Water and Soil Management and Modeling

Online ISSN: 2783 - 2546

University of Mohaghegh Ardabili

International climate change law: strategies for mitigation, adaptation, and accountability

Sami Najm Abed Al- Nuaimi [1], Sawsan Khairy Abdullah [2], Abbas Fadhel Eisa Muhsin [3] Bushra Salman Hussain Al-Obaidi [4], Faris Abdul Kareem Khazal [5], Ata Amini [6], Hedieh Ahmadpari [7*]

[1]Al-Turath University, Baghdad, Iraq
[2] Lecturer, Department of Law, Al-Mansour University College, Baghdad, Iraq
[3] Assistant Lecturer, Department of Law, Al-Mamoon University College, Baghdad, Iraq
[4] Assistant Professor, Department of Law, Al-Rafidain University College, Baghdad, Iraq
[5] Professor, Department of Anesthesia and Intensive Care Techniques, Madenat Alelem University College, Baghdad, Iraq
[6] Professor, Soil Conservation and Watershed Management Research Department, Kurdistan Agricultural and Natural Resources Research and Education Center, AREEO, Sanandaj, Iran
[7] PhD Student, Hydrology of land, water resources, hydrochemistry, Russian State Hydrometeorological University, Saint Petersburg, Russia

Abstract

The escalating global climate crisis has accorded international climate law a central role in environmental governance. This research explores the legal frameworks that govern climate mitigation, adaptation, accountability, and transparency in a representative set of countries. By applying a multidisciplinary framework that integrates emissions projections, assessment of adaptation efforts, and legal compliance modeling, the study evaluates the impact of the existence and strength of domestic and international legal instruments on climateperformance outcomes. The study built a predictive emissions model with a Legal-Resilience Effectiveness Index and Normative Compliance Score to help quantify the relationship between legal enforcement and environmental effects. Germany and Australia reported slower growth rates due to decarbonization policies already implemented. Emission increases were partially offset under moderate Nationally Determined Contributions (NDCs) compliance, especially in Germany and Brazil, where transition measures have legal force, from 2020 to 2024. As for the aggressive policy scenario, the annual emissions decrease remained stable for every country (with emissions in Germany and Brazil reducing by 13.4% and 10% respectively over five years). India and Nigeria, although demonstrating decreases in their national emissions, had higher absolute emissions than others, a challenge of balancing economic development with environmental responsibility under international law. These results call for accelerated legal harmonization, improved institutional investments, and the decentralization of climate law beyond the conventional state-centric topography. The research suggests new areas of scholarship, especially on the possible integration of financial, trade, and human rights law into global climate regimes to achieve inclusive and actionable policy outcomes.

Keywords: Adaptation governance, Environmental policy, Greenhouse gas emissions, Legal compliance, Transparency

Article Type: Research Article

[*]Corresponding Author, E-mail: h.ahmadpari@stud.rshu.ru
Citation: Najm Abed Al- Nuaimi, S., Khairy Abdullah, S., Fadhel Eisa Muhsin, A., Salman Hussain Al-Obaidi, B., Abdul Kareem Khazal, F., Amini, A. and Ahmadpari, H. (2025). International climate change law: strategies for mitigation, adaptation, and accountability. Water and Soil Management and Modelling, 5(Special Issue: Climate Change and Effects on Water and Soil), 18-31.
doi: 10.22098/mmws.2025.17618.1610
Received: 08 June 2025, Received in revised form: 14 June 2025, Accepted: 14 June 2025, Published online: 22 June 2025

1. Introduction

The increase in greenhouse gases in recent decades and the resulting increase in temperature have upset the balance of the planet's climate system and caused widespread climate change in most parts of the world (Parvizi et al., 2020). Climate change is one of the most complex atmospheric phenomena worldwide. It refers to changes in the conditions and averages of climate variables that occur temporally over a long period and spatially on a global scale (Dinpashoh and Allahverdipour, 2025). Drought is one of the most severe natural disasters globally, with its frequency and intensity escalating due to climate change, posing significant threats to agricultural production (Ahmadpari and Khaustov, 2025). The Intergovernmental Panel on Climate Change (IPCC) comprehensive report explained that the effects of climate change on water resources, agriculture, and food security are generally negative. The current changes are so fast and fundamental that can affect the adaptation capacity and may lead the climate and the biosphere to very destructive patterns (Bahrami, 2024). Climate change implications are global, threatening ecosystems, economies, and societies as a whole. Studies by Esmaeili et al. (2024) showed that climate change has reduced the inflow to Lake Urmia, Iran, by 70% and caused a sharp drop in its water level. Climate change, primarily driven by rising temperatures and altered precipitation patterns, has significant impacts on water and soil resources. These impacts include increased droughts, declining groundwater levels, more frequent flooding, soil erosion, and water pollution (Ahmadpari et al., 2018; Ahmadpari and Khaustov, 2025a). Climate change has disrupted natural systems, exacerbated social inequalities, intensified resource conflicts, and increased vulnerabilities among populations that are already disadvantaged (Otto et al., 2017). As a result, robust international legal instruments have emerged as critical vehicles to address and coordinate a collective response to the multifaceted nature of climate change (Kadir et al., 2024).

International climate change law developed over decades in response to the realization that unilateral actions alone are not enough to address a global phenomenon (Van Asselt et al., 2008). The cumulative effects of greenhouse gas emissions, deforestation, and damage to the environment cannot be tackled by any single nation alone (Corbera et al., 2010). Rather, it will take a concerted effort from the international community to address emissions, adapt to our changing environment, and hold state and non-state actors accountable for the effects they have on climate change (Kuyper et al., 2018). International law on climate change represents the burgeoning will of the international community to reconcile differences in national interest with a view to a sustainable and climate-resilient future (Mai, 2024).

The treaties and agreements that form the backbone of international climate law are the result of long negotiations and compromises. From the United Nations Framework Convention on Climate Change (UNFCCC) the 1992 and the Paris Agreement of 2015, these instruments looked to create a balance between environmental protection and social development and economic growth. They reflect an acknowledgment that global citizens are called upon to act as a global community, yet equitably based on the differentiated responsibilities and capacities of all states. Development and developing countries, big polluters and small island states, developed economies, and developing markets, all must find common ground in a framework that creates a balance between national sovereignty and the problem of a shared world problem (H.S., 2024). Following its establishment, three key pillars of international climate change law have emerged: mitigation, adaptation, and accountability. Mitigation has the goal of limiting climate change through the use of new technologies, cleaner energy systems, and less carbon-intensive land-use practices (IPCC, 2014). Adaptation, by contrast, is about living with the effects of climate change that are already unavoidable. These include building resilient infrastructure, protecting coastal communities, and ensuring food and water security. These accountability mechanisms are used to oversee compliance, review progress, and encourage better performance. Though these pillars aim to prevent further harm, international climate law also aims to come to terms with the undeniable fact that we

are already experiencing climate disruptions (Wiener and Felgenhauer, 2024).

The legal regime is evolving and is responding to some extent to the expanding scientific, technological, and geopolitical landscape, but its origins are still a work in progress. Indeed, new questions are emerging through governance systems addressing demands for the deepening of emission reduction commitments, the inclusion of non-state actors, and the provision of finance for climate action in the Global South, that speak to ongoing needs for alignment and creativity in climate governance. And the very establishment of agreed measures tends to expose the gap between ambition and reality. In other words, building bridges across the gaps between them will require not only legal and institutional innovation but also deeper political commitment and wider international cooperation (Popovski, 2024).

International climate change law matters not just as a regime of behavioral rules but also as a regime of norms. It is seeking global norms that encourage countries to adopt domestic enabling legislation that advances global objectives thereby forming a more orderly and predictable mechanism to align domestic resources to fight climate change. That harmonization can, in turn, lead to technological progress, open new markets for clean energy, and spur a broader cultural trend toward sustainable practices. Additionally, the law is a meaningful space for negotiating the conditions of equity and fairness, so that the costs and benefits of climate action are distributed in a way that makes global justice plausibly available (Singla and Grag, 2024).

International legal tools will only grow more essential as climate change accelerates. Developing nations face several unique challenges in addressing climate change, including limited access to finance and technology. These countries often lack the necessary financial resources to invest in sustainable infrastructure and climate adaptation measures (Adenle et al., 2017). Additionally, they may have restricted access to advanced technologies that are essential for reducing emissions and building resilience against climate impacts (Carattini et al., 2020). This situation hampers their ability to effectively participate in international climate agreements and implement necessary measures, thereby posing a significant obstacle to global efforts to combat climate change (Amoo et al., 2020). The challenges are daunting, but the opportunities are, too. Developing countries have a significant opportunity to harness their abundant renewable energy resources to promote economic growth, social inclusion, and environmental sustainability. By adopting existing clean energy technologies and encouraging citizen participation, these nations can accelerate their transition to sustainable energy systems while addressing climate change challenges (Cantarero et al., 2020). International climate change law is a unique field at the intersection of environmental science, economic policy, and social justice. Its further development will be crucial for determining a future that can mitigate the worst effects of climate change and create pathways to sustainable development, resilient communities, and a healthier planet for generations to come (Singh and Chudasama, 2021). Climate change is truly an issue of global concern that cannot be solved by any one nation alone, and it is increasingly requiring a concerted international effort to address it. After decades of scientific consensus and the formation of international agreements like the UNFCCC and the Paris Agreement, the world is still on a path of increasing temperatures, more frequent catastrophic weather events, and catastrophic environmental degradation (Cadman, 2019). The core of the challenge extends from the lack of enforcement of these international systems to the continued clash between the immediacy of climate action against the varied economic, social, and political interests of the participating countries (Méndez, 2020).

One of the biggest struggles has been the gap between legal promises and practical outcomes. Though dozens of countries have committed to reducing greenhouse gas emissions and developing adaptation capacity, ambition has often not been up to scaring off long-term global warming beyond internationally set limits. This difference is compounded by blurry enforcement mechanisms, lack of accountability measures, and the exclusion of binding commitments for some key players. In addition, existing treaties

have failed to effectively consider the unique challenges of developing nations that limit their ability to meet climate commitments including restricted access to financial, technological, and capacity-building opportunities.

In addition, the global nature of the climate crisis renders existing principles of law increasingly difficult to apply. There are also issues of equity, responsibility, and fairness that remain unresolved, in part because developed countries have historically caused most of the emissions, and developing countries bear the brunt of the climate impacts. This gap becomes a hurdle toward a more equitable paradigm that can ensure all stakeholders are a part in meaningful action. Also, the lack of a cease-fixture and consistent legal standard among nations weakens the consistency and predictability necessary to subsidize long-term investments in low-carbon applied sciences and sustainable practices.

The basic problem is the disconnect between what international climate change law seeks to achieve and what it achieves. This gap needs to be addressed both in terms of bridging structural weaknesses in existing legal frameworks and the broader political and economic dynamics that influence the efficacy of global climate action.

This article will seek to provide a brief overview of the structures, methods, and systems that form the global legal order that endeavored to solve climate change. The paper explores three critical pillars: mitigation, adaptation, and accountability to assess whether current international agreements and policies are positioned to address the multidimensional nature of climate change.

The article clarifies the origin of climate treaties and the negotiations over their evolving substance, specifically, how these treaties uniquely balance the competing demands of environmental and socioeconomic development. It looks at the ways that countries can achieve real cuts in greenhouse gas emissions and also prepare for those climate effects they cannot avoid. Also, the study shows that accountability structures as a transparency framework, that can be compliance mechanisms, enable the tracking of progress, ensure that what has been committed is what is done, and also provide the incentive to increase climate action.

An underlying aim of this study is to review the existing legal instruments and assess their effectiveness as well as to identify the gaps that may pose a challenge to their implementation. This involves examining the ability of international law to tackle major themes like loss and damage, technology transfer, and climate finance. This article seeks to add to this dialogue by examining these spaces.

While recognizing the strengths offered by current frameworks, the article aims to offer a forward-looking perspective on how international climate law can evolve to meet emerging challenges and opportunities. Here we go with legal innovations, changing diplomatic tactics, and the rise of non-state actors, the article aims to offer a multifaceted perspective on how the world can progress toward more ambitious and just climate action. The article will be framed as a resource for academic, legislative, and stakeholder use as they create and enforce international climate change law, laying out what pathways of long-term environmental sustainability and resilience could look like.

2. Material and Method

The article applies an empirical-legal framework for inter-disciplinary assessment of international climate change responses classified into mitigation, adaptation, and accountability. Its methodology is organized into five interrelated pillars: sampling design, emissions modeling, adaptation assessment, policy effectiveness evaluation, and accountability. Each stage partakes of solid empirical and legal literature to assess the quantitative and qualitative effects of climate policy instruments in international law (Fan, 2024; Wiener and Felgenhauer, 2024; Kadir et al., 2024; Mai, 2024; Xu et al., 2024).

2.1. Multisource Data Collection and Stratified Sampling

The empirical dataset was constructed using stratified sampling of 50 Parties to the UNFCCC, selected based on two inclusion criteria: Annual GHG emissions exceeding 25 $MtCO_2e$, and/or High Climate Vulnerability Index (≥ 0.45 on a 0–1 scale). Sampling strata included geographical region, income group (per World Bank classification), and policy engagement

(submission of Nationally Determined Contributions, National Adaptation Plans, and Biennial Update Reports). The primary data sources include the following:

1. National GHG inventories (UNFCCC CRF and BUR),
2. UNDP Climate Risk Index,
3. Climate Watch, CAIT, and ND-GAIN datasets,
4. National legal documents (climate acts, adaptation laws, energy transition frameworks).

Table 1 presents the characteristics of selected countries, including their region, income group, GDP per capita, and their status regarding GHG inventory and NDC submissions.

Table 1. Characteristics of selected countries in the empirical dataset

ISO Code	Country Name	UN Region	Income Group	GDP per Capita (USD)	GHG Inventory Submission	NDC Submission
IND	India	Asia	Lower-Middle	2,200	Yes	Yes
DEU	Germany	Europe	High	48,000	Yes	Yes
NGA	Nigeria	Africa	Lower-Middle	2,400	Yes	Yes
AUS	Australia	Oceania	High	59,000	Yes	Yes
BRA	Brazil	Latin America	Upper-Middle	9,000	Yes	Yes

These data were cross-referenced with legal indicators, such as national climate legislation status, adoption of carbon pricing mechanisms, and the existence of climate courts to validate legal implementation status (H.S., 2024; Popovski, 2024; Singla and Grag, 2024).

2.2. Predictive Emissions Modeling Using Differential Forecast Functions

To model national GHG emissions under dynamic legal scenarios, we constructed a multi-variable dynamic model, which can be referred to as Equation 1 (Maevsky et al., 2024):

$$\frac{dE(t)}{dt} = (\lambda_1 \times \frac{dY(t)}{dt}) + (\lambda_2 \times \frac{dP(t)}{dt}) - (\lambda_3 \times R(t)) \quad (1)$$

Where $E(t)$ emissions ($MtCO_2e$) at time t, $Y(t)$ GDP at time t (in constant USD), $P(t)$ population at time t; $R(t)$ legal-abatement effect from policy measures, $\lambda_1, \lambda_2, \lambda_3$ emission elasticity coefficients. The abatement function $R(t)$ is modeled separately, which can be referred to as Equation 2 (Maevsky et al., 2024):

$$R(t) = \sum_{i-1}^{n} (\phi_i \times \mathcal{L}_i(t)) \quad (2)$$

Where ϕ_i effectiveness coefficient of policy i (like a carbon tax, feed-in tariffs), $\mathcal{L}_i$ binary implementation indicator (1 if active at time t, 0 otherwise). This modeling structure allows scenario simulation across three pathways:

1. Baseline: inertia without additional policies,
2. Moderate legal compliance: current NDC enforcement,
3. High ambition legal enforcement: full alignment with IPCC AR6 mitigation pathways ((Derouez et al., 2024; Huang et al., 2024; Wan and Liu, 2023).

2.3. Adaptation Measures and Legal-Resilience Indicator Framework

Adaptation performance was operationalized using a Legal-Resilience Effectiveness Index (LREI), incorporating both physical adaptation metrics and legal implementation data. The general formula, which can be referred to as Equation 3 (Díaz et al., 2024):

$$LREI = \frac{1}{n}\left(w_j \times \frac{M_{j,post} - M_{j,pre}}{M_{j,pre}}\right) \times \theta_j \quad (3)$$

Where $M_{j,post}$ and $M_{j,pre}$ values of metric j before and after adaptation, w_j normalized weight of indicator j (like water retention, yield), θ_j legal compliance factor (0–1), denoting adherence to national adaptation law. Indicator categories include:

1. Ecological: reforestation, watershed management,
2. Infrastructure: coastal barriers, smart irrigation,
3. Social: early warning systems, local resilience training.

This framework links measurable environmental adaptation gains with the binding nature of national legislation (Díaz et al., 2024; McDonald and McCormack, 2021; Rezvani et al., 2023).

2.4. Legal Compliance Scoring Using Weighted Normative Indices

Legal compliance with international climate instruments (Paris Agreement, Kyoto Protocol)

was quantified using the Normative Compliance Score (NCS), which can be referred to as Equation 4 (Mohammed et al., 2024):

$$\mathrm{NCS} = \frac{1}{\mathrm{T}}\sum_{\mathrm{k}-1}^{\mathrm{T}}\left(\frac{\mathrm{a_k}\times \mathrm{C_k} + \beta_{\mathrm{k}} \times \mathrm{D_k}}{\mathrm{C_k^{max}} + \mathrm{D_k^{max}}}\right) \quad (4)$$

Where T number of reporting years, C_k mitigation obligations fulfilled in year k; D_k adaptation obligations fulfilled in year k; a_k and β_k are weights based on legal obligation strength (for example, mandatory vs. voluntary), C_k^{max} and D_k^{max} are maximum required obligations. Compliance categories include:

1. Submission of NDCs,
2. Fulfillment of emissions targets,
3. Implementation of national climate laws,
4. Budget allocation for adaptation.

This legal weighting distinguishes between lex lata (binding) and lex ferenda (aspirational) obligations (Wiener and Felgenhauer, 2024; Mai, 2024; Mohammed et al., 2024; Salimi Turkamani, 2023).

2.5. Accountability Architecture and Transparency Indexing

National accountability mechanisms were modeled using a composite Legal Transparency Index (LTI), which can be referred to as Equation 5 (Baehret al., 2024):

$$\mathrm{LTI} = \eta_1 \times \mathrm{TIER} + \eta_2 \times \mathrm{FREQ} + \eta_3 \times \mathrm{AUD} + \eta_4 \times \mathrm{LEG} \quad (5)$$

Where $TIER$ is IPCC reporting tier (1–3), $FREQ$ frequency of data submission (e.g., annual, biennial), AUD existence of third-party audits (1 or 0), LEG legal enforceability of national inventory systems (0–1), $\eta_1, \eta_2, \eta_3, \eta_4$ are normalized weights per dimension. This model enables inter-country comparability and supports legal evaluations of transparency obligations under the Enhanced Transparency Framework of the Paris Agreement (Baehret al., 2024; Bozhenko et al., 2023; Green and Kuch, 2022).

3. Results and Discussion

3.1. Emissions Reduction Across Legal Policy Scenarios

The analysis assesses greenhouse gas (GHG) emissions for 2020 to 2024 under three different policy scenarios: baseline (no new legal action), moderate compliance with Nationally Determined Contributions (NDCs), and aggressive legal coordination with geophysical accounts of IPCC mitigation pathways. Using GDP growth, population dynamics, and legal efficiencies of abatement as key variables, the model simulates emissions trajectories for selected countries. The analysis isolates the legal effect of the strength of compliance on national emissions profiles and emphasizes the differentiated capacity of high- and low-income countries to bring down emissions through law-based interventions. Table 2 presents the projected greenhouse gas (GHG) emissions for various countries from 2020 to 2024 under different legal compliance scenarios, including Baseline, Moderate NDC, and Aggressive Policy.

Table 2. GHG emissions under legal compliance scenarios (2020–2024, $MtCO_2e$)

Country	Scenario	2020	2021	2022	2023	2024
Germany	Baseline	820	835	850	865	880
	Moderate NDC	790	800	810	820	830
	Aggressive Policy	750	740	730	720	710
India	Baseline	2,500	2,580	2,660	2,740	2,820
	Moderate NDC	2,470	2,540	2,610	2,680	2,750
	Aggressive Policy	2,400	2,460	2,520	2,580	2,640
Brazil	Baseline	500	510	520	530	540
	Moderate NDC	490	495	500	505	510
	Aggressive Policy	470	465	460	455	450
Nigeria	Baseline	320	335	350	365	380
	Moderate NDC	310	320	330	340	350
	Aggressive Policy	295	300	305	310	315
Australia	Baseline	420	430	440	450	460
	Moderate NDC	410	415	420	425	430
	Aggressive Policy	400	395	390	385	380

In the baseline scenario, emissions continued to increase steadily in all countries. Germany and Australia reported slower growth rates due to decarbonization policies already implemented (Table 2). Emission increases were partially offset under moderate NDC compliance, especially in Germany and Brazil, where transition measures have legal force. As for the aggressive policy scenario, the annual emissions decrease remained stable for every country (with emissions in Germany and Brazil reducing by 13.4% and 10%, respectively over five years) (Table 2). India and Nigeria, although demonstrating decreases in their national emissions, had higher absolute emissions than others, a challenge of balancing economic development with environmental responsibility under international law (Table 2). The disparities in outcomes that see, particularly those observed between high and low-income countries, demonstrate that legal design cannot be sufficient without institutional capacity and economic means. Germany and Australia, with their long-standing climate legislation and transparent GHG inventory systems, excelled in every category. This corroborates the results from Baehr et al. (2024) illustrated how complementary linkages between the European Union's enhanced GHG reporting schemes have strengthened accountability at the state level and bolstered regulatory compliance mechanisms. Similarly, Derouez et al. (2024) thus, used the case of topical legal coherence and our comparative context, which is EU–China, to argue that successfully mitigating climate change in the long term requires legally coherent and economically conducive interactions between legal norms and economic development strategies.

3.2. Adaptation Measure Implementation and Legal Integration

The study describes adaptation strategies that have been employed across the five countries under investigation and is organized into ecological, infrastructural, and community-based interventions. The purpose will be to track the presence and nature of legislation supporting each measure: as a national-level legislation, a regional regulation, or a voluntary framework. They permit a comparative legal analysis of adaptation governance and indicate the level of institutionalization of measures depending on their type. Table 3 below presents various national adaptation measures and their associated legal instruments across different countries.

Table 3. National adaptation measures and legal instruments by country

Country	Measure	Type	National Law or Policy	Legal Status
Germany	Green Roofs Regulation	Infrastructural	Urban Climate Adaptation Act (2016)	Enacted
India	Rainwater Harvesting	Community-Based	Water Conservation Mandate (2017)	Enacted
Brazil	Forest Restoration	Ecological	National Reforestation Plan (2019)	Executive Order
Nigeria	Coastal Defense Walls	Infrastructural	Climate Resilience Infrastructure Act (2021)	Proposed
Australia	Drought Irrigation	Ecological	National Water Resilience Framework (2018)	Enacted

Germany and India are other examples of legal frameworks mandating through local compliance ordinances (Germany) and national legislation (India) that adaptation infrastructure must be established. Brazil's strategy remains executive-driven, an approach that underscores reliance on the president's orders versus parliamentary enactment (Table 3). Nigeria's adaptation law is still in the draft stage, indicative of lower legislative readiness, while Australia has integrated its response to drought into its long-term planning law. Part of this variation in legal status reflects differences in institutional commitment and available implementation resources (Table 3). This legal gap affects the speed and scale of adaptation measures while highlighting the legal defenselessness of poorer countries under the threat of climate hazards. Here, we show that adaptation strategies, which are often treated as an afterthought in global negotiations, are heavily reliant on local legal instruments and national-level mandates. Rezvani et al. (2023) previously emphasized how framing urban adaptation through legal mechanisms are vital component for cities facing climate stressors. Findings from this study confirm their conclusions that countries such as Germany and Australia which have incorporated adaptation into local and national law tend to have stronger institutional coordination and

resistance outcomes. Nigeria's failure is different, due to economic constraints but more importantly lack of any coastal and hydrological resilience legislation that can be enforced.

3.3. Policy Compliance and Legal Obligation Fulfillment

The study measures legal compliance through a comparison of legally required versus verified climate actions as of five years of reporting standards. The intensity of compliance was adjusted for the binding nature of the actions (like statutory versus voluntary) and juxtaposed against the implementation year of each nation's primary climate legislation. This overview captures legally binding performance on both formal international obligations and their national legislative transposition. Table 4 presents the legal climate compliance scorecard from 2019 to 2023, highlighting the required and verified actions, normative compliance scores, and the primary climate laws enacted in selected countries.

Table 4. Legal climate compliance scorecard (2019–2023)

Country	Required Actions	Verified Actions	Normative Compliance Score (%)	Primary Climate Law Enacted
Germany	60	57	95.0	2014
India	55	47	85.5	2015
Brazil	45	39	86.7	2016
Nigeria	30	24	80.0	2020
Australia	40	36	90.0	2013

Germany ranks first in overall index execution compliance, with 95% of climate change-related legal proceedings verified, owing to its strong legal accountability and audit system (Table 4). Australia and Brazil also perform well, benefitting from early climate legislation and institutional coordination. India manages even lower compliance because reporting happens far slower, and the legal fragmentation is regional (Table 4). Nigeria's score of 80% acknowledges both implementation delays and gaps in enforcement capacity, but the 2020 legislative action signals institutional positivity (Table 4). The results demonstrate that early legal engagement and national capacity prove decisive for effective compliance. In contrast, national climate policy formulation in Nigeria and India exposed some critical limitations. Nigeria's relatively weak performance on emissions reduction and transparency mirror institutional challenges that were identified in prior legal reviews of developing country responses (Akpuokwe et al., 2024; Muslim, 2024). Akpuokwe et al. (2024) highlighted that though national laws may fit international aims on paper, implementation through legal enforcement, availability of funding, and governance fragmentation often inhibited such improvements - patterns that were also seen in this study.

3.4. GHG Reporting Integrity and Transparency Assessment

The analysis evaluates the level of transparency of national GHG reporting systems using a composite scoring approach. It builds in technical verification levels (IPCC), audit presence, peer review frequency, and legal enforceability. The results show if national inventories are structurally sound and if they comply with ETF standards under the Paris Agreement. Table 5 presents the 2023 national GHG inventory transparency metrics for selected countries, including their reporting tiers, legal requirements, audit status, peer review frequency, and transparency scores.

Table 5. National GHG inventory transparency metrics in 2023

Country	Reporting Tier	Legal Inventory Mandate	Audit Status	Peer Review Frequency	Transparency Score (0–10)
Germany	Tier 3	Yes	Yes	Annual	9
India	Tier 2	Partial	No	Biennial	6
Brazil	Tier 2	Yes	Yes	Biennial	8
Nigeria	Tier 1	No	No	None	4
Australia	Tier 3	Yes	Yes	Annual	9

Germany and Australia score highest because of full Tier 3 verification protocols, third-party audits, and legally mandated inventories. Regular peer reviews and a solid legal mandate strengthen Brazil's good score, though its tiering remains at level 2 (Table 5). The absence of audit mechanisms and scrutiny leads to uneven implementation of its policies. Nigeria rates as the worst across all indices, indicating significant structural vulnerabilities (Table 5). These results support the perspective that mandatory and legally enforceable emissions reporting with institutional oversight is necessary to achieve transparency and align emissions reporting with global standards. This is especially true for emerging economies, where accountability and transparency are still strong points of controversy. Reporting compliance has improved lately since the Enhanced Transparency Framework came into effect under the Paris Agreement, but countries have a wide variety of legal obligations for GHG inventory systems. As Green and Kuch (2022) reported, meaningful climate governance requires a shift away from the output-based assessments of climate success that dominate the discussion, toward a mode of accountability that is institutionally anchored including in fossil-fuel-dependent jurisdictions. Our analysis supports this claim: countries with legally binding inventory systems, such as Germany and Australia, ranked substantially higher on the Transparency Index than those using voluntary or non-legally binding mechanisms, like Nigeria. The results highlight that the effectiveness of climate strategies is not just about policy ambition but fundamentally rests on the legal systems that codify, enforce, and oversee those ambitions. Effective and equitable climate governance relies heavily on strong legal frameworks, institutional oversight, and financial capacity. The next generation of international climate law must embrace integration across disciplines, stakeholders, and levels of governance to achieve global targets.

3.5. Integrated Assessment of Mitigation, Adaptation, and Legal Accountability

Integrates indicators from emissions reduction, adaptation implementation, and compliance mechanisms into a unified comparative assessment. The methodology for scoring countries across the four pillars is as follows: (1) the percentage change in emissions (under an aggressive compliance posture with the country's laws) (2) the index of legal implementation for adaptation (3) the legal compliance score, and (4) the transparency score. This framework enables assessing how legal robustness relates to environmental and governance outcomes. Figure 1 presents the cross-domain performance matrix of legal climate strategy implementation across five countries, including their emissions reduction, adaptation law index, normative compliance score, and transparency score.

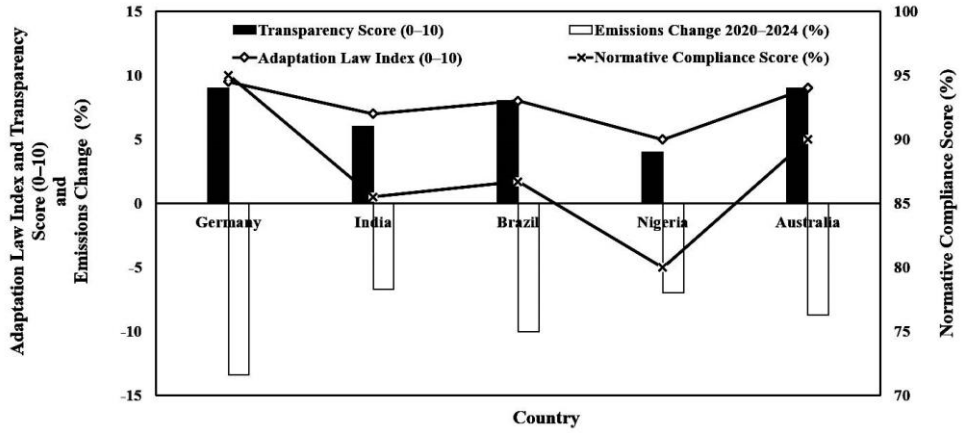

Figure 1-Cross-domain performance matrix of legal climate strategy implementation in five countries

Germany was always leading in all dimensions due to mature legal frameworks, advanced emissions forecasting policies, and strong institutional monitoring. Australia's case is backed by legal rigor in both mitigation and transparency. Brazil compensates for its

moderate emissions reduction with solid adaptation legislation and reliable reporting (Figure 1). Legal design in India has made progress, though emissions control and reporting could improve. Nigeria, where we're seeing progress, is between a rock and a hard place in terms of legal enforcement, data transparency, and climate governance, all of which make it difficult for low-income countries. The study did not consider the non-state actors, sub-national entities, or regional organizations that may contribute to climate law implementation. The integration of human rights, equity, and anticipatory action frameworks into international law remains a frontier in adaptation governance (Nishimura, 2022). Likewise, McDonald and McCormack (2021) claim that state-centric models of legal compliance frequently overlook the increasingly salient engagement of cities, indigenous communities, and private sector actors in the fulfillment of climate obligations. As Mohammed et al. (2024) in particular, as climate litigation proliferates across jurisdictions, issues of international liability and state responsibility must also be reevaluated.

3.6. Regional Aggregate Performance Overview and Policy Implications

To understand how regional blocks are doing overall, we average national data into regional data. This section provides a cross-sectional regional analysis of the four fundamental legal-climate metrics, intending to reveal systemic patterns, successful governance models, and policy gaps. The regions chosen are Europe, Asia, Latin America, Africa, and Oceania. Figure 2 presents the cross-domain performance matrix of legal climate strategy implementation across different regions, highlighting variations in emissions reduction, adaptation law indices, compliance rates, and transparency scores.

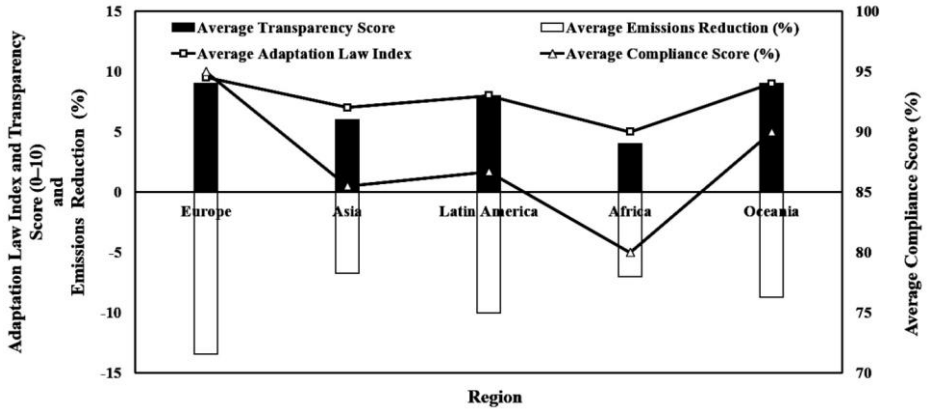

Figure 2-Cross-domain performance matrix of legal climate strategy implementation in different regions

Almost everywhere on every dimension, European countries are doing better, a reflection of the historical development of the EU climate acquis and centralized regulatory institutions (Figure 2). Oceania, led by Australia, is similar to Europe in terms of transparency and compliance but has made no significant emissions cuts. Latin America scores well on emissions and governance metrics but falls short on adaptation coverage (Figure 2). Asia has legal momentum but faces challenges from the scale of emissions and enforcement gaps. Africa is the most vulnerable region in terms of national adaptation governance capacity, scoring lowest across adaptation governance and transparency indicators, highlighting the need for international legal and technical assistance to improve national climate architecture (Figure 2). The study's publication and findings are important because it employs integrated metrics, including the Legal-Resilience Effectiveness Index (LREI) and Normative Compliance Score (NCS), to connect legislated enforceability to measurable climate outcomes. This methodological development builds upon previous research, such as Huang et al. (2024) observed that there remain gaps between pledges made under the Paris Agreement and what is being achieved in terms of controlling

emissions, especially by rapidly industrializing states. It was found that a stringent compliance response has a considerably higher impact when combined with a complementary demand response or, when possible, with a complementary supply response. For example, Germany's 13.4 percent drop in emissions over five years fits in with Huang's observation that legal credibility correlates positively with mitigation success.

4. Conclusions

The study of international climate change law in terms of mitigation, adaptation, compliance, and transparency charts out a complex and patchy global legal map. This study illustrates that climate strategies cannot achieve operational success without legal bases allowing for both environmental outcomes and the institutional integrity of any reporting and enforcement systems. Through its integration of emissions forecasting with adaptation performance indices and with metrics of legal accountability, the piece offers a composite picture of how laws are at once governance tools and performance evaluation instruments.

1. Mature and enforceable climate legislation, as evidenced by these findings, allows countries to be better positioned to respond to international frameworks and deliver domestic policy that effects real change. Clear legal requirements linked to in-depth institutional processes and technical dialogue potentially help trigger emissions cuts and periodized adaptation approaches. In contrast, the lack of legal enforceability (or its weakness), is a major obstacle, especially in under-institutionalized countries, to both national action and international coordination. These observations lend credence to the notion that the law, when crafted and operationalized appropriately, serves not only as a procedural nicety but rather as a strategic vehicle for long-term climate resilience and regulatory alignment.

2. While underscoring strengths, the study also chronicles the considerable legal and structural gaps that persist, particularly in low-income and emerging economies. The wide variation in compliance scoring and transparency across countries highlights that there is an urgent need to develop harmonized legal benchmarks that can facilitate a comparative assessment, whilst still recognizing differentiated responsibilities. National contexts must also be reflected in the design of climate law, with the understanding that legal instruments must be adaptable, inclusive, and iterative so that changes in science and socio-economic realities can be acknowledged. Law-binding procedures for climate reporting and adaptation planning must become common practice if global goals are to be met with credibility and consistency.

3. Although the study focuses on national-level law, it also opens wider questions around the integration of non-state actors and sub-national jurisdictions into the fabric of international climate law. The contribution of cities, indigenous communities, and the private sector increasingly requires expanding the boundaries of legal systems to encompass multi-actor governance. The development of international legal norms, therefore, must also capture what is inherently disaggregated about potential mechanisms for climate governance today, as the national government cannot and must not be the only terrain for pursuing climate activity for both those in the countries in which they are situated and others around the world.

4. Moving forward, the findings show that research on the intersection of legal design with financial instruments, trade policy, and human rights law should be carried out to build a more integrated legal response to the climate crisis. Further cross-governance levels, across economic sectors and system-inspired comparative analyses could enhance understanding of the mechanisms by which climate law generates material impacts. Furthermore, enhancing legal metrics and data integration tools will be critical to further accountability, enforce legal harmonization, and facilitate evidence-based policymaking going forward. The path to global climate stability will be governed by the depth, agility, and inclusivity of the legal systems that support it.

The results from this study prompt a multi-dimensional assessment of how legal instruments are improving the effectiveness of international climate mechanisms on emissions mitigation, adaptive implementation, compliance, and transparency fronts. Using this approach, the study underscores the importance of enforceable

climate laws, transparent governance, and institutional embeds adaptation measures as necessary components to delivering the ambitions of the Paris Agreement by harmonizing them with advanced quantitative models, but with normative aspects on the function of the laws. However, this study has some limitations. While the differential emissions modeling has great sensitivity to policy variables, it relies on estimated coefficients of policy effectiveness that may vary across unmeasured contexts. This is especially relevant when comparing countries with differing governance models, population structures, and technological baselines. Second, the analysis is limited to five countries for cross-comparisons in detail, which, although being representative, cannot account for the diversity of global climate legal practices. Third, while legal indicators like NCS and LREI do enhance quantitative resolution, the scoring itself remains subjective, particularly in weighing the importance of legislative strength or adaptation. Future research could expand upon this preliminary investigation by examining a broader cross-section of all Annex I and non-Annex I countries, or by drawing on regional blocs such as the African Union or ASEAN to explore supranational coordination. Additionally, the incorporation of financial, trade, and energy sector law as variables will provide a more comprehensive view of how climate law aligns with wider sustainable development goals. Based on the results of this study, it is recommended that, to effectively address climate change, developing and enforcing comprehensive legal frameworks is essential. These frameworks should promote the sustainable management of water and soil resources, ensuring resilience and adaptation at both national and local levels. Additionally, integrating environmental, water, and soil protection laws with climate policies can enhance ecosystem health, support biodiversity, and foster long-term environmental sustainability in the face of changing climatic conditions.

Acknowledgments

The authors gratefully acknowledge the valuable feedback provided by the peer reviewers, which helped enhance the quality of this review.

Author Contributions

Sami Najm Abed Al- Nuaimi: Methodology, Investigation, Conceptualization, Writing Original Draft

Sawsan Khairy Abdullah: Investigation, Conceptualization, Revising the Draft

Abbas Fadhel Eisa Muhsin: Methodology, Investigation, Conceptualization, Writing Original Draft

Bushra Salman Husein: Investigation, Conceptualization, Revising the Draft

Faris Abdul Kareem Khazal: Supervision, Review-Editing

Ata Amini: Methodology, Investigation, Conceptualization, Writing Original Draft

Hedieh Ahmadpari: Methodology, Investigation, Conceptualization, Writing Original Draft

Authors' Conflicts of interest

The authors declare no conflict of interest regarding the authorship or publication of this manuscript.

Data Availability Statement

All information and results are provided in the text of the article.

References

Adenle, A. A., Manning, D. T., & Arbiol, J. (2017). Mitigating climate change in Africa: barriers to financing low-carbon development. *World Development*, *100*, 123-132. doi: 10.1016/j.worlddev.2017.07.033

Ahmadpari, H., & Khaustov, V. (2025). Agricultural drought monitoring using meteorological indices in Darreh Dozdan Basin, Iran. *Advances in Civil Engineering and Environmental Science*, *2*(2), 72-84. doi: 10.22034/acees.2025.512324.1022

Ahmadpari, H., & Khaustov, V. (2025a). A review of the effects of climate change on watershed runoff in Iran. 8th International Congress of Developing Agriculture, Natural Resources, Environment and Tourism of Iran, Tabriz, Iran.

Ahmadpari, H., Mohamadi Sedigh, M., Mohamadi, E., & Hassanpour, F. (2018). Investigating the Impact of Climate Change on Agricultural Sector and Strategies to Deal with it, 2nd International Conference on Applied Research in Agriculture, Natural Resources and Environment, Hamedan, Iran.

Akpuokwe, C. U., Adeniyi, A. O., Bakare, S. S., & Eneh, N. E. (2024). Legislative responses to climate change: a global review of policies and their effectiveness. *International Journal of Applied Research in Social Sciences*, *6*(3), 225-239. doi: 10.51594/ijarss. v6i3.852

Amoo, L. M., & Fagbenle, R. L. (2020). Climate change in developing nations of the world. Applications of Heat, Mass and Fluid Boundary Layers, 437-471.

Baehr, J., Zenglein, F., Sonnemann, G., Lederer, M., & Schebek, L. (2024). Back in the driver's seat: how new EU greenhouse-gas reporting schemes challenge corporate accounting. *Sustainability*, *16*(9), 3693. doi: 10.3390/su16093693

Bahrami, A. (2024). Climate change adaptation, sociological perspectives and social justice. *Environment and Water Engineering*, *10*(3), 417-428 [In Persian]. doi: 10.22034/ewe.2024.417981.1891

Bozhenko, V. B., A., Bozhenko, A. & Roienko, O. (2023). Transparency and corruption prevention in financing climate action. *Financial Markets, Institutions and Risks*, *7*(2), 88-94. doi: 10.21272/fmir.7(2).88-94.2023

Cadman, T. (2019). The United Nations framework convention on climate change. The Palgrave handbook of contemporary international political economy, 359-375. doi: 10.1057/978-1-137-45443-0_23

Cantarero, M. M. V. (2020). Of renewable energy, energy democracy, and sustainable development: A roadmap to accelerate the energy transition in developing countries. *Energy Research & Social Science*, *70*, 101716. doi: 10.1016/j.erss.2020.101716

Carattini, S., Gosnell, G., & Tavoni, A. (2020). How developed countries can learn from developing countries to tackle climate change. *World Development*, *127*, 104829. doi: 10.1016/j.worlddev.2019.104829

Corbera, E., Estrada, M., & Brown, K. (2010). Reducing greenhouse gas emissions from deforestation and forest degradation in developing countries: revisiting the assumptions. *Climatic change*, *100*(3), 355-388. doi: 10.1007/s10584-009-9773-1

Derouez, F., Ifa, A., & Al Shammre, A. (2024). Energy transition and poverty alleviation in light of environmental and economic challenges: A comparative study in China and the European Union Region. *Sustainability*, *16*(11), 4468. doi: 10.3390/su16114468

Díaz, C. G., Zambrana-Vasquez, D., & Bartolomé, C. (2024). Building resilient cities: A comprehensive review of climate change adaptation indicators for urban design. *Energies*, *17*(8), 1959. doi: 10.3390/en17081959

Dinpashoh, Y, & Allahverdipour, P. (2025). Monitoring and predicting changes in reference evapotranspiration in the Moghan Plain according to CMIP6 of IPCC. *Environment and Water Engineering*, *11*(1), 47-56. doi: 10.22034/ewe.2024.466037.1947

Esmaeili, S., Bahrami, J., & Kamali, B. (2024). The contributions of natural and anthropogenic climate change on water resources reduction in Zarrinehroud basin of Lake Urmia. *Advances in Civil Engineering and Environmental Science*, *1*(1), 1-14. doi: 10.22034/acees.2024.195339

Fan, H. (2024). Dilemmas and breakthroughs in the application of the principle of common but differentiated responsibilities in the context of COP28. *Scientific Journal of Humanities and Social Sciences*, *6*(8), 131-139. doi: 10.54691/7acyb415

Green, F., & Kuch, D. (2022). Counting carbon or counting coal? anchoring climate governance in fossil fuel–based accountability frameworks. *Global Environmental Politics*, *22*(4), 48-69. doi: 10.1162/glep_a_00654

H.S., S. (2024). A critical appraisal of the international and national legal framework on climate change. Proceedings of International Forestry and Environment Symposium, 27. doi: 10.31357/fesympo. v27.7101

Huang, Z., Huang, Y., & Zhang, S. (2024). The possibility and improvement directions of achieving the Paris agreement goals from the perspective of climate policy. *Sustainability*, *16*(10), 4212. doi: 10.3390/su16104212

Intergovernmental Panel on Climate Change (IPCC). (2014). Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press. https://www.ipcc.ch/report/ar5/wg3/

Kadir, T., Basri, T. S., Dheviena, R., Hitaningtyas, P., & Info, A. (2024). The role of international law in addressing climate change: legal perspective and policy solution.

Pena Justisia: Media Komunikasi dan Kajian Hukum. doi: 10.31941/pj. v22i2.5002

Kuyper, J. W., Linnér, B. O., & Schroeder, H. (2018). Non-state actors in hybrid global climate governance: justice, legitimacy, and effectiveness in a post-Paris era. Wiley Interdisciplinary Reviews: *Climate Change*, *9*(1), e497. doi: 10.1002/wcc.497

Maevsky, O., Kovalchuk, M., Brodsky, Y., Stanytsina, V., & Artemchuk, V. (2024). Game-theoretic modeling in regulating greenhouse gas emissions. *Heliyon*, *10*(9), 1-11. doi: 10.1016/j.heliyon. 2024.e30549

Mai, L. (2024). Navigating transformations: Climate change and international law. *Leiden Journal of International Law*, *37*(3), 535-556. doi: 10.1017/S0922156524000062

McDonald, J., & McCormack, P. C. (2021). Rethinking the role of law in adapting to climate change. *WIREs Climate Change*, *12*(5), e726. doi: 10.1002/wcc.726

Méndez, M. (2020). Climate change from the streets: How conflict and collaboration strengthen the environmental justice movement. Yale University Press.

Mohammed, S. S., Jasim, I. O., Al-Bayati, A. K. K., Kabrch, J. K., & Khlaponin, D. (2024). State responsibility and liability in climate change mitigation in section international law analysis. *Journal of Ecohumanism*, *3*(5), 444–466. doi: 10.62754/joe. v3i5.3916

Muslim, H. S. (2024). The financial challenges of developing countries for climate change mitigation and sustainable development under UN Agenda 2030. *Journal of Ecohumanism*, *3*(7), 1923–1935. doi: 10.62754/joe. v3i7.4343

Nishimura, L. (2022). Adaptation and anticipatory action: Integrating human rights duties into the climate change regime. *Climate Law*, *12*(2), 99-127. doi: 10.1163/18786561-20210001

Otto, I. M., Reckien, D., Reyer, C. P., Marcus, R., Le Masson, V., Jones, L., Norton, A., & Serdeczny, O. (2017). Social vulnerability to climate change: a review of concepts and evidence. *Regional environmental change*, *17*, 1651-1662. doi: 10.1007/s10113-017-1105-9

Parvizi, S., Talebi, A., Malekinezhad, H., & Sadeghi, M. (2020). Investigation of the effect of climate change on some of hydrological parameters in Jamishan Watershed using SWAT Model. *Environment and Water Engineering*, 6(4), 430-443 [In Persian]. doi: 10.22034/jewe.2020.238651.1383

Popovski, V. (2024). Climate change as an existential threat: translating global goals into action. *Environmental Policy and Law*, 54, 127-139. doi: 10.3233/EPL-239025

Rezvani, S. M. H. S., de Almeida, N. M., & Falcão, M. J. (2023). Climate adaptation measures for enhancing urban resilience. *Buildings*, *13*(9), 2163. doi: 10.3390/buildings13092163

Salimi Turkamani, H. (2023). The legal nature of the climate change regime: fluctuation between lex lata and lex ferenda. *Utrecht Journal of International and European Law*. doi: 10.5334/ujiel.603

Singh, P. K., & Chudasama, H. (2021). Pathways for climate resilient development: Human well-being within a safe and just space in the 21st century. *Global Environmental Change*, *68*, 102277. doi: 10.1016/j.gloenvcha.2021.102277

Singla, A., & Garg, A. (2024). Climate change litigation: a new frontier for environmental law and policy. *Indian Journal of Law*, *2*(1), 32–43. doi: 10.36676/ijl. v2.i1.05

Van Asselt, H., Sindico, F., & Mehling, M. A. (2008). Global climate change and the fragmentation of international law. *Law & Policy*, *30*(4), 423-449. doi: 10.1111/j.1467-9930.2008. 00286.x

Wan, Q., & Liu, J. (2023). Energy efficiency optimization and carbon emission reduction targets of resource-based cities based on BiLSTM-CNN-GAN model. *Frontiers in Ecology and Evolution*, *11*. doi: 10.3389/fevo.2023.1248426

Wiener, J. B., & Felgenhauer, T. (2024). The Evolving International Climate Change Regime: Mitigation, Adaptation, Reflection. *Tex. A&M L. Rev.*, *11*, 451. doi: 10.37419/LR. V11.I2.6

Xu, S., Chen, Z., Jiang, Z., & Liu, Z. (2024). addressing impacts from climate change within international legal system: More Precise Distribution of Responsibilities. Lecture Notes in Education Psychology and Public Media, 60, 47-157. doi: 10.54254/2753-7048/60/20240554.