second, we calculate externalities as a share of sectoral output. Normalizing external costs by output allows for cross-sector comparisons and aligns with TCA principles emphasizing proportionality and marginal impact assessment (TEEB, 2018). Third, we rank sectors by both marginal externalities (externalities per unit of output) and total external costs (aggregate external costs that reflect the importance of sector size). This dual ranking highlights sectors that generate large absolute impacts as well as those that are particularly intensive in their use of natural or human capital.

Fourth, we decompose externalities by impact category, distinguishing among the 12 environmental and social impact types included in the GID. This step draws on established valuation frameworks for environmental damage (Tol, 2018; van den Bergh, 2010) and social impacts such as child labor, forced labor, wage inequities, and occupational risks (ILO, 2020). Finally, we analyze the distribution of externalities across value-chain stages—direct, upstream, and downstream—providing insight into where interventions may be most effective. This decomposition is consistent with MRIO-based analyses that identify leverage points in global supply chains (Lenzen et al., 2013).

3.3. Limitations

Several limitations should be acknowledged. First, the GID does not include health-related externalities such as dietary risks or occupational disease burdens, meaning the analysis captures only a subset of the true societal costs of AFS (TEEB, 2018). Second, although the GID integrates global scientific models and harmonized datasets, these may not fully reflect local biophysical conditions, labor market structures, or regulatory environments in Colombia and Peru. Similar limitations have been noted in global MRIO and footprint studies, where local heterogeneity is often underrepresented (Wiedmann & Lenzen, 2018). Third, the monetization of social impacts relies on normative assumptions about the valuation of human well-being, labor rights, and equity—an inherent challenge in social impact assessment (Benoît-Norris et al., 2011). Despite these limitations, the GID remains one of the most comprehensive and methodologically consistent datasets available for cross-country TCA analysis.

4. Key results from the GID analysis

Using the GID, this nationally representative analysis examines: (a) the relative importance and magnitude of environmental and social externalities; (b) how economic sectors are ranked and the structure of externalities within each sector; (c) the overall ranking of environmental and social impact categories; and (d) how externalities are distributed along value chains across upstream, direct, and downstream stages. This analysis provides national-level estimates and looks at the entire AFS. It also focuses on highlights of seven crop production sectors: paddy rice, cereals/grains, oilseeds, wheat, sugarcane/sugar beet, vegetables/fruits/nuts, and other crops.

4.1. Overall externalities

The analysis quantifies the share of externalities in total output and then ranks AFS sectors according to this measure to identify which sectors generate the highest external costs relative to their economic contribution.

Looking at the size of AFS externalities relative to the value of AFS output shows that Colombia and Peru face similar external cost burdens, with externalities representing 12 percent of total output in Colombia and 13 percent in Peru across all sectors. When focusing only on crop production, the burden decreases slightly in both countries—to 10 percent in Colombia and 11 percent in Peru—indicating that non-crop sectors such as livestock, dairy, and processing contribute disproportionately to total external costs (**Table 2**).

Table 2. Overall externalities (relative to total output)

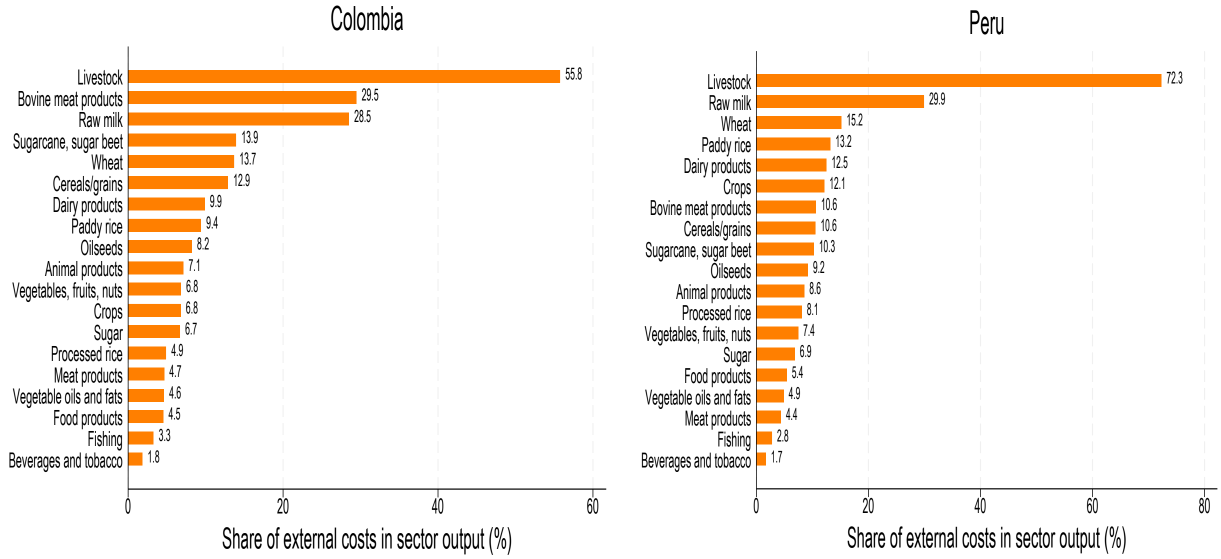
Externalities (as % of output)			
Colombia		Peru	
All AFS Sectors	Crops Only	All AFS Sectors	Crops Only
12.0	10.0	13.0	11.0

Source: Authors' own calculation using the Global Impact Database.
Note: AFS = Agrifood systems.

This pattern aligns with broader evidence from TCA assessments, where environmental pressures (especially land occupation, climate change, and air pollution) and social impacts (notably underpayment and child labor in specific value chains) tend to be more concentrated in animal-source food sectors (Benfica et al., 2024b). The relatively lower externality costs for crops suggest both a more favorable sustainability profile and a clearer opportunity for targeted interventions that can reduce systemwide externalities while supporting productivity growth.

Sectoral rankings of externalities in Colombia and Peru (**Figure 3**) show a highly uneven distribution of environmental and social burdens across agrifood value chains, with animal-source food sectors consistently dominating the top of the ranking. Livestock production is the most externality-intensive sector in both countries—56 percent of sectoral output in Colombia and 72 percent in Peru—reflecting the combined effects of methane emissions, land and water use, feed production, and labor-related social costs. Other animal-related sectors, including bovine meat products, raw milk, and dairy processing also appear among the highest contributors, reflecting the structural concentration of externalities in animal-based systems. In contrast, crop sectors such as cereals, rice, sugarcane, oilseeds, and fruits/ vegetables fall in the middle/low ranking, typically ranging from 6 percent to 15 percent of output. Processed foods, beverages, and fishing consistently rank at the bottom, with externalities below 5 percent.

Figure 3. Sectoral rankings of externalities (as percent of total output)



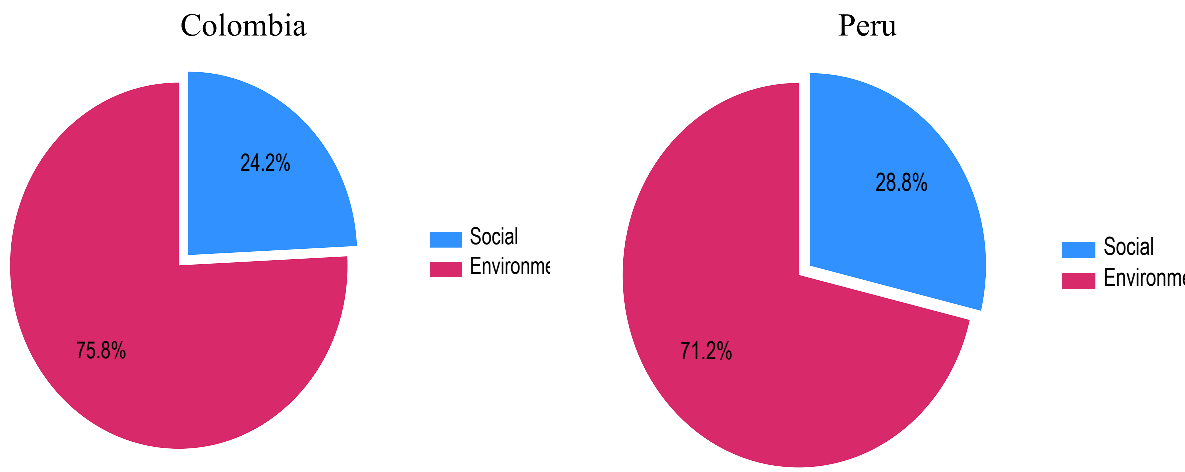
Source: Authors' own calculation using the Global Impact Database.

4.2. Structure of externalities

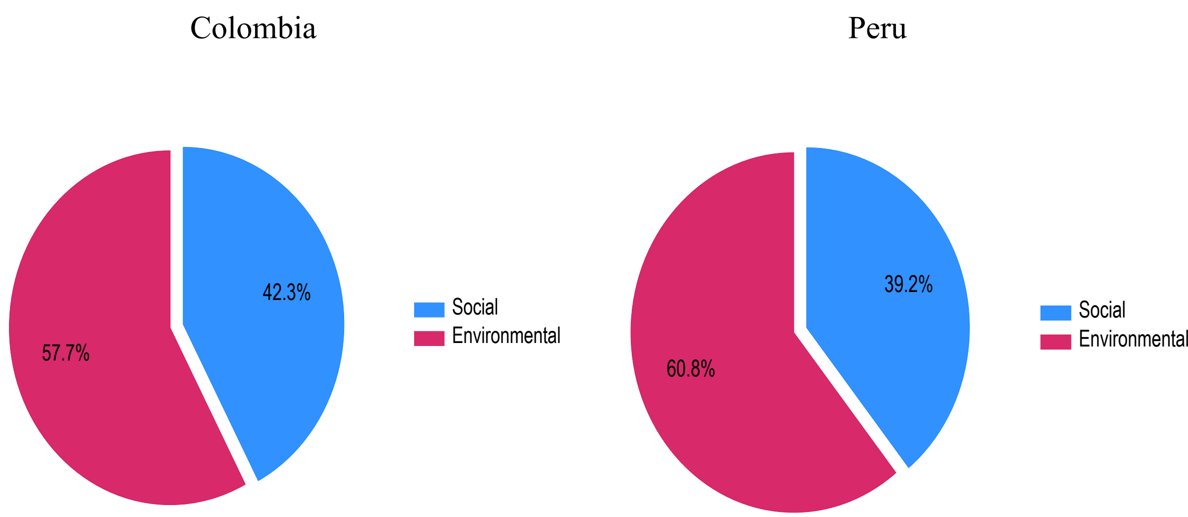
The structure of externalities across Colombia and Peru reinforces a central insight: environmental pressures dominate the AFS, while social costs become far more prominent within crop production (**Figure 4**), reshaping where and how interventions should be targeted. Across all sectors, environmental externalities account for roughly three-quarters of total costs in both countries, reflecting the heavy footprint of livestock systems, particularly methane emissions, land occupation, and water use. Social externalities, while smaller in aggregate, remain substantial and are concentrated in labor-intensive segments of the value chain where underpayment, informality, and occupational risks are more prevalent.

Figure 4. Structure of externalities: Social versus environmental (all sectors and crops)

(a) All agrifood system sectors



(b) Crops only



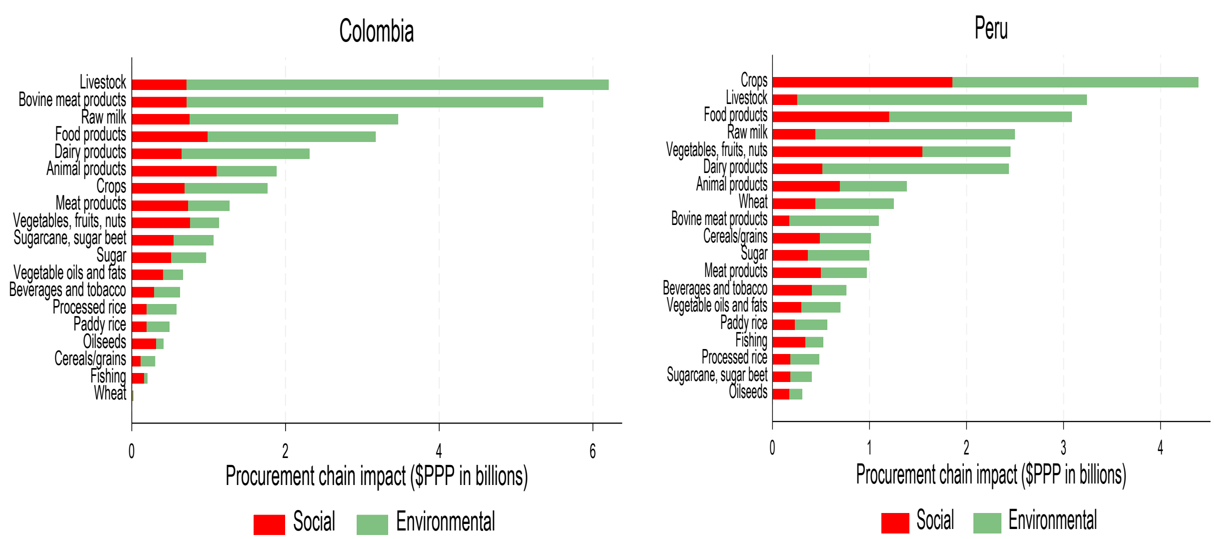
Source: Authors' own calculation using the Global Impact Database.

Once the analysis is narrowed to crops, the balance shifts. Social externalities account for around 40−42 percent, nearly doubling their scale relative to the full AFS. This shift highlights the structural role of labor in crop production, where seasonal work, wage gaps, and informality drive a larger portion of total external costs. Environmental impacts remain the highest, but the relative increase in social costs signals that crop-focused interventions must address both productivity and labor conditions to meaningfully reduce externalities.

4.3. Ranking of sectors and composition of externalities

The ranking and composition of externalities across procurement chains in Colombia and Peru highlights how different product categories contribute to the total external cost burden—and how the balance between environmental and social costs shifts depending on the structure of each country's AFS (**Figure 5**).

Figure 5. Level and structure of external costs ($PPP billions)



Source: Authors' own calculation using the Global Impact Database.

In Colombia, livestock generates the largest combined environmental and social footprint. This reflects the emissions intensity of ruminant systems, land occupation, and upstream feed production, alongside labor-related risks in animal husbandry and processing. Bovine meat products, food, and dairy products follow, each contributing meaningful but smaller shares to the externality profile. Crop-related categories appear mid-ranking, with vegetables, fruits, nuts, sugar-related products, and tubers generating more modest external costs. The distribution underscores a system where environmental pressures from livestock shape the national footprint, while social costs are present but secondary.

Peru's profile differs in an important structural way: crops represent the single largest source of externalities, surpassing livestock. This reflects Peru's strong crop-based export economy—particularly fruits, vegetables, and specialty crops—where labor intensity, wage gaps, and informality elevate social costs, while water use, land degradation, and agrochemical pressures drive environmental impacts. Livestock remains a major contributor but is less dominant than in Colombia. Processed food products, vegetables, fruits, and nuts also play significant roles, reflecting Peru's diversified agrifood export base. Lower-impact categories such as processed oils, sugar-related products, and fishing contribute relatively little to total externalities.

Across both countries, the composition of externalities reveals three consistent patterns. First, animal-source foods carry the highest environmental burdens, especially in Colombia, due to emissions and land use. Second, crop-based value chains carry a higher share of social externalities, especially in Peru, due to labor intensity and informality. Finally, processed foods and beverages consistently generate the lowest external costs, reflecting shorter supply chains and smaller biophysical footprints.[3] These patterns provide a clear basis for differentiated investment strategies: environmental mitigation in livestock systems, social upgrading in crop systems, and targeted efficiency gains in mid-impact value chains.

4.4. The relative importance of external costs

External costs in Colombia and Peru show a consistent hierarchy regardless of the metrics used, that is, unit costs (external costs per dollar of output) or total costs (aggregate external costs), revealing the cost categories in which mitigation efforts can deliver the greatest returns.

Across both countries, environmental externalities rank as the highest unit impacts (**Figure 6**), reflecting the biophysical intensity of livestock and mixed farming systems. Land occupation emerges as the single largest driver per unit of output, followed closely by climate change, water use, and air pollution. These

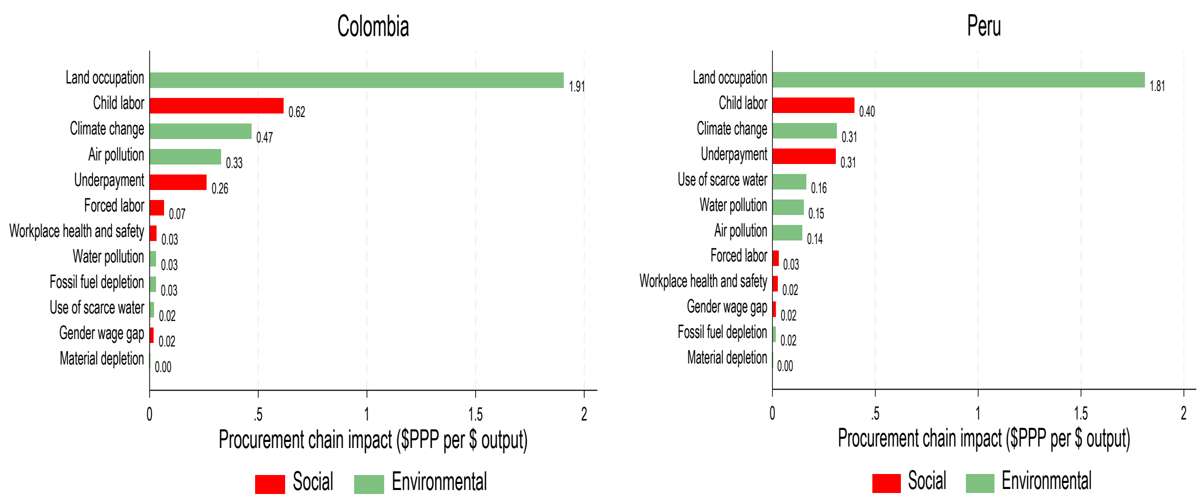
[3] However, they are associated to substantial, negative implications on human health.

environmental pressures are structurally linked to ruminant production, with methane emissions, pasture expansion, and feed requirements generating high marginal footprints.

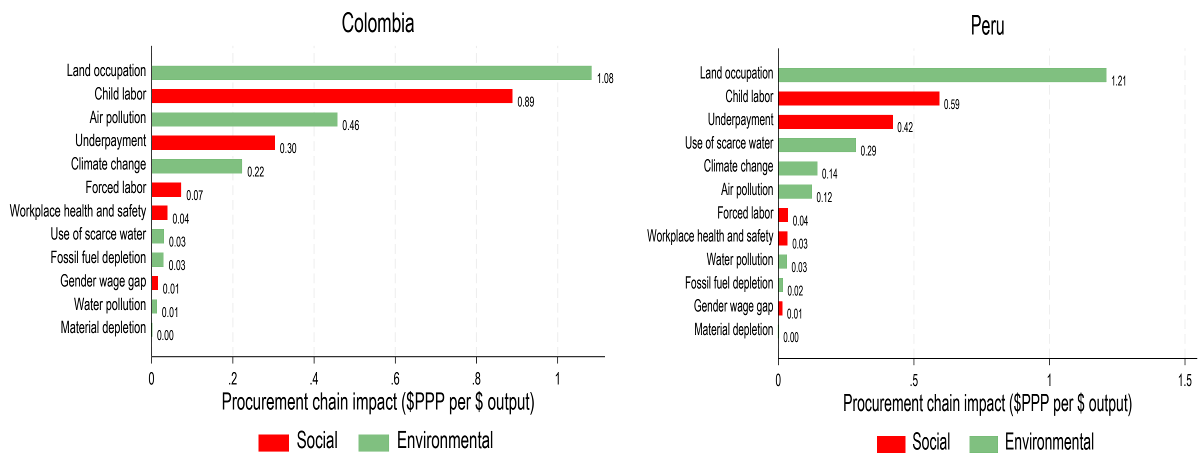
Social externalities, while generally lower in unit terms, still occupy prominent positions in both countries' rankings. Child labor and underpayment consistently appear among the top social impacts per unit, especially in labor-intensive crop sectors. Occupational health risks and gender wage gaps also contribute meaningfully, though at lower magnitudes. The unit-impact rankings therefore highlight a dual pattern: environmental burdens dominate at the margin, but social risks remain significant in specific value chains, particularly those tied to export-oriented or seasonal crop production.

Figure 6. Ranking of external costs per unit of output ($PPP per dollar of output)

(a) All sectors



(b) Crops only

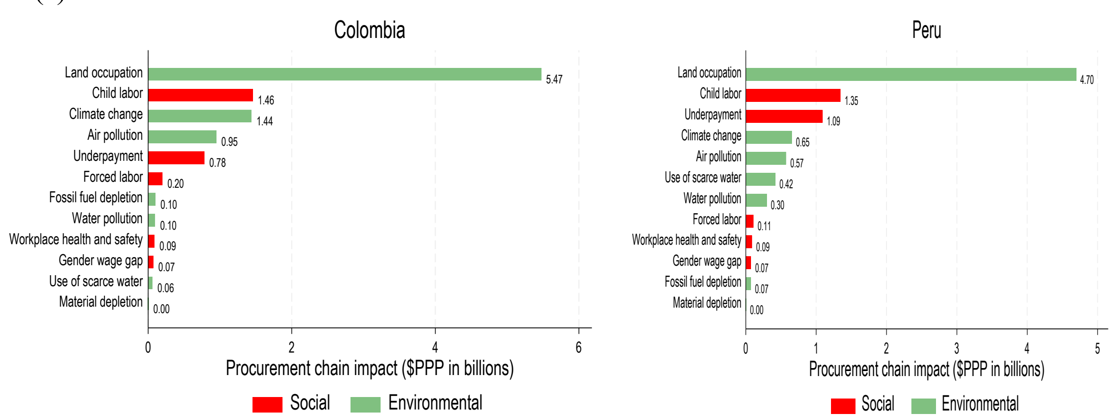


Source: Authors' own calculation using the Global Impact Database.

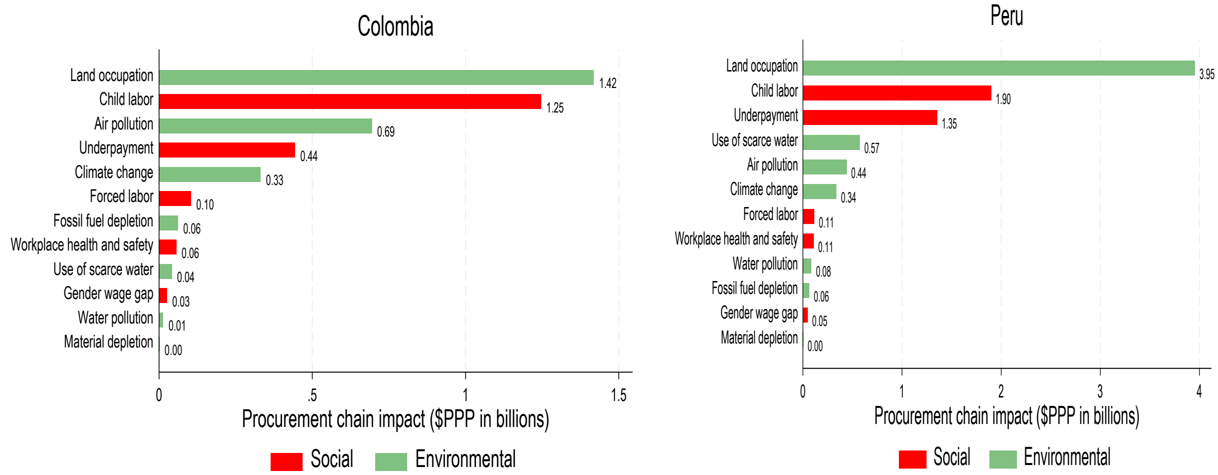
When shifting to total costs (**Figure 7**), the picture broadens. Environmental externalities again dominate in both Colombia and Peru, with land occupation and climate change generating the largest aggregate costs. However, the relative weight of social externalities increases in total terms—especially in Peru—because of the scale of labor-intensive crop sectors. Underpayment and child labor contribute substantial total costs, reflecting the size of the workforce engaged in agriculture and the persistence of informality. This divergence between unit and total costs underscores an important insight: environmental pressures are more intense per dollar of output produced, but social pressures accumulate significantly due to the large number of affected workers.

Figure 7. Ranking of absolute external costs (total impacts), ($PPP billions

(a) All sectors



(b) Crops only



Source: Authors' own calculation using the Global Impact Database.

Together, these rankings provide a clear roadmap for intervention. Environmental mitigation—particularly in livestock—offers the largest marginal reductions in externalities, while social reforms in crop systems can meaningfully reduce total external costs. This dual strategy aligns with the structural differences observed across sectors and countries, and it strengthens the case for differentiated, sector-specific investment priorities.

4.5. Unbundling selected external costs

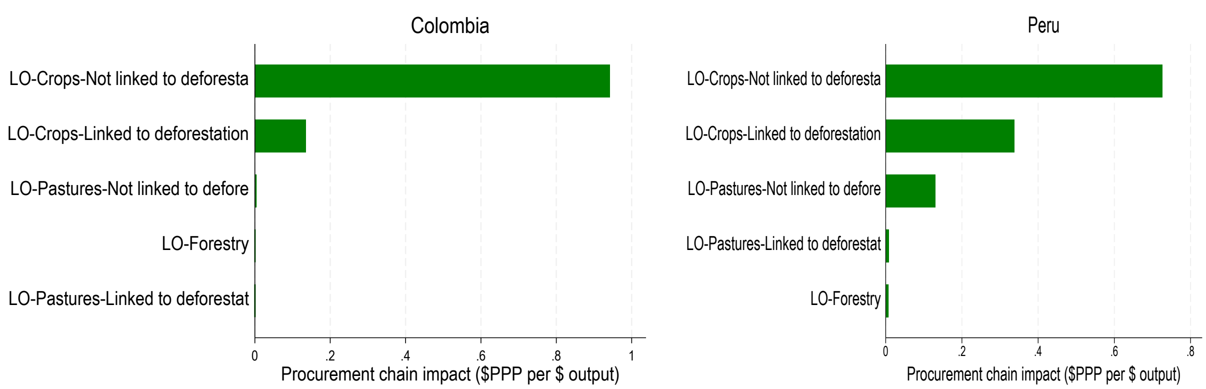
A closer examination of selected individual environmental and social impact categories reveals the distinct pathways through which AFS in Colombia and Peru generate hidden costs. We select environmental and social costs whose impacts have either different dimensions/sources (e.g., land occupation—with links to deforestation; water pollution—fresh water versus marine) or levels of intensity (e.g., child labor—hazardous versus light; forced labor—severe versus less severe). While aggregate measures provide a useful overview of the magnitude of externalities, unbundling these impacts shows that each category has its own logic, spatial distribution, and footprint. This level of granularity is essential for designing targeted interventions, as the drivers of land occupation, water pollution, air pollution, or child labor and forced labor differ markedly across sectors and production systems.

4.5.1. Selected environmental costs

Land occupation

The disaggregation of land-occupation costs reveals clear structural differences in how Colombia and Peru use land across crop and livestock systems. In both countries, the largest external costs stem from crop production that is not linked to deforestation, reflecting the sheer scale of cultivated land and the opportunity costs associated with its use (**Figure 8**). These impacts are notably higher in Colombia, where the external cost per unit of output reaches nearly one dollar, compared with roughly 70 cents in Peru. In contrast, crop production linked to deforestation carries a smaller but still meaningful burden in both countries, with Peru showing a comparatively higher intensity—consistent with ongoing pressures in the Amazon and Andean foothills.

Figure 8. Components of land-occupation costs ($PPP per dollar of output)



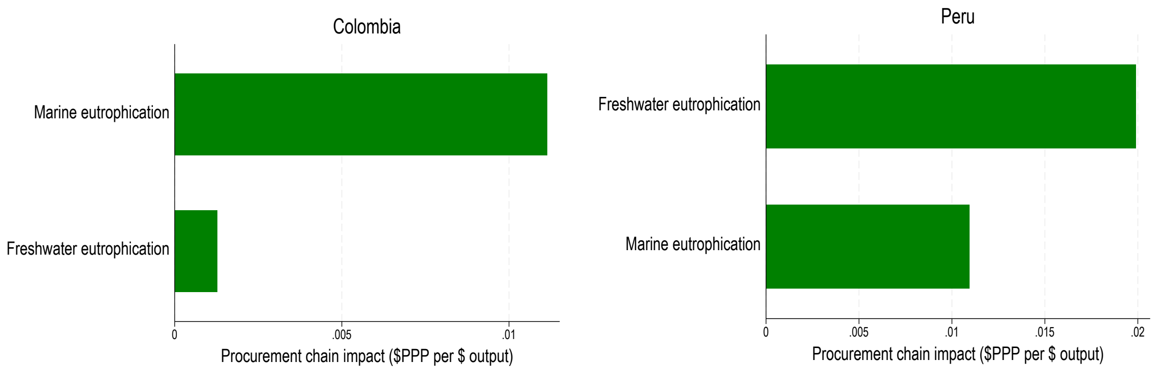
Source: Authors' own calculation using the Global Impact Database.
Note: LO = land occupation

Pasture-related land occupation presents a more differentiated picture: Colombia shows negligible impacts for both deforestation-linked and non-linked pastures, while Peru exhibits modest but visible costs, particularly for non-deforestation pastures. Forestry-related land occupation remains minimal in both contexts. Taken together, these patterns underscore that land-occupation externalities are driven less by active deforestation and more by the extensive land footprint of existing agricultural systems. This result highlights the importance of productivity-enhancing and land-intensification strategies—especially in crop systems—as a key lever for reducing environmental externalities.

Water pollution

The disaggregation of water pollution impacts highlights striking differences in how Colombia and Peru contribute to freshwater and marine eutrophication through their AFS. In Colombia, marine eutrophication is the dominant source of water pollution externalities, albeit at relatively low levels per unit of output (**Figure 9**). This pattern reflects nutrient runoff and wastewater discharges that ultimately reach coastal ecosystems, driven by fertilizer use in coastal catchments and the structure of Colombia's hydrological basins. Freshwater eutrophication, by contrast, registers as negligible, suggesting either lower nutrient loading in inland water bodies or more effective dilution and dispersion dynamics (Pérez Mesa et al., 2024). Peru exhibits the opposite pattern: freshwater eutrophication carries the highest external cost, indicating significant nutrient pressures in inland agricultural zones—particularly in high-value crop systems where fertilizer use is concentrated.

Figure 9. Components of water pollution costs ($PPP per dollar of output)



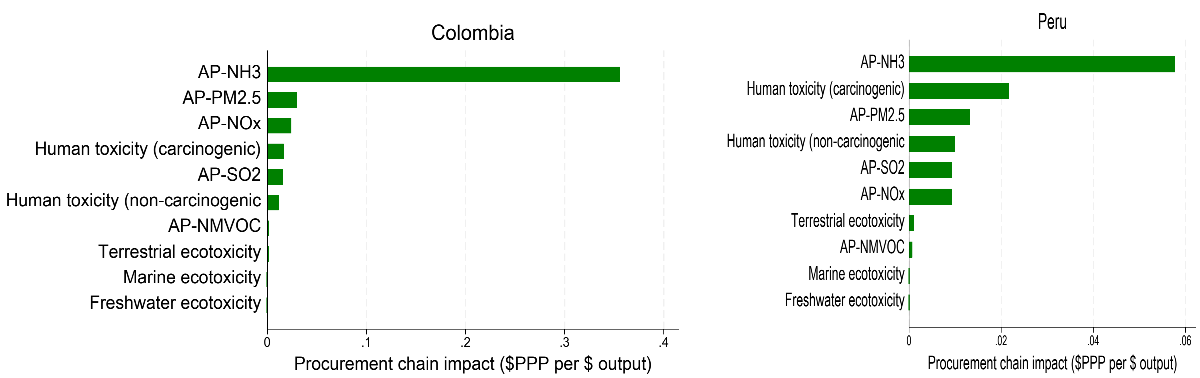
Source: Authors' own calculation using the Global Impact Database.

Marine eutrophication remains relevant but less intense, consistent with Peru's narrower coastal agricultural footprint. These contrasting profiles underscore that water pollution externalities are shaped not only by agricultural practices but also by geography, watershed characteristics, and the spatial distribution of production (Ruiz-Ordóñez et al., 2023). As a result, mitigation strategies must be tailored: Colombia's priorities lie in managing nutrient flows into coastal ecosystems, while Peru faces a more urgent need to address nutrient loading in freshwater systems through improved fertilizer management, erosion control, and watershed-level interventions.

Air pollution

The composition of air pollution costs signals a highly uneven distribution of burdens across pollutants, sectors, and countries, with ammonia (NH_3) emerging as the dominant driver of external costs in both Colombia and Peru (**Figure 10**). In Colombia, ammonia-related impacts are exceptionally high—an order of magnitude larger than any other air-pollution category—reflecting the intensive use of nitrogen fertilizers and the emissions profile of livestock systems, particularly manure management and volatilization from pasturelands. Peru exhibits the same pattern but at a substantially lower intensity, suggesting differences in production systems, fertilizer application rates, and livestock density. Fine particulate matter ($PM_{2.5}$) and nitrogen oxides (NO_x) contribute additional but smaller burdens, linked to combustion processes, mechanization, and postharvest activities.

Figure 10. Composition of air pollution costs ($PPP per dollar of output)



Source: Authors' own calculation using the Global Impact Database.
Note: AP = air pollution; NH_3 = ammonia; NO_x = nitrogen oxides; NMVOCs = non-methane volatile organic compounds; $PM_{2.5}$ = fine particulate matter; SO_2 = sulfur dioxide.

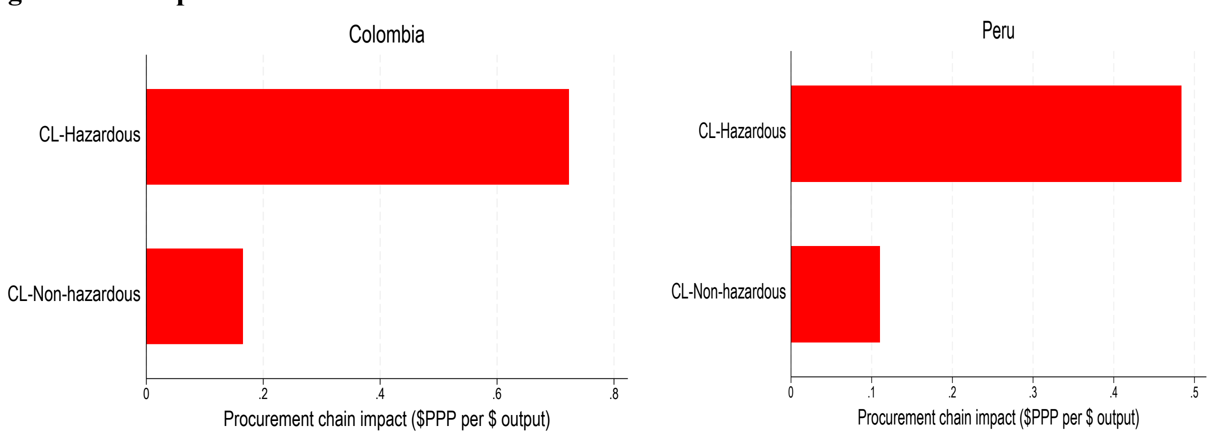
Human toxicity impacts—both carcinogenic and noncarcinogenic—register at modest levels in both countries, indicating exposure risks associated with agrochemical use and processing emissions. Other pollutants, including sulfur dioxide (SO_2), non-methane volatile organic compounds (NMVOCs), and various ecotoxicity categories, contribute minimally to total external costs. The dominance of ammonia underscores that air pollution externalities in AFS are driven primarily by biological and chemical processes intrinsic to livestock and fertilizer-intensive crop systems, rather than industrial emissions. This pattern highlights the importance of targeted mitigation strategies, such as improved manure management, precision fertilization, and low-emissions application techniques. By revealing the pollutant-specific structure of air pollution impacts, the analysis provides a clearer roadmap for interventions that can deliver significant environmental gains with high cost-effectiveness.

4.5.2. Selected social costs

Child labor

The disaggregation of child labor costs reveals a severe and persistent social burden embedded within AFS in both Colombia and Peru (**Figure 11**). Hazardous child labor accounts for most of the child labor costs in each country, reaching more than four times the magnitude of non-hazardous child labor. Colombia exhibits particularly high intensity, with hazardous child labor generating external costs of over 70 cents per dollar of output—substantially higher than Peru's already significant levels. These patterns reflect structural characteristics of agricultural labor markets, where smallholder production, seasonal labor demands, and limited enforcement capacity create conditions in which children are more likely to engage in dangerous tasks such as operating machinery, applying agrochemicals, or performing physically strenuous fieldwork. Non-hazardous child labor, while lower in monetary terms, remains a meaningful contributor to social externalities, signaling the continued reliance on unpaid or underpaid family labor in both countries.

Figure 11. Components of child labor costs



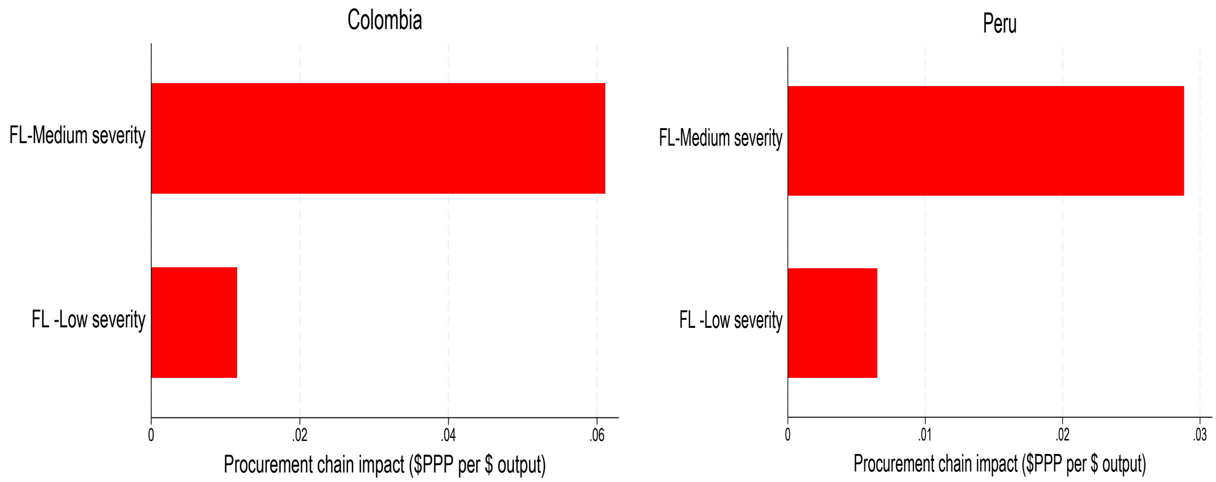
Source: Authors' own calculation using the Global Impact Database .
Note: CL = child labor

Colombia faces more acute risks in hazardous categories, whereas Peru's lower but still substantial levels point to systemic vulnerabilities in crop and livestock sectors. Overall, the disaggregated results underscore that child labor, especially hazardous labor, remains a critical social sustainability challenge. Addressing it will require coordinated interventions that combine stronger labor regulation and enforcement with income-support measures, school-to-work transition programs, and targeted support for smallholder households where economic necessity drives child participation in agricultural work (FAO, 2020; ILO, 2006, 2017, 2018, 2020).

Forced labor

The disaggregation of forced labor costs shows that, while the monetary magnitude of these externalities is smaller than those associated with child labor or underpayment, they nonetheless represent a persistent and systemic social risk within agrifood value chains in both Colombia and Peru (**Figure 12**). Medium-severity forced labor accounts for most of the forced labor related costs, reaching six cents per dollar of output in Colombia and three cents in Peru. These levels, though modest in absolute terms, signal the presence of coercive labor conditions—such as restricted mobility, debt bondage, or exploitative contracting—particularly in segments of the agricultural workforce characterized by informality, migrant labor, and weak oversight. Low-severity forced labor, which captures subtler forms of coercion and limited worker agency, contributes an additional but smaller burden in both countries.

Figure 12. Components of forced labor costs



Source: Authors' own calculation using the Global Impact Database.
Note: FL = forced labor

The higher intensity observed in Colombia suggests more acute vulnerabilities in specific subsectors, potentially linked to regional disparities in labor regulation, the presence of armed actors in rural areas, or the structure of seasonal labor markets. Peru's lower but still notable levels indicate that forced labor risks are embedded across multiple commodity chains, even where formal compliance frameworks exist.

Overall, unpacking the main costs highlights that forced labor remains a critical dimension of social externalities (FAO, 2020; ILO, 2020). Addressing these issues requires strengthening labor inspection systems, improving worker protection in informal and subcontracted arrangements, and enhancing traceability mechanisms that allow downstream actors to identify and mitigate coercive labor practices within their supply chains.

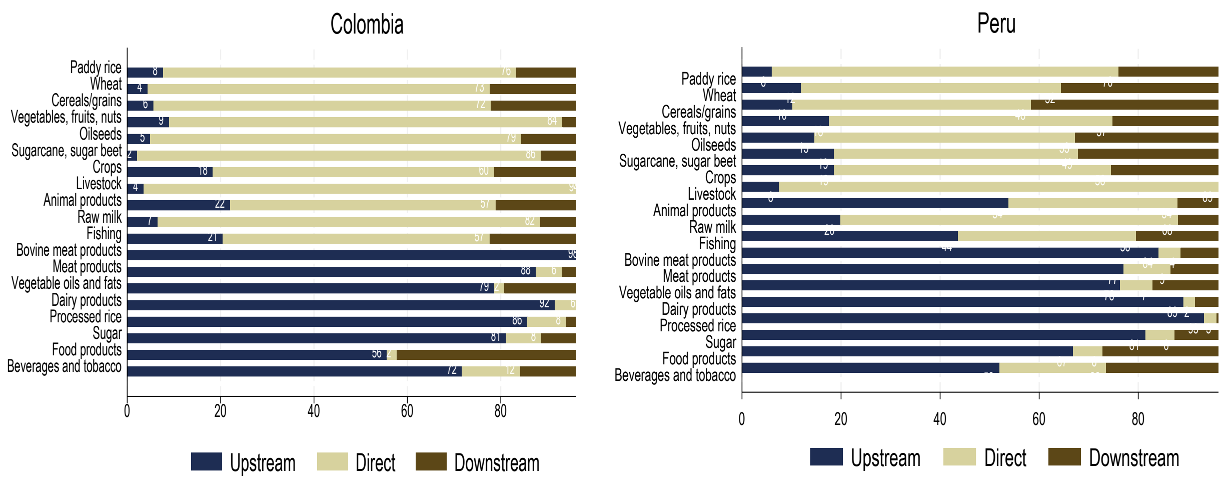
4.6. External costs along value chain stages

Next, we draw on the value chain impact (VCI) data from the GID. The VCI measures the external cost generated when one additional US dollar of value is added in any sector of the global economy. Because sectors are interconnected through upstream suppliers and downstream buyers, adding value in one sector can generate external costs within that sector itself (direct VCI) as well as in related upstream and downstream sectors (Lenzen et al., 2013; UNEP, 2016). For example, adding value in rice production creates externalities not only within rice farming but also in upstream activities such as seed production and in downstream activities such as rice processing.

This stage-based perspective complements the sectoral- and impact-based ranking by showing the origin of externalities along the value chain stages related to each sector.

The distribution of external costs across value-chain stages in Colombia and Peru shows that the location of externalities within the chain—upstream, direct production, or downstream—varies sharply by sector, and these differences matter for where interventions should be targeted (**Figure 13**). Across all sectors, both countries show a broadly similar pattern: For non-crop production sectors, upstream activities account for the largest share of externalities, while for primary agricultural sectors, direct production activities are more prominent, with downstream stages contributing the least. This finding reflects the large environmental footprint of inputs such as land, water, feed, and agrochemicals, as well as the social risks tied to labor-intensive primary production (Poore et at., 2028).

Figure 13. Total external costs along value chain stages (% by sector)



Source: Authors' own calculation using the Global Impact Database.

5. Conclusions and Implications

This paper provides one of the first cross-country applications of the GID to quantify the hidden environmental and social costs of AFS in Colombia and Peru. By applying a TCA framework across 19 sectors, including seven major primary crops, the analysis reveals that both countries face substantial externalities—equivalent to 12 percent of AFS output in Colombia and 13 percent in Peru—that remain invisible in conventional economic assessments, and not reflected in product prices. These findings underscore that the current food systems' performance and overall sustainability are overstated when external costs are excluded, and the path toward sustainable, equitable, and inclusive AFS requires making these costs measurable, visible, and actionable.

Across both countries, environmental externalities dominate, driven primarily by land occupation, climate change, air pollution, and scarce water use. Livestock, dairy, and bovine meat products consistently emerge as the most externality-intensive sectors, pointing to the importance of structural biophysical characteristics, rather than country-specific conditions. Social externalities—especially underpayment, child labor, and gender wage gaps—are smaller in aggregate than environmental externalities but become markedly more noticeable within crop sectors, which are characterized by high labor intensity and informality. The value chain decomposition further signals that most externalities originate at the direct production stage, though upstream and downstream costs vary by category, highlighting the need for interventions beyond the farm gate.

These insights have several implications for policy and investments. First, livestock systems represent the largest opportunity for reducing environmental externalities. Investments in improved feed efficiency, manure management, silvo-pastoral systems, and sustainable grazing practices could yield substantial reductions in climate, land, and water-related costs.

Second, crop sectors—while generating fewer externalities—offer opportunities to scale lower-impact production models and strengthen social sustainability. Addressing wage inequities, improving labor conditions, and reducing child labor would require coordinated action across labor regulations, certification schemes, and supply-chain governance.

Third, the prominence of direct production costs suggests that interventions targeting farm-level practices—such as climate-smart agriculture, integrated pest management, and water-efficient technologies—can generate systemwide reductions in external costs. However, the presence of upstream and downstream externalities indicates that complementary measures are needed in input supply chains, processing industries, and logistics systems. Strengthening product traceability, promoting sustainable procurement standards, and incentivizing low-impact processing technologies can help internalize and ultimately reduce external costs across the full value chain.

Fourth, the analysis highlights the importance of integrating TCA metrics into national planning and investment processes. By revealing the magnitude and distribution of hidden costs, TCA can support more informed prioritization of public spending, guide private sector sustainability strategies, and enhance the design of fiscal and regulatory instruments. Colombia and Peru are already advancing ambitious agendas on climate action, rural development, and food systems transformation; embedding TCA evidence into these processes can help align incentives with long-term societal well-being.

Finally, the study points to areas where further research is needed. The absence of health-related externalities in the analysis—such as dietary risks and foodborne illnesses—implies that the estimates shown here represent a lower-bound of the real overall costs. Local biophysical and labor-market heterogeneity is also imperfectly captured in global datasets, underscoring the value of complementing national-level TCA assessments with localized, high-resolution analyses. Continued investment in data systems, methodological refinement, and cross-country learning would be essential to strengthen the evidence base for TCA in Latin America.

Overall, the findings show that transforming AFS in Colombia and Peru is both necessary and feasible. By making hidden costs visible, TCA provides a roadmap for designing interventions that enhance productivity, reduce environmental degradation, and improve social outcomes. The challenge ahead is to translate this evidence into coordinated action—among ministries, value chain actors, and development partners—to build food systems that are economically viable, environmentally sustainable, and socially just.

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