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Embracing European Green Deal regulations through enabling and restricting drivers: a mixed assessment approach for Colombian case

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Abstract*– The enforcement of the European Green Deal (EGD) has introduced a new regulatory framework for agri-food products entering the European market, emphasizing the transition toward sustainable systems. Considering that 75% of Colombia's exports to Europe come from the agricultural sector, it is imperative to assess the country's readiness to comply with these evolving standards. This study adopted a mixed-methods approach structured in three phases. In the first phase, the alignment of national public policies, regulatory instruments, and legal frameworks with the five core pillars of the EGD was assessed: (1) sustainable use of agrochemicals, (2) circular economy, (3) biodiversity protection, (4) agroecological production, and (5) zero-deforestation traceability. Two indicators were applied: pillar-specific alignment and overall alignment. The second phase involved a scientometric analysis of academic and scientific literature, complemented by expert consultation, to identify and prioritize enabling (EFs) and restricting factors (RFs) affecting the adoption of sustainable practices. In the third phase, differentiated action lines were proposed based on their level of influence and year time-lapse: short term (1–3), medium term (3–5), and long term (+5). The results show that, Colombia still faces significant financial and operational constraints that hinder the full adoption of EGD guidelines. These challenges regarding better policy coordination could compromise the competitiveness of Colombian agribusiness exports in the European market if left unaddressed. However, the analysis of enabling factors highlights key opportunities to advance toward a sustainable agribusiness model. Strengthening economic incentives, aligning regulations, and integrating approaches such as bioeconomy and circular economy into national strategies are essential actions to meet international standards and promote sustainable agricultural development.

***Keywords*-- European Green Deal; sustainability; global policies; drivers; food safety; agribusiness.**

I. Introduction

Since 2019, the European Union (EU) has adopted the European Green Deal (EGD) as a comprehensive strategy to achieve climate neutrality by 2050. This ambitious commitment is based on the implementation of a series of public policy initiatives aimed at ecological transition, with the objective of transforming the current economic model into one that is more modern, competitive, and sustainable—efficient in the use of resources, protective of citizens' health, and responsive to environmental risks [1].

One of the central pillars of the EGD is the "Farm to Fork Strategy", launched in 2020. This initiative seeks to reshape the EU food system toward a sustainable, fair, and resilient model. It includes regulatory proposals related to organic farming, sustainable labelling and packaging, food waste reduction, biodiversity conservation, and ensuring fair incomes for farmers [1,2]. The strategy aims to guarantee food security in the face of climate change and biodiversity loss, reduce the environmental footprint of the food system, strengthen its resilience, and position the EU as a global leader in the transition toward sustainability [3].

Internationally, the EGD has been integrated into various trade frameworks. In the case of Colombia, Ecuador, and Peru, the Multi-Party Trade Agreement with the EU formally recognized the importance of the EGD, including commitments related to agrochemical regulations, traceability, certifications, sustainable packaging, and labelling [4]. In this sense, the EU functions not only as a trading partner but also as a regulatory force pushing for higher environmental, sanitary, and socio-economic standards increasingly demanded by European consumers.

This regulatory context is especially significant for Colombia, given that 75% of its exports to the European Union come from the agricultural sector. Products such as bananas (Musa acuminata), passion fruit (Passiflora edulis Sims), golden berries (Physalis peruviana), avocados (Persea americana), palm oil, coffee, and flowers represent a substantial share of Colombia's exports to Europe. According to the Ministry of Commerce, Industry and Tourism, 80% of Colombian fruit exports, 60% of palm oil, 30% of coffee, and 10% of flowers are destined for the EU [5].

The EU–Colombia Trade Agreement has facilitated an increase in Colombia's non-mining energy exports. Over the course of eight years, these exports have grown from 22% to 62% of the country's export basket. In total, 667 new products have been introduced into the EU market, including 109 from the agri-food sector [6]. These trends demonstrate the strategic importance of the EU as a destination for Colombian agricultural exports and the pressing need to adapt to the evolving sustainability standards of this market.

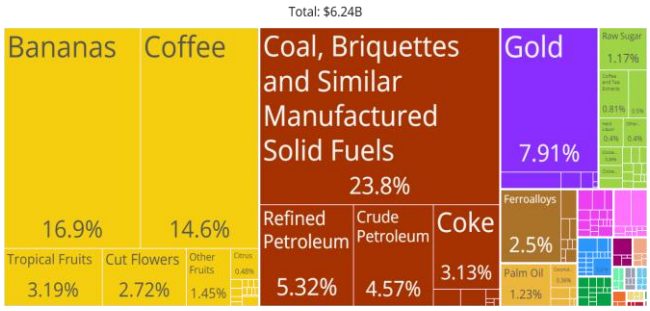

Fig 1. Composition and percentage share of Colombia's main export products to a selected group of European countries in 2024.

Source. Own elaboration based on data from the Observatory of Economic Complexity (OEC), 2024. [Interactive treemap]. Retrieved from https://oec.world/

In this context, it is imperative to evaluate Colombia's level of preparedness to implement the EGD's guidelines. This includes identifying the public policies, laws, and regulations currently in place and assessing their alignment—or misalignment—with the EGD's priorities. Furthermore, it is necessary to understand whether these strategies are facilitating or limiting the entry of Colombian agri-food products into the European market [7]. Emphasis should be placed on Colombia's alignment with five key pillars of the EGD: (1) sustainable use of agrochemicals, (2) circular economy, (3) biodiversity protection, (4) agroecological production, and (5) deforestation-free traceability.

In addition, this analysis must explore the enabling and restricting factors that influence the adoption of these regulatory frameworks. In the literature, enabling factors are defined as drivers or key variables that positively influence the success of a process or initiative [8], whereas restricting factors are elements that inhibit or constrain such processes [9]. In the context of agricultural value chains, these are often referred to as "critical factors," which may either enhance (opportunities) or obstruct (constraints) the performance and development of a system [10].

The experience of countries such as Costa Rica through its export promotion agency PROCOMER demonstrates the importance of evaluating the implications of the EGD for agricultural exports and identifying challenges and opportunities in areas such as pesticide use, production audits, sustainable packaging, organic production, and good agricultural practices [11]. In Colombia, institutions such as ProColombia and the Ministry of Commerce, Industry and Tourism have implemented support mechanisms like the AL-INVEST Verde program, funded by the European Commission, which seeks to promote a transition toward a low-carbon, resource-efficient, and circular economy by providing technical assistance and funding for innovative projects across agriculture, forestry, and intellectual property sectors [12].

At the regional level, collaborative proposals are being developed to help Latin American and Caribbean countries meet EGD-related standards, particularly in the agricultural and agro-industrial sectors though technology and knowledge transfer [13]. These proposals aim to strengthen trade and investment ties through technology transfer, knowledge exchange, and the integration of regional value chains [14].

To determine the enabling and restricting factors influencing the adoption of the European Green Deal guidelines in Colombia's agricultural export sector this research adopts a mixed-methods approach (quantitative and qualitative) and is structured in three phases: (1) an assessment of Colombia's regulatory and institutional alignment with the EGD's five pillars, to identify current laws and public policies in the agricultural sector that are linked to the implementation of the EGD guidelines concerning primary agricultural production (2) a scientometric analysis and expert consultation to identify and categorize the enabling and restricting factors influencing the adoption of the EGD sustainability guidelines for Colombian agri-food exports to the European Union, and (3) the formulation of differentiated strategic actions based on their level of influence and implementation timeframes to minimize the impact of restricting factors on Colombia's agricultural export sector.

II. Materials and Methods

A three-phase methodological design was implemented using a mixed research approach (quantitative and qualitative).

A. Phase 1

Identification and analysis of the alignment of public policies, policy instruments, and legal frameworks related to agricultural production with the EGD. This was assessed using two indicators: alignment level per pillar and overall alignment level, which evaluate the degree of development or response to compliance-oriented actions based on a predefines categories scale-scheme (Fig 1).

B. Phase 2

Identification of enabling and restricting factors (that drive an outcome, influence performance, or create a significant change in a system or process) through a scientometric analysis of the academic and scientific literature, based on keyword co-occurrence and expert criteria analysis based on Martínez-Saldarriaga et al. [15] and Flórez-Martínez & Morales-Castañeda [16].

A comprehensive literature review will be conducted to identify variables influencing the implementation of European Green Deal (EGD) guidelines in Latin American and Caribbean countries. This review will include material published since 2019 both from: 1) indexed Scientific publications retrieved from databases such as Scopus®, Web of Science®, SciELO®, EBSCO Business Source Complete®, and Emerald®. These sources will provide peer-reviewed evidence on policy alignment, sustainability strategies, and regulatory adaptation to EGD standards and, 2) non-indexed sources, of grey literature available on official government websites from Colombia and selected Latin American countries with strong trade relations with the EU, National development plans, trade agreements, and strategic initiatives from ministries of commerce and agriculture, and generalized searches on Google Scholar to expand the information base and capture relevant unpublished or technical documents.

Based on this core of knowledge Identification and Categorization of Influencing Variables that either facilitate or hinder the implementation of EGD-aligned policies, were identified and categorized as: (1) Enabling Factors (EF): Variables that positively influence policy alignment and implementation, and (2) Restrictive Factors (RF): Variables that inhibit, delay, or complicate EGD implementation.

The Expert Validation through Focus Group evaluates the influence of each EF and RF on the alignment of national laws, policies, and initiatives with the EGD. The expert panel included representatives from: Agricultural research

Institutions, The Ministry of Agriculture, ProColombia, Public and private universities, The Ministry of Commerce, Industry and Tourism (MINCIT), and The National Planning Department (DNP). This evaluation will be conducted via a digital survey instrument, structured as a matrix that crosses the EGD guidelines with the identified EFs and RFs (Figure 2). Experts will also validate the alignment scores obtained during the initial policy analysis (Phase 1) and propose strategic actions to strengthen alignment in critical areas.

EGD Guidelines / Laws, Policies and Initiatives	Guideline 1	Guideline 2	Guideline 3	Guideline 4	Guideline n
Policy 1		X			X
Policy 2	X		X		
Policy 3				X	
Policy 4		X		X	
Policy n					X

Category	Category Name	Category Description
1	Not Aligned	Contains no information, proposals, or strategies related to the guideline.
2	Low Alignment	Some general statements suggest potential actions or directions, but there are no details on implementation or any associated strategies.
3	Medium Alignment	The policy outlines clear objectives and general actions, but lacks specific, quantifiable targets.
4	High Alignment	The policy presents a clear mission and objectives, including specific actions and strategies to achieve the guideline. However, it lacks monitoring indicators or compliance measures aligned with the guideline's standards.
5	Full Alignment	Includes comprehensive content aligned with the guideline, encompassing mission, objectives, defined actions and targets, and monitoring indicators that reflect compliance with relevant standards and requirements.

Fig 1. Degree of Development of the Policy, Law, or Regulation assessment matrix scheme
Source. Authors

EGC guidelines / Enabling (EF) Restrictive (RF) factors	Guideline 1	Guideline 2	Guideline 3	Guideline 4	Guideline n
EF1	High				
EF 2		Low			
EF 3					
EF n		High	None	Low	
RF 1					
RF 2		Intermediate	None		Intermediate
RF 3				High	Intermediate
RF n					
Proposed strategies and action lines					

Fig 2. Enabling Factors (EF) and Restrictive Factors (RF) EGD guidelines alignment.
Source. Author

C. Phase 3

Factors with the highest impact were used to design short-term action lines (1–3 years), medium-term actions (3–5 years), and long-term strategies (beyond 5 years). The analysis also guided the definition of the scope of action plans (what to do), target populations and stakeholders (who), and the required tools, methodologies, and strategies (how).

III. RESULTS

This section presents the results obtained through the implementation of the methodological approach across its different phases, each corresponding to the study's specific objectives. A critical analysis is provided, discussing the relevance of the findings within the current context.

A. Phase 1, results

This methodological phase first identified European Green Deal (EGD) guidelines and regulations relevant to the agricultural sector. The Farm to Fork Strategy (F2F), a central pillar of the EGD, promotes a transition toward sustainable food systems by setting ambitious 2030 targets, including a 50% reduction in chemical and highly hazardous pesticides, nutrient losses, and antimicrobials, alongside expanding organic farming to 25% of agricultural land [17]. The strategy comprises around 30 initiatives addressing pesticide use, food labelling, animal welfare, and sustainability, which require legislative translation to become market-relevant [11,18].

Complementing F2F, the Regulation on the Sustainable Use of Plant Protection Products mandates a 50% reduction in pesticide use and risk through Integrated Pest Management, non-chemical alternatives, stricter enforcement, and technological innovation. The regulation applies to EU imports, enforces Maximum Residue Limits (MRLs), restricts pesticide use in sensitive areas, and promotes biological control, with high-risk substances scheduled for phase-out between 2023 and 2029 [19,20]. MRLs remain governed by Regulation (EC) No. 396/2005, covering 513 active substances, with periodic reviews to ensure food safety and environmental protection.

The Circular Economy Action Plan proposes revisions to food labelling regulations to improve transparency on nutrition and sustainability, building on Regulation (EU) No. 1169/2011 and introducing harmonized front-of-pack labelling systems [19,21]. In parallel, the EU Biodiversity Strategy and Organic Action Plan aim to restore ecosystems, reduce pesticide dependence, and expand organic agriculture, with Regulation EU 2018/848 establishing mandatory standards for both EU and non-EU producers.

Additionally, Regulation 1115 prohibits the commercialization of commodities linked to deforestation, imposing due diligence, traceability, and georeferenced supply chain requirements on operators, including third-country exporters, with penalties of up to 4% of EU annual turnover [22,23]. Although not legally mandated, sustainability and social responsibility certifications—such as GlobalG.A.P., Rainforest Alliance, FAIRTRADE, B Corp, and EU Organic—have become de facto market requirements, reinforcing environmental compliance, traceability, and social accountability.

At the national level, Colombian policies were analyzed to assess alignment with EGD principles. Instruments such as the Green Growth Policy (CONPES 3934 of 2018), National

Development Plans (2018–2022; 2022–2026), the 2030 Biodiversity Action Plan, and the Agricultural Climate Change Management Plan promote agroecology, bio-inputs, climate-smart agriculture, and regulatory compliance. Regulatory measures from the Colombian Agricultural Institute (ICA), including resolutions on pesticide labelling, organic certification, and traceability, further support export readiness. Together, these policies demonstrate Colombia's commitment to sustainable agri-food systems and its progressive alignment with EGD requirements, whose degree of implementation was assessed using the proposed methodological matrix (Table1).

IV. DISCUSSION AND CONCLUSIONS

This research confirms that Colombia faces substantial financial, operational, and institutional challenges in implementing the regulatory frameworks required by the European Green Deal (EGD), particularly within its agrifood export sector. Restrictive factors such as the high costs of regulatory compliance, short implementation timelines, and low adoption of bioinputs are significant barriers that could undermine the country's ability to maintain competitiveness in environmentally demanding European markets. In parallel, enabling factors, notably productive transformation plans, economic incentives, and environmental footprint reduction policies highlight strategic opportunities to foster a transition toward sustainable, resilient, and circular agricultural systems.

TABLE 1. DEVELOPMENT DEGREE OF POLICIES, LAWS, OR REGULATIONS FORMULATED OR IMPLEMENTED IN COLOMBIA RELATED TO THE IMPLEMENTATION OF EUROPEAN GREEN DEAL REGULATIONS AND GUIDELINES IN THE AGRICULTURAL SECTOR

	EGD Guidelines						
Colombia agriculture sector public policies initiatives	**1a. Sustainable Use of Plant Protection Products**	**1b. Packaging Regulation: Environmental Sustainability**	**2. Mandatory Nutritional Labelling on Packaging**	**3. Biodiversity Strategy**	**4. Organic/ Ecological Production**	**5. Regulation on Deforestation-Free Products**	**Alignment percentage EGD vs. Colombian public policies initiatives**
AL-INVEST Verde – Colombia Action Program	4	4	4	4	4	4	High 100%
Green Growth Policy	3	1	1	2	3	5	Medium 67%
2018–2022 National Development Plan	1	2	1	3	1	5	Medium 50%
European Union–Colombia Cooperation Agenda	1	3	1	1	3	3	Medium 50%
Sectoral Climate Change Management Plan (PIGCCS), Ministry of Agriculture	1	1	1	5	1	5	Low 33%
Resolution 75487 of 2020 — Implementation of the Globally Harmonized System (GHS) for pesticide labelling	3	1	1	1	1	1	Low 17%
Resolution 187 of 2006 — Regulation on Organic Agricultural Products	2	2	2	2	2	1	High 83%
Resolution 824 of 2022 — Requirements for registration with the Colombian Agricultural Institute (ICA) of production sites, exporters, and packing facilities for the export of fresh plant products	1	2	1	1	2	1	Low 33%
Draft Bill — National Agroecology Plan	2	1	1	1	2	1	Low 33%

Although advances have been made in biodiversity protection and deforestation control, Colombia still lags behind regional peers such as Ecuador, Costa Rica, and Brazil, which have adopted more comprehensive EGD-aligned strategies. By comparison, Costa Rica has developed specific institutional instruments to guide exporters in relation to the European Green Deal through PROCOMER and COMEX [24,25]. Ecuador has formalized agricultural, livestock, and forestry traceability guidelines and reported USD 621 million in organic exports to the European Union in 2024, with 78,156 certified hectares and 8,641 registered organic producers [26,27]. Brazil, in turn, has national and subnational instruments, such as the ABC+ Plan 2020–2030 and SelloVerde MG, which have already been applied to verify deforestation-free coffee destined for the European market [28,29]. Therefore, the regional comparison suggests that Colombia's gap does not stem from an absence of initiatives, but rather from a lower degree of integration, scaling, and operationalization of traceability, financing, and coordinated implementation tools in response to the requirements of the EGD and the EUDR

National frameworks, including the Green Growth Policy, National Development Plans, Climate Change Management Plans (PIGCCS), and biodiversity strategies, provide enabling conditions for bioeconomy, circular economy, and climate-resilient agriculture; nonetheless, stronger integration of agroecological approaches and international standards is required. These gaps were also highlighted during COP16 in Colombia, where FAO called for biodiversity-friendly agriculture, reduced agrochemical dependence, and inclusive participation of Indigenous and local communities [30,31].

In the Colombian context, the EGD is increasingly perceived as a reference framework for transitioning toward a more sustainable and competitive agro-industrial sector, although major challenges persist regarding implementation, financing, and adaptation to heterogeneous local realities across value chains. The Farm to Fork (F2F) strategy is recognized as a comprehensive pathway to enhance rural sustainability and resilience [32], and the findings suggest that Colombia could leverage these guidelines to address environmental degradation and market access constraints through short supply chains, value-chain integration, and agrobiodiversity-based production systems. However, consistent with [33], the direct transfer of European policies without contextual adaptation may be ineffective or counterproductive, underscoring the need for a tailored, gradual roadmap co-created with farmers, rural communities,

and actors within the National Agricultural Innovation and Environmental Systems.

Financing remains a critical bottleneck, as highlighted by [34], who emphasizes the global challenge of mobilizing sufficient resources to support sustainable transitions and advocates for a "just transition" approach that protects small and medium producers. Aligning benefit–cost structures along agri-food value chains can enhance competitiveness, foster local value addition, and reduce greenhouse-gas emissions relative to raw commodity exports [35]. Nonetheless, concerns remain regarding unclear enforcement mechanisms and inconsistencies between EGD biodiversity ambitions and scientific consensus [36], reinforcing the need for stronger governance, regulatory clarity, and science-based agroecological strategies. Effective implementation will require investments in human capacity, infrastructure, monitoring systems, and services to operationalize circular-economy models, bio-input substitution, and sustainable intensification aligned with EGD objectives.

B. Phase 2, results

The scientometric analysis identified global research trends, enabling factors, and constraints related to the implementation of the European Green Deal (EGD) in the agricultural sector. A total of 204 indexed publications retrieved from Scopus®, Web of Science®, EBSCO®, and SciELO® were analyzed using VOSviewer® to map thematic structures through keyword co-occurrence analysis [37]. This approach revealed seven core thematic clusters representing the main research and policy action areas supporting EGD implementation worldwide (Figure 3).

Search equation: *"european green deal" AND (farm OR agricult OR agri-food OR "supply chain" OR framework OR institution* OR regulator* OR initiative OR program OR strateg* OR polic* OR law OR decree OR statute OR program* OR plan OR action OR legislation OR governance OR challenges OR goal OR transition OR adaptation OR assessment OR implementation).*

The dominant research focus highlights agroecology, organic agriculture, and sustainable agroecosystem management, emphasizing food sovereignty, ecological justice, and the reduction of synthetic inputs through bio-inputs and organic waste reuse, thereby reinforcing circular-economy models [38-41]. Complementary trends include sustainable fertilization strategies based on biofertilizers and biostimulants aligned with the Farm to Fork strategy, which improve soil health and nutrient efficiency while reducing dependency on synthetic fertilizers [42-44]. Forest management and carbon sequestration emerge as key mitigation pathways, particularly through agroforestry systems and improved nutrient management in agricultural and livestock systems [45-47].

Additional research clusters highlight biodiversity conservation and biomass valorization, including phytoremediation, biodiversity-friendly crop management, and the transformation of agricultural residues into clean energy and bioactive compounds [48,49,53]. Sustainable pesticide use and food quality are addressed through precision agriculture, biopesticides, and risk-reduction strategies aimed at minimizing chemical inputs while ensuring food safety [50-52]. Waste management and circular use of food by-products further support resource optimization across agri-food systems [43,53]. Finally, biodiversity and ecosystem services research emphasizes soil carbon preservation, sustainable land use, and legal instruments to mitigate soil degradation and ecosystem loss [54-56].

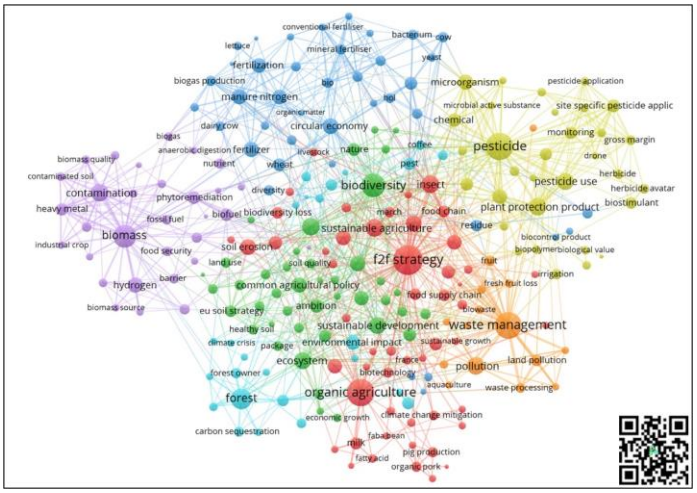

Fig 3. Word Co-occurrence Network and Thematic Clusters Related to Actions and Implementation of the European Green Deal
Source. Own elaboration based on information from Scopus®.
Consultation date: July 2024. Analysis software: VOSviewer®

Overall, the findings reveal a strong convergence toward agroecology-based, circular, and biodiversity-centered approaches as strategic pillars for agricultural sustainability under the EGD. These integrated strategies support ecosystem services, climate-change mitigation, and social equity while promoting safer food systems and reduced environmental footprints, reflecting a holistic transition aligned with EGD objectives.

Based on the analysis of relevant publications, key technological aspects were identified that enable resource optimization and reduce environmental impact, thereby contributing to the transition toward a sustainable food system within the framework of strategies aimed at achieving the sustainability objectives of the European Green Deal in the Colombian context. These aspects include precision agriculture, which, through a holistic approach, can support phytosanitary crop management using sensors, remote sensing, and variable-rate applications (VRA) [57,58]. Its implementation has enabled drastic reductions in agrochemical use, particularly in mechanized applications with direct injection systems, where pesticide cost savings of up to 66% have been reported [59].

Likewise, traceability technology is essential to ensure safety and transparency throughout the agri-food chain, in compliance with the requirements of the "Farm to Fork" strategy [60]. Current analytical and technological advances facilitate product authentication, allowing complex natural substances to be accurately differentiated from their

corresponding synthetic substances, thereby helping to combat food fraud [61]. Similarly, bioinputs engineering promotes the circular economy through the recovery of nutrients —nitrogen, phosphorus, and potassium— from organic waste to produce bio-based fertilizers that replace traditional mineral fertilizers [62]. The development of plant biostimulants also enhances crop resilience to abiotic stresses, such as salinity [63].

Based on information gathered from various sources including national strategies, policies, regulations, decrees, and plans from Colombia and benchmark countries in Latin America, as well as insights from the literature 14 key factors were identified. A keyword co-occurrence map was constructed through scientometric analysis, enabling the identification of research trends based on the association among terms. Subsequently, these trends were described through a semantic construction and, using complementary information—such as national regulatory frameworks and sectoral documents—were categorized as enabling or restrictive factors within the current Colombian context. These factors capture the most relevant aspects of the regulatory and strategic frameworks and are each assigned a code and label for future reference in linking them to proposed strategic action lines.

Enabling factors

- EF1 – Productive Transformation Plans: Implementation of productive transformation plans that integrate sustainable agroecological practices aligned with climate-smart agriculture to support resilient food systems.
- EF2 – Economic Incentives for Bio-inputs: Market-based and financial incentives to promote the increased use of bio-inputs and reduce dependence on synthetic fertilizers and pesticides.
- EF3 – Inclusion of Good Practices: Integration of good practices in livestock farming focusing on food safety, animal welfare, and health; sustainable forest plantation management; and sustainable integration of production systems with native forests.
- EF4 – Policies to Reduce Environmental Footprint and Food Waste: Adoption of policies and legislation aimed at reducing environmental footprints, food loss and waste along the value chain, and protecting soil, water, and ecosystem services.
- EF5 – Bioeconomy and Green Business Policies: Development and implementation of policies and plans promoting bioeconomy principles in agri-food systems, fostering sustainable green business ventures, and supporting innovation and technology for sustainable production

Restrictive factors

- RF1 – Weak Legal Frameworks for Sustainability: Insufficient strengthening of legal frameworks and financial incentives to support ecological transition, especially in agroecological and organic production systems.
- RF2 – Short Implementation Timelines: Limited periods for compliance with various European Green Deal regulations across production chains.
- RF3 – Lower Yields in Organic Production: Lower productivity of organic and agroecological farming systems compared to conventional agriculture.
- RF4 – High Implementation Costs: High costs associated with implementing regulations and due diligence requirements.
- RF5 – Poor Policy Coordination: Lack of coordination and integration among policies, governance frameworks, and strategies related to the implementation of the European Green Deal.
- RF6 – Low Awareness Among Exporters: Limited knowledge among exporters and companies regarding best practices and strategies to meet due diligence obligations along the supply chain.
- RF7 – High Costs of Traceability Systems: High costs and limited implementation of robust traceability systems.
- RF8 – Limited Use of Bio-inputs: Low adoption and limited promotion of biological control methods and bio-input usage.
- RF9 – Lack of Incentives for Diversification and Technology: Absence of incentives for producers and companies to support crop diversification, alternative technologies, and innovative commercialization strategies.

On a second step, a structured survey was conducted to assess the enabling and restrictive factors affecting the implementation of the European Green Deal (EGD) in the Colombian agro-industrial sector. Given the length of the survey, guidelines 2 (Packaging Regulation: Environmental Sustainability) and 3 (Mandatory Nutritional Labelling on Packaging) identified in Phase 1 were merged due to their thematic proximity, resulting in five guidelines rated for each factor. The instrument, based on 14 key factors identified from scientific and technical sources, was distributed to 116 experts from academia, government, research institutions, and export-oriented companies, yielding 20 valid responses. The minimum representative sample size for the study was estimated using the formula proposed by Kish [65]. Based on this formula, statistical validity was determined by setting an estimation error of 0.2, a significance level of 0.05, and a proportion of 0.5 to obtain the largest possible sample size, resulting in n=20 [64]. Most respondents held postgraduate degrees and had extensive professional experience, with 81% demonstrating at least moderate knowledge of EGD regulations according to a five-level self-assessment scale adapted from [66].

The results confirmed a high level of consensus regarding the relevance of the identified factors: 11 were rated as having high influence and 3 as medium influence, with none considered low. Productive transformation plans and agroecological practices emerged as the most significant enabling factors, while economic incentives for bio-inputs were identified as critical to reducing chemical dependency. Conversely, lower yields in organic systems, limited adoption of bio-inputs, weak policy coordination, short compliance timelines, high implementation costs, and insufficient technical

capacity were highlighted as major restrictive factors, particularly affecting small producers. Overall, the findings underscore the importance of integrated governance, targeted training, and financial incentives to support Colombia's transition toward EGD-aligned, sustainable agribusiness systems (Table 2). Furthermore, experts proposed additional EF and RF (Table 3).

C. Phase 3, results

Based on the results of Phases 1 and 2, high-incidence enabling and restrictive factors were used to define short- and medium-term strategic action lines. Since no factor was rated as having low incidence, no line of action was considered for long-term implementation. Key enabling factors include productive transformation plans, economic incentives for bio-inputs, and policies aimed at reducing environmental footprints, all of which support agroecological practices, circular economy integration, and sustainable agricultural and livestock systems. Their effectiveness, however, depends on coordinated implementation and institutional capacity (Table 2).

Major restrictive factors include high regulatory compliance costs, tight implementation timelines, limited adoption of bio-inputs, weak policy coordination, and insufficient incentives. These constraints disproportionately affect small and medium producers and limit Colombia's ability to meet European Green Deal requirements, particularly in export-oriented value chains requiring sustainability certification and traceability.

Productive transformation and circular economy approaches, reinforced during COP16, emerge as central pillars for improving sustainability and competitiveness. Addressing governance fragmentation through policy alignment with EGD guidelines and COP16 commitments—supported by targeted incentives and technical assistance—is essential to enable an effective and equitable ecological transition in Colombia's agricultural sector.

TABLE 2. EXPERTS INCIDENCE RATING OF ENABLING AND RESTRICTIVE FACTORS

Factor Type	Factor	Sustainable Use of Pesticides	Packaging & Nutritional Labelling	Biodiversity Strategy	Organic Production	Deforestation-Free Products	Majority Rating
EF	Implementation of productive transformation plans	High	Medium	High	High	High	High
EF	Economic and market incentives for bio-inputs	High	Medium	Medium	High	Medium	Medium
EF	Inclusion of good practices in livestock and forest systems	High	Medium	High	Medium	High	High
EF	Policies to reduce environmental footprint and food loss	High	Medium	High	High	High	High
EF	Policies promoting bioeconomy and green businesses	High	Medium	High	Medium	Medium	Medium
RF	Weak legal frameworks and financial incentives	High	Medium	High	High	High	High
RF	Short compliance deadlines for EGD regulations	High	High	Medium	Medium	High	High
RF	Lower yields in organic production systems	Medium	Medium	Medium	High	Medium	Medium
RF	High costs of regulation and due diligence	High	Medium	High	High	High	High
RF	Poor policy coordination and governance	High	High	High	High	High	High
RF	Low awareness on best practices and due diligence	High	High	High	High	High	High
RF	High costs and low implementation of traceability	High	High	High	High	High	High
RF	Low use and promotion of bio-inputs	High	Medium	High	High	High	High
RF	Lack of incentives for diversification and technology	High	High	High	High	High	High

TABLE 3. ENABLING AND RESTRICTIVE FACTORS IDENTIFIED BY EXPERTS

Code	Factor	Description	Category	Incidence
FH6	Public CTI policies	Sectoral public policies for science, technology, and innovation (STI) focused on bioeconomy missions	Enabling	High
FH7	High biomass production capacity	High capacity for sustainable biomass production for bioeconomy-related businesses	Enabling	Medium
FH8	Intensification of tech transfer programs	Expansion of technology transfer and training programs to support implementation of best agricultural practices	Enabling	High
FH9	Alignment of national policies with the EGD	Alignment of national interests with EGD principles, boosting regenerative agriculture, circular economy, and nature-based solutions	Enabling	High
FR10	Impacts of Free Trade Agreements (FTAs)	FTAs' negative impact on emerging economies by limiting development, growth, and green export participation	Restrictive	Medium
FR11	Compliance with labor rights	Challenges in ensuring full compliance with labor rights	Restrictive	High
FR12	Participation of research centers	Limited awareness and engagement of research centers in sustainable innovation for EGD implementation	Restrictive	Medium

Code	Factor	Description	Category	Incidence
FR13	Promotion of sustainable products	Lack of promotion policies and differential financing for bioservices and bioenergy to develop sustainable products	Restrictive	Medium

TABLE 4. KEY PROPOSED STRATEGIES

Implementation Timeline	Strategic Action Line	Target Population	Responsible Institutions	Associated Factors
Short	Strengthen regulatory and financial frameworks for agroecology, including a national organic certification system and financial support for sustainable production.	Small and medium-scale producers, organic producer associations, sustainable agribusinesses	MinAgriculture, Ministry of Environment, Finagro	FH1, FH5, FH6, FH9, FR1, FR5
Short	Implement technical support and training programs to promote bioinputs and sustainable soil management with economic incentives.	Producers seeking organic certification, agricultural biotech researchers, modern agribusinesses	MinAgriculture, ICA, Ministry of Science and Tech, Agrosavia, SENA	FH2, FR9, FR13
Short	Design tailored economic incentives for sustainable producers and exporters, including subsidies, soft loans, and tax benefits.	Small and medium-scale producers, organic producer associations, sustainable agribusinesses	MinAgriculture, Ministry of Environment, Finagro, ProColombia, Ministry of Science and Tech	FH2, FH5, FR3, FR8, FH8
Short	Launch pilot projects for resilient livestock production using technologies that reduce GHG emissions and improve efficiency.	Medium and large livestock farmers, agribusiness exporters, technical specialists	MinAgriculture, Ministry of Environment, SENA, ProColombia	FH1, FH4, FH6, FR9, FR12
Short	Update legal frameworks to align with the EGD through sustainable production and circular economy in agribusiness.	Small and medium farmers, producer associations, researchers, environmental consultants	MinAgriculture, Ministry of Environment, ICA, ProColombia	FH4, FH5, FR1, FR5
Medium	Promote the adoption of sustainable technologies (biotech, renewables, resource efficiency) and international cooperation for certification and innovation.	Small and medium producers, producer associations, agribusiness companies, technical specialists	MinAgriculture, Ministry of Environment, ADR, Research Centers, ProColombia, Producer Associations, Financial Institutions	FH1, FH3, FH8, FR3, FR6, FR9, FR12
Short	Establish an interinstitutional committee to align national policies with EGD requirements through integrated environmental, social, and economic strategies.	All producer segments, producer associations, export companies, technical specialists	MinAgriculture, Ministry of Environment, ICA, Research Centers	FH4, FH5, FH6, FH9, FR1, FR12, FR10, FR11
Medium	Facilitate ecological transition through credit, insurance, and technical training in organic and agroecological systems, improving profitability and EU market access.	All producer segments, producer associations, export companies, technical specialists	ProColombia, ICA, MinAgriculture, Research Centers, SENA	FH1, FH2, FH3, FH8, FR2, FR7, FR9, FR11, FR12, FR13

IV. DISCUSSION AND CONCLUSIONS

This research confirms that Colombia faces substantial financial, operational, and institutional challenges in implementing the regulatory frameworks required by the European Green Deal (EGD), particularly within its agrifood export sector. Table 4 strategies and a timeline framework (Figure 4), comprise a roadmap base line.

These strategies focus on affront restrictive factors such as the high costs of regulatory compliance, short implementation timelines, and low adoption of bioinputs are significant barriers that could undermine the country's ability to maintain competitiveness in environmentally demanding European markets. In parallel, enhance enabling factors, designing notably productive transformation plans, economic incentives, and environmental footprint reduction policies highlight strategic opportunities to foster a transition toward sustainable, resilient, and circular agricultural systems.

The lower yields observed in organic production systems should be understood as a transition gap that can be mitigated through productive transformation plans based on agroecology and Agriculture 4.0 technologies. Evidence indicates that organic yields are generally lower than conventional yields; however, this difference does not constitute a uniform pattern across all crops, territories, or production systems, as the magnitude of the gap may vary depending on the production context and the type of management implemented. In particular, crop rotations and polycultures can reduce the organic–conventional yield gap to approximately 8–9%, demonstrating the potential of agroecological diversification to sustain both productivity and sustainability [67].

Complementarily, Agriculture 4.0 technologies—including sensors, drones, geospatial monitoring, variable-rate applications, and decision-support systems—enable the optimization of input use and cost reduction without compromising yields [52,68,69]. Therefore, the proposed productive transformation plans should integrate bioinputs, sustainable soil management, crop diversification, technical assistance, financing, and digital innovation, in order to reduce the productivity gap in organic and agroecological systems without increasing environmental pressure or dependence on synthetic inputs.

The integration of traceability systems and the use of bioinputs constitutes an operational strategy to advance compliance with the standards associated with the European Green Deal. Together, these two components can strengthen productive sustainability and the competitiveness of agrifood export chains, provided that they are accompanied by technical assistance, economic incentives, digital capacities, and institutional mechanisms that facilitate their adoption by small- and medium-scale producers [70-73].

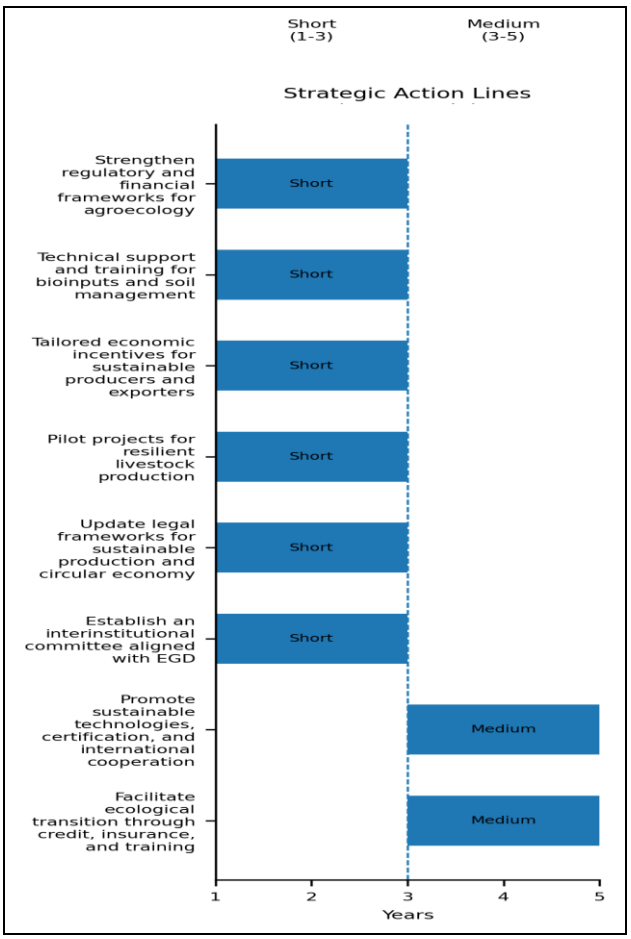

Fig 4. Gantt-style timeline of proposed Strategic Action Lines for the implementation of EGD-aligned measures in Colombia's agribusiness sector.

A technical flow-type diagram (Fig 5) is proposed to illustrate how a traceability system—associated with restrictive factor RF7—and a bioinputs system—associated with enabling factor EF2—can operate complementarily at the farm level to support compliance with European Green Deal standards , according to the following approaches:

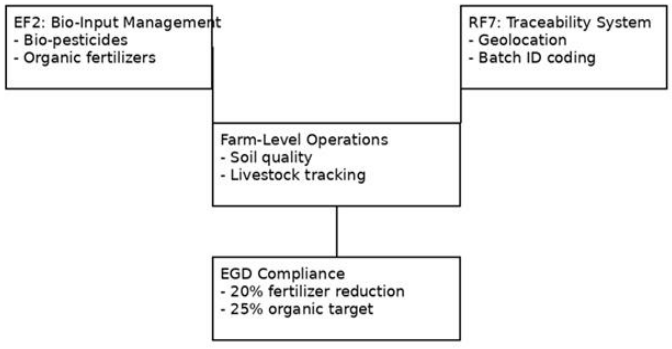

Fig 5. Farm-Level Traceability and Bio-Input architecture to support compliance with European Green Deal standards

- Bio-Input System (EF2): Focuses on replacing synthetic chemicals with biological alternatives to meet EGD goals of reducing chemical pesticides by 50% and fertilizers by 20% by 2030. Production & Application: Includes microbial inoculants, bio-pesticides, and organic fertilizers sourced locally or from centralized bio-input resource centers (BRCs). Targeted Use: Technologies like foliar sprays and seed treatments ensure efficient nutrient delivery.
- Traceability System (RF7): Provides the data backbone required for transparency and verifying that products meet sustainability criteria. Data Capture: Uses IoT sensors and RFID tags to monitor environmental conditions (e.g., temperature, humidity) and location in real-time. Geospatial Tracking: Collects geolocation data of production plots to ensure no deforestation (crucial for EUDR compliance).Authentication: Advanced methods like DNA barcoding or isotope profiling verify the origin and authenticity of the bio-inputs and final products.
- EGD Standards Compliance: The integrated data from EF2 and RF7 is used to generate Audit Ready Reporting for European regulators.
- Sustainability Validation: Demonstrates reduced environmental footprint through recorded usage of bio-inputs instead of synthetics.
- Consumer Transparency: Facilitates "Farm to Fork" visibility via QR codes on packaging, allowing consumers to verify ethical and sustainable production practices.

The study employed a mixed-method approach, integrating policy analysis, document review, and expert surveys, which proved effective for triangulating perspectives and identifying both systemic gaps and institutional strengths. The use of alignment matrices provided a valuable tool to assess the coherence between national regulatory instruments and the EGD, while expert consultation enriched the findings with sector-specific insights.

Despite limitations, including the size of the expert sample and reliance on secondary data the findings confirm broader evidence that developing countries require tailored support to implement strict environmental regulations. The existence of sustainability-oriented policies alone is insufficient; effective implementation requires coordination, incentives, and context-sensitive strategies that reflect local production realities.

The results align with key messages from COP16, where productive transformation and circular economy were reaffirmed as essential pillars for increasing sustainability and competitiveness in agriculture. The conference further emphasized the role of ecosystem restoration, agroecological practices, and coordinated governance in achieving biodiversity and climate goals objectives closely tied to the EGD framework.

Regarding the restrictive factor related to poor policy coordination, the creation of an intersectoral coordination committee is proposed, involving the Ministry of Agriculture and Rural Development, the Ministry of Science, Technology and Innovation, the Ministry of Trade, Industry and Tourism, and the Ministry of Environment and Sustainable Development. This committee would be coordinated by the

National Planning Department and would be responsible for the design, implementation, and monitoring of roadmaps aimed at establishing effective strategies for compliance with and implementation of EGD guidelines in the Colombian context.

Regarding the restrictive factor associated with the potential negative impacts of free trade agreements, the evidence reviewed suggests that the restriction does not stem from the FTA itself, but rather from the regulatory, financial, and technological asymmetries that arise when preferential market access is conditioned on compliance with strict environmental standards. In the context of the European Green Deal, instruments such as the EUDR may operate as incentives for sustainable transition, but also as technical or non-tariff barriers when producers and exporters lack sufficient capacities for traceability, certification, financing, and institutional adaptation [74]. At the same time, trade agreements can serve as useful platforms for cooperation and environmental governance when they incorporate sustainable development mechanisms, institutional dialogue, and technical support [75]. Consequently, for Colombia, the challenge lies in strengthening internal compliance capacities—traceability, financing, technical assistance, certification, and interinstitutional coordination—so that the environmental requirements of the European market do not result in the exclusion of small-scale producers but rather become an opportunity for sustainable differentiation.

To meet these demands, it is critical that Colombia: (1) Strengthens legal frameworks and streamlines regulatory alignment with EGD standards; (2) Develops incentive structures and financing mechanisms that lower entry barriers to sustainable production; (3) Promotes inter-institutional coordination to overcome policy fragmentation: (4) Invests in technical assistance and technology transfer for producers.; and, (5) Fosters international partnerships and interdisciplinary research to design holistic, evidence-based solutions.

Ultimately, ensuring policy coherence, regulatory simplification, and cross-sectoral alignment with EGD principles is essential for enabling Colombia's agricultural sector to meet international sustainability standards based on the strategic integration of bioeconomy, circular economy, and sustainable agriculture into Colombia's national policy agenda. In consequence concrete institutional actions will be essential for aligning with the European Green Deal and for enhancing the long-term sustainability and market access of its agricultural exports.

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