

Climate Change and the Transformation of International Environmental Law: Tensions, Justice, and Regulatory Challenges (2014–2024)

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ABSTRACT

Climate change has intensified tensions surrounding international environmental law, requiring a reinterpretation of its principles and governance mechanisms. This study examines how literature published between 2014 and 2024 has conceptualized the transformation of international environmental law, particularly in relation to the evolution of legal principles, methodological trends, regulatory gaps, and thematic research patterns. A B-SLR approach is used, integrating bibliometric analysis and systematic review of a corpus of articles indexed in Web of Science and Scopus, selected using the PRISMA protocol and a semantic classification system based on Natural Language Processing. The findings reveal sustained growth in scientific output and an intellectual structure configured around climate justice, polycentric governance, green economy, and human rights. Qualitative analysis shows a transition towards more flexible and adaptive legal models, accompanied by the expansion of climate litigation and the use of human rights frameworks to reinforce state obligations. However, critical issues related to regulatory fragmentation, dependence on soft law, and institutional weakness persist. Overall, international environmental law is undergoing a profound and still incomplete process of reconfiguration in the face of the accelerating climate crisis.

Keywords: *Natural Language Processing (NLP); Semantic classification; Systematic review; International environmental law; Climate change.*

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1. INTRODUCTION

Climate change constitutes one of the most complex structural challenges of the international system, due to its cumulative effects on ecosystems, economies and political structures that intensify historical inequalities between the Global North and the Global South [1–3]. The literature demonstrates that differential vulnerability to extreme weather events is related to persistent patterns of ecologically unequal exchange, financial dependence, and asymmetries in the distribution of environmental risks [4–6]. This structural inequality reveals substantive limits in the contemporary climate governance architecture, which has failed to redress the imbalances generated by centuries of unequal capital accumulation and emissions [7,8].

Numerous authors argue that the acceleration of global warming has outpaced the responsiveness of traditional environmental law, which remains fragmented, insufficient and dependent on voluntary compliance by states [3,9,10]. Climate governance operates under a polycentric structure where multiple agreements, trade

rules, private standards, subnational institutions and transnational networks with varying degrees of authority converge, creating a complex regime that is difficult to coordinate [11–13]. This polycentric web widens decision spaces, but also generates risks associated with regulatory incoherence and the multiplication of overlapping rules [14–16].

The literature highlights that contemporary climate governance debates focus on environmental justice, equity, and differentiated liability due to the inequitable distribution of losses, damages, and mitigation costs [17–19]. Recent research shows that climate impacts will exacerbate pre-existing vulnerabilities and disproportionately affect indigenous communities, rural populations and small island states [1,20]. In this context, the legitimacy of international responses depends on the ability of law to integrate robust principles of distributive, procedural and recognition justice [21,22].

The advance of market mechanisms-including emissions trading schemes, REDD+ projects, voluntary carbon markets, and corporate offsets-has expanded the influence

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of private actors in defining climate policy, introducing logics of economic efficiency that generate tensions with equity and sustainability objectives [7,23]. These mechanisms have produced regulatory benefits in some contexts, but have also evidenced inequities in the distribution of benefits, risks of corporate capture and deficits in legal accountability [1,6].

In parallel, the literature underlines that international environmental law faces limits stemming from the absence of coercive mechanisms, dependence on state will and insufficient integration between trade, energy, investment and human rights systems [24,25]. These factors consolidate a field characterized by tensions between normative ambition, political feasibility and structural inequalities.

1.1. Transformations of international environmental law in the face of climate change.

International environmental law has undergone profound doctrinal and normative transformations in response to climate change, forcing the reinterpretation of key concepts such as common but differentiated responsibility, intergenerational equity, precaution, cooperation, and transboundary no-harm [3,17,26]. The Paris Agreement redefined the climate regime by replacing legally binding commitments with a system based on nationally determined contributions (NDCs), transparency and periodic review (Falkner, 2016; Rajamani et al., 2021). This shift produced tensions between state sovereignty, international pressure and policy coherence by introducing a hybrid model combining voluntariness, strategic reciprocity and diffuse accountability [8,27].

Several studies highlight that regime transformations are not limited to the normative dimension, but incorporate epistemological changes derived from the interplay between science, politics and global legitimacy mechanisms [24]. This process includes the growing importance of metrics, indicators, and technical standards that define climate decision-making [23,28]. Regime evolution also reflects the influence of non-state actors such as companies, NGOs, cities, and local communities whose participation redefines obligations, responsibilities, and narratives of legitimacy [29].

Likewise, the literature provides critical evidence on the uneven impacts of market-based mechanisms, REDD+ programs and carbon offsets, particularly in communities in the Global South [1,4,6]. These dynamics have strengthened demands for fairer, more inclusive approaches oriented towards the effective protection of human rights [18,22].

1.2. Current status of research (2015-2025).

Between 2015 and 2025, research in climate governance and international environmental law experienced sustained growth, reflected in increased work on climate litigation, climate justice, carbon markets, polycentricity, regulatory innovation, and transnational governance [1,10,12]. The field has analyzed how global institutions, national governments, subnational jurisdictions, and private actors

form a multilevel structure that defines contemporary climate action [14,15].

However, numerous studies evidence persistent limitations in the legal effectiveness of the climate regime due to the absence of coercive mechanisms, reliance on state will and institutional inequalities between the Global North and the Global South [20,30,31]. Fragmentation between trade, energy, investment and human rights continues to hinder regulatory coherence [24,25].

Finally, studies on institutional learning, epistemic networks and adaptive governance highlight that climate regime resilience depends on continuous processes of interaction between science, public authorities and civil society [32–34].

Rationale and Purpose of the Study.

This study examines how the academic literature published between 2015 and 2025 conceptualizes the transformations of international environmental law in the face of climate change using a B-SLR approach that integrates bibliometric analysis and systematic review [35,36]. The corpus was selected from the PICo model and records indexed in Scopus and Web of Science, ensuring completeness, reliability and traceability [37,38].

The analysis identifies thematic trends, policy challenges, institutional patterns and structural gaps in contemporary climate governance [9,11]. It also examines the role of polycentrism, climate justice, normative innovation and doctrinal evolution in international environmental law in a context of increasing climate urgency [5,20].

The central contribution is to provide a critical synthesis to guide future research and strengthen multilevel environmental regulatory frameworks, endowing them with greater coherence, equity, and effectiveness [29,39].

1.3. Research Questions.

Based on the conceptual, methodological and normative gaps identified in recent literature, this study formulates four research questions aimed at structuring the B-SLR analysis and guiding the interpretation of the findings:

RQ1. How has climate change influenced the evolution of international environmental law principles, particularly in relation to equity, differentiated responsibility, cooperation, and precaution?

RQ2. What methodological trends predominate in academic research on climate change and international environmental law during the period 2014-2024?

RQ3. What normative gaps, institutional tensions and emerging challenges does the literature identify in the interaction between the climate regime, international law and global governance mechanisms?

RQ4. What thematic patterns, knowledge communities and research clusters structure this field of study and how do they relate to the transformations of the international climate regime?

2. MATERIALS AND METHODS

The present research is based on a mixed design that integrates the Systematic Literature Review (SLR) with computational bibliometric analysis, following the guidelines of the PRISMA protocol (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) [36]. The central objective consisted of analyzing the influence of climate change on the evolution of international environmental law during the last decade (2014-2024).

Given the magnitude of the bibliographic corpus, an Artificial Intelligence-assisted selection strategy was implemented, in accordance with current trends of automation in research synthesis, for the purpose of human bias reduction and optimization of screening accuracy [40].

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protocol [36]. The objective was to analyze the influence of climate change on the evolution of international environmental law during the period 2014–2024. Given the size of the corpus, an automated classification strategy based on Natural Language Processing (NLP) was applied in order to reduce human bias and optimize accuracy in the initial screening [40].

2.1. Search Strategy and Data Sources.

Data collection took place on November 17, 2025 in the Web of Science (WoS) and Scopus databases. The selection of these sources responds to their wide coverage and rigorousness in the indexing of high quality scientific literature, being recognized standards for comparative bibliometric studies [41].

Specific Boolean search equations were designed for the retrieval of literature on the intersection between climate change, environmental law and global governance (see Table 1).

Table 1. Search strings and filters applied.

Database	Search Equation	Filters
Web of Science	TS=("climate change" OR "global warming") AND TS=("international environmental law" OR "environmental treaties" OR "environmental governance" OR "environmental regulation")	Type: Article Language: English OR Spanish Year: 2014-2024
Scopus	TITLE-ABS-KEY("climate change" OR "global warming") AND TITLE-ABS-KEY("international environmental law" OR "environmental treaties" OR "global environmental governance" OR "international legal framework")	Type: Article Language: English OR Spanish Year: 2014-2024

¹ Own Elaboration.

2.2. Automated Processing and Debugging

The execution of the data processing was carried out through a Python pipeline, structured in three methodological phases.

2.2.1. Fusion and Deduplication (Phase 1)

The initial search yielded a total of 1,595 records (1,362 from WoS and 233 from Scopus). For the integration of these heterogeneous databases, preprocessing algorithms based on the principles of computational scientometrics described by Ruiz-Rosero et al. (2017) were applied in the development of the ScientoPy tool.

The strict deduplication process consisted of two algorithmic steps to ensure the integrity of the single corpus (see Table 2):

1. Identification by DOI: Removal of records with identical digital identifiers.
2. Fuzzy Matching: For records without DOIs, the rapidfuzz library was used for normalized title matching.

Table 2. Statistics of the debugging and duplicate removal process.

Metric	Number	Percentage
Initial Records (Total)	1,595	100%
Web of Science	1,362	85.4%
Scopus	233	14.6%
Duplicates Removed (Total)	115	7.2%
Final Single Corpus	1,444	90.5%

² Own elaboration.

Following this procedure, a corpus of 1,444 articles was consolidated. Subsequently, a metadata quality filter was applied to discard those records that lacked essential information (title, abstract and complete keywords). This process excluded 431 incomplete documents, resulting in a

final valid corpus of 1,013 articles. This dataset (n=1,013) formed the basis for both bibliometric analysis and semantic classification.

2.2.2 NLP Linguistic Pre-processing (Phase 2)

For text preparation for semantic analysis purposes, the spaCy library (en_core_web_sm model), recognized for its efficiency in natural language processing and deep tokenization tasks [42], was used. A synthetic variable (text_clean) was generated by concatenating the title, abstract and unified keywords.

The cleaning protocol included:

- Normalization: use of unidecode for character standardization.
- N-gram protection: Preservation of key compound terms (e.g. "climate_change", "paris_agreement") in order to maintain their semantic integrity.
- Lemmatization: Reduction of terms to their root and elimination of stopwords, an action that reduces noise in the vector analysis.

2.3. Supervised Semantic Classification (Phase 3)

For the final selection of the studies, a hybrid classifier was developed that combines the power of modern language models with expert rules.

2.3.1. Semantic Similarity with SBERT

The Sentence-BERT (SBERT) model, a modification of the BERT architecture that uses Siamese networks for the generation of semantically meaningful sentence embeddings [43], was employed. Specifically, the pre-trained model (all-mpnet-base-v2) was used, which has demonstrated superior performance in natural language understanding by relying on permuted and masked language modeling training [44].

The algorithm computed the cosine similarity between each item vector and a "Gold Standard" composed of 5 theoretical statements on normative fragmentation and climate justice, with the assignment of a semantic score (S_{sem}) from 0 to 1.

2.3.2. Composite Scoring and Selection

A dictionary-based lexical score (S_{lex}) was integrated to ensure the presence of mandatory legal terminology. The final decision was based on a Final Relevance Score (R_{final}):

$$R_{final} = (S_{sem} \times 0.80) + (S_{lex} \times 0.20)$$

selection process.

The semantic component was prioritized (80%) due to MPNet's ability to capture context beyond explicit keywords.

Final Inclusion Criteria: Selection for full reading was limited to articles from the valid corpus (n=1,013) classified as High Relevance ($R_{final} \geq 0.80$).

Screening Result: The automatic system classified the 1,013 valid documents as follows:

- Discard ($R_{final} < 0.50$): 424 items.
- Low Relevance ($0.50 \leq R_{final} < 0.65$): 378 articles.
- Medium Relevance ($0.65 \leq R_{final} < 0.80$): 172 articles.
- High Relevance ($R_{final} \geq 0.80$): 39 articles.

2.3.3. Human validation and quality control of the PLN classification system

The automated classification system functioned as a support tool rather than an autonomous selection mechanism. The intervention of two specialized researchers made it possible to delimit the thematic scope of the study and ensure the conceptual relevance of the corpus.

To validate the semantic classifier thresholds, the researchers reviewed the articles classified as High Relevance (n = 39), applying the defined inclusion and exclusion criteria. The adjustments made ensured consistency between the automated classification and expert judgment. Discrepancies were resolved by consensus.

An additional verification was performed on 10% of the automatically discarded articles. No records met the eligibility criteria, confirming the conservative behavior of the system and reducing the risk of erroneous exclusions.

Finally, articles classified as High Relevance (n = 39) were read in full. Eleven documents were excluded due to lack of access or thematic deviation, resulting in a final sample of 28 studies for qualitative analysis. Figure 1 illustrates the selection process. Figure 1 illustrates the

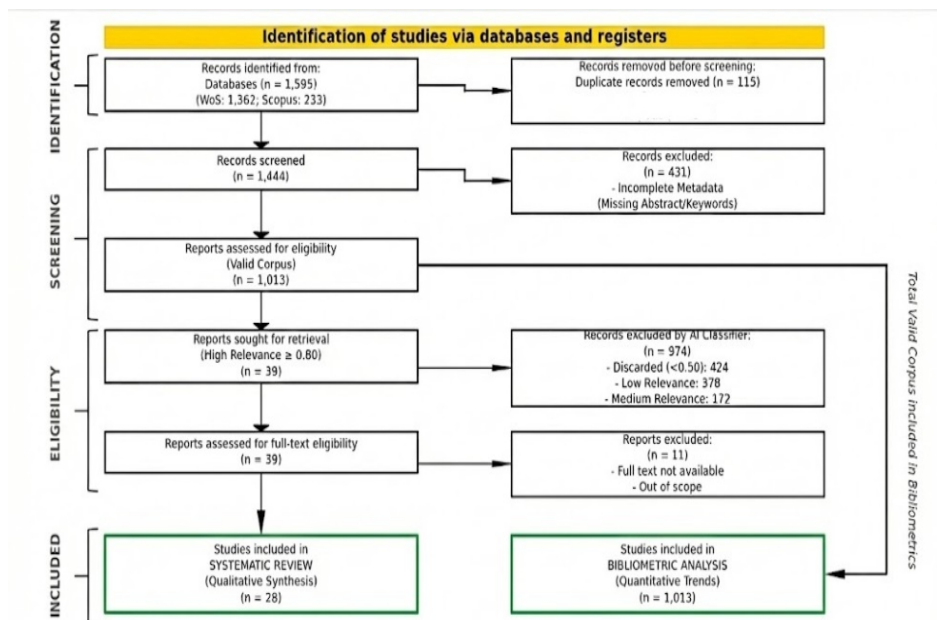


Figure 1. PRISMA flowchart of the AI-assisted study selection process. Source: Own elaboration.

2.4. Bibliometric analysis

The descriptive analysis was performed on the complete valid corpus ($n = 1,013$), which contains the complete metadata (title, abstract and keywords). Network visualization tools (VOSviewer) and Python libraries (Matplotlib, Pandas) were used to examine the dynamics of annual production, scientific collaboration networks and the evolution of keywords in the period studied.

3. RESULTS

3.1. Bibliometric Results: Trends and Field Structure

3.1.1 Annual scientific production (RQ2)

Scientific production shows a sustained growth between 2014 and 2024. The number of publications shows a continuous increase starting in 2017 and peaks in 2022, with 181 indexed articles. This increase confirms the expansion of the field and its growing academic relevance, in parallel with the intensification of regulatory debates and international climate litigation.

Citation indicators reflect a period of high influence between 2016 and 2021. The highest value of Average Total Citations per Article is recorded in 2017 (74.33 citations per article), suggesting the consolidation of

seminal papers during those years. From 2022 onwards, a decrease in the citation averages is observed, an effect attributable to the shorter time window of citability, rather than to a reduction in thematic relevance.

The Average Citations per Year per Article indicator confirms this trajectory: it grows steadily until 2022 (16.81 citations per year) and presents lower values in 2023 and 2024, consistent with the limited time to be cited, see Figure 2.

In summary, the data evidence three main patterns:

1. Continuous growth of production, with higher intensity since 2018 and a maximum in 2022.
2. High citability in core years (2016-2021), associated with key advances in climate governance and legal principles.
3. Apparent decline in impact in recent years, explained by lower temporal exposure rather than a loss of relevance.

These results confirm that the field experienced a phase of thematic expansion and academic consolidation, especially during the 2016-2021 period.

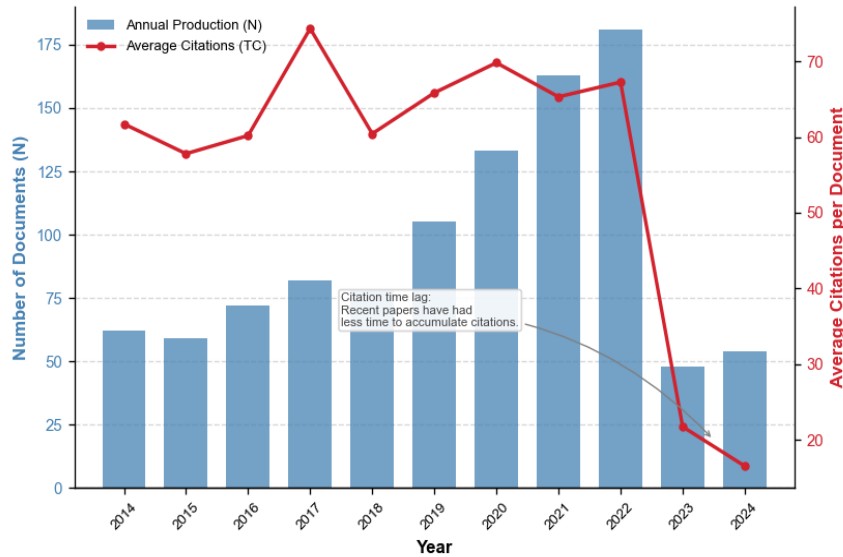


Figure 2. Annual scientific production and citation impact in climate change and international environmental law studies (2014-2024). Source: Own elaboration.

3.1.2. Most influential authors (RQ4)

The network shows a reduced set of authors with consistent contributions in environmental governance, climate adaptation and environmental law. Alex Y. Lo and Michelle Scobie lead the production, with five publications each and an h-index of 5. Lo concentrates on emissions trading schemes in China and urban climate governance, while Scobie contributes to the study of policy coherence, climate justice and governance in Caribbean SIDS.

In the second level of influence are Joshua J. Cousins, Brian C. Chaffin and Daniel A. DeCaro, whose research reaches high citation levels. Chaffin and DeCaro integrate a consolidated line on adaptive governance, institutional design and legal principles for social-ecological systems;

both are involved in highly cited articles that shape the field. Cousins stands out for her work on green infrastructure, environmental justice, and nature-based solutions, with publications exceeding 100 citations.

The analysis also identifies emerging authors such as Sandra Hincapié, who introduces Latin American perspectives on state capacities, human rights and rights of nature. Other relevant authors - such as Niemeyer, Shinn and Vandenbergh - contribute approaches on ecological democracy, private governance and adaptation in social-ecological systems. Overall, the network reveals a mixed structure composed of a well-articulated core of highly cited researchers and a peripheral set that introduces new geographic and thematic dimensions to the field, see Figure 3.

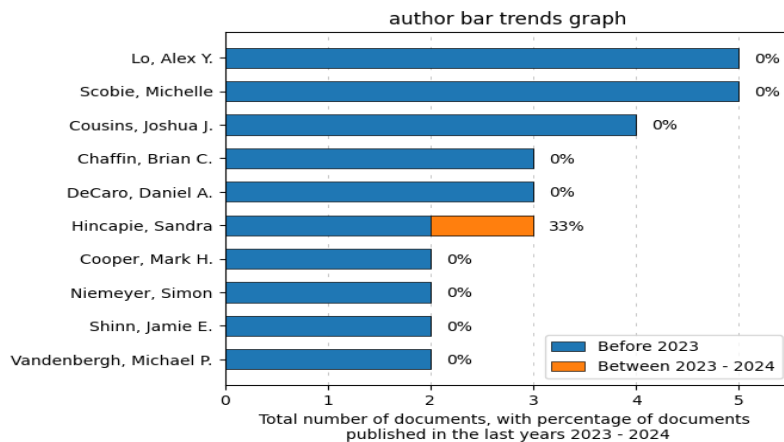


Figure 3. A Network of authors with the highest production and influence (2014-2024). Source: Own elaboration

3.1.3. Most Relevant Journals and Thematic Foci (RQ2)

Scientific production is concentrated in a consolidated core of interdisciplinary journals. Sustainability is the most productive source, with 40 articles and the highest h-

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index (35), reflecting its central role in environmental governance, energy transition and climate policy issues. *Environmental Science and Policy* and *Global Environmental Change* stand out for their high citation and for studies that analyze the science-policy interface, institutional effectiveness and climate governance mechanisms.

Journals such as *Ecology and Society* and *Land Use Policy* provide socioecological and adaptive management approaches relevant to the study of nature-based solutions and land use policies. In the political and policy arena, *International Environmental Agreements*, *Environmental Politics*, *Global Environmental Politics* and *Geoforum* address international regimes, climate justice and non-state actor dynamics.

Finally, sources such as *Journal of Cleaner Production*, *Energy Policy*, *Energy Research and Social Science* and *Journal of Environmental Management* complement the field with empirical evidence on emissions, energy governance, economic instruments and environmental performance. Overall, the most influential journals combine legal, political and socio-environmental approaches, confirming the cross-cutting nature of the field, see Figure 4.

Figure 4.

Most productive and influential journals in climate change and international environmental law (2014-2024).

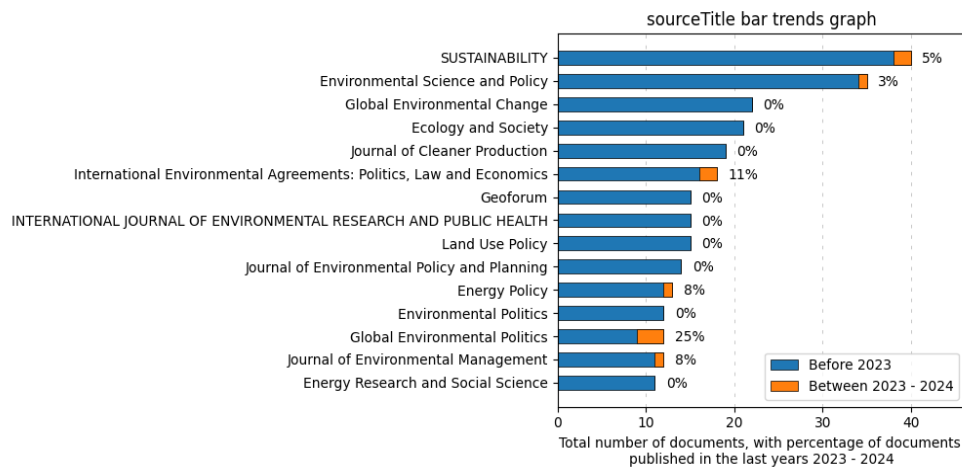


Figure 4: Most productive and influential journals in climate change and international environmental law (2014-2024).

Source: Own elaboration

Source: Own elaboration.

3.1.4. Keyword Co-occurrence Network (RQ4)

The keyword co-occurrence analysis (visualized in Figure 5) reveals a polycentric intellectual structure, articulated around the central node "climate change" (615 occurrences). The network evidences the interdisciplinary nature of the field through five consolidated research fronts:

- **Economics and Energy Transition (Cluster 1):** Dominates the discussion on mitigation, linking economic growth with green innovation, energy efficiency and CO₂ emissions reduction.
- **Adaptive Governance (Cluster 2):** Focuses on the resilience of social-ecological systems, highlighting the role of local communities and participatory resource management.
- **International Law and Justice (Cluster 3):** Constitutes the legal core of the map. It connects multilateral treaties (Paris Agreement, Kyoto Protocol) with emerging demands for climate justice and human rights.

- **Ecosystems and Land Use (Cluster 4):** Addresses the biophysical dimension, focusing on ecosystem services, biodiversity and conservation mechanisms such as REDD+.
- **Global Political Theory (Cluster 5):** Examines the structural tensions of the regime, questioning institutional legitimacy, neoliberalism and climate security in a fragmented system.

Taken together, these clusters demonstrate that research has moved from a purely environmental concern to a holistic approach that amalgamates legal, economic and social justice dimensions.

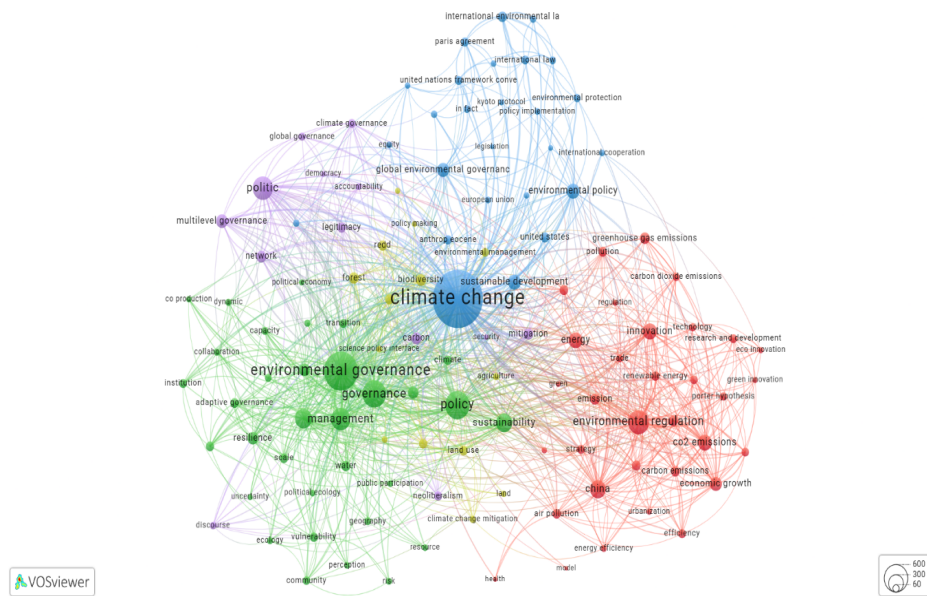


Figure 5. Network of keyword co-occurrence in climate change and international environmental law studies (2014–2024). Source: Own elaboration

3.1.5. Geographical Distribution of Scientific Production (RQ4)

The analysis of international co-authorship (Figure 6) reveals a polycentric structure organized in ten clusters, which obey logics of geographical proximity, historical ties and thematic affinities. The network evidences a clear hegemony of the Global North, although with a growing articulation of networks in the Global South. Four main dynamics of cooperation can be distinguished:

- U.S. hegemony and China: the United States consolidates as the central node of the network (261 documents), by leading a strategic block with links to the Middle East (Cluster 8). China (188 documents) articulates Cluster 5, which connects Asia-Pacific economies with Eastern Europe, confirming its leading role in climate governance research.
- The Anglo-Saxon and European Axis: There is a core of high academic influence formed by the United Kingdom, Germany and Australia (Cluster 3), characterized by high citation levels. This axis is complemented by the Northern European network (Cluster 6), where Sweden and the Scandinavian countries prioritize research on energy transition, and by specialized networks led by the Netherlands and Belgium (Clusters 9 and 10).
- Ibero-American and Global South networks: A strong cohesion is identified in the Ibero-American-Mediterranean block (Cluster 1), where Spain and Italy act as bridges to Latin America. In parallel, Brazil leads a regional network (Cluster 4) focused on the governance of tropical forests, while Canada (Cluster 2) serves as a connecting node in an intercontinental

network that integrates several African and French-speaking nations.

- Asian Innovation: Japan and Austria are the backbone of a Euro-Asian group (Cluster 7) oriented predominantly towards technological innovation and mitigation systems.

This configuration demonstrates that, although production is concentrated in traditional powers, the complexity of climate change has forced the creation of transnational research architectures that transcend classic administrative boundaries.

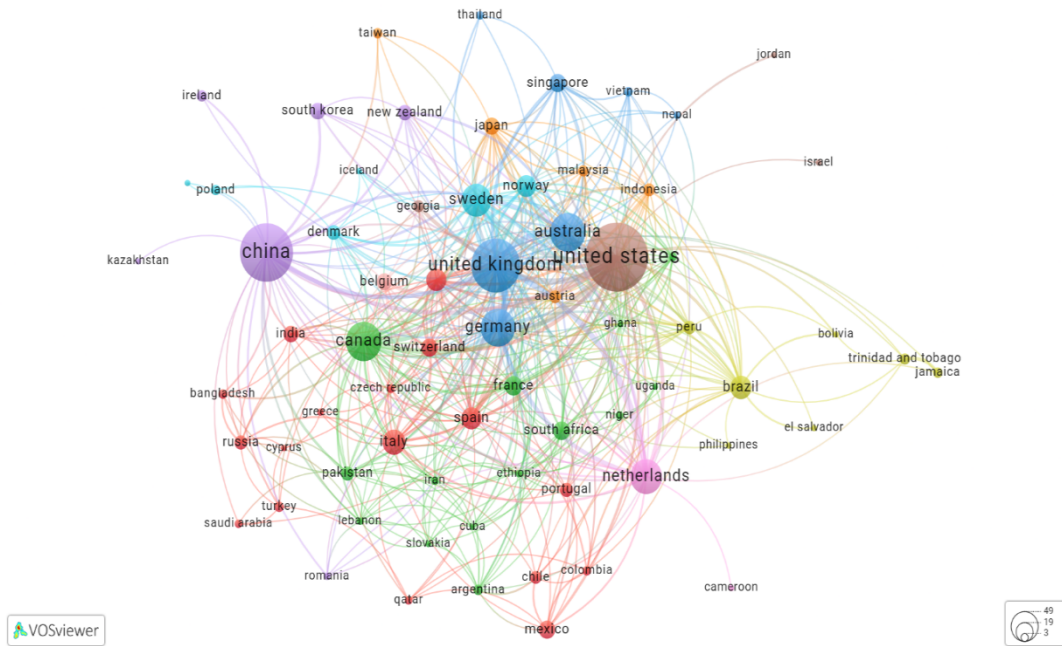


Figure 6. International co-authorship network between countries (VOSviewer, 2014-2024). Source: Own elaboration

3.1.6. Organizational Network (RQ4)

The institutional network (Figure 7) shows a clear concentration in universities in the United States, China, United Kingdom, Australia, Canada and the Netherlands. The United States leads in production and citation, with institutions such as the University of California, Cornell University and Colorado State University, which form the structural core of the network. China ranks second in volume and is articulated through universities such as Peking University, Tsinghua University and Sun Yat-sen University, which specialize in environmental regulation and carbon markets.

The United Kingdom and Australia form a highly influential bloc, represented by the London School of Economics, University of Oxford, Monash University and

Australian National University, with an emphasis on governance, climate justice and institutional analysis. In turn, Wageningen University & Research stands out as the strongest European node, with the highest volume of output and a high centrality of connection. The remaining clusters group institutions from Scandinavia, Canada, New Zealand, Japan and Latin America with lower volume, but with stable links to the main nodes.

Overall, the network evidences a polycentric global system, although marked by asymmetries: Northern countries concentrate most of the research, while Latin American, African and Southeast Asian institutions participate with less intensity and act as peripheral nodes within the structure.



Figure 7. Institutional collaboration network (2014-2024). Source: Own elaboration

3.2. Results of the Systematic Review (Qualitative)

The qualitative analysis was based on 28 highly relevant studies selected using the AI algorithm. This section addresses the evolution of legal principles (RQ1) and normative gaps (RQ3). The results are presented based on five macrothemes derived from the qualitative coding process:

1. The results are presented from five macrothemes derived from the qualitative coding process:
2. Climate litigation and jurisprudential transformation.

3. Multilevel governance, cooperation and alignment.
4. Normative evolution and adaptability of international law.
5. Climate justice and human rights.
6. Structural gaps and persistent challenges.

Table 3 details the methodological and thematic characteristics of the included studies.

Table 3. General characteristics of the included studies.

Author(s) and year	Type of study	Method	Region or main case	Central theme
Cox (2016)	Doctrinal-jurisprudential	Case study	The Netherlands	Duty of care and climate litigation
Galvão Ferreira (2016)	Doctrinal	Case study	The Netherlands	CBDR in domestic litigation
Minnerop (2019)	Systematic legal	Jurisprudential study	Europe	Duty of care under the ECHR
Smith-Carrier & Manion (2022)	Juridico-socio-political	Theoretical review	Canada	Social movements and human rights
Rydberg (2024)	Comparative legal	Jurisprudential review	Global	Trends in climate litigation
Voigt (2023)	Doctrinal Legal	Regulatory review	Global	Interpretive power of the Paris Agreement
Meckievi & Viñuales (2024)	Conceptual legal	Advisory opinion analysis	Global	Strategic use of advisory opinions
Buser (2024/2025)	Doctrinal legal	Regulatory comparison	EU and global	Planetary jurisdiction
Savaresi (2018)	Comparative legal	Doctrinal analysis	Global	Traditional knowledge
Hsu et al. (2017)	Governance	Comparative analysis	Subnational	Vertical/horizontal alignment
Stranadko (2022)	Governance	Interviews and documentary analysis	U.S.-EU US-EU	Translateral cooperation

Elsässer (2024)	Institutional governance	Interviews+documents	Rio Conventions Secretariats	Institutional interplay
Polizzi (2020)	Conceptual legal	Doctrinal review	Global	Adaptive law
Santos (2017)	Normative	Theoretical analysis	Global	Global justice and Paris
Espinosa-Garcés (2024)	Institutional	Analytical essay	UN	Structural reforms
Schrijver (2021)	Historical Legal	Doctrinal analysis	Global	Sovereignty and environmental obligations
Savaresi (2018)	Legal	Doctrinal	Global	Traditional knowledge
Hargrove et al. (2019)	Quantitative empirical	Panel data	162 countries	Governance and treaties
Yang et al. (2024)	Legal	Comparative analysis	Arctic	Black carbon
Olashore (2019)	Comparative Legal	Documentary	Nigeria, Kenya, Botswana	National implementation
Putra (2021)	Legal	Documentary review	Global	HRD as climate complement
Lucero & Ravetllat (2021)	Legal	Sacchi Case	Global	Jurisdiction and NNA
Huggins (2018)	Conceptual	Theoretical analysis	Global	Hot differentiation ("hot law").
Gareau & Lucier (2018)	Historical-political	Documentary analysis	Global	Neoliberalization of treaties

³ Own elaboration.

3.2.1. Climate litigation and jurisprudential transformation (RQ1)

The literature shows that climate litigation profoundly transformed the legal understanding of international environmental obligations. The Urgenda case constitutes the most cited and analyzed turning point [45,46]. These studies indicate that courts can derive concrete state obligations from human rights, precautionary principles, and scientific standards, which strengthened the enforceability of climate action at the national level.

Recent research highlights that climate litigation expanded into corporate liability cases, greenwashing and juvenile lawsuits [47], and that international precedents reshape legal reasoning in jurisdictions that previously rejected these claims [48]. The novel use of the CBDR principle as an interpretive tool in domestic courts is also documented (Galvão Ferreira, 2016).

The progressive incorporation of arguments based on human rights and duties of protection became a robust trend, reinforced by cases such as Sacchi [49], where

extraterritorial jurisdiction and child victim status in climate contexts were recognized.

3.2.2. Multilevel Governance and Cooperation (RQ2)

Governance studies reveal that the global climate regime operates through polycentric structures where subnational actors, international secretariats and transnational networks acquire a central role. Hsu et al. [50] show that policy coherence occurs through combinations of vertical and horizontal alignment, while Stranadko [51] documents the emergence of translateral cooperation, a key form of informal bilateralism in the post-Paris context.

Elsässer [52] notes that the secretariats of the Rio Conventions exert a soft influence on discourse and coordination, although they face limits stemming from resource scarcity, divergent mandates, and the politicization of the UNFCCC. Overall, the literature indicates that climate governance has evolved into a distributed system, dependent on multiple centers of authority, see Table 4.

Table 4. SLR thematic synthesis.

Macro-theme	Articles included	Key findings
Climate litigation	Cox (2016), Minnerop (2019), Galvão Ferreira (2016), Rydberg (2024), Smith-Carrier & Manion (2022), Lucero & Ravetllat (2021).	Duty of care, human rights, expansion of jurisdiction, juvenile cases, use of climate science.
Multilevel governance	Hsu et al. (2017), Stranadko (2022), Elsässer (2024).	Vertical/horizontal alignment, subnational cooperation, institutional interplay.

Regulatory developments.	Polizzi (2020), Voigt (2023), Meckievi & Viñuales (2024), Huggins (2018).	Adaptive law, interpretative power of the Agreement, "hot law".
Climate justice and HR.	Smith-Carrier & Manion (2022), Putra (2021), Santos (2017)	HRDs as normative basis, positive obligations, intergenerational justice
Structural gaps	Yang et al. (2024), Olashore (2019), Gareau & Lucier (2018), Savaresi (2018), Espinosa (2024), Schrijver (2021)	Fragmentation, institutional weakness, functional sovereignty, lack of regulation.

⁴ Own elaboration.

3.2.3. Normative developments in international law (RQ1)

The doctrinal literature argues that the scale and complexity of climate change force international law to adopt flexible normative models. Polizzi [53] proposes the concept of "adaptive law", while Huggins [54] explains that climate constitutes a hot law situation that generates constant legal innovation, especially in the differentiation of responsibilities between countries.

Voigt [55] argues that the Paris Agreement possesses "external normative power" that influences the interpretation of other treaties, while Meckievi and Viñuales [56] show that climate advisory opinions redefine the lawfulness of state conduct.

3.2.4. Climate justice and human rights (RQ1 and RQ3)

The convergence between human rights and climate change represents one of the strongest patterns in SLR. Putra [57] argues that human rights complement and strengthen the climate regime by providing enforceable obligations and monitoring mechanisms. Santos [58] highlights that the Paris Agreement adopts hybrid equity criteria, but avoids resolving deep distributional issues.

The Sacchi case [49], evidences advances in extraterritorial jurisdiction and victim recognition, although procedural limitations of the OPCAT persist, see Table 5.

Table 5. Critical normative factors identified in the literature.

Category	Evidence in studies	Legal implication
Climate duty of care	Cox (2016), Minnerop (2019).	Sets science-based precautionary standards.
Human rights as climate baseline	Putra (2021), Smith-Carrier & Manion (2022)	Underpin positive obligations
Climate soft law	Polizzi (2020), Voigt (2023)	Facilitates flexibility, but reduces coercion
Extraterritorial jurisdiction	Lucero & Ravetllat (2021), Buser (2024)	Expands state responsibility
"Hot" differentiation	Huggins (2018)	Explains regulatory instability
Advisory opinions	Meckievi & Viñuales (2024)	Reconfigure perception of legality

⁵ Own elaboration.

3.2.5. Persistent structural gaps (RQ3)

The studies agree that international environmental law maintains serious deficiencies. Yang et al. [59] expose the lack of regulation of black carbon in the Arctic; Olashore [60] identifies institutional weakness in several African countries; Gareau and Lucier [61] explain the

"neoliberalization" of historical treaties; Espinosa-Garcés [62] highlights the fragmentation of the UN; and Schrijver [63] emphasizes that state sovereignty is transformed, but does not disappear as a barrier to global action, see Table 6.

Table 6. Common limitations of the literature.

Limitation identified	Studies where it appears	Consequence
Normative fragmentation	Yang et al. (2024); Espinosa (2024)	Lack of regulatory coherence
Lack of enforcement	Polizzi (2020); Voigt (2023)	Reduced state compliance
Reliance on soft law	Savaresi (2018); Santos (2017)	Legal insecurity
Institutional deficit	Olashore (2019); Schrijver (2021)	Low domestic implementation
Political resistance	Huggins (2018); Gareau & Lucier (2018)	Multilateral deadlock
Lack of empirical data.	Smith-Carrier & Manion (2022)	Difficulty in measuring real impact

⁶ Own elaboration.

4. DISCUSSION

The literature review reveals that climate change is profoundly transforming international environmental law, mainly through the expansion of climate litigation, the reinterpretation of existing principles and the institutional adaptation of the global regime. This process is clearly observed since the *Urgenda* case, considered a turning point by recognizing a state duty of care based on scientific evidence and human rights, forcing the Netherlands to increase its mitigation target [45,46]. Derivative jurisprudence has shown that national courts can turn political commitments into enforceable legal obligations, especially when international standards such as those of the IPCC are integrated. Also, the strategic use of the principle of common but differentiated responsibilities (CBDR) in domestic courts has expanded its interpretive scope and strengthened climate enforceability in developed countries [64].

The expansion of litigation is not limited to domestic enforceability. Studies show progress in the recognition of extraterritorial jurisdiction and affected groups, as in the *Sacchi* case, where the Committee on the Rights of the Child recognized the status of children and adolescents as climate victims beyond national borders, even though the case was inadmissible [49]. These developments are evidence that human rights systems are becoming a key normative complement to the limitations of the international climate regime [57].

In parallel, the literature describes a transition towards flexible and adaptive legal frameworks. Climate law operates under conditions of high uncertainty and accelerated change, which has prompted more dynamic normative models, where soft law and evolutionary principles take on a central role [53,54]. Within this logic, the Paris Agreement is positioned as a norm of cross-cutting interpretation capable of influencing other regimes, from human rights to the law of the sea, expanding its scope beyond the formal text [55].

Multilevel governance also emerges as a decisive component. Subnational governments, cities and transnational networks play a growing role in climate action, generating "translateral" forms of cooperation that complement traditional diplomacy [50,51]. Likewise, the secretariats of the Rio Conventions exercise soft coordination functions, albeit limited by resources, politicization and divergent mandates [52].

Finally, structural gaps persist: insufficient regulatory frameworks for critical areas such as Arctic black carbon [59], uneven implementation in developing countries [60] and regulatory weakening due to neoliberal economic influences [61]. These limitations explain the growing demand for profound reforms in the global environmental architecture, including the creation of more robust and coherent institutions [61] and the redefinition of sovereignty as environmental responsibility [63].

Overall, international environmental law is moving towards a more enforceable, dynamic and polycentric model, although it still faces obstacles that limit its real effectiveness in the face of the accelerating climate crisis.

5. CONCLUSIONS

The integrated analysis shows that climate change has substantially transformed international environmental law, both in its normative foundations and in its implementation mechanisms. The literature reviewed shows that traditional principles-equity, precaution, cooperation, and common but differentiated responsibilities-have acquired more demanding interpretations due to the scale of climate risk and increasing pressure for state action consistent with science. The studies identify that national courts and international human rights bodies strengthen these obligations, consolidating standards such as duty of care, due diligence and protection of vulnerable populations.

The research shows that climate governance adopts a polycentric structure where courts, international bodies, subnational actors, companies and social movements interact. This scenario generates legal innovation, particularly in climate litigation, hybrid enforcement, integration of human rights and expansion of standards from the Paris Agreement to other international regimes. Likewise, debates on extraterritorial jurisdiction, functional sovereignty and climate justice reveal the emergence of more ambitious frameworks to address transboundary impacts.

The selected studies confirm that legal fragmentation persists, although there is progressive move towards greater regulatory coherence through transparency mechanisms, advisory opinions, inter-institutional coordination and articulation between legal systems. It is also identified that states must strengthen national frameworks, improve institutional capacities and harmonize their climate commitments with obligations under international human rights law.

Overall, the literature between 2015 and 2025 shows an expanding field that redefines the architecture of international environmental law, while posing significant challenges related to equity, participation, regulatory effectiveness, and global climate accountability.

Limitations of the study

The study has limitations arising from the nature and scope of the B-SLR approach. The selection of documents was based exclusively on publications indexed in Scopus and Web of Science, which excludes gray literature, technical reports, non-indexed judicial documents, and doctrinal analyses of limited circulation. This restriction may reduce the diversity of perspectives and geographic representativeness, especially in regions of the Global South with lower indexed production.

Also, the review is limited to the period 2015-2025, which limits the analysis of previous historical transformations

and reduces the ability to assess subsequent emerging trends. The multidisciplinary nature of international environmental law also implies that certain relevant works in political science, legal sociology or environmental economics did not meet the criteria for methodological inclusion.

Finally, the studies identified present methodological heterogeneity, which makes it difficult to establish systematic comparisons between doctrinal, jurisprudential and empirical approaches. The absence of uniform metrics on regulatory effectiveness or regulatory impact reduces the possibility of making solid quantitative evaluations. These limitations do not affect the overall validity of the analysis, but point to the need for more extensive, comparative and transdisciplinary future research.

This section is not mandatory but can be added to the manuscript if the discussion is unusually long or complex.

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References must be numbered in order of appearance in the text (including citations in tables and legends) and listed individually at the end of the manuscript. We recommend preparing the references with a bibliography software package, such as EndNote, ReferenceManager or Zotero to avoid typing mistakes and duplicated references. Include the digital object identifier (DOI) for all references where available.

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