Workshop Proceedings:

High-Level Dialogue on Responding to the Climate Emergency to Protect Human Rights

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Foreword

Solving global warming is many things: a scientific challenge, a technological challenge, a political challenge, a societal challenge. As the damaging impacts of climate change manifest before our eyes, and as the urgency of decarbonization and replacing fossil fuels becomes ever greater, we should take deeply seriously another dimension: global warming as a human rights challenge.

Climate change implicates numerous human rights issues, from rights to life and security to rights to culture and livelihood and more. At stake is not only whether global warming is slowed and halted, but how quickly, in what manner, and by whom, among other questions. Indeed, in substance, climate change has been a human rights issue since its emergence as a political topic in the 1980s. Over three decades later, as the climate emergency increasingly becomes a crisis to avert, rather than a mere problem to manage, it is past time the human rights dimensions of the challenge are faced directly.

In October 2023, the Oxford Sustainable Law Programme was privileged to host a High-Level Dialogue on Responding to the Climate Emergency to Protect Human Rights, bringing together scientists, lawyers, and judges to discuss this defining issue of our time. These proceedings memorialize much of the content of those discussions. Like for any great challenge, the solutions needed are dynamic and produced through living relationships and evolution, and we trust these dialogues are a step along that path.

Dr. Benjamin Franta, Senior Research Fellow and Head of the Climate Litigation Lab, Oxford Sustainable Law Programme, Smith School of Enterprise and Environment and Faculty of Law.

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The Role of Courts in Addressing the Climate Emergency

Durwood Zaelke, Trina Chiemi, and Erika Gerstenberger[1]

1. Introduction

Climate advocates are enlisting the courts in the battle for the survival of civilization and the ecosystems civilization depends upon, pitting an emerging legal movement committed to protecting environmental and human rights *against* a historically powerful legal system that protects capitalism and has, until lately, largely ignored the climate emergency.

Climate change is destroying ecosystems, agriculture, and human health for present and future generations. Early climate cases focused primarily on cutting carbon dioxide (CO_2), responsible for about half of warming, to address these damaging impacts. Now, cases are starting to address the non-CO_2 super pollutants causing the other half of warming, primarily methane and other short- lived climate pollutants (SLCPs). Cases targeting SLCPs recognize that within a decade—and perhaps sooner—human-caused warming will trigger self-reinforcing feedback loops and push the planet past potentially irreversible tipping points, and that cutting SLCPs is the best and currently the only known way to slow near-term warming in the next two decades.

Legislators have been slow to develop the law needed to stop climate pollution and address the climate emergency. Climate litigation, including in human rights courts, is helping fill the gap and helping develop the more muscular law needed for civilization to survive in our rapidly warming world.

A. The Need for Speed in Climate Action

We are already seeing the impacts of extreme weather at 1.1–1.2°C of post-Industrial Revolution warming,[2] and the window for effective mitigation is quickly closing.[3] The

[1] Founder and President of the Institute for Governance & Sustainable Development (IGSD); IGSD Research Associate and Founding Co-Chair of Fast Action on Climate to Ensure Intergenerational Justice; IGSD Law Fellow.

[2] Intergovernmental Panel on Climate Change (2023) AR6 SYNTHESIS REPORT: CLIMATE CHANGE 2023, P. Arias, et al. (eds.), 6; J. Hansen, M. Sato, & R. Ruedy (12 January 2023) *Global Temperature in 2022*, Columbia University.

[3] N. S. Diffenbaugh & E. A. Barnes (2023) *Data-driven predictions of the time remaining until critical global warming thresholds are reached*, PROC. NAT'L. ACAD. SCI. 120(6), 2; Y. Xu, V. Ramanathan, & D. G. Victor (2018) *Global*

Intergovernmental Panel on Climate Change (IPCC), the leading international body assessing climate science, established that human activity has "undoubtedly" warmed the planet by increasing greenhouse gas (GHG) concentrations, and that limiting warming to the 1.5°C target in the Paris Agreement is critical for the health and safety of the planet and its people.[4] If the world fails to reduce near- term warming immediately—which cannot be achieved by cutting CO_2 alone[5]—we risk triggering climate tipping points that could put us on a path towards a 'hothouse Earth.'[6]

New research shows that cutting methane and other SLCPs can avoid four times more warming at 2050 than cutting CO_2 alone.[7] Cutting CO_2 by shifting to clean energy cuts co-emitted cooling aerosols, and because these planet-cooling aerosols fall out quickly, this "unmasks" existing warming, for a net increase in the near-term.[8] As a result, only 0.1°C of avoided warming could be achieved by 2050, with cooling starting to ramp up in 2060.[9] Protecting existing carbon sinks also can provide fast climate mitigation. Cutting near-term

warming will happen faster than we think, Comment, NATURE 564(7734), 30–31. Since Xu, Ramanathan, and Victor comment was published, the IPCC has updated its estimate for when 1.5 °C will be exceeded: see Intergovernmental Panel on Climate Change (2021) CLIMATE CHANGE 2021: THE PHYSICAL SCIENCE BASIS, V. Masson-Delmotte, et al. (eds.), TS-9. See also J. E. Hansen, et al. (submitted 8 December 2022) *Global warming in the pipeline*, ATMOS. OCEAN. PHYS. (preprint), 39; J. E. Hansen, et al. (13 October 2023) *El Nino Fizzles. Planet Earth Sizzles. Why?*, Columbia University.

[4] See generally IPCC, AR6 SYNTHESIS REPORT; CLIMATE CHANGE 2022: MITIGATION OF CLIMATE CHANGE, P. R. Shukla, et al. (eds.); IPCC, CLIMATE CHANGE 2022: IMPACTS, ADAPTATION, AND VULNERABILITY, H.-O. Pörtner, et al. (eds.); IPCC, CLIMATE CHANGE 2021; GLOBAL WARMING OF 1.5 °C, V. Masson-Delmotte, et al. (eds.).

[5] G. B. Dreyfus, et al. (2022) *Mitigating climate disruption in time: A self-consistent approach for avoiding both near-term and long-term global warming*, PROC. NAT'L. ACAD. SCI. 119(22), 1; J. Rogelj & R. Lamboll (submitted 27 September 2023) *Non-CO2 emissions reductions implied by IPCC estimates of the Remaining Carbon Budget*, NAT. (preprint), 1.

[6] W. Steffen, et al. (2018) *Trajectories of the Earth System in the Anthropocene*, PROC. NAT'L. ACAD. SCI. 115(33), 8254, 8256; D. I. Armstrong McKay, et al. (2022) *Exceeding 1.5°C global warming could trigger multiple climate tipping points*, SCIENCE 377(6611), 7; IPCC, AR6 SYNTHESIS REPORT, 36, 42; IPCC, CLIMATE CHANGE 2021, 4-96 (Table 4.10 lists 15 components of the Earth system susceptible to tipping points).

[7] Supra note 4; International Energy Agency (2023) THE IMPERATIVE OF CUTTING METHANE FROM FOSSIL FUELS: AN ASSESSMENT OF THE BENEFITS FOR THE CLIMATE AND HEALTH, 3.

[8] Dreyfus, *Mitigating climate disruption in time*, 1; IPCC, CLIMATE CHANGE 2022: MITIGATION, SPM-31; United Nations Environment Programme & World Meteorological Organization (2011) INTEGRATED ASSESSMENT OF BLACK CARBON AND TROPOSPHERIC OZONE, 254; V. Ramanathan & Y. Feng (2008) *On avoiding dangerous anthropogenic interference with the climate system: Formidable challenges ahead*, PROC. NAT'L. ACAD. SCI. 105(38), 14248.

[9] Y. Xu & V. Ramanathan (2017) *Well below 2 °C: Mitigation strategies for avoiding dangerous to catastrophic climate changes*, PROC. NAT'L. ACAD. SCI. 114(39), 7.

warming to reduce climate risks and staying withing the limits to adaptation are critical to building resilience.

B. EXPANDING EVIDENCE BASE FOR CLIMATE ATTRIBUTION

To succeed in a lawsuit, plaintiffs must credibly attribute the harm they experience to an actor responsible for that harm. An expanding body of scientific and historical evidence in climate attribution strengthens the legal basis for redressing harms and supports litigation that is calling for accountability.[10] Attribution studies can now link climate change to specific extreme weather events and the damage they cause.[11]

Climate modelling helps identify mitigation pathways to keep the planet within the Paris guardrails, slow self-amplifying feedback loops where the planet warms itself, and avoid or at least delay irreversible tipping points. This includes calculating the carbon budget to identify how much additional climate pollution can be emitted before warming breaches the Paris guardrails.[12] Some courts have used the carbon budget to reject new fossil fuel projects because they are inconsistent with the remaining budget to meet the Paris targets, and some have used the risk of tipping points to justify faster mitigation.

Other studies have identified the contribution of the major climate polluters. Just 108 fossil fuel and cement producers have been responsible for almost 70% of global industrial GHG emissions of CO_2 and methane since the Industrial Revolution.[13] Since the 1960s, the major fossil fuel companies have known that the planet was warming due to fossil fuel CO_2 emissions from its products and spent billions of dollars to spread doubt and misinformation on the climate

[10] R. Stuart-Smith, *et al.* (2021) ATTRIBUTION SCIENCE AND LITIGATION: FACILITATING EFFECTIVE LEGAL ARGUMENTS AND STRATEGIES TO MANAGE CLIMATE CHANGE DAMAGES, Oxford Sustainable Law Programme, Environmental Change Institute, & Smith School of Enterprise and the Environment, 3; R. Stuart-Smith, *et al.* (2021) *Filling the evidentiary gap in climate litigation*, NAT. CLIM. CHANG. 11(8), 654

[11] S. Herring, *et al.* (2023) *Explaining Extreme Events from a Climate Perspective*, AM. METEOROL. SOC.

[12] M. Meinshausen, *et al.* (2009) *Greenhouse-gas emission targets for limiting global warming to 2 °C*, NATURE 458(7242), 1158; P. Griffin (2017) THE CARBON MAJORS DATABASE: CDP CARBON MAJORS REPORT 2017, CDP & Climate Accountability Institute, 13; Rogelj, *Non-CO2 emissions reductions implied by IPCC estimates*.

[13] R. Heede (9 December 2020) Press Release: Update of Carbon Majors 1965-2018, CLIMATE ACCOUNTABILITY INSTITUTE, 2; R. Heede (2014) *Tracing anthropogenic carbon dioxide and methane emissions to fossil fuel and cement producers*, 1854–2010, CLIM. CHANGE 122(1–2), 234.

crisis.[14] Instead of warning the public, they deliberately followed the blueprint of the tobacco industry's misinformation campaign.[15]

These developments provide tools to hold polluters accountable—especially the major fossil fuel companies—and mandate that governments and industry keep within the temperature guardrail by cutting both CO_2 and non-CO_2 emissions.

2. Overview of Climate Litigation

According to the databases from Columbia Law School's Sabin Center and London School of Economics' Grantham Institute, there are over 2,500 ongoing or concluded climate cases.[16] Globally, the number of climate-related cases has more than doubled since 2015, with nearly a quarter filed between 2020 and 2022, including 81 cases challenging inadequate government response. This includes 285 climate cases in 23 European countries, where three-quarters are against governments and a growing number against private polluters. More than 60 cases have been filed before the Courts of the European Union, and 12 cases are pending before the European Court of Human Rights. The Grantham Institute also reports that "more cases in Europe to date have had direct outcomes that *advance* climate action (113 cases 'favorable' to climate action vs. 86 'unfavorable')." The Sabin Center's U.S. climate change litigation database includes nearly 1,700 cases, with over 850 additional global cases in over 55 countries, including before international and regional courts and tribunals, and investor-State disputes before arbitral tribunals. Cases opposing climate protection are included. These databases show the wide variety of climate-related cases, identifying the type of defendants, causes of action, principal laws invoked, and more.

Other academic and public interest centers focusing on climate litigation include the *Institute for Governance & Sustainable Development*, New York University's *Climate Litigation Accelerator*,

[14] N. Banerjee, L. Song, & D. Hasemyer (2015) *Exxon: The Road Not Taken*, INSIDE CLIMATE NEWS; G. Supran, S. Rahmstorf, & N. Oreskes (2023) *Assessing ExxonMobil's global warming projections*, SCIENCE 379(6628), 1; B. Franta (2018) *Early oil industry knowledge of CO2 and global warming*, NAT. CLIM. CHANGE 8.

[15] See N. Oreskes & E. M. Conway (2011) MERCHANTS OF DOUBT: HOW A HANDFUL OF SCIENTISTS OBSCURED THE TRUTH ON ISSUES FROM TOBACCO SMOKE TO GLOBAL WARMING; B. Franta (2022) *Weaponizing economics: Big Oil, economic consultants, and climate policy delay*, ENV. POL. 31(4); A. Westervelt (2016) Drilled, Critical Frequency.

[16] Sabin Center for Climate Change Law, About, Climate Case Chart [accessed Oct. 15, 2023].

Oxford University's [Climate Litigation Lab](), the [Center for Climate Integrity](), and the Union of Concerned Scientists' [Hub for Climate Litigation]().

According to Grantham, areas to watch include cases involving personal responsibility, cases challenging commitments that over-rely on 'negative emissions,' and cases targeting SLCPs such as methane.[17] The following cases illustrate several types of climate litigation.

A. HOLDING GOVERNMENTS ACCOUNTABLE

I. URGENDA: A LANDMARK CASE

Urgenda Found. v. The Netherlands (2019)[18] is a landmark climate case that inspired over 70 cases against governments and corporations worldwide. Here, the Supreme Court of the Netherlands ruled that the Dutch government must reduce its GHG emissions by 25% below 1990 levels by 2020, upholding The Hague Court of Appeals decision that Articles 2 (right to life) and 8 (right to respect for private and family life) of the European Convention for the Protection of Human Rights and Fundamental Freedoms provide a positive obligation for the government to reduce its climate emissions because climate change threatens the life and well-being of people in the Netherlands. The Court also relied on the "precautionary principle" and "no harm principle" of international law.

The case was first filed in 2015. Both parties agreed that GHG levels must be reduced to achieve the 1.5 or 2°C Paris targets. The dispute was whether the State's commitment to cut emissions by 20% by 2020 was sufficient. The Court rejected the State's argument that negative emission strategies allowed the State to postpone more aggressive mitigation until 2030, noting that the negative emission strategies were speculative. The Court also rejected the argument that determining the amount of climate mitigation was an issue solely for the legislative branch. The Supreme Court opinion is based on the extensive and undisputed factual record and informed by the 184-page advisory opinion with 597 endnotes by the Dutch Procurator General and Advocate General. The Attorneys General cited the relevant IPCC reports that confirm that warming beyond 1.5/2°C would lead to dangerous climate impacts, including crossing tipping points that would lead to abrupt and irreversible changes in the

[17] J. Setzer & C. Higham (2022) GLOBAL TRENDS IN CLIMATE LITIGATION: 2022 SNAPSHOT, Grantham Research Institute on Climate Change and the Environment & Centre for Climate Change Economics and Policy, 41–43.

[18] Hoge Raad [HR] [Supreme Court] The Hague, Dec. 20, 2019, 19/00135 (*De Staat Der Nederlanden v. Stichting Urgenda*) (Neth.).

climate. The Court adopted this reasoning to find that current Dutch climate targets are insufficient to meet the climate emergency.

Since the decision, the Dutch government agreed to shut down all coal power plants by 2030 and invest in renewable energy. After the decision, the Dutch government released its 2019 National Climate Act, a legally binding plan to reduce GHG emissions by 49% by 2030 and 95% by 2050 (below 1990 levels). By 2020, the Netherlands had reduced its emissions by ~25.5% below 1990 levels, although COVID-19 pandemic-induced shutdowns helped achieve most of these reductions.[19] In its 2022 budget, the Dutch government pledged to allocate €35 billion to address climate change, which includes at least 30 of the 54 suggested "Urgenda measures" to reduce emissions.

II. APPLYING URGENDA PRINCIPLES

Three similar cases that invoke the same human rights principles are pending at the European Court of Human Rights: *Duarte v. Portugal* (2020), *Verein KlimaSeniorinnen Schweiz v. Switzerland* (2020), and *Carême v. France* (2021).[20] In these cases, the applicants (Portuguese youth, Swiss senior women, and French former mayor of Grand-Synthe) argue that their governments' failure to reduce emissions with the ambition needed to limit warming to Paris temperature guardrails violates their human rights under Articles 2 and 8 of the European human rights convention, citing *Urgenda*. They seek a binding order from the Court for their respective governments (or 33 governments in *Duarte*) to reduce emissions in line with Paris temperature limits. The Court fast-tracked these cases to its Grand Chamber because of their importance and impact on future climate change cases. Hearings for *KlimaSeniorinnen* and *Carême* were held in March 2023, and the *Duarte* hearing was held in September 2023. Rulings are expected in 2024.

In a statement, the Council of Europe Commissioner for Human Rights confirmed that "the increasing number of climate change-related applications provide the [European Court of Human Rights] with a unique opportunity to continue to forge the legal path towards a more complete implementation of the [European human rights] Convention, to expand and give more

[19] See Statistics Netherlands & National Institute for Public Health and the Environment (9 February 2022) Urgenda reduction target for GHG emissions achieved in 2020, STATISTICS NETHERLANDS.

[20] See *Duarte v. Portugal*, 20 Eur. Ct. H.R. 39371 (2020); *Verein KlimaSeniorinnen Schweiz v. Switzerland*, 20 EUR. CT. H.R. 53600 (2020); and Carême v. France, 21 EUR. CT. H.R. 7189 (2020).

meaning to its existing case-law on the environment, and to offer real-life protection to individuals affected by environmental degradation and climate change."[21]

B. Holding Corporations Accountable

A growing number of cases seek liability and damages from corporations for past emissions and deception, including in U.S. courts, which are summarized by the *Center for Climate Integrity*.

I. Mandating Emissions Reductions

Following *Urgenda*, the District Court of The Hague in the Netherlands extended the same principles to a private corporation: Royal Dutch Shell (RDS). In *Milieudefensie v. Royal Dutch Shell* (2021),[22] the Court ordered Shell to immediately reduce its entire energy portfolio (aggregate Scope 1–3 emissions[23]) by 45% below 2019 levels by 2030, mandating an "obligation of result" for RDS' direct emissions and a "significant best-efforts obligation" for RDS' indirect emissions. The Court reasoned that Shell's actions breached its legal obligations because it continued to be a major emitter, with climate plans that were "intangible, undefined and non-binding."

The Court ruled that RDS is obligated to follow a domestic duty of care standard, informed by international and multilateral soft law instruments, including the 2015 Paris Agreement, as well as the European human rights convention (citing *Urgenda*) and International Covenant on Civil and Political Rights, which affirm the rights to life and respect for private and family life. The Court concluded that while the plaintiffs cannot directly invoke these human rights instruments because they apply to relationships between States and citizens, they play an important role in the relationships between corporations and citizens and therefore are legitimate tools for interpreting the duty of care standard. The Court relied on several international business instruments, including the United Nations Guiding Principles on Business and Human Rights,

[21] Council of Europe Commissioner for Human Rights (2021) *Third party intervention by the Council of Europe Commissioner for Human Rights*, Application No. 39371/20, 5.

[22] Rechtbank Den Haag [Rb.] [The Hague District Court] The Hague, May 26, 2021, C/09/571932 / HA ZA 19-379 (Milieudefensie v. Royal Dutch Shell plc.) (Neth.).

[23] Scope 1 emissions are direct GHG emissions from sources owned or controlled by the reporting entity. Scope 2 emissions are indirect GHG emissions from the production of electricity, heat, or steam purchased by the reporting entity. Scope 3 emissions are all other indirect GHG emissions. World Business Council for Sustainable Development & World Resources Institute (2004) THE GREENHOUSE GAS PROTOCOL: A CORPORATE ACCOUNTING AND REPORTING STANDARD, 25.

to determine that businesses must respect human rights and follow a global standard of expected conduct, which includes an individual responsibility to fulfill their human rights obligations independent of State policies. This duty requires companies to avoid causing or contributing to adverse human rights impacts through its direct or indirect activities. While both parties agreed that dangerous climate change is a global problem that cannot be solved by RDS alone, the Court determined that this does not absolve RDS of its partial responsibility to reduce its emissions. The Court specified that its decision is provisionally enforceable and cannot be delayed pending an appeal, but Shell has not yet complied with the order, instead filing an appeal, which was accepted. Hearings are scheduled for April 2024.

II. MAKING POLLUTERS PAY

In *Lliuya v. RWE* (2015),[24] a Peruvian farmer filed a complaint in a German court, arguing that GHG emissions from Germany's largest electricity producer, RWE, contributed to melting mountain glaciers in Peru that threatened his hometown. The plaintiff alleges that RWE knowingly contributed to climate change through its GHG emissions and bears some measure of responsibility for the melting glaciers and seeks reimbursement for a portion of expected flood protection costs proportional to RWE's contribution to overall GHG emissions (0.47%). The District Court of Essen originally dismissed the complaint, but the Higher Regional Court of Hamm reversed, holding that the plaintiff's complaint was well-pled and admissible. The case raises cross- jurisdictional claims and questions of measuring transboundary pollution and uses climate attribution science to calculate a polluter's responsibility. This case is ongoing.

In September 2023, the state of California filed a historic lawsuit against "Big Oil" (including defendants Exxon Mobil, Shell, Chevron, ConocoPhillips, BP, and the American Petroleum Institute) for decades of deception and damage that costed California taxpayers billions of dollars.[25] The 135-page complaint details the specific ways the defendants are substantially responsible for both causing and accelerating climate change and spreading misinformation and deceiving the public about climate change impacts.[26] The California lawsuit follows the

[24] Oberlandesgericht [OLG] [Higher Regional Court] Essen, Dec. 16, 2016, 2 O 285/15 (Lliuya v. RWE AG) (Ger.).

[25] Complaint for Abatement, Equitable Relief, Penalties, and Damages, *State of California v. Exxon Mobil Corp.*, CGC-23-609134 (Super. Ct. Cal., Sept. 15, 2023).

[26] *See generally, id.*, 32-96.

over 40 states and municipalities that have filed lawsuits filed in the U.S. seeking to hold major oil and gas corporations accountable for their emissions and deception.[27]

III. Applying Criminal Law

In *Mun. of Bayamón v. Exxon Mobil Corp.* (2022),[28] 16 municipalities in Puerto Rico, a U.S. territory, filed a 247-page class action complaint in U.S. federal district court against several fossil fuel companies seeking $124 billion in damages for Hurricanes Maria and Irma that caused "apocalyptic damage" to their island. The plaintiffs argue that the companies' historical GHG emissions significantly contributed to the intensity of these hurricanes, citing IPCC reports, and that they are liable for knowingly contributing to climate change and implementing a "fraudulent marketing scheme" to continue selling their products. This case is the first to present a cause of action under the 1970 Racketeer Influenced and Corrupt Organizations (RICO) Act, arguing that the defendants committed a pattern of racketeering activities, including mail and wire fraud. This case builds on the successful use of RICO claims in civil contexts, including the 2006 district court case holding that several tobacco companies violated RICO when they knowingly deceived the American public about the adverse health effects of smoking.[29] This case is ongoing.

C. Holding Financial Institutions Accountable

Other climate litigation aims to hold financial institutions accountable for continuing to fund fossil fuel projects, including litigation challenging investor-state dispute settlements and penalizing greenwashing.

I. Stopping Banks from Financing Fossil Fuels

Climate change presents a significant risk to the financial system, and climate litigators are starting to address the role of the financial sector.[30] In the first climate change lawsuit against

[27] *See generally* Center for Climate Integrity (13 October 2023) *Cases Underway to Make Climate Polluters Pay*.

[28] *Mun. of Bayamón v. Exxon Mobil Corp*., 3:22-cv-01550, 4–246 (D.P.R., Nov. 22, 2022).

[29] *U.S. v. Philip Morris USA, Inc.*, 449 F.Supp.2d 1, 852 (D.C.C. 2006).

[30] S. Trust, *et al.* (2023) THE EMPEROR'S NEW CLIMATE SCENARIOS: *LIMITATIONS AND ASSUMPTIONS OF COMMONLY USED CLIMATE-CHANGE SCENARIOS IN FINANCIAL SERVICES*, 6.

a commercial bank, *Notre Affaire à Tous v. BNP Paribas* (2023),[31] NGOs filed a summons against a French bank, arguing that BNP failed to comply with the French duty of vigilance law by continuing to fund fossil fuel projects. The law requires companies to establish a plan to prevent the violation of human rights and environmental damage that may occur during business operations. If the plan is inadequate, any citizen can ask for injunctive relief to force the company to comply. The plaintiffs argue that while BNP claims to be committed to staying below the 1.5°C limit, its climate plan is "incomplete, vague and imprecise" and incompatible with international and national climate commitments. The plaintiffs seek a court order to force BNP to comply with its legal climate obligations, terminate new financing of fossil fuel projects, divest from fossil fuel investments, and adopt measures compatible with the 1.5°C guardrail by reducing Scope 1–3 emissions by at least 50% below 2020 levels by 2030, including reducing methane emissions from the energy sector by 64%. This case is ongoing.

II. Challenging the Energy Charter Treaty

In *Soubeste v. Austria* (2022),[32] European youth sued 12 European governments in the European Court of Human Rights for participating in the Energy Charter Treaty (ECT) seeking an order for the governments to exit the treaty. The ECT is an investor protection treaty with an investor-state dispute settlement provision that allows foreign investors to bring claims to binding arbitration tribunals against countries for actions that threaten energy investments, including government actions to phase out or otherwise regulate fossil fuels to comply with Paris targets. The youth plaintiffs assert that these countries' membership under the ECT violates their Paris Agreement commitments and the rights to life and respect for private and family life protected under the European human rights convention. In November 2022, the Court adjourned the case pending the outcome of *Duarte*, *KlimaSeniorinnen*, and *Carême* (discussed *supra*). During the pendency of the case, the Netherlands, Germany, France, and other countries announced their intent to exit the ECT, using similar justifications presented in *Soubeste*.[33]

In related cases, courts in the Netherlands and Germany limited the ability of energy companies to seek compensation under the ECT. In *RWE and Uniper v. The Netherlands*

[31] Tribunal judiciaire de Paris [TJ] [Judicial Court of Paris] Paris, Feb. 23, 2023. (Notre Affaire à Tous v. BNP Paribas) (Fr.).

[32] *Soubeste v. Austria*, 22 EUR. CT. H.R. 39125 (2022).

[33] *Id.*

(2022),[34] the District Court of The Hague, the Netherlands, held that the Dutch government did not have to pay damages to two major energy companies, RWE and Uniper, for the government's planned coal phase-out, stating that the Dutch government's coal ban did not unlawfully infringe on property rights and was foreseeable because the companies failed to take necessary action to meet climate goals.

In *The Netherlands v. RWE and Uniper* (2022),[35] the Higher Regional Court of Cologne, Germany ruled in favor of the Dutch government, which filed an anti-arbitration injunction against RWE and Uniper, and held that their arbitration claims are inadmissible because the ECT arbitration clause is incompatible with European Union (EU) law. After the decision, the German government agreed to nationalize Uniper if it withdrew its pending arbitration claim, which it did in March 2023 as a condition of the €34.5 billion bailout. RWE's ECT arbitration claim is still pending.

3. Incorporating the Need for Speed in Climate Litigation

Given the limited time to bend the warming curve down—somewhere between zero and 10 years before the Paris 1.5°C guardrail is breached—climate litigation is starting to focus on cutting SLCPs, particularly methane, and protecting forests and other carbon sinks, as the only known strategies for slowing warming in the critical near-term. Cutting SLCPs can cut the rate of global warming in half and Arctic warming by two-thirds, and avoid four times more warming at 2050 than cutting CO_2 alone.[36]

A. Cutting Short-Lived Climate Pollutants

In *Gloucester Res. Ltd. v. Minister for Plan.* (2019) ("Rocky Hill"),[37] the Land and Environment Court of New South Wales, Australia, upheld the government's denial of a permit to expand a coal mine, holding that the coal mine was not in the public's interest because it would adversely impact the land, community, and local culture. The plaintiff, the mining company, argued that

[34] RWE AG v. Kingdom of the Netherlands, ICSID Case No. ARB/21/4 (2021); Uniper SE v. Kingdom of the Netherlands, ICSID Case No. ARB/21/22 (2021).

[35] Oberlandesgericht [OLG] [Higher Regional Court] Cologne, Sep. 1, 2022, 19 SchH 14/21 (The Netherlands v. RWE and Uniper) (Ger.).

[36] Dreyfus, *Mitigating climate disruption in time*, 1; United Nations Environment Programme & Climate & Clean Air Coalition (2021) GLOBAL METHANE ASSESSMENT: BENEFITS AND COSTS OF MITIGATING METHANE EMISSIONS, 21.

[37] *Gloucester Res. Ltd. v Minister for Plan.* [2019] NSWLEC 7 (Austl.).

the government gave undue weight to the climate risk posed by the mine, stating that its expected climate emissions were negligible compared to overall global emissions and would occur regardless of whether the project was approved. The Court rejected these arguments because none of the evidence supported the alternative scenario that emissions would sustain or rise in other areas if this project were not approved, and a hypothetical alternative scenario did not justify approving a source that was certain to cause emissions. The Court further explained that the carbon budget was influenced (and reduced) by uncertainties regarding the probability of exceeding temperature thresholds, the impacts of non-CO_2 GHGs such as methane, and the impacts of feedbacks, which could "virtually wipe out" the remaining carbon budget. The Court stated that even if the project only represents a small fraction of global emissions, the global problem of climate change must also be addressed through local actions. The mining company declined to appeal, making this ruling final. This precedent-setting victory influenced subsequent decisions in Australia to reject additional coal mines.

The *Rocky Hill* precedent was cited in another landmark Australian case, *Waratah Coal v. Youth Verdict* (2022),[38] brought by First Nations youths who objected to the approval of a new coal mine. In a 372-page decision, the Land Court of Queensland recommended against the approval of a mining lease and environmental authority to open a new coal mine, relying on the science of tipping points and feedbacks. The Court used the carbon budget, which it identified as "the most robust way to determine the changes in human activity required to meet the aims of the Paris Agreement," to assess the significance of the proposed mine's future impacts. To calculate the remaining carbon budget, the Court chose a climate scenario that would avoid feedback loops and tipping points. While the Land Court's decision in this case was advisory, its lengthy analysis of feedback loops and tipping points is instructive for future cases.

In *McEvoy v. Diversified Energy* (2022),[39] private landowners burdened with abandoned oil and gas wells brought a class action in federal district court in West Virginia against the well owners to enforce plaintiffs' right to have the wells plugged to stop methane emissions and other environmental and health impacts. The plaintiffs assert that the oil and gas companies fraudulently transferred these wells to undercapitalized entities that could not properly decommission the wells. The final pretrial conference is scheduled for April 2024.

[38] Waratah Coal Pty. Ltd. v. Youth Verdict Ltd. & Ors. (No 6) [2022] QLC 21 (Austl.).

[39] McEvoy v. Diversified Energy Co., 2022 WL 17978816 (N.D. W. Va. 2022).

B. PROTECTING CARBON SINKS

Halting the destruction of carbon sinks so they can continue to remove and store carbon is a fast mitigation strategy that also protects biodiversity. Deforestation, combined with accelerating warming, threatens to enhance climate feedbacks and cross ecosystem tipping points. In *Future Generations v. Ministry of the Env't* (2018),[40] the Supreme Court of Colombia ordered the government to immediately create and implement plans to reduce deforestation in the Colombian Amazon as part of its national and international obligations. The plaintiffs are youth activists who filed a *tutela* (a Colombian constitutional claim to protect rights) against several bodies of the Colombian government and corporations to seek a court order to reduce deforestation of the Colombian Amazon to zero. The Court held that the government failed to comply with its climate targets, which threatened the youth plaintiffs' fundamental rights, including the rights to life, health, and freedom, and ordered the government to implement immediate measures.

In *Inst. of Amazonian Stud. v. Brazil* (2020),[41] an environmental NGO (Instituto de Estudos Amazônicos) filed a class action to compel the Brazilian government to comply with its binding national climate law that requires reducing the annual deforestation rate in the Amazon region by 80% by 2020. The plaintiffs seek both an order requiring the Brazilian government to comply with its national climate law and recognition of a new fundamental right to a stable climate for present and future generations. The plaintiffs argue that climate stability is a necessary precondition of the preservation of fundamental rights provided by the Brazilian Constitution, and the Brazilian government's neglect of its obligations to reduce and control deforestation in the Amazon violates this implicit duty. This case is ongoing.

Protecting carbon sinks also requires stopping bioenergy—burning trees and biomass for energy— which is sometimes incorrectly categorized as a "renewable" source of energy, even though it reduces carbon sinks and immediately releases CO_2 and black carbon when biomass

[40] Corte Suprema de Justicia [C.S.J.] [Supreme Court], Civil. abril 5, 2018, M.P. L. A. T. Villabona, STC4360-2018, No. 11001-22-03-000-2018-00319-01 (Future Generations v. Ministry of the Env.) (Colom.).

[41] TRF-4, Agravo de Instrumento No. 5033746-81.2021.4.04.0000/PR, Relatora: Desa. Vânia Hack de Almeida, 13.12.2021, 108, Revista do Tribunal Regional Federal da 4a Região [R.T.R.F.], 27.04.2022, 81 (Instituto de Estudos Amazônicos v. União) (Braz.).

is burned.[42] In *Robin Wood v. European Commission* (2022),[43] NGOs filed an annulment action with the EU Court of Justice to block the European Commission's categorization of forest bioenergy as sustainable under the Sustainable Finance Taxonomy. This action was spurred when the European Commission rejected the NGOs' prior formal request for internal review of their criteria of "sustainable" industries. Currently, it classifies bioenergy as an activity that "contribute substantially to climate change mitigation or adaptation."[44] If successful, it would allow EU countries to redirect subsidies and investments into energy sources that are legitimately renewable.

In *In re Application of Hawai'i Electric Light Co., Inc.* (2023),[45] Hawai'i's Supreme Court upheld the rejection of a power purchase agreement between an electric utility company and a biomass power plant projected to emit over 8 million metric tons of carbon over the next 30 years with a speculative tree-planting offset plan that would leave a carbon deficit until 2047. The unanimous Court held that the right to a clean and healthy environment under the Hawaiian Constitution includes the right to a "life-sustaining climate system." The concurrence by Justice Wilson added that the right to a life-sustaining climate system is also embedded in both the Hawaiian Constitution's due process right to "life, liberty, and property" and in the public trust doctrine. He concluded that, "Given the climate emergency, and the need to limit atmospheric CO_2 concentrations to below 350 ppm in order to leave Hawai'i's future generations a habitable earth ... the State of Hawai'i is constitutionally mandated to urgently reduce its [GHG] emissions in order to reduce atmospheric CO_2 concentrations to below 350 ppm."

C. Ensuring Intergenerational Climate Justice

The planet is currently warming at an unprecedented rate and is likely to reach 1.5°C of warming above pre-industrial levels by the early 2030s absent immediate and aggressive

[42] L. Bloomer, *et al.* (2022) *A Call to Stop Burning Trees in the Name of Climate Mitigation*, VT. J. ENVT'L. LAW 23, 94; M. S. Booth (2018) *Not Carbon Neutral: Assessing the Net Emissions Impact of Residues Burned for Bioenergy*, ENVIRON. RES. LETT. 13(3), 8; J. D. Sterman, L. Siegel, & J. N. Rooney-Varga (2018) *Does Replacing Coal with Wood Lower CO2 Emissions? Dynamic Lifecycle Analysis of Wood Bioenergy*, ENVIRON. RES. LETT. 13, 8.

[43] *Robin Wood v. European Commission*, 2022 O.J. (C482).

[44] EU Technical Expert Group on Sustainable Finance (2020) TAXONOMY: FINAL REPORT OF THE TECHNICAL EXPERT GROUP ON SUSTAINABLE FINANCE, European Commission, 60 (Table 5.2).

[45] See In the Matter of the Application of Hawai'i Electric Light Company, Inc. For Approval of a Power Purchase Agreement for Renewable Dispatchable Firm Energy & Capacity, No. SCOT-22-0000418, 2023 WL 2471890 (Haw. Mar. 13, 2023), 2472050 (Wilson, J., concurring).

action.[46] Dr. James Hansen and his colleagues have warned of a short-term climate shock after calculating that the planet may be locked into 1.5°C this year, and 2°C by 2050 under current policies.[47] Today's current warming of 1.2°C is already violating the rights of future generations, and exceeding the 1.5°C guardrail would fail to secure intergenerational climate justice and result in human rights violations, particularly for children, the youth, and future generations.

As the *Urgenda* case noted, "any postponement of the reduction of emissions therefore means that emissions in the future will have to be reduced on an increasingly large scale in order to make up for the postponement," which will have to be "increasingly far-reaching" and likely to be "riskier."[48] According to the *Urgenda* court, the duty of the State "to take preventive measures to counter the danger [of climate change impacts], even if the materialization of that danger is uncertain"[49] is consistent with the precautionary principle, which "therefore requires that more far- reaching measures should be taken to reduce greenhouse gas emissions, rather than less far- reaching measures."[50]

Young people are increasingly going to the courts to demand action to ensure planetary stability. According to the Sabin Center, 34 climate cases have been brought by and on behalf of children and youth, which generally focus on: "(i) insufficient efforts to reduce carbon emissions and meet climate commitments, (ii) insufficient efforts to implement mitigation and adaptation measures and (iii) specific regulatory approvals that are expected to have dramatic climate impacts."[51]

Recent wins, including in Germany and the U.S., have marked a potential tide turning for youth climate litigants.

[46] IPCC, CLIMATE CHANGE 2021, 42; Diffenbaugh, Data-driven predictions of the time remaining, 2; Xu, Global warming will happen faster than we think, 3.

[47] Hansen, *Global warming in the pipeline*, 39; Hansen, *El Nino Fizzles. Planet Earth Sizzles. Why?*.

[48] Urgenda v. The Netherlands, ¶ 7.4.3.

[49] *Id.*, ¶ 5.3.2.

[50] *Id.*, ¶ 7.2.10.

[51] United Nations Environment Programme (2023) GLOBAL CLIMATE LITIGATION REPORT: 2023 STATUS REVIEW, 40.

In *Neubauer v. Germany* (2021),[52] the Federal Constitutional Court of Germany ruled in favor of youth plaintiffs who argued that the State's Federal Climate Protection Act was insufficient to protect their fundamental rights under German Basic Law, which imposes a constitutional obligation of the State to take action on climate. The Act stipulated a 55% reduction in GHG emissions below 1990 levels by 2030 and directed the legislature to update annual emission reduction amounts in 2025 for the period of 2031 and beyond. The Court held that the German law obliged the State to safeguard fundamental freedoms across time and ensure that the opportunities associated with fundamental freedoms are shared proportionately across generations. Relying on the science of carbon budgets and discussing the increased future risks posed by tipping point dynamics, the Court found that the climate law failed to fairly distribute the remaining budget between current and future generations, which allowed the current generation to consume a greater portion of the remaining carbon budget with less mitigation effort while placing a disproportionate risk and burden on future generations. The Court ordered the government to outline specific and clear emissions targets for the period beyond 2031 by the end of 2022 to "avoid future freedom being curtailed suddenly, radically and with no alternatives." In response to the decision, the German government amended the emissions reduction requirement in the federal climate act to 65% below 1990 levels by 2030.

Recently, in *Held v. State* (2023),[53] Judge Seeley of the First Judicial Court of Montana ruled in favor of the youth plaintiffs, holding that the state of Montana violated the plaintiff's constitutional rights. In 2020, 16 Montanan youth filed a complaint for declaratory and injunctive relief against the state of Montana and its environmental regulatory agencies, alleging that the State's fossil fuel- based energy system violates their constitutional rights. In August 2023, in a 103-paged decision,[54] Judge Seeley found that the 2023 update to the Montana Environmental Policy Act and Montana's State Energy Policy Act violated the plaintiff's rights to a clean and healthful environment and right to relief protected by Montana's state Constitution. Further, Judge Seeley held that this right to a clean and healthful environment is complemented by an affirmative duty by the state government to take active steps to realize this right, which requires reducing GHG emissions that contribute to and

[52] *Bundesverfassungsgericht* [BverfG] [Federal Constitutional Court] 1 BvR 2656/18, Mar. 24, 2021 (*Neubauer v. Germany*) (Ger.)

[53] *Held v. State*, CDV-2020-307 (1st Dist. Ct. Mont., Aug. 14, 2023).

[54] *Id.*, 94-96.

exacerbate global warming, and providing adequate environmental impact assessments that analyzes the scope and scale of fossil fuel projects' impacts to the environment.

In her detailed "Findings of Fact," Judge Seeley correctly identified the Earth's energy imbalance—"the difference in energy from sun arriving at the Earth and the amount radiated back to space"—as the "most critical scientific metric" for determining the amount of global heating and climate change we have already experienced and will continue to experience, confirming the "scientific certainty" that Earth's energy imbalance, caused primarily by carbon dioxide from fossil fuel pollution as well as methane, will further warm the Earth and exacerbate warming impacts.[55] Further, she notes that "each additional ton of [GHGs] ... exacerbates impacts to the climate ... [and] the long-term severity of the heating and the severity of Plaintiff's injuries ..." and "risks locking in irreversible climate injuries."[56] Without immediate climate action, the injuries will become "increasingly severe and irreversible," and disproportionately impact children and youth. This is caused and contributed by Montana's GHG emissions, which "can be measured incrementally and cumulatively," both locally and globally.[57]

4. Advisory Opinions and the Growing Power of Courts

As the planet approaches the 1.5°C guardrail within the next ten years or less, lawyers are becoming more aggressive in using the law to enforce strong and fast climate action. Legal theories to protect the climate, particularly in the critical near-term, continue to evolve, including by reinforcing legal principles like the precautionary principle, and introducing new principles such as just energy transition, loss of chance of survival, and ecocide.

Additionally, advisory opinions (AOs)—generally non-binding court analyses that interpret broadly applicable questions of law—are being used to strengthen climate law.[58] In December 2022, the Commission of Small Island States on Climate Change asked the International Tribunal for the Law of the Sea to issue an AO on States' responsibilities regarding climate

[55] *Id.*, 22-23.

[56] *Id.*, 24.

[57] *Id.*, 88.

[58] D. Zaelke & J. Cameron (1990) *Global Warming and Climate Change - An Overview of the International Legal Process*, AM. U.J. INT'L L. & POL'Y 5(2).

change's effects on coastal communities and the marine environment.[59] In January 2023, the Governments of Chile and Colombia submitted a joint request for an AO from the Inter-American Court of Human Rights under the American Convention on Human Rights on States' duties under human rights law to protect present and future generations from the effects of climate change.[60] In March 2023, after a campaign led by Vanuatu, island nations, and youth organizations,[61] the United Nations General Assembly adopted by consensus a draft resolution requesting an International Court of Justice AO on climate change and human rights.[62]

The Inter-American Court previously issued a significant Advisory Opinion in 2017 for protecting the environment.[63] As the Sabin Center notes, this AO "opened the door for rights-based climate litigation through the recognition of States' responsibilities for transboundary harms (including climate change-related harms) and the precautionary principle."[64] AOs that address the climate crisis as a human rights issue can support and strengthen climate litigation by endorsing the best available climate science and clarifying legal principles that can strengthen climate protection, including for vulnerable groups. This provides a way for civil society, especially young people, to hold their governments and corporations accountable for climate inaction.

The cases discussed in this paper show climate litigation trends that promote accountability as scientific findings and continuing discoveries of oil companies' historic deception strengthen the evidence base for future litigation.[65] While the legal system is often a slow solution to the fast- moving problem of a planet that is already too warm, courts can provide enforceable

[59] Commission of Small Island States on Climate Change and International Law (12 December 2022) Request for Advisory Opinion; International Tribunal for the Law of the Sea (15 February 2023) Request for an Advisory Opinion Submitted by the Commission of Small Island States on Climate Change and International Law, Case No. 31.

[60] Republics of Colombia & Chile (9 January 2023) Request for an advisory opinion on the Climate Emergency and Human Rights submitted to the Inter-American Court of Human Rights by the Republic of Colombia and the Republic of Chile.

[61] See Pacific Island Students Fighting Climate Change and World's Youth for Climate Justice.

[62] United Nations (29 March 2023) General Assembly Adopts Resolution Requesting International Court of Justice Provide Advisory Opinion on States' Obligations Concerning Climate Change, Meetings Coverage, General Assembly 12497; United Nations General Assembly (1 March 2023) Request for an advisory opinion of the International Court of Justice on the obligations of States in respect of climate change, A/77/L.58.

[63] The Environment and Human Rights, Advisory Opinion OC-23/17, Inter-Am. Ct.H.R. (ser. A) (Nov 15, 2017).

[64] M. A. Tigre, N. Urzola, & J. S. Castellanos (17 February 2023) *A Request for an Advisory Opinion at the Inter-American Court of Human Rights: Initial Reactions*, SABIN CENTER FOR CLIMATE CHANGE LAW.

[65] *Supra* notes 9, 13, 14.

solutions that support longer-term climate justice and can sometimes deliver the fast mitigation needed to reduce near-term warming and keep the planet safe while ensuring a fast and just energy transition.

Timely Judicial Recognition and Protection of Climate Rights

Mike Wilson[1]

1. Timely Judicial Recognition and Protection of Climate Rights

A judge is meant to be an instrument of justice. Equally apparent is the principle that the rule of law is the force by which judges are meant to achieve justice. Yet, it is beyond cavil that historically injustice arising from privilege has proven to be an intractable impediment to the just application of the rule of law by judges. Men and women vying to be judges once selected may be ill-equipped to exercise the independence necessary to apply the rule of law to end systematic injustice caused by powerful special interests. Evidently, time is often needed for the rule of law to catch up to injustice. The premise of this article is that the climate emergency upends the historically gradual evolution of the rule of law to address injustice. Faced with the climate emergency, judges have little time – perhaps seven years – to apply the rule of law to protect the rights of citizens, to a life sustaining climate. Absent unprecedented judicial independence, climate injustice will persist, worsen and cause the erosion of the rule of law as cascading environmental catastrophe ensues. The greatest intergenerational injustice in history, the knowing destruction of a life-sustaining climate, is now before the world judiciary.

2. Historical Delay of Justice by Courts

Historically, courts have delayed justice during pivotal periods in our Nation's history. During the agricultural era the buying and selling of human beings so central to the agricultural economy was found to be constitutional. During the industrial era – when child labor was deemed essential to manufacturing – regulation of working conditions of children was found to be unconstitutional. The refusal of male judges to initially recognize the right of women to vote is well-known. Eventually, the failure of judges to apply the rule of law justly gave way to a more authentic application of principles of equal protection, due process and social justice, requiring a diminution of the unjust privilege of those interests who benefitted from slavery, child labor and disenfranchisement of women.

[1] Justice of the Supreme Court of Hawaiʻi.

The most difficult contemporary issue now faced by the world judiciary is the greatest intergenerational injustice in human history: the knowing violation of the right of future generations to a life-sustaining climate.

3. Threat to Survival from Violation of Environmental Rule of Law

The uncontested clarion call of impending environmental disaster issued by all but two of the countries of the world at the 2015 Paris Agreement has gone unheeded. The declaration of 193 States plus the European Union that the environmental collapse constituting an existential threat to the survival of humanity will likely occur if global warming since preindustrial times reaches 1.5°C has proven prophetic. Global warming to the present already-dangerous level of about 1.2°C evinces a failure to heed the dire warning of the United Nations' Intergovernmental Panel on Climate Change in 2015. Now the emergency is upon us with the highest level of atmospheric CO_2 levels in at least the last 2 million years and likely the last 3 million years. At present, about 420 ppm of CO_2 is in the atmosphere, 70 ppm more than the global planetary safe boundary of 350 ppm, which is the CO_2 target to prevent global warming above 1°C. Global CO_2 emissions from fossil fuels were 63 per cent higher in 2021 than they were when international climate negotiations began in 1990. At present levels of greenhouse gas emissions, global warming will reach 1.5°C in approximately ten years. As the secretary general of the United Nations warned in December of 2021, the devastation to human culture wrought by global warming to 1.5°C will far exceed the human suffering and economic disaster caused by the COVID 19 pandemic. Secretary General Guterres identified climate change as the single greatest threat to the natural environment and human societies that "the world has ever experienced."[2] At the most recent United Nations climate convention in November 2022, Secretary General Guterres warned the gathering of more than 100 princes, presidents, and prime ministers that "we are on a highway to climate hell with our foot on the accelerator."[3]

The hell posed by 1.5°C global warming will soon be worsened. Based on current policies in place, the planet is projected to warm to 2.6 to 2.9°C this century (most likely 2.7°C); if pledged emission reductions are considered, this warming reduces to about 2.4°C. By the end of the century, at present rates of greenhouse gas emissions, the atmosphere of Earth will heat to

[2] U.N. Secretary-General, Promotion and Protection of Human Rights in the Context of Climate Change, ¶ 1, U.N. Doc. A/77/226 (July 26, 2022).

[3] United Nations, *Secretary-General's remarks to High-Level opening of COP27* (Nov. 7, 2022).

4.8°C.[4] The effect of 4.8°C warming will be collapse of the rule of law, the end of the global economy and significant depopulation.

The audience reading this article will know that the heating of the Earth from growing anthropogenic release of greenhouse emissions is already causing environmental catastrophe—catastrophic fires in the western United States, Canada, Europe, the high Arctic and Australia; catastrophic heating of the ocean to over 100°F (37.8°C) in Florida; coral reefs are undergoing unprecedented bleaching this summer from Florida to Colombia; atmospheric and oceanic heatwaves are occurring more frequently at intensities that would be impossible without human- caused global heating, with attendant human deaths and marine die-offs; catastrophic rain constituting "water bombs" with enormous destructive force, for example requiring one year of rebuilding of the north side of the island of Kaua'i; catastrophic flooding of New York City during hurricane Sandy; unprecedented lethal heat in Phoenix to above 115°F (46.1°C); catastrophic flooding of a third of Pakistan; impending catastrophic displacement of virtually the entire population of the countries of Tuvalu and Kiribati from sea-level rise; catastrophic disappearance of glaciers and the loss of water resources in mountains around the world; catastrophic death to exponentially increasing numbers of poor children who are unable to escape the heating of the atmosphere to sustained lethal temperatures over 100 degrees and the flooding of their homes. Most recently, global warming contributed to the complete elimination by fire of one of my community's major cities, Lahaina, when wildfires raged into the city. Over one hundred people were killed, and thousands of buildings destroyed. The role that human greenhouse gas emissions played in this disaster is still being assessed.

As Justice Antonio Benjamin of the National Judicial Tribunal of Brazil has stated, climate change is the single most important issue facing the judges of the world. The failure of traditional international, national and subnational governance systems and the private sector to protect future generations from climate destruction is reminiscent of past failures to prevent systematic widespread injustice. Young people today and the future generations they represent are treading the path worn before them by slaves, children exploited in factories, oppressed women and so many others who have sought to apply the rule of law to systematic widespread injustice. It is a path fraught with opposition from formidable private economic entities – the fossil fuel energy industry, its lobbyists and its array of extraordinarily well-compensated lawyers. International Energy Agency (IEA) Executive Director Fatih Birol says

[4] U.S. Global Change Research Program, FOURTH NATIONAL CLIMATE ASSESSMENT, Vol. I, Chapter 6 (2017).

the energy industry as a whole made $4 trillion in profits in 2022, more than double its recent annual average of $1.5 trillion.[5] US oil producers have made more than $200 billion in profits since Russia's invasion of Ukraine. Within the span of one year, 2021 to 2022, the five Big Oil companies – ExxonMobil, Chevron, Shell, BP, and TotalEnergies – more than doubled their profits.[6] Securing a total profit of $59.2 billion, U.S. oil giant ExxonMobil recorded the highest total. In 2021, the company's profits were $23 billion or less than half of 2022's profits. ExxonMobil was joined by Chevron, whose profits rose by over 134% to $36.5 billion, and Shell, whose profit of $39.9 billion was the highest in the company's 115-year history.[7] Four oil companies (Chevron, ConocoPhillips, Exxon and Shell) had total sales of approximately $1 trillion dollars in 2022. "A sum greater than the total economic output of Colombia, South Africa or Switzerland."[8]

Amid its year of record profit, the oil and gas industry spent $124.4 million on federal lobbying.[9] And this investment has been extraordinarily successful. According to the International Energy Agency, fossil fuel subsidies hit a global high of $1 trillion in 2022—the same year Big Oil pulled in a record $4 trillion of income. In the United States, by some estimates taxpayers pay about $20 billion dollars every year to the fossil fuel industry.[10]

With billions in profits, hundreds of millions of dollars in government subsidies and a cadre of helpful scientists, the energy industry and its partners in the financial management industry constitute a mighty opposition to the community of young people and municipalities in the United States that seek application of the rule of law to protect themselves from the knowing destruction of the environment upon which their future depends.

The resort of future generations and indigenous people to the federal courts of the United States for redress from entities that violate their right to a life-sustaining climate has been

[5] O. Rosane, *Oil and Gas Sector Made $4 Trillion in Profits in 2022, IEA Chief Says*, ECOWATCH (Feb. 16, 2023).

[6] G. Bhutada, Ranked: The Largest Oil and Gas Companies in the World, VISUAL CAPITALIST (Oct. 25, 2021).

[7] V. Sharma, *Big Oil Profits Reached Record High Levels in 2022*, VISUAL CAPITALIST (Apr. 26, 2023); J. Desjardins, *Becoming Big Oil: How the 10 Largest Oil Companies Were Born*, VISUAL CAPITALIST (Nov. 30, 2015).

[8] I. Ivanova, *4 oil companies had total sales of $1 trillion last year*, CBS NEWS (Feb. 2, 2023).

[9] I. Sayki & J. Cloutier, *Oil and gas industry spent $124.4 million on federal lobbying amid record profits in 2022*, OPEN SECRETS (Feb. 22, 2023).

[10] U.S. Committee on the Budget, Sen. Whitehouse on Fossil Fuel Subsidies: "We are Subsidizing the Danger", (Mar. 5, 2023).

largely rejected. Unlike jurisdictions in other countries whose courts apply the rule of law to claims seeking protection from knowing environmental damage to a life-sustaining environment,[11] the federal courts of the United States have thus far abdicated responsibility to apply the rule of law to claims that alleged knowing contamination of the atmosphere with deleterious levels of greenhouse gas emissions in violation of the constitutional right to a life-sustaining climate. One of the most prominent examples of a federal court abdicating its responsibility to leave future generations a habitable planet is the Ninth Circuit's reversal of the District Court of Oregon's decision recognizing that youth plaintiffs have a substantive due process right to a stable climate capable of supporting human life.[12] In a decision consistent with the application of the environmental rule of law to climate claims in other countries, the United States District Court for the District of Oregon aptly explained how "[f]ederal courts too often have been cautious and overly deferential in the arena of environmental law, and the world has suffered for it."[13] The concern of the District Court proved prescient when it was reversed by the Ninth Circuit Court of Appeals. In *Juliana v. United States*, two of the three members of the Ninth Circuit Court of Appeals panel dismissed the youth plaintiffs due process and public trust claims against the federal government based on the proposition that Plaintiffs have no standing because the application of certain remedies to the climate crisis would be too complex for judicial decision-making.[14] In a cavalier aside, the majority acknowledged the existential threat facing the youth plaintiffs caused by the United States government:

> "In the mid-1960s, a popular song warned that we were "on the eve of destruction." The plaintiffs in this case have presented compelling evidence that climate change has brought that eve nearer. A substantial evidentiary record documents that the federal

[11] *See, e.g.*, Hof's-Hague, 9 October 2018, RvdW 2018, 13-1396 m.nt. DGJ (Urgenda Foundation/State of the Netherlands, Ministry of Infrastructure and the Environment) (Neth.) (ordering the Dutch government to limit greenhouse gas emissions to 25% below 1990 levels by 2020, finding that "[d]ue to the severity of the consequences of climate change and the great risk of hazardous climate change occurring – without mitigation measures – the court concludes that the State has a duty of care to take mitigation measures"); Ashgar Leghari v. Federation of Pakistan, (2015) W.P. No. 25501/2015, 10 (Pak.) (where a farmer sued the Pakistani national government for failure to reduce greenhouse gas emissions, the court determined that "the delay and lethargy of the State in implementing [its climate] Framework offend[ed] the fundamental rights of the citizens."); Gloucester Res. Ltd. V. Minister for Planning, [2019] NSWLEC 7 (Austl.) (upholding the denial of an application to construct a coal mine, noting that the climate change impacts of the project outweigh its economic benefits).

[12] *Juliana v. United States*, 217 f. supp 3d 1224 (dis. or. 2016), rev'd and remanded, 947 f.3d 1159 (9th cir. 2020).

[13] *Id.* at 1262.

[14] *Juliana v. United States*, 947 F.3d 1159 (9th Cir. 2019), at 1171 ("it is beyond the power of an Article III court to order, design, supervise, or implement the plaintiffs' requested remedial plan" which would require a "comprehensive scheme to decrease fossil fuel emissions and combat climate change.").

government has long promoted fossil fuel use despite knowing that it can cause catastrophic climate change, and that failure to change existing policy may hasten an environmental apocalypse."[15]

In a formidable dissent, Judge Josephine Staton took to task the majority's supposition that youth plaintiffs are barred from bringing claims against the United States for knowingly threatening their substantive due process right to a stable climate capable of supporting human life.[16] As Judge Staton explained, claims vindicating the right to a life-sustaining climate system are redressable by courts; a remedial plan requiring the government to reduce greenhouse gas emissions in an amount necessary to ensure a stable climate system is not a remedy that defies judicial decision making so as to render it nonjusticiable:

> "Our history is no stranger to widespread, programmatic changes in government functions ushered in by the judiciary's commitment to requiring adherence to the Constitution. Upholding the Constitution's prohibition on cruel and unusual punishment, for example, the Court ordered the overhaul of prisons in the Nation's most populous state. [citing *Brown v. Plata*, 563 U.S. 493 (2011)] And in its finest hour, the Court mandated the racial integration of every public school – state and federal – in the Nation, vindicating the Constitution's guarantee of equal protection under the law. [citing *Brown v. Bd. of Educ. (Brown I)*, 347 U.S. 483 (1954); *Bolling v. Sharpe*, 347 U.S. 497 (1954)] In the school desegregation cases, the Supreme Court was explicitly unconcerned with the fact that crafting relief would require individualized review of thousands of state and local policies that facilitated segregation. Rather, a unanimous Court held that the judiciary could work to dissemble segregation over time while remaining cognizant of the many public interests at stake …
>
> …
>
> Plaintiffs' request for a "plan" [in the instant case] is neither novel nor judicially incognizable. Rather, consistent with our historical practices, their request is a

[15] *Id.* at 1164.

[16] Judge Staton described the climate emergency in detail: "What sets this harm apart from all others is not just its magnitude, but its irreversibility. The devastation might look and feel somewhat different if future generations could simply pick up the pieces and restore the Nation. But plaintiffs' experts speak of a certain level of global warming as "locking in" this catastrophic damage. Put more starkly by plaintiffs' expert, Dr. Harold R. Wanless, "[a]tmospheric warming will continue for some 30 years after we stop putting more greenhouse gasses into the atmosphere. But that warmed atmosphere will continue warming the ocean for centuries, and the accumulating heat in the oceans will persist for millennia[.]"" *Juliana*, 947 F.3d at 1176 (Staton, J., dissenting).

recognition that remedying decades of institutionalized violations may take some time. Here, too, decelerating from our path toward cataclysm will undoubtedly require "elimination of a variety of obstacles." Those obstacles may be great in number, novelty, and magnitude, but there is no indication that they are devoid of discernable standards."[17]

The remedy for violation of the right to a stable climate capable of supporting human life is discreet: to reduce greenhouse gas emissions. In comparison, desegregating the schools of the United States is a significantly more complex remedial undertaking.

A request by the Juliana youth plaintiffs for a full *en banc* review of the two-judge Majority provided a further example of the hostile reception of the federal courts to climate claims. The plaintiffs' request to the largest federal circuit in the United States for an *en banc* hearing was denied.[18] Notwithstanding its status as the signature climate case in the United States,[19] and the compelling dissent of Judge Staton, the Ninth Circuit Court of Appeals provided no opinion as to why an issue recognized by all three members of the *Juliana* panel as an existential "problem approaching 'the point of no return'",[20] lacked the importance necessary to gain the consideration of an *en banc* panel of Ninth Circuit appellate judges.[21] The Ninth Circuit sent a clear message to young people and future generations who seek protection from knowing environmental damage to a life- sustaining environment: they have no standing to seek redress in the federal courts of the United States. Review of the *Juliana* Ninth Circuit oral argument was mandatory for all my law clerks and legal externs. It is a formidable, disturbing message to all men and women who seek application of the rule of law in federal court to protect future generations from wanton destruction of a life-sustaining environment by the federal government.

Another recent example of federal courts refusing the application of statutorily based environmental rule of law to climate claims is the majority opinion of the United States Supreme Court in *West Virginia vs. EPA*.[22] The majority deprived the federal Environmental Protection

[17] *Juliana*, 947 F.3d at 1188-89 (Staton, J., dissenting).

[18] *Juliana v. United States*, 986 F.3d 1295 (9th Cir., Feb 10., 2021) (order denying petition for rehearing *en banc*).

[19] R. Meyer, *A Climate-Lawsuit Dissent That Changed My Mind*, THE ATLANTIC (Jan. 22, 2020).

[20] *Juliana*, 947 F.3d at 1166.

[21] *Juliana*, 986 F.3d at 1296.

[22] *West Virginia vs. EPA*, 124 S. Ct. 2587, 213 L. Ed. 2d 896 (2022).

Agency of "the power needed – and the power granted – to curb greenhouse gases" from power plants. As the dissent explained: "the Court today prevents congressionally authorized agency action to curb power plants' carbon dioxide emissions ... I cannot think of many things more frightening."[23] No doubt, the future posture of the United States Supreme Court majority on claims for redress of constitutional and statutory climate rights violations is frightening to those who seek protection in federal court.

Thus, it is apparent that "the modern [federal] judiciary has enfeebled itself to the point that law enforcement can rarely be accomplished by taking environmental predators to court."[24] The stark failure of the federal judiciary to grant redress to present and future generations alleging knowing destruction of a life-sustaining climate system relegates implementation of the climate rule of law to state judiciaries.[25]

Unlike the Juliana majority, the Hawai'i State Supreme Court does not, in the words of Judge Staton, choose to "throw up [our] hands."[26] In contrast to the federal judiciary, the Hawai'i Supreme Court has recognized the constitutional right to a life- sustaining climate.[27]

But this not the only basis for recognizing such a right under the Hawai'i Constitution. The right to a life-sustaining climate system is also guaranteed by the due process clause of Article I, section 5 of the Hawai'i Constitution. The due process clause of Article I, section 5 of the Hawai'i Constitution guarantees that the State will not deprive a person of "life, liberty or property without due process of law[.]" Article I, section 5 of the Hawai'i Constitution protects both procedural and substantive due process rights.[28] Substantive due process safeguards

[23] *Id.*, 142 S. Ct. at 2828 (Kagan, J., dissenting).

[24] A. T. Goodwin, *A Wake Up Call for Judges*, 2015 WIS. L. REV. 785, 785-86, 788 (2015) (*citing* Mary Christina Wood, Nature's Trust: Environmental Law for a New Ecological Age (2014)).

[25] *See Juliana*, 217 F.Supp.3d at 1262 (D. Or. 2016) ("The current state of affairs ... reveals a wholesale failure of the legal system to protect humanity") (citations and quotations omitted), rev'd and remanded, 947 F.3d at 1159.

[26] See *Juliana*, 947 F.3d at 1174 (Staton, J., dissenting); *see also*, *Aji P v. State of Washington*, 497 P.3d 350, 353 (Wash. 2021) (Gonzalez, J., dissenting) ("The court should not avoid its constitutional obligations that protect not only the rights of these youths but all future generations who will suffer from the consequences of climate change.").

[27] *MECO*, 150 Hawai'i 528, 538, n.15 (2022), on the strength of Article 9 of the Hawai'i Constitution, empowering the State to protect a healthy environment.

[28] *See, e.g.*, *KNG Corp. v. Kim*, 107 Hawai'i 73, 82, 110 P.3d 397, 406 (2005).

fundamental rights which are “implicit in the concept of ordered liberty.”[29] The identification and protection of fundamental due process rights is inherent in the judicial duty of all judges of the State of Hawai‘i.[30] Fundamental rights that are implicit in the concept of ordered liberty can be enumerated or unenumerated in the Constitution.[31] In other words, “[t]he genius of the [c]onstitution is that its text allows future generations [to] protect...the right of all persons to enjoy liberty as we learn its meaning.”[32] Determination of whether a right is protected by substantive due process requires inquiry into whether the right “is so rooted in the traditions and collective conscience of our people that failure to recognize it would violate fundamental principles of liberty and justice that lie at the base of all our civil and political institutions.”[33] It is beyond cavil that a life-sustaining climate system is implicit in the concept of ordered liberty and lies “at the base of all our civil and political institutions.”[34] Indeed, a stable climate is the foundation upon which society and civilization exist in Hawai‘i and throughout the globe.[35]

Recently, the Montana First Judicial District Court affirmed Montana’s commitment to safeguard and ensure youth-plaintiffs’ fundamental constitutional right to a clean and healthful environment – which includes climate as part of the environmental life-support system – and therefore their dignity, health and safety, equal protection of the law, and their very liberty.[36] The Court held unconstitutional state laws precluding state consideration of the effects of fossil fuel emissions from proposed fossil fuel projects. It found that the statutes failed to provide

[29] *In the Interest of Doe*, 99 Hawai‘i 522, 533, n.14 (2002) (quoting *Washington v. Glucksberg*, 521 U.S. 702, 720–21 (1997)).

[30] *See, e.g.*, *State v. Quino*, 74 Haw. 161, 177, 840 P.2d 358 (1992) (Levinson, J., concurring) (“[A]s the ultimate judicial tribunal in this state, this court has final, unreviewable authority to interpret and enforce the Hawai‘i Constitution.”) (internal quotations and citations omitted).

[31] *See, e.g.*, *State v. Abellano*, 50 Haw. 384, 391–93 (1968) (Levinson, J., concurring) (explaining that the Constitution protects unenumerated rights because “[i]t is fundamental error to argue that the framers believed their subjective intentions were to control the construction of the Constitution in the centuries to come.”).

[32] *Juliana*, 217 F. Supp 3d at 1249 (D. Or. 2016) (quoting *Obergefell v. Hodges*, 135 S. Ct. 2584, 2598 (2015)), rev’d and remanded, 947 F.3d 1159 (9th Cir. 2020).

[33] *KNG Corp.*, 107 Hawai‘i at 82 (internal citations and quotations omitted); see also, *Baehr v. Lewin*, 74 Haw. 530, 556 (1993) (internal citations and quotations omitted).

[34] *Id.*

[35] *See Minors Oposa v. Sec’y of the Dep’t of Envt’l & Ntural Res.*, G.R. No. 10183, 33 I.L.M. 173, 187-88 (Jul 30, 1993) (Phil.) (“[U]nless the rights to a balanced and healthful ecology ... are mandated as state policies ... the day would not be too far when all else would be lost not only for the present generation, but also for those to come—generations which stand to inherit nothing but parched earth[.]”).

[36] *Held v. Montana*, No. CDV-2020-307, slip op. at 91, 97–98, 102–3 (Mont. First Judicial Dist. Ct Aug. 14, 2023).

“adequate remedies for protection of the environmental life support system from degradation”. As with the Hawaii Constitution, the Montana Constitution guarantees the right to a life-sustaining climate system, and the courts are tasked with animating that guarantee. The Court noted the judiciary’s vital role in enforcing constitutional rights: “This judgment will influence the State’s conduct by invalidating statutes prohibiting analysis and remedies based on GHG emissions and climate impacts, alleviating Youth Plaintiffs’ injuries and preventing further injury.”[37] Moreover, any “reduction in Montana’s GHG emissions that results from a declaration . . . would provide partial redress of Plaintiffs’ injuries because the amount of additional GHG emissions emitted into the climate system today . . . will impact the long-term severity of the heating and the severity of Plaintiffs’ injuries. ... It is possible to affect future degradation to Montana’s environment and natural resources and injuries to these Plaintiffs.”[38] The Court found that “every ton of carbon dioxide matters” and every ton avoided will help alleviate the climate crisis. The U.S. EPA, a defendant in the *Juliana* litigation, responded with approval to the *Held v. Montana* ruling: “[It] sets a precedent for intergenerational accountability and environmental justice, ensuring that the decisions made today positively impact the well-being of tomorrow’s generations.”[39]

Without an “effective response to climate change” that prevents catastrophic climate change impacts, “the integrity of the rule of law” itself is subject to collapse.[40] The effects of failing to reduce atmospheric CO_2 concentrations to below 350 ppm will lead to “social, political and economic chaos, and in that chaos[,] the rule of law cannot survive.”[41] Thus, the due process clause of Article I, section 5, which protects against the deprivation of life, liberty and property, requires the State of Hawai‘i to act to ensure that there is a life-sustaining climate system capable of supporting the health and survival of Hawai‘i’s people and the rule of law itself.

[37] *Id.* at 101:1-4.

[38] *Id.* at 89:10-15, 16-17.

[39] *See* Attachment 2, *EPA Statement on Montana Court Ruling in Favor of Youth and their constitutional right to a healthful environment* (last visited Aug. 21, 2023).

[40] Cinnamon P. Carlarne, U.S. Climate Change Law: A decade of Flux and an Uncertain Future, 69 AM.U.L.REV. 387, 477 (Dec. 2019).

[41] T. Burke, *Rule of law and climate change* (June 30, 2021); Supreme Court judge Francois Kunc, Australian Financial Review (Oct. 11, 2018) (“At its worst, inadequately mitigated climate change could undo our social order and the rule of law itself ... It is no longer either difficult or alarmist to imagine a day when, in extremis, the defen[s]e, external affairs and immigration powers of the Commonwealth [of Australia] are invoked to support measures not seen since World War II to deal with the social, political, economic and physical effects of climate change.”).

The conclusion that the due process right to "life, liberty [and] property" under Article I, section 5 subsumes the right to a life-sustaining climate is supported by the fact that a life-sustaining climate system underlies all other constitutional guarantees.[42] In other words, the right to a life-sustaining climate system is deserving of fundamental status as essential to our scheme of ordered liberty because it is "preservative of all rights."[43]

For example, the Hawaii Supreme Court has recognized "that parents have a substantive liberty interest in the care, custody, and control of their children protected by the due process clause of article 1, section 5 of the Hawai'i Constitution."[44] If there is no guarantee of a stable climate system capable of supporting human life, our present children and future generations stand to inherit "nothing but parched earth[.]"[45] Thus, the right to "care, custody, and control" of one's child becomes meaningless without an environment enabling parents to safely raise their families.[46] A stable climate system is fundamental to Hawai'i's constitutional guarantees, including "the right to personal security[,]"[47] and the right to bodily integrity.[48]

4. Conclusion

A signature fact distinguishing the climate emergency as the greatest environmental threat ever faced by humanity is that a brief period of time remains for courts to protect climate rights upon which the lives and well-being of future generations depend. The failure of the federal

[42] *Juliana*, 217 F. Supp. 3d at 1248–49 (D. Or. 2016) ("Often, an unenumerated fundamental right draws on more than one [c]onstitutional source. The idea is that certain rights may be necessary to enable the exercise of other rights, whether enumerated or unenumerated"), rev'd and remanded, 947 F.3d 1159.

[43] *Yick Wo. v. Hopkins*, 118 U.S. 356, 370, 6 S. Ct. 1064, 1071 (1886).

[44] *In the Interest of Doe*, 99 Hawai'i at 533, 57 P.3d at 458.

[45] *Minors Oposa v. Sec'y of the Dep't of Envt'l & Ntural Res.*, 187–88.

[46] *In the Interest of Doe*, 99 Hawai'i at 533, 57 P.3d at 458.

[47] *See, e.g.*, *State v. Bonds*, 59 Haw. 130, 134, 577 P.2d 781, 784 (1978) (citations and quotations omitted).

[48] *See, e.g.*, *State v. Yong Shik Won*, 137 Hawai'i 330, 372 P.3d 1065 (2015) (explaining the right to bodily integrity in the context of unreasonable searches and seizures). Note that rights which this court has concluded are not "implicit in the concept of ordered liberty" are far from the right to a life-sustaining climate system. *See, e.g.*, *State v. Mallan*, 86 Hawai'i 440, 445, 950 P.3d 178, 183 (1998) (the right to possess and use marijuana is not a fundamental right implicit in the concept of ordered liberty); *see also*, *State v. Mueller*, 66 Haw. 616, 628, 671 P.2d 1351, 1359 (1983) (the right to engage in sexual conduct for a fee is not a fundamental right implicit in the concept of ordered liberty).

judiciary to achieve climate justice renders paramount the duty of state courts to apply normal principles of due process, equal protection, and public trust to recognize the right to a life-sustaining environment. The future of our planet and the survival of future generations depend on judges doing their jobs with courage to achieve the just application of the climate rule of law.

State Obligations in the Context of Climate Change

Dinah Shelton[1]

Overview

States have been reluctant to accept strict or absolute liability in international law, with the exception of a few state-sponsored activities. Instead, they have developed the concept of due diligence to establish the standard of care required of them to comply with their treaty-based and customary norms of conduct. What diligence is due depends on the magnitude of the threat posed, the likelihood of it occurring, and, to some extent, the ability of the state to respond to it. The climate emergency poses the highest magnitude of threatened harm and it is imminent in arriving to cause unparalleled damage to life. States must legally do something. They must take all measures within their power to address and mitigate the foreseeable consequences of this imminent peril.

1. Introduction

The principle that a state is responsible for causing environmental harm outside its territory in breach of an international obligation has been slow to evolve to address the allocation of loss due to accidents or resulting from climate change. The issue was not before the arbitral tribunal in the well-known dispute between the United States and Canada concerning the activities of the Canadian smelter located in Trail, British Colombia.[2] The arbitral tribunal asserted a general duty on the part of a state to protect other states from injurious acts caused by individuals within its jurisdiction. Summing up, the tribunal found that "no State has the right to use or permit the use of its territory in such a manner as to cause injury by fumes in or to the territory of another or the properties or persons therein, when the case is of serious consequence and the injury is established by clear and convincing evidence."[3]

The tribunal noted the difficulty of determining what constitutes an injurious act. Despite claims for absolute prohibition of harmful activities, the tribunal agreed with national court precedents

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[2] 1931-1941, 3 U.N.R.I.A.A. 19051931-1941, 3 U.N.R.I.A.A. 1905.

[3] 3 U.N.R.I.A.A. 1938, 1965.

that states should take reasonable precautions to prevent harm, the same as those it would take to protect its own inhabitants. It seemed that a state's failure to regulate or prevent serious harm from polluting activities, in instances where it would protect its own inhabitants, would constitute a wrongful act.

The *Trail Smelter* arbitration set the foundations for discussions of responsibility and liability in environmental law[4] but it did not decide the question of whether a state exercising due diligence would be liable if harm results despite the state's best efforts. More generally, the tribunal did not clarify whether a state is liable only for intentional, reckless, or negligent behavior (fault-based conduct) or whether it is strictly liable for all serious or significant transboundary environmental harm.

In subsequent developments, international environmental law has come to distinguish responsibility, which arises upon breach of an international obligation, from liability for the injurious consequences of lawful activities. Progress towards clarification on this subject remains slow. Even more in question, however, is what diligence is due when the issue is one of the actions required to mitigate the known or reasonably foreseeable consequences of climate change.[5]

2. State Responsibility

Following the Trail Smelter Arbitration, the ICJ asserted a general duty to avoid transboundary injury in the 1949 *Corfu Channel* case, which referred to "every State's obligation not to allow knowingly its territory to be used contrary to the rights of other states."[6] The same year as this decision, the United Nations Survey of International Law concluded that there is "general recognition of the rule that a State must not permit the use of its territory for purposes injurious to the interests of other States in a manner contrary to international law."[7] Principle 21 of the

[4] The case continues to be invoked. In 1972, Canada referred to the judgment when an oil spill in Washington polluted beaches in British Colombia. 11 CAN.Y.B.INT'L L 333-34 (1973).

[5] On these topics, see T. Scovazzi, "State Responsibility for Environmental Harm," 12 YBIEL 43 (2001); Lammers, "International Responsibility and Liability for Damage Caused by Environmental Interferences," 31 EPL 42 (2001); R. Bratspies & R. Miller, eds. Transboundary Harm in International Law; Lessons from the Trail Smelter Arbitration (2006); G. Handl, "Transboundary Impacts, in D. Bodansky, J. Brunnee & E. Hey, Oxford Handbook of International Environmental Law (2007); A. Boyle, "State Responsibility and International Liability For Injurious Consequences of Acts Not Prohibited By International Law: A Necessary Distinction," 39 ICLQ 1 (1990).

[6] I.C.J. Rep. (1949) p. 22.

[7] (1949) U.N. Doc. A/CN.4/1/Rev.1 (U.N. Pub. 1948. V.1(1)), 34.

1972 Stockholm Declaration restated the norm formulated in the Trail Smelter Arbitration and other cases as follows:

> States have, in accordance with the Charter of the United Nations and the principles of international law ... the responsibility to ensure that activities within their jurisdiction or control do not cause damage to the environment of other States or of areas beyond the limits of national jurisdiction.

The rule was reiterated in Principle 2 of the 1992 Rio Declaration and again confirmed in the 2002 World Summit on Sustainable Development. It has also been reaffirmed in declarations adopted by the United Nations, including the Charter of Economic Rights and Duties of States and the World Charter for Nature, and has been adopted by other international organizations and conferences.[8] Its content is inserted in the Convention on the Law of the Sea[9] as well as in Art. 20 of the ASEAN Convention on the Conservation of Nature and Natural Resources.[10] The 1979 Geneva Convention on Long Range Transboundary Air Pollution reproduces Principle 21 stating that it "expresses the common conviction that States have" on this matter.

Principle 2 of the Rio Declaration also appears in the preamble of the 1992 UN Framework Convention on Climate Change and Article 3 of the Convention on Biological Diversity. The International Court of Justice recognized in a 1996 advisory opinion that "[t]he existence of the general obligation of states to ensure that activities within their jurisdiction and control respect the environment of other states or of areas beyond national control is now part of the corpus of international law relating to the environment."[11] This statement was repeated in the judgment concerning the *Gabçikovo-Nagymaros Project*, in which the Court also "recall[ed] that it has recently had occasion to stress . . . the great significance that it attaches to respect for the environment, not only for states but also for the whole of mankind."[12]

[8] *See e.g.*, Preliminary Declaration of a Program of Action of the European Communities in respect to the Environment, O.J. C 112/1, Dec.20, 1973; Final Act, Conference on Security and Cooperation in Europe, Helsinki, Aug. 1976.

[9] UNCLOS Art.194(2).

[10] ASEAN Agreement on the Conservation of Nature and Natural Resources, 15 EPL 64 (Kuala Lumpur, July 9, 1985).

[11] *Legality of the Threat or Use of Nuclear Weapons,* Advisory Opinion, I.C.J. Reports 1996, pp.241-242, para 29.

[12] Sept. 25, 1997, para 53.

While Stockholm Principle 21 and similar formulations could be read to impose absolute state responsibility for any transfrontier harm, whether intentional or accidental, states generally have not invoked it to assert claims for non-intentional harm, however damaging the impact. The well-known Chernobyl incident is a case in point.[13] Following the April 26, 1986 explosion in reactor Number 4 of the Chernobyl nuclear power plant, the resulting fire melted a portion of the uranium fuel. Although there was no nuclear explosion and the core of the reactor did not melt, the fire which engulfed the reactor was serious and released a large quantity of radioactive material into the air.

Large amounts of fallout occurred near the plant and spread beyond. Between April 27 and May 8, nearly 50,000 persons were evacuated from towns located within a 30-kilometer radius of the plant. Two persons were immediately killed by the explosion, 29 died shortly after, and hundreds were afflicted with radiation poisoning. The foreign consequences were also severe, even though no deaths were immediately attributed to the accident. Following rapid changes in the wind direction, the radioactive cloud which had formed crossed the airspace of a series of countries beginning with those of Scandinavia. Four days after the incident, radiation measurements along the Swedish coast were ten times higher than normal. The radioactive cloud moved south, crossing Germany, Austria, Switzerland, Yugoslavia and Italy.

No conventional international regulation applied at the time the incident occurred in the Soviet Union. The interpretation then given to the Convention on Long-Range Transboundary Air Pollution[14] excluded pollution by radioactive elements. The USSR was not a contracting party to the Vienna Convention on Civil Liability for Nuclear Damage.[15] Indeed, among the states that suffered effects from the radioactive cloud, only Yugoslavia had signed and ratified the Convention. There remained, therefore, only the recourse to general rules of international environmental law; after consideration *none* of the affected states presented a claim to the Soviet Union for the damage they suffered.

In the aftermath, apparently no government pushed to conclude a rule imposing strict liability for such environmental harm. Negotiations would no doubt have been lengthy and perhaps unsuccessful over such matters as proximate harm, and mitigation of damages. The difficulty

[13] See L. Malone, *The Chernobyl Accident: A Case Study in International Law Regulating State Responsibility for Transboundary Nuclear Pollution*, 12 COL.J. ENV'L L. 203, 222 (1987).

[14] Geneva, November 13, 1979.

[15] May 21, 1963.

of evaluating the cost of the consequences of the Chernobyl accident, especially the preventive and precautionary measures taken by the affected countries, also may have been a determinant factor in avoiding the issue of state responsibility. This reluctance also seems, however, to be consistent with the general reticence displayed towards rules imposing strict liability on a state for damages caused by it, its citizens, or non-state actors like business entities, in another State. The emphatic preference remains measures of prevention rather than cure, using due diligence as the requisite standard of care.

In August 2001, the International Law Commission completed its Draft Articles on the Responsibility of States for Internationally Wrongful Acts, which the U.N. General Assembly "took note of" in Res. 56/83 (Dec. 2001). According to Article 2 of the ILC Articles, there is an internationally wrongful act of a State when conduct consisting of an action or omission constitutes a breach of an international obligation of the State. Article 3 adds that the characterization of an act of a State as internationally wrongful is governed by international law. In other words, the primary rules of conduct for states, that is, their rights and duties, establish whether an act or omission constitutes a wrongful act. At present, as discussed herein, only a handful of treaties make states strictly liable for any harm that occurs in another state's territory as a result of specific activities, even if the state has otherwise complied with its legal obligations.

3. Strict Liability of States in Treaties

Strict liability is foreseen in texts regulating activities considered as especially new or dangerous, such as the exploration and exploitation of the outer space, and which are largely conducted by state actors. The Convention on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and other Celestial Bodies,[16] provides both for state responsibility and strict liability. First, Article VI provides that the States Parties bear international responsibility for national activities in outer space, including the moon and other celestial bodies, whether such activities are carried on by governmental agencies or by non-governmental entities. The activities of non-governmental entities in outer space require authorization and continuing supervision by the appropriate state, thus ensuring state involvement. Article VII of adds that each state that launches or procures the launching of an object into space and each state from whose territory or facility an object is launched, is liable to another state or to its natural or juridical persons for harm caused by such object, or its

[16] January 27 1967, International Environmental Law, Multilateral Agreements (EMUT) 967:07.

component parts, on the Earth, in air space or in outer space, including the moon and other celestial bodies. Taken together, these two provisions distinguish between responsibility based on fault in outer space (Article VI) and strict liability for the consequences of space activities on Earth (Article VII).

The Convention on International Liability for Damage Caused by Space Objects[17] develops these principles and gives several details concerning their implementation. According to its Article II, a launching state is absolutely liable to pay compensation for damage caused by its space object on the surface of the Earth or to aircraft in flight. Exoneration from strict liability is granted to the extent that a launching state establishes that the damage has resulted from another State's gross negligence or from that State's intentional act or omission. No exoneration will be granted in cases where the damage has resulted from activities conducted by a launching state in breach of international law.

Within the Antarctic system, efforts to conclude a liability annex to the 1991 Madrid Protocol partially succeeded in June 2005, with conclusion of a limited agreement on environmental emergencies. The agreement, adopted as Annex VI to the Protocol on Environmental Protection, will enter into force once all the present Consultative Parties have ratified it.[18] The scope of potential liability extends to all governmental and non-governmental activities for which advance notice is required under the Treaty, including tourism. The Liability Annex Article 1, stipulates that it applies:

> to environmental emergencies in the Antarctic Treaty area which relate to scientific research programmes, tourism and all other governmental and non-governmental activities in the Antarctic Treaty area for which advance notice is required under Article VII(5) of the Antarctic Treaty, including associated logistic support activities.

Importantly, Article 2(b) of the Liability Annex defines an environmental emergency as "any accidental event that has occurred, having taken place after the entry into force of this Annex, and that results in, or imminently threatens to result in, *any significant and harmful impact on the Antarctic environment*." [emphasis added] Therefore, any activity that only has a minor or transitory impact on the environment will not be covered by the Annex. The rationale behind this is that every human activity will have some impact on the fragile Antarctic environment

[17] March 29, 1972.

[18] As of the end of 2022, 19 of the 27 Antarctic Treaty Consultative Parties had accepted the Annex.

and if non-significant situations would trigger strict liability, the result would create *ade facto* tax/compensation regime rather than a liability regime.

Each state party is to require its operators to undertake reasonable preventive measures, establish contingency plans for responses to incidents with potential adverse environmental impacts, and take prompt and effective responsive action when an emergency results from its activities. When the defaulting operator is a state operator and no party took response action, the state operator is liable to pay the equivalent of the costs of response action that should have been taken. This sum is paid into a fund.[19]

4. Strict State Liability for Harm from Hazardous Lawful Activities

Since 1978, the International Law Commission has considered the question of "international liability for injurious consequences arising out of acts not prohibited by international law." In 1997, the ILC decided to deal only with the question of prevention of transboundary damage from hazardous activities and it presented to the U.N. General Assembly a completed set of 19 articles on this topic.[20] The General Assembly reviewed the articles and, pressed by certain member states, asked the ILC to continue working on the topic of international liability, "bearing in mind the interrelationship between prevention and liability...."[21]

By July 2004, a draft set of principles on Allocation of Loss in the Case of Transboundary Harm Arising Out of Hazardous Activities was provisionally adopted by the Commission on first reading,[22] and, after comments by states, adopted on second reading in May 2006.[23] To a large extent, these efforts can be seen to supplement and complete the ILC Articles on

[19] Article 12 of the Liability Annex mandates the Secretariat of the Antarctic Treaty to maintain and administer a fund for the reimbursement of the reasonable and justified costs incurred by a party or parties in taking response actions to environmental emergencies.

[20] *See* Draft Articles on Prevention of Transboundary Harm from Hazardous Activities, in Report of the International Law Commission on the Work of its Fifty-Third Session, UN GAOR, 56th Sess. Supp. No. 10, U.N. Doc. A/56/10 370 (2001).

[21] Res. 56/82 of 18 January 2002.

[22] U.N. Doc. A/59/10, pp. 153-156.

[23] See Draft Report of the International Law Commission on the Work of its Fifty-Eighth Session, Chapter V: International Liability for Injurious Consequences Arising out of Acts not Prohibited by International Law (International Liability in Case of Loss from Transboundary Harm Arising out of Hazardous Activities), U.N. Doc. A/CN.4/L.693/Add.1, 9 June 2006.

Responsibility of States for Internationally Wrongful Conduct,[24] although the content of the adopted rules appears largely to repudiate state liability when the state has complied with the Articles on Prevention.

The principles on loss correctly approach the issue as one of allocating the risk of loss due to harm resulting from lawful economic or other activities, when the relevant state has complied with its due diligence obligations to prevent transboundary harm. The articles provide a general framework for States to adopt domestic laws or conclude international agreements to ensure prompt and adequate compensation for the victims of transboundary damage caused by lawful hazardous activities. It also explicitly states that an additional purpose of the draft principles is "to preserve and protect the environment in the event of transboundary damage, especially with respect to mitigation of damage to the environment and its restoration and reinstatement." This principle should be read in the light of the broad definitions of damage,[25] environment,[26] and hazardous activity[27] set forth in Principle 2. The last definition extends liability considerably beyond that provided in most domestic laws, including for failure to prevent harm from any activity which poses a risk of causing significant harm. This might well apply to any activity emitting greenhouse gases or other substances that are linked persuasively to climate change.

The articles only support strict liability between States if a State itself is the operator.[28] Other obligations are also placed on the state: it must promptly notify all states that are potentially or actually affected; ensure that appropriate response measures are taken; and provide domestic remedies. Other measures that are recommended include consulting on measures of mitigation, seeking the assistance of competent international organizations, and providing appropriate access to information on remedies. In addition, states may negotiate specific agreements on the topic of strict liability.

[24] Report of the International Law Commission on the Work of its Fifty-Third Session, UNGAOR, 55th Sess., Supp. No. 10, U.N. Doc. A/56/10 (2001).

[25] In addition to personal and property losses, damage includes "loss or damage by impairment of the environment, the costs of reasonable measures of reinstatement of the environment, including natural resources, and the costs of reasonable response measures. Principle 2(1)(iii-v).

[26] "Environment' includes natural resources, both abiotic and biotic, such as air, water, soil, fauna and flora and the interaction between the same factors, and the characteristic aspects of the landscape. Principle 2(b).

[27] In probably the broadest definition given in the draft articles, a hazardous activity "means an activity which involves a risk of causing significant harm." Principle 2 (c).

[28] The Commentary to the Draft Principles expressly states that "[i]t is envisaged that a State could be an operator for purposes of the present definition." A/CN.4/L.693/Add.1 at p. 41, para. 33.

There are clearly circumstances in which the primary obligation of a state is to ensure/insure that harm does not occur. Nonetheless, the ILC appears to have decided that strict liability of states does not even have support as a measure of progressive development in the law.[29] Instead, the ILC limits itself to noting that certain categories of hazardous activities might be included in treaties providing for state-funded compensation schemes to supplement civil liability.

Strict liability of states thus remains controversial, with the preference clearly being in favor of imposing civil liability on operators. Those subject matters for which state liability has been accepted in practice upholds this preference because they largely concern activities typically undertaken by government actors, at least until recently: e.g. outer space exploration and exploitation and Antarctic scientific research. States seem willing to accept liability for their own conduct, but not for that of private actors.

5. Strict Liability of Non-State Actors

Current treaties on civil liability of non-State actors number about one dozen, nearly all of them concerned with a single hazardous activity (e.g. nuclear energy or oil transport). Several conventions address vessel-source marine pollution or nuclear damage, while pollution from offshore oil and gas exploitation, carriage of dangerous goods by various means of transport, and transboundary movements of hazardous wastes are each regulated by a single treaty. Even more than nuclear operations, environmental injury caused by marine oil pollution is regulated by an entire system based on the 1969 International Convention on Civil Liability for Oil Pollution as modified in 1971, 1976, 1984 and 1992[30] together with the 1971 Convention on the Establishment of an International Fund for Compensation for Oil Pollution Damage, also modified by protocols.[31] The 1969 Convention established the liability of the owner of a ship[32]

[29] P.S. Rao, Third Report on the Legal Regime for Allocation of Loss in Case of Transboundary Harm Arising out of Hazardous Activities," UN Doc. A/CN.4/566 (2006) para. 31.

[30] In contrast to the treaty system, some states, notably the US, have enacted national legislation with much higher limits of liability, including some contexts in which liability is unlimited. See Oil Pollution Act of 1990, Public Law 101-380, enacted following the Exxon Valdez disaster of 1989.

[31] IMO Doc. 92 FUNA/A.8/4.

[32] The owner of the ship is not responsible if he can prove that the damage resulted from an act of war, hostilities, civil war, insurrection or a natural phenomenon of an exceptional, inevitable and irresistible character. The same is true if the damage results from an act or omission of a third party done with intent to cause damage or results from the negligence or other wrongful act of any government or other authority responsible for the maintenance of lights or other navigational aids.

for pollution damage caused by oil escaping from the ship as a result of an incident on the territory of a party. Other marine liability conventions include the 1976 International Convention on Civil Liability for Oil Pollution Damage Resulting from the Exploration for or Exploitation of Submarine Mineral Resources,[33] and the 2001 Convention on Civil Liability for Bunker Oil Pollution Damage.[34]

Strict liability for maritime pollution was extended to other hazardous substances in 1996 with the adoption of the International Convention on Liability and Compensation for Damage in Connection with the Carriage of Hazardous and Noxious Substances at Sea (HNS Convention).[35] Art. 1(6) of the HNS Convention defines damage to include, in addition to loss of life or personal injury or the loss of or damage to property, loss or damage by contamination of the environment caused by hazardous and noxious substances, provided that compensation for impairment of the environment other than loss of profit from such impairment is limited to the costs of reasonable measures of reinstatement actually undertaken or to be undertaken, and the costs of preventive measures to avoid further loss or damage caused.

The owner of a ship registered in a contracting state and carrying oil in bulk as cargo must maintain insurance or other financial guarantee of compensation in case of liability for pollution damage. An insurance or guarantee certificate must be issued to each ship by the appropriate national authority, and contracting states are obliged to prevent a ship from trading unless the appropriate certificate has been issued. Each state must recognize the certificates issued by other contracting states.

The 2001 International Convention on Civil Liability for Bunker Oil Pollution Damage addresses the category of vessels responsible for the majority of oil spills. In contrast to earlier conventions dealing with damage caused by the cargo of relatively small and well-defined categories of vessels, the Bunker Convention potentially applies to all ships. The definition of "pollution damage" is identical to that of the 1992 Convention on Civil Liability. It is also subject to the same limitation in that it does not cover damage to the environment in itself, but only clean-up costs and the loss of profit suffered by victims such as fishermen and local industries dependent on ocean resources and the tourist trade. Actions for compensation may only be

[33] Dec. 17, 1976, 16 I.L.M. 1451 (1977).

[34] International Convention on Civil Liability for Bunker Oil Pollution Damage (March 23, 2001), IMO Doc LEG/CONF.12/DC/1.

[35] May 3, 1996, LEG/CONF.10/8/2 (9 May 1996).

brought in the courts of the states where damage was suffered. Ships must carry certificates attesting to their financial security and claims for compensation may be made directly against the insurer or other provider of financial security.

For land-based activities, a Protocol on Liability and Compensation for Damage resulting from Transboundary Movements of Hazardous Wastes and their Disposal[36] further developed the regime of civil liability for environmental damage. Its purpose is to provide a comprehensive regime for adequate and prompt compensation for damage resulting from transboundary waste movements, including illegal traffic. It defines damage broadly to include loss of income directly deriving from an economic interest in any use of the environment, when that loss is incurred as a result of impairment of the environment. Compensation extends to the cost of measures of reinstatement of the impaired environment, limited to the costs of measures actually taken or to be undertaken and the costs of preventive measures, including any loss or damage caused by such measures.

Preventive measures are defined as any reasonable measures taken by any person in response to an incident to prevent, minimize, or mitigate loss or damage, or to effectuate environmental clean- up. The Protocol applies to damage due to an incident occurring during a transboundary movement of hazardous wastes and other wastes and their disposal, including illegal traffic. The Basel Protocol imposes strict liability on, first, the person who provides notification of a proposed transboundary movement according to Art. 6 of the Basel Convention, and, thereafter, the disposer of the wastes. Liability for damage is subject to financial limits, but those potentially liable shall establish and maintain insurance or other financial guarantees.

In sum, the liability agreements have several common features:

a. Identification of the polluter is assured.
b. The system imposes strict liability for damage, but specifies a limited set of excuses.
c. Jurisdictional competence is determined by designating the proper forum.
d. Time limits are imposed.
e. Liability limits are coupled with mandatory insurance requirements.
f. The execution of judgments is assured.

[36] Basel, Dec. 10, 1999.

In the Advisory Opinion OC-23/17, the IACtHR stated “[w]hen transboundary harm or damage occurs, a person is responsible under the jurisdiction of the State of origin if there is a causal link between the action that occurred within its territory and the negative impact on the human rights of persons outside its territory. The exercise of jurisdiction arises when the State of origin exercises effective control over the activities that caused the damage and the consequent human rights violation.” The CRC applied this principle in the *Sacchi et al v Argentina et al*. case.[37] The CRC went a step further, though, stating that “the alleged harm suffered by the victims needs to have been reasonably foreseeable to the State party at the time of its acts or omissions.” It is well established by science in the context of the climate emergency that the world is very aware that any additional warming matters. It is also well established that global warming today is already impacting human rights beyond the territory where the warming has first been felt. It is also well established that the main sources of global warming, therefore sources of GHG’s emissions, can be traced to specific territories to determine jurisdiction and obligations.

Therefore, as the CRC stated in *Sacchi*: “[i]n accordance with the principle of common but differentiated responsibility, as reflected in the Paris Agreement, the Committee finds that the collective nature of the causation of climate change does not absolve the State party of its individual responsibility that may derive from the harm that the emissions originating within its territory may cause to children, whatever their location.” The IACtHR observed that States Parties’ GHGs contribute to “the increase in frequency and intensity of meteorological phenomena attributable to climate change, which, regardless of their origin, contribute cumulatively to the emergence of adverse effects in other States.” States Parties are “responsible not only for actions and omissions in its territory, but also for those within its territory that could have effects on the territory or inhabitants of another State” and “have the obligation, within their jurisdiction, to regulate, supervise and monitor activities that may significantly affect the environment inside or outside their territory.” In the context of the climate emergency, this means that all State activities within the 1.5°C guardrail, refrain from destroying carbon sinks or from authorizing new exploration and exploitation of fossil fuels. In addition, they must regulate methane and black carbon to ensure near zero methane emissions.

[37] Decision of September 22, 2021. CRC/C/88/D/104/2019.

As a rule, strict liability is linked with known hazardous activities and States draft agreements to designate such activities. States are patently reluctant to accept international regulation in any other domain where economic interests may play a major role.

6. The Obligation of Due Diligence

Due diligence first appeared in the law of neutrality and in the law concerning injury to aliens.[38] Due diligence made a more recent appearance in international human rights law. Between mid- 1988 and early 1989, for example, the Inter-American Court of Human Rights decided cases based on petitions filed by the families of disappeared persons against the government of Honduras. In the cases of Angel Manfredo Velasquez Rodriguez and Saul Godinez Cruz, the Court unanimously found that Honduras had violated the rights of personal liberty, humane treatment, and life guaranteed by the American Convention on Human Rights.[39] As a result, the Court decided that Honduras must pay fair compensation to the victims' next-of-kin.

The Court determined that both Velasquez Rodriguez and Godinez Cruz were kidnapped under circumstances falling within a systematic practice of disappearances, that persons connected with the army or under its direction carried out the kidnappings, and that there was no evidence that either man had disappeared to join subversive groups. Based on these findings, the Court held Honduras responsible for the disappearances. Moreover, the State was responsible even if the disappearances were not carried out by agents who acted under cover of public authority, because the State's apparatus failed to act to prevent the disappearances or to punish those responsible. Therefore, because Honduran officials either carried out or acquiesced in the kidnappings, the Court concluded that the government “failed to guarantee the human rights affected by” disappearances.

The issues and principles in these cases centered on state responsibility for human rights violations. Petitioners alleged violations of articles 4, 5, and 7 of the Convention. The Court found that infringements of the rights contained in these provisions inevitably involve violation of Convention article 1, which sets out the general obligations of states and contains the generic basis of liability. The Court viewed article 1 as establishing the conditions under which

[38] G. Bartolini, ‘The Historical Roots of the Due Diligence Standard’ in Krieger et al (eds), Due Diligence in the International Legal Order, 23.

[39] Velasquez Rodriguez, Inter-Am. Ct.H.R. at 75-76, ¶ 194; Godinez Cruz, Inter-Am. Ct. H.R. at 159-60, ¶ 203. See, D. Shelton, “Private Violence, Public Wrongs, and the Responsibility of States,” 13 *Fordham Int’l L. J.* 1 (1989/1990).

a particular act, which violates one of the rights recognized by the Convention, can be imputed to a state party, thereby establishing its international responsibility.

As interpreted by the Court, article 1(1) contains several separate duties. First, a State shall respect the rights and freedoms recognized by the Convention. This "must necessarily comprise the concept of the restriction of the exercise of state power." The existence of a legal system designed to permit exercise of human rights does not alone ensure compliance with a State's obligations, because rights may be violated in spite of legal protections. Thus, the Court declares, whenever a State organ, official, or public entity violates a protected right, this constitutes a failure of the duty to respect the rights and freedoms set forth in the Convention because public power is used to infringe the rights recognized. In general, then, a State is responsible for the acts and omissions of its agents undertaken in their official capacity, even if they are acting outside the scope of their authority or in violation of internal law. Intent or motivation is irrelevant.

Second, the States must "ensure" the free and full exercise of the rights recognized by the Convention. This obligation requires States "to organize the governmental apparatus and, in general, all the structures through which public power is exercised, so that they are capable of juridically ensuring the free and full enjoyment of human rights." This implies that States must prevent violations of the rights recognized by the Convention. In addition, the state must attempt to investigate, prosecute, and punish violations of human rights, restore the right violated, and provide compensation as warranted for damages resulting from the violation.

The existence of affirmative duties to prevent and to remedy human rights violations implies, as a consequence, that state responsibility extends to omissions by State actors. The Court cites the example of a State that is not directly responsible for a human rights violation because the act is that of a private person, but that becomes responsible because of "the lack of due diligence to prevent the violation or to respond to it as required by the Convention." In addition, the Court declared that where human rights violations committed by private parties are not seriously investigated, "those parties are aided in a sense by the government, thereby making the State responsible on the international plane."

The Court concluded that the State is liable for disappearances such as those of Velasquez Rodriguez and Godinez Cruz, which were found to be "carried out by [agents] who acted under cover of public authority." Significantly, the Court added that even if State complicity were not proven, the failure of the State "to act, which is clearly proven, is a failure on the part of Honduras to fulfill the duties it assumed under Article 1(1) of the Convention" to ensure the full and free exercise of human rights. Thus, although the state may not bear initial responsibility for acts of private violence, responsibility may be imputed because of the "lack of due diligence" to prevent or remedy violations committed by non-state actors.

The Court echoed here the traditional law of state responsibility for injury to aliens. Prior to the establishment of international systems for the protection of human rights at the end of World War II, international law recognized a state's right to bring a claim against another state because of breaches of international law causing injury to the person or property of its nationals. In the Mavrommatis Palestine Concessions, the Permanent Court of International Justice states that "[i]t is an elementary principle of international law that a State is entitled to protect its subjects, when injured by acts contrary to international law committed by another State, from whom they have been unable to obtain satisfaction through the ordinary channels."[40]

The great innovation of international human rights law was to extend the protections formerly afforded aliens to all individuals. Today, as the Honduran cases made clear, one of the international obligations imposed upon states by treaty and custom is to "respect and ensure" internationally recognized human rights. Because of this duty, a state's failure to act to prevent or remedy human rights violations committed by private entities may constitute the breach of an international obligation, giving rise to State responsibility. In respect of economic, social, and cultural rights (ESCR) the obligations are also those of due diligence, although constrained by the State's capacity in many instances; the constraint does not apply, however, when the alleged violation concerns the "minimum core" of a right. This is crucial in cases where the right involved is the right to water or the right to food, for example.

The Human Right to Life in the context of the climate emergency entails the human right to resilience, as a manifestation of the human right to life. It implies mandatory obligations on States and non-State actors. These mandatory obligations are:

- To manage the risks and the threats that will otherwise make resilience futile, by adopting all the measures necessary to a consistent path to remain under 1.5°C and to ensure time to build resilience by slowing the rate of warming in the near term.
- To ensure the means to reduce vulnerability and therefore strengthen resilience of people and ecosystems that are essential for the enjoyment of the human right to life,

[40] *The Mavrommatis Palestine Concessions (Greece v. Gr. Brit.)*, 1924 P.C.I.J. (ser. A) No. 2, 6, 12 (Aug. 30).

by allocating funds to the public budget and incentivizing private investments for fast mitigation actions and adaptation measures.

The Court can set up a set of indicators to evaluate if States are addressing the climate emergency:

a. Develop and implement measures to address climate change;
b. Have a fully-funded public budget allocated to build resilience;
c. Adopt national development goals compatible with 1.5°C temperature rise or less;
d. Develop, enact, and implement the regulations and laws that are necessary to address the climate emergency, including those relating to methane, air quality, and criminal conduct;
e. Create and strengthen the institutions necessary to address the climate emergency; *and*
f. Protect sinks and halt deforestation.

Since 1972, the obligation of due diligence has also appeared in numerous environmental conventions, which have obliged the parties to take "appropriate" or similar measures.[41] In addition, international courts and tribunals have spelled out due diligence obligations with regard to the land, watercourses and marine environment.[42]

Due diligence obligations serve to manage risks. Some risks stem from natural or technical phenomena that may threaten persons, property, or ecosystems. Risk management by States may be hampered by a limited knowledge about the nature and scope of the risk, the difficulty

[41] Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter (adopted 19 November 1972, entered into force 30 August 1975) 1046 UNTS 120 art 1; Vienna Convention for the Protection of the Ozone Layer (adopted 22 March 1985, entered into force 22 September 1988) 1513 UNTS 293 art 2; Convention on the Protection and Use of Transboundary Watercourses and International Lakes (adopted 17 March 1992, entered into force 6 October 1996) 1936 UNTS 269 art 2(1); Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal (adopted 22 March 1989, entered into force 5 May 1992) 1673 UNTS 57 art 4(2); Convention on the Protection of the Alps (adopted 7 November 1991, entered into force 6 March 1995) OJ L61/32 art 2(2); Convention on the Transboundary Effects of Industrial Accidents (adopted 17 March 1992, entered into force 19 April 2000) 2105 UNTS 457 arts 3(1) and 6(1); Convention on the Law of the Non-Navigational Uses of International Watercourses (adopted 21 May 1997, entered into force 17 August 2014) 36 ILM 700 arts 7(1) and (2); Revised Protocol on Shared Watercourses in the Southern African Development Community (adopted 7 August 2000, entered into force 22 September 2003) (2001) 40 ILM 321 art 3(10)(a); and many more.

[42] *Pulp Mills on the River Uruguay* (Argentina v Uruguay) (Judgment) [2010] ICJ Rep 14 [101], [197], [204] and [223]; *Certain Activities Carried out by Nicaragua in the Border Area (Costa Rica v Nicaragua) and Construction of a Road in Costa Rica along the San Juan River (Nicaragua v Costa Rica)* (Merits) [2015] ICJ Rep 665 [104], [153], [168] and [228]; *Responsibilities and Obligations of States Sponsoring Persons and Entities with Respect to Activities in the Area* (Advisory Opinion, 1 February 2011) ITLOS Reports 2011 [110]–[112] see below for further discussion.

of actually proving the presence and degree of the risk, doubts about causes and effects, and the necessity of dealing with numerous contributing factors and actors. In order to deal with these problems, the precautionary principle has been designed as a legal tool.[43] As an example, the precautionary principle might justify requiring environmental impact assessments to include information about carbon usage and emissions.[44]

Due diligence facilitates dealing with uncertainty in the face of a plurality of diverse actors and varying risk proximity. In international climate law, risk proximity is contingent both on States' resources for action and on their past contributions to climate harm, making the capacity of a State a relevant factor. It is especially important in climate change, as the knowledge about its causes and its consequences becomes clearer and the risks threaten catastrophic harm. Article 4(1) of the Paris Agreement on Climate Change refers, inter alia, to 'efforts to eradicate poverty' while Article 2(2) permits States to consider 'different national circumstances.'[45] This gives developing States more leeway for setting national policy priorities by weighing interests in poverty eradication and development against concerns of climate protection. The balancing process informs the due diligence standard in the concrete instance of implementation.

In the absence of any rules on strict liability, obligations for the prevention of harm to the environment generally require States to act with due diligence in respect of activities by public and by private actors.[46] The development of international law on due diligence has derived in large part from the ILC's Articles on Prevention of Transboundary Harm, which provide that "[t]he State of origin shall take all appropriate measures to prevent significant transboundary harm or at any event to minimize the risk thereof."[47] The question is, what are the "all appropriate measures" required of States in confronting the known consequences of global climate change?

[43] See eg United Nations Framework Convention on Climate Change (adopted 9 May 1992, entered into force 21 March 1994) 1771 UNTS 107 art 3(3).

[44] See, *Held v. The State of Montana*, CVD-2020-307 (Mont.Dist Ct.) filed Aug. 14, 2023.

[45] Paris Agreement (adopted 12 December 2015, entered into force 4 November 2016), UNTS Registration No 54113; Lavanya Rajamani, 'Due Diligence in International Climate Change Law' in Krieger et al (eds), *Due Diligence in the International Legal Order* 163, 173–177.

[46] See, generally, the ILA Study Group documents: "Due Diligence in International Law (2012-2016)," Study Groups, International Law Association, accessed 20 January 2021.

[47] Article 3, ILC, Draft Articles on Prevention of Transboundary Harm from Hazardous Activities, II(2) U.N.Y.B.I.L.C., 2001, 148.

The ILC Articles specify that the measures to be taken are those "generally considered to be appropriate and proportional to the degree of risk of transboundary harm, also using the term "a reasonable standard of care."[48] The Commission's Articles built on the recognition of the duty to prevent transboundary harm in Principle 21 of the 1972 Stockholm Declaration, echoed in Principle 2 of the 1992 Rio Declaration, both of which refer to States' responsibility to ensure that activities within their jurisdiction or control do not cause damage to the environment of other States or of areas beyond the limits of national jurisdiction.

Obligations to prevent transboundary environmental harm are often viewed in terms of the distinction between obligations of conduct and obligations of result. Illustrating the contrast between obligations of conduct and obligations of result, in the *Nuclear Weapons Advisory Opinion*, the ICJ, once it determined that it could not conclude definitively whether the threat or use of nuclear weapons would be lawful or unlawful in the extreme circumstance in which the very survival of a State was at stake, it unanimously found an obligation to negotiate in good faith to reach an agreement. The obligation went beyond a "mere obligation of conduct." It was "an obligation to achieve a precise result by adopting a particular course of conduct."

In international dispute settlement, recent contentious judgements and advisory opinions by international courts and tribunals attest to the growing importance of due diligence. The ICJ decided the *Case Concerning Pulp Mills* (*Argentina v. Uruguay)*[49] which was followed by an important advisory opinion adopted the Seabed Disputes Chamber of the ITLOS on *Responsibilities and Obligations of States Sponsoring Persons and Entities with Respect to Activities in the Area*.[50]

In the *Case Concerning Pulp Mills*, the ICJ expressly identified Articles 36 and 41 of the Statute of the River Uruguay as obligations of conduct requiring due diligence in their execution, including when carrying out environmental impact assessment and the selection of production technology. Article 41(a) of the Statute of the River Uruguay provided that the two parties were "to protect and preserve the aquatic environment and, in particular, to prevent its pollution, by prescribing appropriate rules and measures in accordance with applicable international agreements and in keeping, where relevant, with the guidelines and recommended actions of

[48] *Id.*

[49] Case Concerning Pulp Mills on the River Uruguay (Argentina v Uruguay) (Judgment), ICJ Reports, 2010, 14.

[50] Responsibilities and Obligations of States Sponsoring Persons and Entities with Respect to Activities in the Area (Advisory Opinion), ITLOS Reports, 1 February 2011, 10.

international technical bodies."[51] This required an environmental impact assessment conducted with due diligence.[52]

In the ITLOS Advisory Opinion, the Chamber responded to questions posed by the International Seabed Authority concerning the UNCLOS obligations and liability of states sponsoring mining- related activity on the deep seabed. The initial question was "What are the legal responsibilities and obligations of States Parties to the Convention with respect to the sponsorship of activities in the Area in accordance with the Convention, in particular Part XI, and the 1994 Agreement relating to the Implementation of Part XI of the United Nations Convention on the Law of the Sea of 10 December 1982?" The Chamber explained that UNCLOS's Article 139(1) "obligation to ensure" that activities in the Area were carried out in conformity with Part XI of UNCLOS required measures that were "reasonably appropriate." The Chamber identified this as the obligation sponsoring States to ensure contractors' compliance with the rules, regulations and procedures of the International Seabed Authority, contracts or plans of work for exploration and exploitation, and relevant provisions of the Convention's Part XI, Annex III on prospecting, exploration, and exploitation.

The obligation of the State of origin to take preventive measures was one of due diligence. The Chamber called due diligence a "variable concept," changing over time in *light of the risks involved, and new scientific or technical knowledge concerning these risks*, citing the commentary on the ILC Articles on Prevention of Transboundary Harm. Sponsoring states were "bound to make best possible efforts to secure compliance by the sponsored contractors." This was not the same as guaranteeing that the harm would not occur, but it required measures that were "reasonably appropriate." Some States' obligations further indicated the specific measures required, including their enforcement, such as implementation of a precautionary approach, adoption of best environmental practices, and conduct of environmental impact assessment.

The next question directly concerned liability, asking "What is the extent of liability of a State Party for any failure to comply with the provisions of the Convention, in particular Part XI, and the 1994 Agreement, by an entity whom it has sponsored under Article 153, paragraph 2(b), of the Convention?" The Chamber responded that sponsoring States were exempt from liability

[51] *Pulp Mills*, para. 187.

[52] *Id.*, paras. 204, 209.

where they had taken all necessary and appropriate measures to secure effective compliance as specified in Article 139(2) read together with other key provisions.

The final question asked was, "What are the necessary and appropriate measures that a sponsoring State must take in order to fulfil its responsibility under the Convention, in particular Article 139 and Annex III, and the 1994 Agreement?" The Chamber held that sponsoring States were required to adopt laws, regulations and administrative measures in good faith and taking into account the various options in a manner that was reasonable, relevant and conducive to the benefit of mankind as a whole. The Chamber clearly recognized that the sponsoring State may make "policy choices" but it gave some general indications; e.g., the sponsoring State might find it necessary to include provisions in its domestic law concerning contractors, financial liability and technical capacity, conditions for the issue of sponsorship certificates and penalties for contractors' non-compliance.

Contractors' contractual obligations to the ISA had to be made enforceable under sponsoring States' domestic law. States' direct obligations under UNCLOS further indicated the requisite laws, regulations, and measures.

At its heart, due diligence is concerned with supplying a standard of care against which fault can be assessed. It is a standard of reasonableness, that seeks to take account of the consequences of wrongful act or omission and the extent to which such consequences could have been avoided by the State that either authorized the relevant act or which failed to prevent its occurrence. Due diligence standards preserve for States a significant measure of flexibility in discharging their international obligations. The use of due diligence makes the international legal system adaptable to meet particular needs of States within a diverse international community. It avoids perfect equality of obligations in favor of a more flexible equitable approach to encourage broader participation in treaty and customary regimes.

In recent years, the search for equity has affected the law on environmental protection and natural resources, where the concept of common but differentiated responsibilities informs what diligence is due.[53] The concept of "common but differentiated responsibilities" emerged from the 1992 Rio Conference on Environment and Development and the treaties that were concluded in conjunction with it.

[53] See M. Koskenniemi, From Apology to Utopia: The Structure of International Legal Argument (1989), p. 391.

Three factors justify such an equitable approach. The first is the need to adopt measures of environmental protection that are designed and implemented in such a way as to support States in achieving their development objectives. Secondly, the responsibility of developed States for environmental damage, at least since the industrial revolution, and their disproportionate consumption of the Earth's resources, plus their contributions to the climate change threat, demand that they accept the major burden to combat the global problem. Thirdly, the developed States have greater financial and technological capacity to meet the costs of transition towards more environmentally sustainable use of resources. Technological advances can also enhance States' capacities to reduce negative impacts or render them cheaper, that is, more cost-effective.

Reflecting these considerations, the Rio Declaration, Principle 7, provides:

> States shall cooperate in a spirit of global partnership to conserve, protect and restore the health and integrity of the Earth's ecosystem. In view of the different contributions to global environmental degradation, States have common but differentiated responsibilities. The developed countries acknowledge the responsibility that they bear in the international pursuit to sustainable development in view of the pressures their societies place on the global environment and of the technologies and financial resources they command.

Principle 4 further proclaims that environmental protection "shall" constitute an integral part of the development process. Elsewhere, the Rio Declaration requires States to apply the precautionary approach "according to their capabilities." The precautionary principle was cited in the *Tatar* case by the European Court of Human Rights, which held it to be a binding norm of European law.[54]

Due diligence is thus an open-ended principle that avoids difficulties that can arise in reaching agreement on rules and in the enforcement of such rules. Due diligence tends to focus on whether States have taken reasonable and appropriate steps to avoid or mitigate injury to other States. Moreover, the content of due diligence duties can and do evolve over time. For example, the obligation to undertake environmental impact assessment has been progressively strengthened.[55]

[54] *Tatar v. Romania*, App. No. 67021/01, judgement of 27 Jan. 2009.

[55] *Pulp Mills on the River Uruguay, Case Concerning (Argentina v Uruguay)* (Merits) [2010] ICJ Rep 14 (*Pulp Mills Case*); *Certain Activities Carried out by Nicaragua in the Border Area (Costa Rica v Nicaragua)* and *Construction*

There are limits to this flexibility, however, such as in the law applicable to diplomatic missions and diplomatic immunity, where special duties of protection apply irrespective of the capacity of the receiving State.[56] This duty is over and above due diligence.[57] Similarly, in *Responsibilities and Obligations of States Sponsoring Persons and Entities with Respect to Activities in the Area (Seabed Mining Advisory Opinion)*[58] the ITLOS Seabed Disputes Chamber rejected the argument that marine environmental protection obligations could be adjusted according to the level of development of a State. It would “jeopardize uniform application of the highest standards of protection of the marine environment” if there were to develop sponsoring States “of convenience”.[59] This decision balances two competing objectives: on the one hand, the notion of common but differentiated responsibilities takes account of the historical and economic disadvantages faced by developing States, and, on the other hand, the important interest in protecting the global environmental commons.

‘Reasonableness’ is determinative of which measures States should take in a duly diligent manner.[60] Indeed, one might describe a due diligence obligation as an obligation for the State to take *all measures it could reasonably be expected to take*.[61] Even in the instance of preventing the commission of genocide, the standard articulated by the ICJ in order to incur international responsibility was that a State ‘manifestly failed to take all measures’ that were ‘within its power’ to take.[62]

of a Road in Costa Rica along the San Juan River (Nicaragua v Costa Rica), Judgment of 16 December 2015 (cf. the Separate Opinion of Judge Donoghue’s in which she observed that due diligence and environmental impact assessment should not be fixed and prescribed, and that there should be ‘scope for variation in the way that States of origin conduct the assessment’).

[56] Vienna Convention on Diplomatic Relations 1961, Article 22(2).

[57] J. Crawford, *Brownlie’s Principles of Public International Law* (8th ed, 2012), p. 403.

[58] (2011) 50 ILM 458.

[59] *Id.*, para. 159.

[60] *See also* I. Brownlie, *Principles of Public International Law* (7th ed, 2008), p. 526 and H. E. Zeitler, ‘The Guarantee of “Full Protection and Security” in Investment Treaties Regarding Harm Caused by Private Actors’ (2005) 3 *Stockholm International Arbitration Review* (2005), 1.

[61] J. W. Salacuse, *The Law of Investment Treaties* (2010), p. 217.

[62] *Application of the Convention on the Prevention and Punishment of the Crime of Genocide (Bosnia and Herzegovina v Serbia and Montenegro)*, Judgment of 26 Feb 2007, ICJ Reports 2007 para 430. (*Genocide case*)

As noted in the *Seabed Mining Advisory Opinion*, '[due diligence obligations] may also change in relation to the risks involved in the activity.'[63] This is also reflected in the ILC's Draft Articles on the Prevention on Transboundary Harm. The Commentary to Article 3 of the Prevention Articles explains that due diligence standard should be 'appropriate and proportional to the degree of risk of the transboundary harm.'[64] The UN Guiding Principles on Business and Human Rights also accepts that due diligence requirements increase in situations in which the risks of harm are known to be particularly significant.[65] States can usually only be expected to act in accordance with a due diligence obligation to prevent harm if the State has knowledge of the situation which requires action,[66] but the State may be under an obligation to attempt to gain knowledge of activities within its territory or jurisdiction. As observed in the *Corfu Channel* case, 'the fact of...exclusive territorial control exercised by a State within its frontiers has a bearing upon the methods of proof available to establish the knowledge of that State as to such events.'[67] It may allow the State which is the victim of an international wrong 'a more liberal recourse to inferences of fact and circumstantial evidence.'[68] In that case, the Court concluded that the laying of the minefield in the channel 'could not have been accomplished without the knowledge of the Albanian Government.'[69] Albania was held responsible because it either knew or should have known about the activity.

These considerations – degree of risk of harm and knowledge/should have known - have particular resonance in the context of the risks stemming from global climate change. There is no longer any doubt that the Earth is facing catastrophic events stemming from human-induced climate change. In these circumstances, a State cannot be considered to have acted diligently

[63] *Seabed Mining Advisory Opinion,* (2011) 50 ILM 458, para. 117.

[64] International Law Commission, Draft Articles on Prevention of Transboundary Harm from Hazardous Activities, UN GAOR 56th Sess., Supp. No. 10, UN Doc. A/56/10 (2001), Commentary to article 3, para. 11.

[65] *Guiding Principles on Business and Human Rights: Implementing the United Nations "Protect, Respect and Remedy" Framework*, UN Human Rights Council, UN Doc. A/HRC/17/31 (Mar. 21, 2011). Principle 17(b) explicitly states that due diligence 'will vary in complexity with ... the risk of severe human rights impacts'. See also Principle 7, requiring States to pay particular attention to the human rights-related risks of businesses operating in conflict-affected areas, and Principle 3 (assessing the adequacy of laws in light of evolving circumstances) and Principle 21 (formal reporting where business operations or contexts pose risks of severe human rights impacts).

[66] H. E. Zeitler, 'The Guarantee of "Full Protection and Security" in Investment Treaties Regarding Harm Caused by Private Actors', 3 *Stockholm International Arbitration Review* (2005) 1, p. 14.

[67] *Corfu Channel* case [1949] ICJ Rep 1, p. 18.

[68] *Id*.

[69] *Id*.

when the State has knowingly refused to take any measures. In the case of *Wena v. Egypt*,[70] the Tribunal found that the failure by the State to take action against those responsible for the forceful seizure of Wena's property was a breach of the required protection and security.[71] This conforms with due diligence as understood in international environmental law, to the extent that a State has to act diligently in the event of foreseeable harm.

Advances in scientific understanding and technological capabilities can increase the degree of care required over time. The extent of risk or advances in scientific knowledge that allow us to perceive more accurately the extent of risk, will also influence the degree of diligence required.[72] This can also be seen in the relationship between the principles of precaution and prevention. States should take a precautionary approach to 'threats of serious or irreversible damage.'[73] They must take 'cost-effective measures' in light of those threats and 'must not disregard those risks.'[74] As a tool to manage risk in conditions of incertitude, due diligence appears as a companion of the precautionary principle, in that it demands States establish laws and procedures to avert foreseeable disasters.

If science shows that the risk of damage is not merely theoretical but proven, the principle of prevention takes over; where there is a likelihood of significant harm, a State that permits an operation to proceed is acting wrongfully.[75] Thus, as scientific understanding advances over time there are distinct shifts in the due diligence standard: if the damage decreases in severity from 'serious or irreversible' (precautionary approach) to (merely) 'significant' (principle of prevention). Secondly, while States should only give due regard to uncertain risks and are encouraged to take 'cost-effective measures' to reduce the risk (the precautionary approach), a known risk or likelihood of negative impact triggers a State duty to exercise a much higher degree of diligence to prevent the damage (the principle of prevention). Physical changes beyond a State's control, such as an earthquake, a flood or volcano, may also render an activity

[70] *Wena Hotels Ltd. v. Arab Republic of Egypt*, ICSID Case No. ARB/98/4.

[71] *Id*.

[72] *Id*., para 117; Pisillo-Mazzeschi 1992, above n 103, p. 44: First Report, above n 25, p. 29; ILC Draft Articles on Prevention of Transboundary Harm, commentary to article 3, para 11.

[73] Rio Declaration, above n 61, principle 15.

[74] *Seabed Mining Advisory Opinion* (2011) 50 ILM 458, para 131.

[75] *Pulp Mills* [2010] ICJ Rep 14, para. 101.

more hazardous and hence increase the degree of diligence required of a State if it is aware or it should have been of the possibility of such hazards occurring.[76]

In sum, due diligence duties can increase or decrease through changes in customary international law. The Prevention Articles provide 'an authoritative statement on the scope of a State's international legal obligation to prevent a risk of transboundary harm.'[77] According to the Commentaries, this obligation is one of 'due diligence' that requires the State to 'exert its best possible efforts to minimize the risk.'[78] The standard of due diligence is that which is generally considered to be appropriate and proportional to the degree of risk of harm in the particular instance.[79] The State is expected to put in place administrative, financial and monitoring mechanisms,[80] require its prior authorization for climate-risking activities, and play an active role in regulating them.[81]

Natural or juridical persons at risk of harm must be provided access to justice in the courts of the State, unless there is agreement on alternate means of redress.[82] The provision of access to remedy may itself be part of the due diligence obligation to prevent or minimize the risk of harm, at least to the extent that access to courts could be used to seek measures designed to prevent harm.

[76] ILC Draft Articles on Prevention of Transboundary Harm, ILC Draft Articles on Prevention of Transboundary Harm from Hazardous Activities 2001, above n 32, commentary to article 1, para 15.

[77] J. Crawford, *Brownlie's Principles of Public International Law* (8 ed, 2012) pp. 356-7.

[78] *Id.*, Commentary to article 3, pp. 391-396.

[79] *Id.*, Commentary to article 3 at para. 11.

[80] *Id.*, Commentary to article 3 at para. 15.

[81] *Id.*, articles 6 and 7.

[82] *Id.*, article 15 and Commentaries.

The Climate Emergency and its Impact on Peace-Building, Transitional Justice, and Guarantees of Non-Repetition[1]

Oscar Parra Vera[2]

1. Introduction

One of the aspects of the climate emergency that is relevant to examine in depth in comparative law is related to the relationship between this crisis and peacebuilding, particularly in transitional justice processes. Indeed, land dispossession and forced displacement, among other serious crimes, have been associated with one of the main factors that has triggered violence: inequity in land distribution and serious problems of access to land. The greater the devastation of land, the greater the levels of war and armed conflict. This devastation of land has generated massive population displacements, greater vulnerability for peasants and other specially protected groups, extreme poverty, as well as problems and challenges for investment to transform marginal situations, particularly in rural areas.

It is therefore important to analyze the impact of the climate emergency as a factor that accelerates violence and armed conflicts. One of the issues that may be related to this impact concerns the type of victimization that can be found in nature as a subject of rights. As I will explain in this text, it is possible to find in comparative law the consolidation of categories such as "territory as victim," the recognition of diverse subjectivities around nature (rivers as victims of armed conflict, for example), as well as the qualification of diverse crimes against nature in the framework of international criminal law.

The climate emergency can also have a very negative impact on the implementation of peace agreements related to the land issue. Indeed, the crisis may make land restitution unfeasible, either because the dispossessed lands are subject to devastation or non-viability, or because it becomes unfeasible to guarantee to various collective subjects (such as ethnic peoples) the enjoyment of the land with which they have a special connection for the development of their uses and customs. The climate emergency may make several dimensions of reparation

[1] Translated from Spanish with DeepL.

[2] Magistrate, Colombia's Special Jurisdiction for Peace.

measures and guarantees of non- repetition unfeasible. By generating more problems in land distribution, the climate emergency may generate the emergence of new wars associated with dispossession and food insecurity.

On these issues, Cárdenas and Rodríguez (2004) and Echavarría *et al.* (2023) have highlighted complex and multifaceted causal relationships between armed conflicts and nature. In their view, control of natural resources has historically motivated territorial conquests and state and interstate wars.[3] Furthermore, armed conflicts have been exacerbated in highly biodiverse areas[4] and have increased the dynamics of warfare around the control and exploitation of natural resources.[5]

As the context, dynamics and consequences of armed conflicts have been studied in greater depth, it is possible to understand that there is a close relationship between war and the environment, influencing the causes that generate a conflict, its duration and perpetuation over time, and the consequences it has on the development of a society. As stated by Echavarría, *et al.* (2023), these relationships can even cause other risks of violence and aggravate them, manifesting themselves in situations such as food insecurity, gender-based violence, economic crises, and migration.[6]

These interactions between armed conflict and the environment contextualize why climate emergencies can have a negative impact on peacebuilding and should be analyzed in the framework of transitional justice. At this point, Brankovic (2023) argues that the relationship between transitional justice and climate justice is an opportunity to imagine, implement and expand the field of action of a transformative transitional justice. Thus, transitional justice

[3] M. Cárdenas & M. Rodríguez Becerra (eds.) (2004) GUERRA, SOCIEDAD Y MEDIOAMBIENTE, Foro Nacional Ambiental, Fundación Eberth Stiptung Colombia, Universidad de los Andes. Bogotá D.C.; Echavarría Á., *et al.* (2023) *Towards a sustainable peace: An analysis of the implementation of the Final Agreement and its relationship with the environment*, Peace Accords Matrix/Kroc Institute for International Peace Studies/Keough School of Global Affairs.

[4] See among others, D. Rodríguez, C. Rodríguez, & H. Durán (2017), who, based on an exhaustive review of the literature, highlight that 81% of the armed conflicts that occurred globally between 1950 and 2000 took place in areas of high biodiversity. D. Rodriguez, C. Rodriguez, & H. Duran (2017) ENVIRONMENTAL PEACE: *CHALLENGES AND PROPOSALS FOR THE POST-AGREEMENT*, Documents 30 Ideas para Construir la Paz, Derecho Justicia y Sociedad De Justicia.

[5] United Nations Environment Programme (2009) From conflict to peacebuilding: The role of natural resources and the environment.

[6] Echavarría, Towards a sustainable peace, 28.

becomes a tool to think through climate solutions creatively, address damages caused against the environment and accountability for past and future actions.[7]

Within this framework of discussion, this text focuses, first, on an analysis of the way in which the devastation of nature encourages armed conflict and prevents or hinders peacebuilding. Second, it analyzes the handling of “nature as victim” in the Truth Commission and the Special Jurisdiction for Peace in Colombia. Third, it assesses the role of reparations concerning serious environmental damage. These decisions and reports make visible the path taken by Transitional Justice in Colombia in the identification and determination of the damages caused, how environmental crimes are charged, and the pending challenges in restorative matters.

2. The Devastation of Nature as a Cause of Armed Conflicts. Natural Resources as Sources of Financing and Perpetuation of Armed Conflicts

The struggle for access, control, exploitation and income distribution of natural resources triggers tensions and disputes as an underlying factor of armed violence.[8] Hence, in highly biodiverse areas, armed confrontations over territorial control and exploitation of their resources are constant, especially when these tensions are exacerbated in social contexts of poverty and lack of opportunities.[9]

Natural resources are a direct source of financing for the actors in an armed conflict. Competition for their access, control, exploitation, and income distribution triggers a multifaceted relationship that produces violence.[10]

Areas rich in biodiversity have been used to strengthen means of financing conflict actors through extractivist activities such as logging, illicit crops and illegal mining. Rodríguez, Rodríguez and Durán (2017) highlight two types of negative impacts caused on the environment: direct damage and indirect damage.

[7] J. Brankovic (2023) Transitional and Climate Justice: New Opportunities for Justice in Transition, THE INTERNATIONAL JOURNAL OF TRANSITIONAL JUSTICE 17, 185-191, 183-186.

[8] Rodríguez, Rodríguez, & Duran, ENVIRONMENTAL PEACE, 20-26.

[9] *Id.,* 19.

[10] *Id.,* 17

A. Direct Damages

Direct damages arise from actions carried out by those involved in the conflict, in which the natural environment is intentionally attacked. International jurisprudence has built a broad line around the imputation of crimes related to the indiscriminate attack on the environment, being "Ecocide" the criminal type that best suits the intentionality of intentional damage against the environment.[11]

The different armed groups that existed/exist have obtained part of their resources by exploiting or taxing extractivist activities such as coca, timber, gold, and charcoal.[12] In Colombia, the diversity of armed actors: guerrillas, paramilitary groups, criminal and drug trafficking gangs, have historically confronted each other in key areas that affect the dynamics of territorial control and resource exploitation, under the logic of achieving different objectives. In this regard, the Peace and Reconciliation Foundation points out:[13]

> Illegal armed groups derived part of their livelihoods from the exploitation or taxation of extractive economies, from coca to gold, timber and charcoal. This implies a high involvement of strategic ecosystems in the areas of influence of illegal and war economies. The natural and geographic conditions of the Colombian territory have always played a determining role in sustaining and strengthening the insurgencies (...)
>
> The areas covered by forest layers were always strategic for the hiding of insurgencies and the construction of camps. It is for this reason, among others, that the guerrillas were historically consolidated in the territories as control agents against the phenomena of land grabbing and the legal and illegal logging of forests.

Some of the objectives pursued by the armed actors in the Colombian conflict include:

i) Territorial control of routes for the production and trafficking of illicit substances and narcotics,

ii) Territorial control of areas with non-renewable natural resources of high commercial value (gold, emeralds, coal, and oil) for their clandestine exploitation and/or illicit

[11] *Id.,* 23-26.

[12] I. Pardo (2022) The role of natural resources in Colombia's armed conflicts.

[13] Peace and Reconciliation Foundation (2018) *War and post-conflict in Natural Protected Areas. Peace, post-conflict and human rights line*.

commercialization (causing the contamination of rivers with mercury and cyanide, causing damage to the geography and its natural wealth).

iii) Attacks against nature motivated by political reasons and/or with State involvement, which have caused contaminated bodies of water and losses and impacts on water sources and wetlands.

It should be emphasized that authors such as Neira, *et al.* (2019), have estimated that, although the notion of 'ecocide' covers a varied semantic field, in all cases, it aims to make visible anthropic damages with such a high severity to the environment, which endanger the bases of survival of both human beings and many other species, constituting a crime that must be punished.[14]

The environmental degradation generated by the blowing up of oil pipelines by some actors in the conflict, the environmental consequences of illicit crops, the use of harmful chemicals (such as mercury and cyanide) in illegal mining, logging, hunting of animals, use of water resources and the generation of untreated waste are some of the many examples of these types of crimes that have had an impact on the dynamics of the conflict in Colombia.

As estimated by Molina *et al.* (2022), logging and deforestation have direct negative socio-environmental effects due to their destructive action, impacting fauna and flora and fragmenting communities, who live the drama of experiencing the destruction of their habitats and the tactical pressure of intimidation by criminal agents. "Thus, the drivers of deforestation severely destabilize the physical, mental and psychological well-being of local peasants and indigenous people."[15]

B. Indirect Damages

Indirect damages relate to actions that impact the environment without necessarily having been the main intention of the participants in the conflict.[16]

[14] H. Neira, L. Russo, & B. Álvarez (2019) *Ecocidio*, Fruto parcial del proyecto 1181322, Comisión Nacional de Investigación, Científica y Tecnológica, Chile, REVISTA DE FILOSOFÍA 76, 131.

[15] D. E. Molina-Orjuela, S. G. Chavarro Ospina, & B. O. Guzmán Alvarado (2022) *Impactos del conflicto armado colombiano sobre el medio ambiente y acciones para su efectiva reparación*, REVISTA CIENTÍFICA GENERAL JOSÉ MARÍA CÓRDOVA 20(40), 1098-1099.

[16] J. McNeely (2004) *Conserving forest biodiversity in times of violent conflict*, Cambridge University Press.

Indirect damages are visible in State policies when the investment previously made in environmental conservation and protection and/or environmental institutions is considerably reduced, or when a conflict actor forces the migration of people to a specific territory, and causes without estimating it an imbalance in the availability of natural resources in such territory.[17]

In the Colombian case, the government has for many years used as an anti-drug policy the fumigation of illicit crops, consisting of spraying chemical herbicides to confront and curb these illegal activities. However, as reported by the World Wildlife Fund, this strategy has had a variety of social effects and harmful consequences for the natural environment and people's health:[18]

> (...) A 2015 study by the World Health Organization (WHO) revealed that glyphosate can cause four types of cancer: hepatic, pancreatic, kidney and lymphatic. (...)
>
> Aerial spraying is associated with the displacement of people living in the sprayed territories, given the impact of spraying on self-supply crops and contamination of water sources (...) aerial spraying not only kills the coca leaf, but also eradicates everything that has been planted in a territory, putting at risk biodiversity, the minimum vitality and livelihoods of some vulnerable populations.

3. Nature from the Perspective of Transitional Justice in Colombia: Climate Justice and Peace Building

As noted, armed conflicts often have a catastrophic impact on the environment, pollution, disruption and destruction of biodiversity are common consequences. Affected infrastructure and lack of environmental regulation during conflicts can have long-term effects on the health of ecosystems and communities.[19] All these aspects must be valued in peacebuilding processes that arise in the framework of negotiations to end armed conflicts.

The relationship between climate justice and transitional justice should therefore be explored. Climate justice seeks to address the grave injustices of climate change by promoting

[17] Rodríguez, Rodríguez, & Duran, ENVIRONMENTAL PEACE.

[18] Word Wide Fund for Nature (2022) Banning glyphosate spraying: Colombia's moment.

[19] Comité Internacional de la Cruz Roja (2019) El medio ambiente natural, una víctima olvidada de los conflictos armados.

transparent decision-making processes, a fair distribution of natural resources, and recognition of the value of the diverse ontologies and epistemologies associated with the protection of nature. On this point, Brankovic (2023) believes that most of the existing literature on the relationship between transitional justice and climate justice has been limited to a reformist approach that "focuses on technical, market-driven solutions [and aimed at] adopting minimal alternatives to appease criticism rather than generating changes in power dynamics or resource redistribution."[20]

Alternatively, their wager is to not only apply the basic mechanisms of transitional justice to address the climate crisis in new ways, but also to learn from critiques of transitional justice to consider a broader and more transformative approach.[21] This involves using intersectional processes as a means to analyze historical inequalities and identify synergies between a range of different stakeholders, which can enable new and innovative solutions to crises to emerge.[22]

Thus, the relationship or overlap between transformative transitional justice and climate justice presents new possibilities in both research and practice. Climate justice pushes transitional justice to take into account *something beyond the human being* and to address potential transboundary harms. In turn, transitional justice gives climate justice the experience of the possibility of normative change in retrospective and forward-looking processes.[23]

In sum, the link between climate justice and transitional justice allows for the creation of transformative transitional justice. It demonstrates that looking beyond international and state mechanisms allows other practices (including emerging practices) to be understood as transitional justice measures, such as those that are community-based and focused on victim participation.[24]

Under these notions, the following are some of the insights provided by the Integral System for Peace in Colombia and its Institutions, which consolidate a historical path towards the understanding of new cosmovisions, ontologies and concepts regarding the understanding of

[20] Brankovic, Transitional and Climate Justice, 185.

[21] *Id.*, 185.

[22] *Id.*, 187.

[23] *Id.*, 188.

[24] *Id.*, 188.

the armed conflict from an environmental vision as a mechanism of transformative climate justice, aimed at addressing the climate crisis as a complex phenomenon.

A. Nature as a Sentient Being Subject to Pain: Contributions of the Truth Commission

Birds of life that turn into birds of death when they sing in a strange way or suddenly stop singing. Blood moons, rambunctious bees, dogs barking at the wrong time. Signs that can also be read as warnings, as symptoms of a rarefied ecosystem. The first to notice them can be the trees, the animals, the natural elements. Those sensitive forms that, likewise, have witnessed, suffered and participated in the war.

"Emissaries of Nature."[25]

The Commission for the Clarification of Truth, Coexistence and Non-Repetition ([La Comisión para el Esclarecimiento de la Verdad, la Convivencia y la No Repetición] CEV), as a state institution of transitional character created for the vizualization of the patterns and explanatory causes of the internal armed conflict, conceived in its testimonial volume "*when the birds did not sing*" a notion of nature as a sentient being**.** In her words:[26]

> (...) nature is more than a stage or a theater of operations. On the contrary, it is the cause of confrontation, a sentient being whose voice demands particular attention. Another challenge for our society is to learn to listen to nature. The question then arises: is nature's pain a form of truth? Yes, if we accept that forests or mangroves have a feeling that we have disregarded. Accepting that pain allows us to relate to nature as a victim, a witness of its suffering and that of others who coexisted with it.

In this sense, one contribution of the work of the Truth Commission in Colombia was to overcome a vision of transitional justice focused exclusively on an anthropocentric vision, that is, one that revolves solely around the human being. In the Commission's report it is possible to see a critique of this model. It takes up again a vision of nature as a subject of rights, but delves into nature as a sentient being**,** affected by the war and where landscapes were affected. In this sense, the Commission sought to make visible the way in which places that

[25] Comisión para el Esclarecimiento de la Verdad, la Convivencia y la o Repetición (CEV) (2022) Informe "Resisting is not enduring. Violence and harm against ethnic peoples in Colombia".

[26] *Id.*

have been, for example, filled with landmines, are places that have radically transformed their landscape, the conditions of use, the daily life of that place.[27]

The CEV goes beyond a vision of the armed conflict that concentrates exclusively on the human being, whether as victim or victimizer. The report delves into the way in which natural environments, ecosystems and species also suffered affectations and alterations in their habitats, forcing them to reinvent themselves in order to remain there. This vision of the Commission for the Clarification of the Truth is reinforced in the sixth finding of its report *"Resisting is not enduring. Violence and harm against the ethnic peoples of Colombia"*, where the CEV (2022) considers that:[28]

> (...) as living integrity and sustenance of life and cultural identity, territory and nature were victims of the armed conflict. These suffered multiple damages and were desecrated by the violent actions of armed groups in association with economic or political sectors that benefited from the conflict.

This environmental degradation in the context of the war has generated alterations in the climate and biodiversity of the planet. The CEV frames nature as a victim of the Colombian conflict in light of three central axes: i) environmental degradation, ii) extinction of flora and fauna species, and iii) cultural loss. These precisions are relevant to think about the corresponding reparations for the recovery of the territories affected by the violence, as well as the loss of animal and forest species. The concept of cultural loss refers to the existence of emotional, psychological, moral, political, and socio-cultural damage caused by actions against the environment, which have triggered collective effects on communities, linked to attacks on the links and relationships with biodiversity that forge their identity.[29]

This notion of nature as a victim of armed conflict has also been developed in several decisions of the Special Jurisdiction for Peace (SJP), as explained below.

[27] L. Sánchez (29 August 2022) *Una conversación con Alejandro Castillejo, comisionado de la verdad*, Universidad de los Andes [Video], YouTube.

[28] CEV, Informe, 28.

[29] L. Rincon (2022) *La naturaleza en el conflicto armado*, Departamento de Medio Ambiente, Universidad de los andes.

B. The Special Jurisdiction for Peace, the Territory as Victim and the Imputation of Environmental Crimes as International Crimes

In this segment, we will analyze how (i) the environment and the territory have been valued as victims in the framework of the macro-cases promoted by the SJP. We will also study (ii) various challenges associated with the determination of damages, (iii) the imputation of crimes against the environment and (iv) the restoration of the damage caused.

I. Territory and Nature as Victims in Transitional Criminal Justice Processes

In making visible the multiple forms of violence and the serious impacts that occurred in the context of the armed conflict, the SJP has pointed out that such violence "(...) was not only directed against human life, but also against the life of the territory and the existence of all beings and spirits that inhabit it, as well as their way of living, understanding, giving meaning and relating to each other and to the natural world, which are characteristic of ethnic peoples."[30]

The first of these judicial decisions was reflected in the framework of a territorial case of the JEP, case 02,[31] where the Chamber for the Recognition of Truth, Responsibility and Determination of Facts and Conduct (SRVR), recognized as an accredited victim of the armed conflict the Katsa Su territory, of the Awá People, by means of Auto SRVBIT - 079 of November 12, 2019. In the words of the JEP, in this recognition:[32]

> (...) the ancestral territory acquires all the rights of any other victim to obtain the rights to truth, justice, reparation and the guarantee of non-repetition. In this sense, its inclusion as a victim draws attention to the possibilities of making visible a series of damages and impacts of the armed conflict that extend beyond human beings, understanding that the territory is inseparable from the people and recognizing the profound interrelationships of indigenous peoples, black and local communities with the territory they inhabit.

[30] Jurisdicción Especial para la Paz (JEP) (2022) *The environment as a silent victim*, Un diagnóstico de las afectaciones en el posacuerdo (2017 - 2022), Unidad de Investigación y Acusación.

[31] This case was opened by the Recognition Chamber on July 10, 2018, having as its main focus the prioritization of the territorial situation in the Department of Nariño, in relation to the serious problem of Human Rights violations and serious affectations to International Humanitarian Law, which impacted indigenous communities, Afro-Colombian groups, black population, peasants, women and LGBTI people in the municipalities of Tumaco, Ricaurte and Barbacoas.

[32] JEP, *The environment as a silent victim*.

Recently, last July 11, 2023, the JEP accredited the Cauca River as a victim of serious affectations suffered in the armed conflict in Colombia. For the JEP:[33]

> between 2000 and 2004, a systematic conduct permitted by the public forces, and carried out by paramilitary groups, consisted of murdering people and throwing them into the Cauca River so that they could never be found. This not only affected the lives of these people, but also the environment. Thousands of corpses were thrown into the river. This affected its waters, the species that inhabit it and profoundly damaged the relationship of dozens of ethnic communities with nature.

Underlying these decisions is a debate between cosmological and ontological views on how nature should be valued in the context of judicial processes. The challenge is how to harmonize anthropocentric approaches, from an ethnic point of view, but also from other vulnerable non-ethnic communities such as the ecocentric approach.

Now, with regard to the extended impacts beyond *the human*, the JEP (2022) has justified the need to abandon the anthropocentric paradigm of nature. In their words:[34]

> (...) From a philosophical and legal perspective, four powerful reasons stand out for abandoning the anthropocentric paradigm. First, because the legal protection of the ecological environment guarantees the satisfaction of fundamental rights such as life, water and health. Secondly, because it protects the rights of future generations, since they are the ones who inherit the negative impacts of the predatory actions of human beings in the present and the past. Thirdly, because the sustainability of life on earth itself is compromised when the purely profit-oriented vision is imposed and nature is seen as a permanent instrument for plundering and the production of economic wealth. And, fourthly, because the legal recognition of certain abiotic elements as subjects of rights allows for the restoration of the damage caused and, in this way, the satisfaction of guarantees of non-repetition.

In this way, a new way of recognizing environmental rights can be glimpsed, which can contribute greatly to the anthropocentric detachment that limits climate justice.

[33] *Id.*

[34] *Id.,* 21-22.

In the first place, as I pointed out in a clarification of vote to the first imputations in this matter, it is possible to evaluate nature from two approaches: the first, conceiving it as a "resource that must be allocated and managed efficiently for the benefit of human beings," and the second, seen as "a subject of rights and not as an object of human exploitation."[35] On this point, in assessing the first decisions of accreditation as victims to the territories of indigenous communities, Huneeus and Rueda (2021) have pointed out that:[36]

> "these applications made by the Awá, Nasa and Sia in particular, hold in themselves the suggestion that there is something about the spiritual bond between the Colombian rural population and their land that even peoples who do not identify themselves as indigenous or black Colombians can learn from."

Huneeus and Rueda (2021) assert that these resolutions are intended to emphasize that, on the one hand, these ethnic groups are distinct from the majority and should be treated differently and, on the other, that there is something universal, albeit forgotten, in the bond with the land that they articulate. They also argue that it is implicit in the way indigenous petitioners juxtapose their views with those of "Westerners," or compare their care for the land with the damage caused by Western ways of relating to it.

Now, it has been argued that by formally accrediting and recognizing the ethnic territories of indigenous peoples and Afro communities as collective victims of the armed conflict and as subjects of rights and reparations, the SJP recognizes that the effects of the armed conflict go beyond the rights of humans and include other non-human forms of life, thus adopting a biometric posture.[37] However, both positions are ultimately epistemologically anthropocentric, in the sense that both are expressions of very human constructs, reflecting the human understanding of what is "*human*" and what is "*nature*" and of the relationship between both concepts.[38]

[35] O. Parra (2023) Clarification of vote of Magistrate Oscar Parra Vera regarding the SRVR Order No. 001 of 2023 (Case 05), 15 March 2023, Chamber for the Acknowledgment of Truth, Responsibility and Determination of Facts and Conduct. Special Jurisdiction for Peace, ¶ 46.

[36] A. Huneeus & P. Rueda Sáiz (2020) *Territory as a Victim of Armed Conflict*, INT'L. J. TRANS. JUST. 15(1), 228.

[37] L. Ordóñez-Vargas, L. C. Peralta, & E. Prieto-Rios (2023) *An Ecocentric Turn in the Transitional Restorative Justice Process in Colombia*, INT'L. J. TRANS. JUST. 17(1), 9.

[38] Parra, Clarification of vote (Case 05), ¶ 53.

A purely eco-centric approach, which understands nature as a subject of rights due to its intrinsic value and alien to the human link, could lead to the disregard of the historical presence of communities in the territories. For this reason, the search for strategies that promote the indivisible and interrelated link between human beings and nature has been promoted.[39]

In this regard, I agree with Ordoñez *et al.* (2023), in estimating that in the current Colombian transitional model "anthropocentric, eco-centric and bio-centric visions converge and coexist, and consider nature both as an exploitable object and as a subject of rights."[40]

Thus, it is important to emphasize that nature is a victim in itself. Both in terms of its impact on indigenous groups[41] makes visible various components of the special relationship of these peoples and can be harmonized with scenarios of reparation to nature in the sites geographically linked to these communities. This requires starting with transitional criminal justice charges that, beyond focusing on the anthropocentric requirement of affecting human beings, give due importance to crimes that protect nature as such. I believe that this is the step taken by the Special Jurisdiction for Peace in the first indictments developed in 2023, as I explain below.

II. Imputation in the Territorial Situation of the Municipalities of Tumaco, Ricaurte and Barbacaos

The SJP has made progress in determining patterns of macro-criminality associated with the commission of environmental crimes. In a first decision on the matter, focused on the territorial situation in the region of northern Cauca and southern Valle del Cauca (macro case 05), the SJP charged 14 war crimes and crimes against humanity to 10 members of the Jacobo Arenas and Gabriel Galvis mobile columns of the FARC-EP.

The JEP charged, among other crimes, the destruction of the environment, attacks against the civilian population, the use of anti-personnel mines, murders and disappearances of leaders

[39] *Id.*, ¶ 65.

[40] Ordóñez-Vargas, Peralta, y Prieto-Rios, *An Ecocentric Turn*, 15-16.

[41] However, from a point of view beyond the ethnic peoples involved, the ecocentric perspective means that the entity of the object of protection covered by environmental crimes must be based on the protection of the environment itself, and on its relational elements, which make it a complex entity of rights. Parra, Clarification of vote (Case 05), ¶ 64.

of ethnic and peasant communities, persecution, recruitment and use of children and adolescents in the context of the conflict.[42] For the JEP:[43]

> "The [FARC] affected the environment in a widespread and lasting manner [...] by installing mines, carrying out attacks with explosives, and violently invading indigenous and Afro- descendant territories, especially affecting the páramos located in the region. They also charged for activities such as the sale of coca and marijuana, and illegal mining, obtaining substantial resources from activities that deeply affected the region's ecosystems."

Likewise, the Chamber explained that the evident consequences on nature affected not only the people living in the area, but also "*autonomously the environment of the area and especially the territories*," emphasizing the importance of recognizing the environment as a victim of the conflict.

Thus, the Chamber of Recognition considered the existence of a symbiotic relationship between human rights and environmental rights, in such a way that one cannot be understood without the other, and there is an obligation to take a cross-cutting view of environmental impact that not only focuses on human beings, but also examines their relationship with the territory and the impacts on the environmental balance.[44]

Thus, the SRVR recognized that the illegal mining activities[45] and the agricultural reconversion for the production of illicit crops[46] reflected two of the activities, drivers of violence, that unleash

[42] JEP, *The environment as a silent victim*.

[43] *Id.*

[44] *Id.*

[45] For the Chamber, "it is impossible to assume that illegal mining, carried out without any technical protocol of care, could have been carried out at that level and intensity without the consent of the FARC-EP. For the former guerrillas, the extraction of precious metals became a generous vein that allowed them to obtain resources in a rapid and sustained manner. But the consequences were not long in coming. This activity dealt a severe blow to the enormous biodiversity of the area, altered the relationship of the communities with their ancestral lands and left an indelible mark that will forever mark the passage of the war." JEP (2023) Order of Determination of Facts and Conduct, Case 05, SRVR 001, 1 February 2023, ¶ 524.

[46] For the JEP, "illicit crops in turn promoted a particular concentration of effects on the environment. Their development created a vicious circle driven by the expansion of a productive frontier to make land available for this type of production. Just one of these activities has the power to produce an irreparable impact. The combination of the two generates environmental damage whose footprint may be totally irreversible". Id., ¶ 524.

extensive impacts of the war on nature.[47] According to the Chamber, the ambiguous attitude of the FARC-EP ended up generating serious effects on the environment:[48]

> "Disturbances such as the planting of illicit crops in locations typical of paramos generated variations in the structure and composition of the same, which resulted in a decrease in species and microorganisms in the area, these results were the product of activities derived from agriculture, such as the invasion of exotic weeds, the loss of organic matter and soil nutrients, and the use of agrochemicals such as pesticides and herbicides which resulted in the destruction of the soil structure and therefore the water retention capacity."

In accordance with these considerations, the Chamber determined a route of responsibility for the guerrillas belonging to the extinct FARC-EP, linked to the notion of "de facto environmental authority in the zones of influence," concluding based on its procedural pieces that the FARC-EP "did not have an active policy to prevent the damage caused by illegal mining and illicit crops. In reality, they were only a rent-seeking authority to finance their operations."[49]

In conclusion, for the JEP, the FARC broke with the environmental balance of the region, in the framework of this complicity with illegal mining and the expansion of the illicit agricultural frontier. These activities left a drastic footprint on the environment, one that will probably take generations to erase.[50]

Regarding the determination of the victims of these crimes, the SRVR estimated that there were individual[51] and collective impacts that fell on the communities of northern Cauca and southern Valle del Cauca, making it clear that "the greatest burden of the conflict was borne by the most marginalized and excluded communities, concentrated mainly in the ethnic and Afro-descendant populations."[52]

[47] JEP, *The environment as a silent victim*.

[48] *Id.*

[49] *Id.*

[50] *Id.*

[51] Likewise, the Chamber considered the repercussions of these effects on non-ethnic or racial communities, such as the peasant population settled in the territory. JEP, Order of Determination of Facts and Conduct.

[52] *Id.*

Charges of war crimes for environmental and territorial damages. Addressing the legal qualification of the crimes committed by the FARC-EP, the Chamber considered that environmental damage by the FARC-EP constituted a crime not subject to amnesty, in accordance with applicable law, insofar as such conduct could be qualified as war crimes and constituted a violation of fundamental rights recognized by international law as part of the crime of persecution.[53] The Chamber of Recognition also stated that the "ethnic, racial, territorial and environmental approaches would be applied simultaneously and in a complementary manner, with a view to ensuring that the anthropocentric and eco-centric perspectives of environmental protection complement, rather than contradict, each other."[54]

Thus, the SRVR proceeded to describe the protection of the environment[55] in international humanitarian law (IHL) – where its disproportionate impact was considered a serious violation of IHL – and then, in international criminal law (IPL) – considering applicable criminal norms related to the destruction of the environment and the precautionary principle.[56] Thus, the chamber decided to use the war crime of Article 8(2)(e)(xii) of the Rome Statute[57] consisting of: "Destroying or seizing property of an adversary, unless the necessities of the conflict make it imperative."[58] In their words:[59]

> "The IPR protects individual and collective legal goods through multiple crimes (...) The environment has a very special nature, since in addition to enjoying an autonomous protection, it is embodied in places and material objects that have a legal regulation through the law of goods. Therefore, with regard to internal conflicts, the protection of

[53] *Id.*

[54] *Id.*

[55] For the JEP (2023), environmental damage could qualify as crimes against humanity, from an anthropocentric and cultural perspective, as well as the war crime of environmental destruction, which recognizes that the environment is a victim in itself. JEP, Order of Determination of Facts and Conduct, ¶ 1006

[56] JEP, *The environment as a silent victim*.

[57] The elements of the war crime in Article 8(2)(e)(xii) "destroying enemy property or appropriating enemy property" are as follows: "1. that the perpetrator destroyed property or seized property; 2. that such property was owned by an enemy party; 3. that such property was protected from destruction or appropriation under the international law of armed conflict; 4. that the perpetrator was aware of the circumstances establishing the status of the property; 5. that the destruction or appropriation was not justified by military necessity; and 6. that the conduct took place in the context of and was related to an armed conflict that was not of an international character." (ER, Article 8, 1998).

[58] JEP, *The environment as a silent victim*.

[59] *Id.*

> the environment can also occur through crimes related to the protection of property, which does not exclude the importance of its autonomous protection, but rather highlights the pluriofensive nature of this type of conduct."

The SJP pointed out that this war crime could occur when the attack is directed against the adversary's property of a public or private nature, including those of a civilian nature – as is the case with the environment. Thus, it was affirmed that the attack on natural resources by the FARC- EP also implied an attack on the State understood as an adversary in the armed conflict.[60] In addition, the Chamber added that the environment within the framework of the prioritized territory (i) was protected because it did not offer a definitive or imperative military advantage, nor does it fall within the necessity established by the ICC when "*the perpetrator has no other option*" than to destroy the property, which was not present in the case of attacks on the environment.[61]

Likewise, the SRVR reinforced its categorization as a war crime in accordance with the jurisprudence of international criminal law in the *Tadic* case, corroborating the elements necessary to determine the effects on the environment in the prioritized territory as: a violation of sufficient gravity that violated the principle of distinction in that:[62]

> "(...) The environment is considered a civil good. Concurring with the fact that consequences were generated for the ethnic communities by affecting their identity in terms of their direct relationship with the territory as part of their cosmovision and the traditional exercise they have over it; thus generating a direct violation of their human rights and the prohibition of discrimination under international humanitarian law."

Thus, the SRVR concluded that the environmental damage in the prioritized territory, in accordance with the patterns of macro-criminality determined in the Chamber,[63] constituted a generalized conduct that disregarded the principles of precaution, distinction and

[60] JEP, *The environment as a silent victim*.

[61] *Id*.

[62] *Id*.

[63] Including the systematic use of personal mines, the serious effects on ethnic and non-ethnic communities in the territory, and the methods of warfare used in the framework of the conflict. JEP, Order of Determination of Facts and Conduct, ¶ 1043-1045.

proportionality, and that its investigation, prosecution and punishment was appropriate in accordance with IHL, IPR and domestic law.[64]

Finally, the SRVR also ruled on the admissibility of the crimes against the environment attributed to the FARC EP in the prioritized territory, stating that i) they constitute a conduct that the State has the obligation to prosecute and punish, ii) they were not subsumed in crimes of a political nature and iii) they constituted serious violations of human rights, IHL and domestic law – particularly due to the multicultural nature of the Colombian State and the differentiated protection of its ethnic population.[65]

On the other hand, the JEP emphasized that "the impacts on nature that occurred not only affected the people who inhabited the area, but also autonomously the environment of the area and especially the territories, since it is a crime of pluriofensive nature." In this way, he recalled that crimes against the environment and its natural resources imply the recognition of victims other than individual human beings, including in some cases elements of nature and communities in the area. Thus, it emphasized the profound effects suffered in the specific case of the Inga, Kokonuko, Misak, Totoro, Yanacona, Nasa peoples, among others, where the effects caused to the environment by the war – illicit crops, illegal mining, among others – not only caused damage to natural resources but also deteriorated the autonomy, unity, solidarity, identity and culture of these peoples and communities.[66]

For the court, these environmental damages caused extensive damage – due to the density of the geographical area and territories affected-, lasting damage – due to the long recovery period implied by the damage – and serious – due to the disturbance and/or significant damage to human life, natural economic resources, and other assets, affecting the composition of the national ecosystem's own cycle.

In a second indictment, corresponding to the territorial situation in the municipalities of Tumaco, Ricaurte and Barbacoas in the Department of Nariño, the JEP charged 15 members of the Mariscal Sucre and Daniel Aldana Mobile Columns and the 29th Front of the Western Alfonso Cano Bloc of the extinct FARC-EP with war crimes and crimes against humanity. They were charged with, among other crimes, the destruction of territory and nature, attacks against

[64] JEP, *The environment as a silent victim.*

[65] *Id.*

[66] *Id.*

the civilian population, the use of anti-personnel mines, murders and disappearances and forced displacements, persecution, recruitment and use of children and adolescents in the context of the conflict.[67] Serious, differentiated, and disproportionate damage to the population, Indigenous peoples[68] and territory.[69]

Among the profiles of the victims in Case 02 were leaders and authorities, children, civilians, teachers, families living in extreme poverty, peasant communities, urban and rural populations, people with diverse sexual orientations and gender identities and expressions (OSIEGD) and the Territory and Nature of the prioritized municipalities.[70]

For the SRVR, between 1990 and 2016, the FARC-EP, in the framework of the implementation of the policy of social and territorial control, carried out 71 acts of destruction against Nature, the Katsa Su Gran Territorio Awá, the Eperara Euja Territory of the Eperara Siapidaara and the ancestral Territory of the Black and Afro-Colombian People, of the Lands of Peasant Communities and of the urban population. These activities of destruction of nature corresponded to systematic actions consisting of the dumping of crude oil derived from the attacks against the infrastructure of the Trans-Andean Pipeline and the control and development of illegal gold mining activities. As can be seen, the territories of the Peoples and Communities were interpreted as spoils of war, central to the political, military, and economic ends of the FARC.[71]

For the Chamber of Recognition, these violations consolidated a macro-criminal pattern of destruction of nature and territory, corresponding to a dual geostrategic interest: 1) the purpose of exercising and expanding their territorial authority over the State, regional society and its ecosystems by demonstrating their capacity to dispute, blockade and destroy the State's oil

[67] JEP, *The environment as a silent victim*.

[68] Between 1995-2012 there were at least 166 homicides of indigenous people belonging to the Awá People; between 2003 and 2017 there were 10 massacres, of which 57 victims were killed; between 2002 and 2012 there were at least 18 mass displacements, leaving 1,530 people as victims.

[69] Such as: Deaths caused by landmines, forced economic exploitation, confinement and forced displacement, extrajudicial executions, attacks on the region's electrical infrastructure, recruitment and use of indigenous and Afro- Colombian children, sexual and gender-based violence against women and girls and violence due to prejudice against people with diverse or non-normative sexual orientations and gender identities and expressions, destruction of Nature and Territory, among others. JEP, Order of Determination of Facts and Conduct.

[70] JEP, *The environment as a silent victim*.

[71] *Id*.; Parra, Clarification of vote (Case 02).

infrastructure and 2) the need to consolidate social, economic and environmental control over gold mining as a primary source of financing resources in the region.[72]

Regarding illegal gold mining, the SRVR estimated the concurrence of 13 facts that generated the destruction and contamination of nature in the prioritized territory, causing, among many other consequences:[73]

> "(i) the removal of soil on the banks of rivers and streams; (ii) the removal of vegetation cover using backhoes and bulldozers; (iii) the dumping of hazardous substances, such as cyanide and mercury; and (iv) the construction of artificial wells with leftover material from the removed soil."

These phenomena "triggered the degradation of the life, health and food of the multiple beings that inhabit these natural environments (...), weakening and in some cases disintegrating the natural, cultural and spiritual links of the Peoples and communities with the Territory."[74] For the SRVR:[75]

> "(...) the mountains, the mangrove swamp, the crop fields and all the diversity of living entities that have inhabited there were converted into a military objective, instrumentalized as a strategic resource to be exploited, contaminated and transformed into a source of financing for the war economy."

As a result, the SRVR estimated that there were high rates of contamination, degradation, and destruction of ecosystems rich in biodiversity, which, in the context of the prioritized territory, directly affected the complex socio-ecological relationships between the various living entities. It was then highlighted that the environmental impacts extended to urban populations and peasants in the region, generating a serious environmental crisis with severe socio-ecological effects that deepened the existing humanitarian crisis in these populations.[76]

Damage to the territory of ethnic peoples, peasants' lands, and urban society. The JEP has promoted an understanding of the damage caused from an intercultural perspective that

[72] *Id.*

[73] *Id.*

[74] *Id.*

[75] *Id.*

[76] *Id.*

takes into account the worldviews of ethnic peoples, peasant communities and urban societies. It has used what the JEP calls a "relational ontological approach," which considers the existence of a relationship with and in the territory, where the natural world does not reflect a relationship of domination, but is revealed as a social relationship, inseparable, and complementary "*to the extent that the entities that populate the territory manifest themselves as living*."[77]

With this understanding, the SRVR considered it appropriate to take a conceptual approach to the notions of territory according to each victimized population/community. With respect to ethnic peoples, it considered:[78]

> "For the Ethnic Peoples, the Territory is alive, it is an integral and interrelational living being, it is a subject of rights, it is the source of knowledge, protection, cultural identity, languages, their own law, traditional medicine, and food sovereignty. It is the guarantee to safeguard the cosmovision and the physical, cultural and spiritual survival, which is governed by the law of origin, natural law and its own law. The Territory is not understood in a horizontal or linear way, it is integrated by diverse worlds, diverse tutelary spirits, in diverse levels, all interrelated. Hence, the special relationship they have with their natural living spaces, which is not restricted to human relations, nor does it divide the human from the non-human."

Addressing this notion for Afro-Colombian Communities, he noted:[79]

> "For the Black Afro-Colombian People, territory is life and is the place where communities develop their culture, their identity and their existence as a collective subject. The right to territory for the Black Afro-Colombian People includes the protection of their ancestral territories, their collective forms of property, traditional production practices and internal organization processes (...) It is the space where they recreate their way of seeing the world, through rituals and daily activities such as: fishing, hunting, artisanal mining and agriculture through the development of mingas, mano cambiada, barter, gifts, among others."

[77] *Id.*

[78] *Id.*

[79] *Id.*

Valuing this notion for peasant communities, he considered:[80]

> "On the other hand, the peasantry, as a historical intercultural subject with memory, knowledge and practices, maintains a special relationship with the land and nature, through small-scale agricultural production forms, the reproduction of cultural practices, from which derives its political-organizational organization, characterized by being associative and family-based. (...)
>
> For the peasants, the land is the place where their culture is built from their daily activities of planting, harvesting, animal care, among others, a special relationship with the land and nature. There they develop their collective peasant identity through community, neighborhood and family life, where domestic animals are also their relatives; and through the different ways of working and caring for the land."

Finally, regarding the urban population and organizations, he highlighted:[81]

> "For the urban population, the natural environment, which includes beaches, estuaries, rivers and mountains, is the place where their culture, knowledge, food sovereignty, care for mangroves, mollusks and fish, and where zotea plants (chillangua, lemongrass, arnica, chirará, among others) are cared for."

It should be noted that the JEP identified environmental damage generated by the military strategies developed during the armed conflict. In effect, changes were determined in air quality due to emissions of polluting gases, geomorphic landscapes, in the physicochemical characteristics of the soil, the hydrological dynamics of rivers, the physicochemical and biological properties of water, the structure and composition of biodiversity (flora and fauna) and the structure and composition of fish populations by disrupting life cycles (for example, the spawning of female eggs). Likewise, the JEP determined changes in vegetation cover and decreased habitat for fauna in the territories, as well as a change in land uses.[82]

Regarding the qualification of crimes, an important aspect of this charge is the dialogue of the SJP with the systems of justice of the Ethnic Peoples in order to safeguard and respect ethnic and cultural integrity. On this point, legal pluralism is projected as a tool to prevent hegemonic

[80] *Id.*

[81] *Id.*

[82] *Id.*

legal systems from breaking into the worldview of these Peoples, in such a way that their rights and demands framed in transitional justice can be satisfied.[83]

Methodologically, what is promoted in this type of analysis is a vision from relevant national and international sources, but also arguing from the visions of the peoples and communities with respect to their territories. This is the only way to transcend from an anthropocentric vision to an integral vision. In this regard, the JEP points out that the understanding of the natural environment as a concept:[84]

> "has migrated from recognizing Nature and the Territory as a resource to be exploited for people and their benefit (anthropocentrism), to: (i) recognizing an equal value to all forms and expressions of life, regardless of their contribution, ecosystemic or economic role (biocentrism); (ii) to granting it a holistic perspective in which an interdependence of humans with nature is recognized (ecocentrism); (iii) an intrinsic link between nature and culture, and the diversity of the human species as part of nature and manifestation of multiple forms of life (bioculturalism); and (iv) an understanding of a web of life of interrelationships based on interactions with one another, i.e., "*all types of living beings depend on each other for their existence and are interwoven in a vast and continuously evolving web*.""[85]

The JEP highlighted the importance of including in its assessments the notions of "good living,"[86] specific to some ethnic peoples, "ecosophy," an element of the coexistence of some Afro- Colombian communities[87] and "ecoterritory,"[88] coming from visions of ethnic peoples,

[83] *Id.*

[84] *Id.*

[85] *Id.*, citing A. Escobar (2014) (A World of Many Worlds (2020), C. G. Bermudez (2020), and N. Pakari (2013).

[86] Quoting Pacari (2013), the JEP refers to the notion of Good Living of Sumak Kawsay for its connotations of holistic articulation with Pachamama, nature, it has to do with the legal-political institutionality and it has to do with a system of economy; and these dimensions that are intertwined with each other.

[87] On the notion of "ecosophy" the JEP (2023), citing Zapata et al (2015), refers that it evokes the strong inscription of the ecological in philosophical systems of the Afro-Colombian People: "[a]mong Afro-Colombians neither plants nor animals exist per se, but added, complemented and qualified through the word, by the minds of the people." Parra (2023) Aclaración de voto (Caso 02).

[88] ecoterritory, "alludes to the defense of the territory, understood as a place in which the ways of living and relating to the environment are inseparable from ecological and environmental disputes" (citing Olarte and Florez, 2021, P. 8).

peasant communities and social movements, as well as the visions and cultures of peasant communities of the natural environment.

Now, in accordance with these assessments, the Reconnaissance Chamber proceeded to conduct the imputation study of the war crime contained in Article 8(2)(b)(iv) of the ER, consisting of “Intentionally launching an attack, knowing that it will cause incidental loss of life, injury to civilians or damage to civilian objects or extensive, long-term and severe damage to the natural environment which would be manifestly excessive in relation to the concrete and direct overall military advantage anticipated.” In this regard, it was noted that, although this provision is part of the serious violations of the laws and customs applicable in International Armed Conflicts, the ER does not have a similar provision for Non-International Armed Conflicts, therefore, it proceeded to conduct the study of the requirements of the Tadic Test in the panorama of the macro criminality patterns determined.[89] In addition, the crime of destruction of cultural property and places of worship 8(2)(e)(iv) was charged.

As can be seen, the evolution of the jurisprudence of the SJP complements the initial assessment made of the imputation used in case 05, since the understanding of nature, exclusively as a civil asset, fell short as the only argument for its protection:[90]

> “(...) a relationship with the “*adversary*” should not be required. It is therefore considered that the application of Article 8(2)(e)(xii) ER may not correspond to the understanding of nature, territory and sacred sites that ethnic peoples have claimed. Also, this article could hinder a recognition of the environment as a human right of the collectivity, or even as a subject of rights with its own legal personality. Third, this provision could be insufficient to protect the environment, since neither the environment as a whole nor some of its parts, such as migratory bird species or straddling fish stocks, nor the high seas, outer space and the ozone layer, are entirely within the territory or jurisdiction of a State.”

[89] With respect to the requirements of this Test, the Chamber determined that it was indeed i) a violation of IHL, ii) existing in customary law iii) with serious consequences for the victims iv) attributable to individual criminal responsibility of the responsible actors. JEP, *The environment as a silent victim*; Parra, Clarification of vote (Case 02).

[90] Parra, Clarification of vote (Case 02).

4. The Dilemma of Environmental Remediation in the Implementation of Peace: Restoration of Environmental Damage in Colombia's Integral System

As this document has shown, the dynamics of violence and war have a terrible impact on nature. Therefore, the relationship with nature will also play a key role in peace building. Indeed, the implementation of peace agreements associated with conflicts over land and natural resources will be marked, among others, by the implementation of environmental laws and policies and the participation of citizens in environmental decisions.[91]

Therefore, one of the greatest challenges facing Colombian transitional justice is the reparation of nature and environmental reparation in a context of climate emergency such as the current one. In this regard, the JEP has opted for the implementation of a restorative system in order to coordinate the execution of its own sanctions and of the conditionality regime, seeking the due materialization of the restorative component of these sanctions, so that they are adequate to the needs and particularities of the victims.[92]

Regarding these own sanctions, the following should be noted. In relation to the implementation of the restorative component of the SJP, several types of sanctions were foreseen, among them, a type of restorative sanctions called "own sanctions." These sanctions do not involve imprisonment and are focused on those most responsible who provide full and detailed truth and accept responsibility before the SJP. The sanctions themselves have a restorative component that translates into work, works and activities with restorative-restorative content (hereinafter TOAR), and a retributive component that consists of the effective restriction of freedoms and rights. The JEP's sanctioning model represents a change to the retributive logic and the traditional prison model, since it is guided by a restorative paradigm that seeks to contribute to the reconstruction of social ties and reconciliation between victims and participants.[93]

Authors such as Echavarría *et al.* (2023) consider that the paths of reparation linked to the restoration and reparation of the environment imply a redirection of the TOAR in order to contribute to: i) the rehabilitation of the territory; ii) the restitution of territories to ancestral and

[91] Echavarría, *Towards a sustainable peace*, 121.

[92] *Id.*, 114-115.

[93] United Nations Development Programme (2022) What are TOARs and why are they necessary to advance reparations and reconciliation?.

peasant communities; and iii) the guarantees of non-repetition through actions to prevent damage to the environment and the territory. Other authors have highlighted that it is necessary to promote, through these restorative sanctions, the protection of peoples, communities, inhabitants, knowledge, cosmovisions, and ontologies, understanding environmental peace as that where the relationship between humanity and nature is restored.[94]

From this dynamic of protection, it will be possible to set out the route of reparation and restoration of the damages caused to the living beings that inhabit the territory and nature, with actions such as environmental education, the reconditioning of ecosystems and symbolic reparation measures that make visible the role of environmental peace. These steps are essential to implement various provisions of the Peace Agreement related to the protection of environmental leaders, the eradication of illicit crops, the fight against deforestation, various changes in the exploitation of renewable and non-renewable natural resources,[95] and the restitution of land resulting from dispossession in the context of forced displacement.

[94] U. Hernández (2023) The Sharm El-Sheikh declaration: Reflections and approaches in light of environmental peace from a complex and Latin American perspective, REVISTA ELECTRÓNICA IBEROAMERICANA 17(1), 50.

[95] Natural resources are key in financing conflicts, decreasing the likelihood of demobilization of armed groups and increasing the possibility of new groups emerging with the aim of taking control over these for their own benefit, in turn, natural resources keep the conflict ongoing. Rodríguez, Rodríguez, & Duran, ENVIRONMENTAL PEACE, 39.

The Human Right to Benefit from Progress in Science and Technology (The Right to Science) and its Relevance for the Climate Change Emergency

Cesare P. R. Romano and Andrea Boggio[1]

1. Introduction

This paper was prepared at the request of the Oxford University Sustainable Law Programme for the Oxford High-Level Dialogue on Responding to the Climate Emergency to Protect Human Rights (2 and 3 October 2023). It intends to bring to the attention of participants the human right to benefit from progress in science and technology – also known, more succinctly, as "the right to science" (RtS) – and its relevance for discussions relating to obligations States have, as a matter of international human rights law, in regard to addressing the climate change emergency.

The RtS is one of the oldest internationally recognized human rights. It was codified as early as May 1948 in the American Declaration of the Rights and Duties of Men (ADHR) of the Organization of America States (OAS).[2] It is certainly no exaggeration to say that the RtS is a gift of Latin America to the world.[3] From there, it spread to other major international human rights instruments and countless national constitutions.

Yet, despite being one of the oldest international human rights and the remarkable diffusion it has had, the RtS is probably the least known and least understood of all human rights. Some have benignly called it the "Sleeping Beauty" of human rights.[4] Perhaps it should be called the

[1] Professor of Law, Loyola Law School; Professor of Legal Studies, Bryant University.

[2] Organization of American States (1992) American Declaration of the Rights and Duties of Man, adopted May 2, 1948, by the Ninth International Conference of American States as OAS Res XXX, reprinted in Basic Documents on Human Rights in the Inter-American System, OEA/Ser L V/II.82 Doc 6 Rev 1, at 17.

[3] C. Romano (2022) The Origins of the Right to Science: The American Declaration on the Rights and Duties of Man, in THE RIGHT TO SCIENCE: THEN AND NOW, H. Porsdam & S. Porsdam Mann (eds.), Cambridge University Press.

[4] W. Schabas (2015) Looking Back: How the Founders Considered Science and Progress in Their Relation to Human Rights, EUR. J. HUM. RIGHTS 4, 1. In 2009, Audrey Chapman lamented that it was "so obscure and its interpretation so neglected that the vast majority of human rights advocates, governments, and international human rights bodies seem to ignore its existence." See A. Chapman (2009) Towards an Understanding of the Right to Enjoy the Benefits of Scientific Progress and Its Applications, J. HUM. RIGHTS 8.

"Cinderella" of human rights since, for long, it has been largely neglected by States, international organizations and legal scholarship. That is probably due to the fact that it is an extremely complex right, containing in itself several distinct human rights. Its normative content has befuddled States, international organizations and generations of scholars for generations. Only recently, progress has been made towards clarifying its normative content.

The adoption in 2009 of the *Venice Statement on the Right to Enjoy the Benefits of Scientific Progress and its Applications*,[5] a document authored by a group of experts convened under UNESCO's auspices, sparked renewed interest in defining the normative content of this right. In March 2020, the UN Committee on Economic, Social and Cultural Rights (CESCR) adopted *General Comment 25 on Science and Economic, Social and Cultural Rights (article 15(1)(b), (2), (3) and (4) of the International Covenant on Economic, Social and Cultural Rights - ICESCR*), another landmark in the long history of the evolution of this right.[6] At this point in history it is probably the most authoritative statement of the normative content of the RtS. In parallel, UNESCO has led several normative initiatives that have also contributed to the revival of interest, among scholars and practitioners, in the relationship between science, technology and international law.[7] Nowadays there is a rapidly expanding literature probing the various aspects of the RtS, including a forthcoming book, to be published by Oxford University Press and that we co-authored, mapping its normative content.[8] This paper applies some of the findings of the book to the specific issue of the climate change emergency.

2. Normative Basis of the RtS

The RtS is codified in several major international human rights instruments. They are:

[5] UNESCO, Venice Declaration on the Right to Enjoy the Benefits of Scientific Progress and its *Applications (Article 15(1)(b)* (ICESCR) (July 16-17, 2009). This statement was commented on by A. Müller (2010) *Remarks on the Venice Statement on the Right to Enjoy the Benefits of Scientific Progress and its Applications, (Article 15(1)b ICESCR)*, HUM. RIGHTS LAW REV. 10(4); American Association for the Advancement of Science, Science and Human Rights Coalition (2013) DEFINING THE RIGHT TO ENJOY THE BENEFITS OF SCIENTIFIC PROGRESS AND ITS APPLICATIONS: *AMERICAN SCIENTISTS' PERSPECTIVES*, M. Weigers Vitullo & J. Wyndham.

[6] CESCR (30 April 2020) *General Comment 25 on Science and Economic, Social and Cultural Rights (article 15 (1) (b), (2), (3) and (4) of the International Covenant on Economic, Social and Cultural Rights)*, E/C.12/GC/25.

[7] *See* supra notes 26-33.

[8] C. Romano & A. Boggio, THE HUMAN RIGHT TO SCIENCE, Oxford University Press (forthcoming 2024).

- American Declaration of Human Rights (1948),[9] Art. XIII.

  "Every person has the right to take part in the cultural life of the community, to enjoy the arts, and to participate in the benefits that result from intellectual progress, especially scientific discoveries.

  He likewise has the right to the protection of his moral and material interests as regards his inventions or any literary, scientific or artistic works of which he is the author."

- Universal Declaration of Human Rights (1948) (UDHR),[10] Art. 27.

  "1. Everyone has the right freely to participate in the cultural life of the community, to enjoy the arts and to share in scientific advancement and its benefits.

  2. Everyone has the right to the protection of the moral and material interests resulting from any scientific, literary or artistic production of which he is the author."

- International Covenant on Economic, Social and Cultural Rights (1966) (ICESCR),[11] Art. 15.

  "The States Parties to the present Covenant recognize the right of everyone: ....
  (b) To enjoy the benefits of scientific progress and its applications;
  (c) To benefit from the protection of the moral and material interests resulting from any scientific, literary or artistic production of which he is the author.

  2. The steps to be taken by the States Parties to the present Covenant to achieve the full realization of this right shall include those necessary for the conservation, the development and the diffusion of science and culture.

  3. The States Parties to the present Covenant undertake to respect the freedom indispensable for scientific research and creative activity.

  4. The States Parties to the present Covenant recognize the benefits to be derived from the encouragement and development of international contacts and co-operation in the scientific and cultural fields."

[9] OAS, American Declaration of the Rights and Duties of Man.

[10] United Nations General Assembly, *Universal Declaration of Human Rights,* 217 A (III), December 10, 1948.

[11] UNGA, *International Covenant on Economic, Social and Cultural Rights (ICESCR)*, adopted December 16, 1966, in force since January 3, 1976, UNTS, Vol. 993, p. 3.

- Additional Protocol to the American Convention on Human Rights in the Area of Economic, Social and Cultural Rights (Protocol of San Salvador) (1988),[12] Art. 14.

  "The States Parties to this Protocol recognize the right of everyone: ....
  b. To enjoy the benefits of scientific and technological progress;
  c. To benefit from the protection of moral and material interests deriving from any scientific, literary or artistic production of which he is the author.

  2. The steps to be taken by the States Parties to this Protocol to ensure the full exercise of this right shall include those necessary for the conservation, development and dissemination of science, culture and art.

  3. The States Parties to this Protocol undertake to respect the freedom indispensable for scientific research and creative activity.

  4. The States Parties to this Protocol recognize the benefits to be derived from the encouragement and development of international cooperation and relations in the fields of science, arts and culture, and accordingly agree to foster greater international cooperation in these fields."

- Revised Arab Charter on Human Rights (2004),[13] Art. 42.

  "1. Every person has the right to take part in cultural life and to enjoy the benefits of scientific progress and its application.

  2. Every person has the right to take part in cultural life and to enjoy the benefits of scientific progress and its application.

  3. The States parties shall work together and enhance cooperation among them at all levels, with the full participation of intellectuals and inventors and their organizations, in order to develop and implement recreational, cultural, artistic and scientific programmes."

- Association of Southeast Asian Nations (ASEAN) Declaration of Human Rights (2012),[14] Art. 32.

[12] OAS, Additional Protocol to the American Convention on Human Rights in the Area of Economic, Social and Cultural Rights ("Protocol of San Salvador"), adopted Nov. 17, 1988, entered into force Nov. 16, 1999.

[13] Arab League, Arab Charter on Human Rights (revised), adopted May 22, 2004, in force Mar. 15, 2008.

[14] ASEAN, *ASEAN Declaration on Human Rights*, adopted Nov. 18, 2012 at the 21st ASEAN Summit.

"Every person has the right, individually or in association with others, to freely take part in cultural life, to enjoy the arts and the benefits of scientific progress and its applications and to benefit from the protection of the moral and material interests resulting from any scientific, literary or appropriate artistic production of which one is the author."

Although the RtS is not codified *per se* in the European and African regional human rights regimes, several of its elements can be found in the European Convention on Human Rights,[15] Charter of Fundamental Rights of the European Union,[16] African Charter of Human and Peoples' Rights[17] and related instruments,[18] as well as in hundreds of national constitutions.[19]

Countless soft law international legal instruments, both universal and regional, have echoed and expanded on the normative content of the RtS. The RtS, or elements of it, have been elaborated upon by the UN General Assembly.[20] Last but not least, there are several recommendations of the United Nations Educational, Cultural and Scientific Organization UNESCO that address it, or elements of it, including the *1974 Recommendation on the Status of Scientific Researchers*,[21] the *2017 Recommendation on Science and Scientific Researchers*,[22] the *2017 Declaration of Ethical Principles in Relation to Climate Change*,[23] the

[15] Council of Europe, *European Convention for the Protection of Human Rights and Fundamental Freedoms (European Convention on Human Rights)*, adopted Nov. 4, 1950, in force Sept. 3, 1953, ETS No. 005.

[16] European Union, *Charter of Fundamental Rights of the European Union*, proclaimed Dec. 7, 2000 by the European Parliament, the Council of Ministers and the European Commission, Official Journal of the European Union, 2000/C 364/01.

[17] OAU, *African Charter on Human and Peoples' Rights*, adopted June 27, 1981, in force Oct. 21, 1986, UNTS Vol. 1520.

[18] African Union, *Protocol to the African Charter on Human and Peoples' Rights on the Rights of Women in Africa (Maputo Protocol)*, CAB/LEG/66.6, adopted on September 13, 2000, in force Nov. 25, 2005.

[19] *See generally* C. P. R. Romano & A. Boggio (2020) *The Right to Benefit from Progress in Science and Technology*, MAX PLANCK ENCYCLOPEDIA OF COMPARATIVE CONSTITUTIONAL LAW.

[20] See, e.g., UNGA, *Declaration on the Use of Scientific and Technological Progress in the Interests of Peace and for the Benefit of Mankind*, A RES 3384 (XXX) (10 November 1975).

[21] UNESCO, *Recommendation on the Status of Scientific Researchers*, adopted at the 18th session of the General Conference on 20 November 1974, 18 C/Resolutions [accessed 22 September 2023].

[22] UNESCO, *Recommendation on science and scientific researchers*, adopted at the 39th session of the General Conference on 13 Nov. 2017, 39 C/Resolutions [accessed 22 September 2023].

[23] UNESCO, *Declaration of Ethical Principles in Relation to Climate Change*, adopted at the 39th session of the General Conference on 13 Nov. 2017, SHS/BIO/PI/2017/2 [accessed 22 September 2023].

2021 Recommendation on Open Science,[24] the *2021 Recommendation on the Ethics of Artificial Intelligence*,[25] the *1997 Universal Declaration on the Human Genome and Human Rights*,[26] the *2003 International Declaration on Human Genetic Data*,[27] and the *2005 Universal Declaration on Bioethics and Human Rights*.[28]

All in all, nowadays, it is possible to conclude that most of the normative content of the RtS, if not all of it, is customary international law.[29]

3. Normative Content

Regardless of whether one looks at the formulation of the RtS in the American Declaration, UDHR, ICESCR, or Protocol of San Salvador, scholarly works on the history and normative content of the right to science agree that it is a very complex right, containing several more specific rights.[30] Granted, that is not unusual. Human rights norms, in their purest form, are abstract and terse statements that leave much room for rationalization, such as “everyone has the right to a fair trial,” “everyone has the right of adequate conditions of living” or “everyone has the right to health.” Upon taking a closer look, one invariably discovers that each right contains several discrete and more precise rights.

[24] UNESCO, *Recommendation on Open Science*, adopted by the General Conference of UNESCO at its 41st session, 23 Nov. 2021, SC-PCB-SPP/2021/OS/UROS [accessed 22 September 2023].

[25] UNESCO, *Recommendation on the Ethics of Artificial Intelligence*, adopted at the 41st session of the General Conference on 24 November 2021, SHS/BIO/PI/2021/1 [accessed 22 September 2023].

[26] UNESCO, *Universal Declaration on the Human Genome and Human Rights*, adopted at the 29th session of the General Conference on 11 November 1997, BR/2001/PI/H/1 [accessed 22 September 2023].

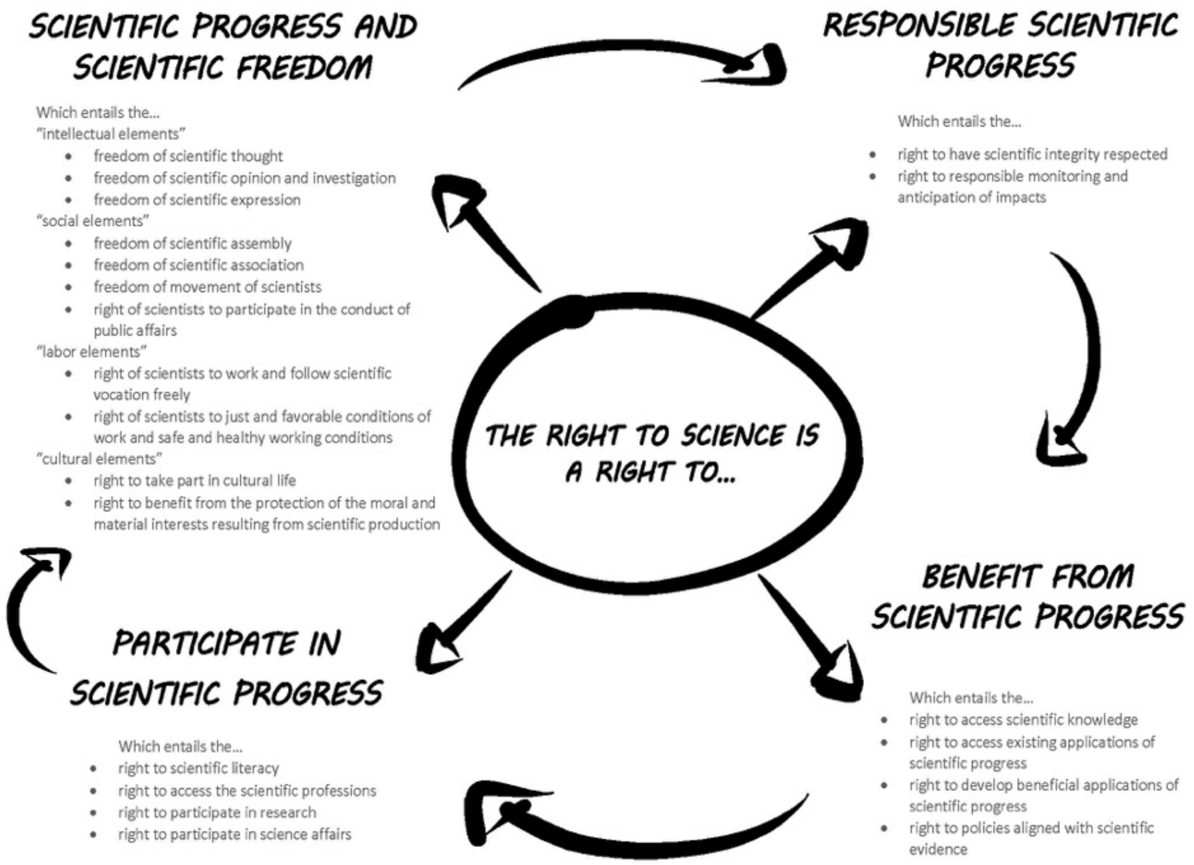
[27] UNESCO, *International Declaration on Human Genetic Data*, adopted at the 32nd Session of the General Conference on October 16, 2003, 32 C/Resolutions [accessed 22 September 2023].

[28] UNESCO, *Universal Declaration on Bioethics and Human Rights*, adopted by the General Conference on 19 October 2005, 33 C/Resolutions [accessed 22 September 2023].

[29] Romano & Boggio, *supra* note 8.

[30] See Chapman, supra note 3; Y. Donders (2011) The Right to Enjoy the Benefits of Scientific Progress: In Search of State Obligations in Relation to Health, MED. HEALTH CARE PHILOS. 14(4); R. Yotova & B. M. Knoppers (2020) The Right to Benefit from Science and Its Implications for Genomic Data Sharing, EUR. J. INT. LAW 31(2); S. Porsdam Mann, H. Porsdam, & Y. Donders (2020) ‘Sleeping Beauty’: The Right to Science as a Global Ethical Discourse, HUM. RIGHTS Q. 42(2).

In our forthcoming book, we identified twenty-one distinct rights that are contained within the RtS.[31] We grouped them into four interrelated but distinct clusters of rights: (1) the right to scientific progress and scientific freedom; (2) the right to responsible scientific progress; (3) the right to participate in scientific progress; and (4) the right to benefit from scientific progress. Each cluster contains several discrete rights, which we sometimes break down into sub-groups for clarity.



[31] Of course, our taxonomy is not intended to be conclusive, as other scholars might break down the right to science differently, or find in it other rights. It is also likely that law will develop as conceptions of scientific progress evolve, thus reshaping the normative content of law. The groups we have identified are neither clearly divided nor easy to separate from other rights or groups of rights. For example, the clusters of "right to scientific progress" and "right to responsible scientific progress" are interconnected and intertwined with the so-called "rights" and "duties of science." Likewise, the normative content of the four clusters is intertwined. For example, the enrollment of an individual in a biomedical research protocol, which is guaranteed as part of the "right to participate in scientific progress," leads to the production of scientific knowledge, which is the core of the "right to scientific progress," and of new drugs, medical devices or other therapies, which realize the "right to benefit from scientific progress."

For each right, we traced where it is recognized and in what terms. The legal instruments we relied on to reconstruct the normative content of the right include the international legal instruments mentioned above, relying both on the wording of those instruments, the drafting history, subsequent practice of States and interpretation given by implementation monitoring bodies; the recommendations of UNESCO we mentioned; several of dozens of legal instruments and documents of international (i.e. UN), and regional organizations (OAS, Council of Europe (CoE), European Union (EU), African Union (AU)); hundreds of national constitutions; national and – admittedly limited – international jurisprudence; and legal scholarship and declarations adopted by national and international societies and expert groups.

4. Applying the RtS to the Climate Change Emergency

A discussion of all twenty-one rights contained in the RtS is certainly beyond the scope of this paper, even when limited to climate change response. For brevity's sake, we will limit ourselves to only those that are mostly relevant. The 2017 UNESCO *Declaration of Ethical Principles in relation to Climate Change (DEPCC)* provides a handy roadmap.[32]

The Recommendation was adopted by the General Conference (the plenary organ) of UNESCO on 15 November 2017. As the name suggests, it intends to provide all UNESCO Member States (currently 194, including the United States),[33] with a set of ethical principles "of decision-making, policy formulation, and other actions related to climate change."[34] States are urged to keep them in mind "in all decisions and actions related to climate change that are taken internationally, regionally, nationally, sub-nationally and locally."[35] The principles are grouped under six titles: "prevention of harm;"[36] "precautionary approach;"[37] "equity and justice;"[38] "sustainable

[32] UNESCO, *supra* note 23.

[33] The United States was not a member between January 2019 and July 2023.

[34] DEPCC, *supra* note 23, Art. 1.1.

[35] *Id.,* Art. 1.2.

[36] *Id.,* Art. 2.

[37] *Id.,* Art. 3.

[38] *Id.*, Art. 4.

development;"[39] "solidarity;"[40] and "scientific knowledge and integrity in decision-making."[41] Each breaks down in several sub-principles and comments. The section stating the principles[42] is followed by a section detailing how they should be applied.[43]

Before discussing it, should be stressed that, while the declaration is not legally binding per se, it does have legal importance that should not be discounted. UNESCO declarations and recommendations are legal instruments in which "the General Conference formulates principles and norms for the international regulation of any particular question and invites Member States to take whatever legislative or other steps may be required in conformity with the constitutional practice of each State and the nature of the question under consideration to apply the principles and norms aforesaid within their respective territories."[44] Recommendations and declarations require a simple majority to be adopted rather than the two-thirds majority required for conventions, reflecting their non-binding nature. Yet, that does not mean they are without legal significance or effect. As Nico Schrijver noted, UNESCO's recommendations and declarations have at least three main functions in international law-making.[45] First, if norms already exist on a given subject, they have a declaratory function, in that they can restate the law as it already exists at that particular juncture. Second, they have an interpretative function, as they can further clarify and interpret already existing norms. That is the case of the right to science, since it is already codified in hard law instruments, global and regional. Finally, if there are not yet norms regulating the matter, they might have a programmatic function, helping create momentum for the creation of new international norms. This can assist in setting the agenda, direction, and basic principles to inspire subsequent action. Because recommendations and declarations are not subject to ratification, it is difficult to quantify their impact on States.[46] However, it may be

[39] *Id.*, Art. 5.

[40] *Id.,* Art. 6.

[41] *Id.*, Art. 7.

[42] *Id.*, Art. 2-7.

[43] *Id.*, Art. 8-15

[44] UNESCO, Rules of Procedure concerning recommendations to Member States and international conventions covered by the terms of Article IV, paragraph 4, of the Constitution, adopted by the General Conference at its 5th session and amended at its 7th, 17th, 25th, 32nd and 35th sessions, Article 1(b).

[45] N. Schrijver (2007) UNESCO's Role in the Development and Application of International Law: An Assessment, in UNESCO: STANDARD-SETTING AT UNESCO: ESSAYS IN COMMEMORATION OF THE SIXTIETH ANNIVERSARY OF UNESCO, Vol. 1, Y. Abdulqawi (ed.), 383.

[46] At its twelfth session in 1970, the General Conference of UNESCO "drew attention to the distinction to be drawn between the obligation to submit an instrument to the competent authorities, on the one hand, and the ratification

argued that they are the expression of the *opinio juris* of the adopting body, and potentially, the Member States who voted in their favor.

Finally, it should be noted that, while the DEPCC enunciates *ethical* principles, as we will see, it is possible to ground them in *legal* obligations States have deriving from the above-mentioned international legal instruments.

In the next sections, we will address what duties stemming from the RtS that States and "other relevant actors", including scientists, have regarding the climate emergency. The order in which we will discuss the duties reflects the policy flow from building the record of evidence, creating the conditions for making policies, adopting the policies, to tracking their effects. Thus, we will discuss first the duty to ensure integrity in decision-making — a duty that imposes obligations mostly on scientists. Then, we will discuss the duty to ensure literacy in science in general, and on climate change, in particular. We will continue with the duty to share and disseminate knowledge relating to climate change in general, and adaptation and mitigations strategies in particular. Next will be the duty to ensure participation in science affairs, particularly in climate change-related policy debates, and the duty to align policies with best available scientific knowledge. We will conclude with the duty to adopt a precautionary approach and the duty to anticipate, avoid or minimize harm — a duty that imposes obligations mostly on States but also creates some obligations for scientists. Each section will close with our main normative takeaways resulting from our reading of the RtS in the context of the climate change emergency.

A. Duty to Ensure "Integrity in Decision-making"

According to the DEPCC:

> "... to optimally aid in decision-making, science needs to meet the highest standards of research integrity by being impartial, rigorous, honest, and transparent, and should give adequate estimates of uncertainty in order to provide decision-makers with insight into,

of a convention or the acceptance of a recommendation, on the other. Submission to the competent authorities does not necessarily imply ratification of conventions or acceptance in full of recommendations. On the other hand, it is incumbent upon Member States to submit all recommendations and conventions without exception to the competent authorities, even if no ratification or acceptance measures are contemplated in a particular case." UNESCO, Records of the General Conference, Sixteenth Session, Paris, 12 October-14 November 1970, Vol. I (Resolutions), 154, ¶ 18.

> and understanding of, the underlying risks as well as opportunities, and guidance to their formulating long-term strategies."[47]

Moreover,

> "States, according to Article 6 of the UNFCCC and Article 12 of the Paris Agreement adopted under the Convention, and other relevant actors should: (a) take measures which help protect and maintain the independence of science and the integrity of the scientific process. This includes assisting in maintaining strong scientific standards as well as transparency at all levels with respect to scientific funding, methodologies and research conclusions."[48]

Both scientists and States have obligations to ensure integrity in decision-making. However, scientists have the primary responsibility because science is largely self-governing, and must be kept so.

I. Duties of Scientists

"Internal obligations" of scientific responsibility concern scientists' respect for the norms and values of science. The internal duties of scientists to science and the scientific community are acknowledged in CESCR General Comment 25.[49] Integrity also appears in the discussion of the principles of transparency and participation, which the CESCR considers "essential to make science objective and reliable, and to ensure that it is not subject to interests that are not scientific or are inconsistent with fundamental human rights principles and the welfare of society."[50] Furthermore, "[s]ecrecy and collusion are in principle contrary to the integrity of science at the service of humanity."[51]

Besides the DEPCC, scientific integrity is mentioned in various standard-setting instruments adopted by UNESCO. We already mentioned the 1975 *Declaration on Science and the Use of Scientific Knowledge* requiring scientists to "maintain high standards of scientific integrity and

[47] DEPCC, *supra* note 23, Art. 7.1.

[48] *Id.,* Art 7.4.a.

[49] *Ibid.,* Art. 19 ("Scientific research must "incorporate ethical standards to ensure its integrity").

[50] *Ibid.,* Art. 53.

[51] *Id.*

quality control."[52] Scientific integrity also features prominently in the 2017 UNESCO *Recommendation on Science and Scientific Researchers*, which indicates that "effective scientific research calls for scientific researchers of integrity and intellectual maturity, combining high, intellectual qualities and respect for ethical principles."[53] After its adoption, UNESCO identified ten priority areas for implementing and monitoring the Recommendation on Science and Scientific Researchers.[54] Among them are "scientific integrity and ethical codes of conduct for science and research and their technical applications."[55] The Universal Declaration on the Human Genome and Human Rights provides that "meticulousness, caution, intellectual honesty and integrity in carrying out their research as well as in the presentation and utilization of their findings" are "responsibilities inherent in the activities of researchers."[56] Article 15 of the International Declaration on Human Genetic Data reads:

> "The persons and entities responsible for the processing of human genetic data, human proteomic data, and biological samples should take the necessary measures to ensure the accuracy, reliability, quality and security of these data and the processing of biological samples. They should exercise rigour, caution, honesty and integrity in the processing and interpretation of human genetic data, human proteomic data or biological samples, in view of their ethical, legal and social implications."[57]

The *Universal Declaration on Bioethics and Human Rights* calls States to promote "[p]rofessionalism, honesty, integrity and transparency in decision-making."[58] UNESCO elaborated scientific integrity standards further in the *Recommendation on the Ethics of Artificial Intelligence*, which refers to "sound"[59] and rigorous"[60] scientific research, and the

[52] UNESCO, *Declaration on Science and the Use of Scientific Knowledge*, *supra* note 289, ¶ 41.

[53] UNESCO, *Recommendation on Science and Scientific Researchers*, *supra* note 22, ¶ 12.

[54] UNESCO Executive Board (2020) Implementation of standard-setting instruments, Part IV: Implementation of the 2017 Recommendation on Science and Scientific Researchers - Preparation of the next consultation, 209 EX/18.IV.

[55] UNESCO (2019) Focused implementation: the 10 key areas of the UNESCO Recommendation on the Status of Scientific Researchers (2017), SHS/2019/PI/H/6.

[56] UNESCO, Universal Declaration on the Human Genome and Human Rights, supra note 26, Art. 13.

[57] UNESCO, International Declaration on Human Genetic Data, supra note 27, Art. 15.

[58] UNESCO, Universal Declaration on Bioethics and Human Rights, supra note 28, Art. 18.1.

[59] UNESCO, Recommendation on the Ethics of Artificial Intelligence, supra note 25, Preamble, 3.

[60] *Id.*, ¶ 110, 131(a).

Recommendation on Open Science, which identifies "quality and integrity" as a foundational value for open science.[61]

At the regional level, scientific integrity is acknowledged in Article 4 of the *Oviedo Convention on Human Rights and Biomedicine*, which reads, "[a]ny intervention in the health field, including research, must be carried out in accordance with relevant professional obligations and standards,"[62] and in its *Additional Protocol on Biomedical Research*.[63] In 2005, the European Union adopted the *European Charter for Researchers*, whose standards address professional responsibility, professional attitude, good research practices, public engagement, regular and structured relationships between research trainees and supervisors, and continuing professional development.[64] Yet, no national constitution includes provisions on scientific integrity.

A full discussion of the normative content of the duty to ensure scientific integrity is beyond the scope of this paper. Here, suffice to say that scientific integrity has at least two dimensions: the scientists' duty to respect science's goal of producing valuable knowledge (research integrity or integrity *of* science), and their duty to behave responsibly as members of the scientific community (scientific citizenry or integrity *in* science).[65] Common to both dimensions are the essential responsibilities of the scientific community, which consist of three steps: (1) the scientific community must *define and communicate* the scientific integrity standards that its members are expected to follow in conducting scientific activities; (2) scientists must educate themselves and *adhere* to said standards; and (3) the scientific community must *monitor* and *enforce* adherence to these scientific integrity standards.

[61] UNESCO, *Recommendation on Open Science*, *supra* note 24, ¶ 13(a).

[62] CoE, Convention for the Protection of Human Rights and Dignity of the Human Being with regard to the Application of Biology and Medicine: Convention on Human Rights and Biomedicine (Oviedo Convention), adopted April 4, 1997, entered into force January 12, 1999, ETS No. 164, Art. 4.

[63] CoE, Additional Protocol on Biomedical Research, adopted June 30, 2004, effective September 1, 2007, ETS No. 195, Art. 8 ("Scientific quality - All research must be scientifically justified, meet generally accepted scientific quality criteria and be conducted in accordance with relevant professional obligations and standards under the supervision of an appropriately qualified investigator.").

[64] European Commission (2005) European Charter for Researchers and Code of Conduct for the Recruitment of Researchers.

[65] M. Hammersley (2020) On Epistemic Integrity in Social Research, in HANDBOOK OF RESEARCH ETHICS AND SCIENTIFIC INTEGRITY, R. Iphofen (ed.), Springer International.

Scientific integrity standards are the technical norms that regulate scientific inquiries. Crafted over centuries,[66] these standards are neither universal nor fixed. Universality is defeated because each scientific discipline and sub-discipline needs standards unique to the scientific practices in that domain. They are not fixed because they must be revisited constantly as the scientific knowledge frontier progresses. The non-universal and non-fixed nature of scientific integrity standards means that the exact normative expectations can only be defined in a particular research context at a specific time. As learned practitioners in each field, scientists are thus the most knowledgeable sources and the ideal producers of these standards. Consequently, society must entrust the scientific community with the self-governing power to set, monitor, and enforce integrity standards, and respect the self-regulation of science.

II. Duties of States

States' duties stemming from the right to responsible scientific progress and scientific responsibility are somewhat limited in scope. Mostly, they are secondary (indirect responsibility for ensuring scientific responsibility) to the duties owed by the scientific community. They are primary (direct responsibility for ensuring scientific responsibility) only when scientific activities are conducted in governmental research facilities, by government-employed scientists, or when directly funded with public money.[67] In both cases, States must respect the self-regulatory powers and practices of the scientific community, protect them from undue external influences, political or economic, and fulfill scientific responsibility by enabling, reinforcing, supplementing, monitoring, and correcting the scientific community's practices. They must also ensure that science's self-regulation does not violate the human rights of scientists.

III. Normative Takeaways

The main obligations resulting from the RtS that States have in connection with the duty to ensure integrity in decision-making regarding climate change can be summarized as a duty to:

[66] According to the traditional narrative, research integrity emerged after World War II in Europe and North America. See for example J. Horner & F. Minifie (2011) Research Ethics I: Responsible Conduct of Research (RCR) - Historical and Contemporary Issues Pertaining to Human and Animal Experimentation, J. SPEECH LANG. HEAR. RES. 54(1). However, for a critique of this narrative, see L. L. Roberts (2020) Historicizing Research Integrity and Fraud, HIST. SCI. 58(4). Together, these articles demonstrate that research integrity has older and more geographically diverse roots.

[67] For a review of scientific integrity efforts by federal agencies, foundations, nonprofit organizations, professional societies, and academia in the United States between 1989 and 2016, *see* A. Kretser, D. Murphy, & J. Dwyer (2017) *Scientific Integrity Resource Guide: Efforts by Federal Agencies, Foundations, Nonprofit Organizations, Professional Societies, and Academia in the United States*, CRIT. REV. FOOD SCI. NUTR. 57(1).

- Ensure that the science circulating on international and domestic science-policy interfaces is reliable and up to date;
- Ensure that international and domestic science-policy interfaces are free from undue influence (corporate, political or other);
- Ensure disclosure of all forms of conflict of interest;
- Ensure that international and domestic science-policy interfaces are free from pseudoscience and "junk science."[68]

B. Duty to Promote "Literacy in Science and Climate Change"

Article 7.4.b of the DEPCC urges States to:

> "raise awareness and promote literacy in science in all sectors and amongst their populations in order to underpin strong and collective action and understanding of how to respond to climate change."[69]

Article 11, entitled "education" recommends States and "pertinent actors" to:

> "1. Advance curricula, as appropriate, taking into account UNESCO's work and initiatives on Education for Sustainable Development and Education for Climate Change, Article 6 of the UNFCCC, and Article 12 of the Paris Agreement adopted under the Convention, so that they build awareness and knowledge about humankind's relation to the Earth's climate system and ecosystems as well as about present generations' responsibilities to future generations, and so that they promote the principles of this Declaration.
>
> 2. Ensure that, in accordance with national laws, all people, irrespective of gender, age, origin, and persons with disabilities, migrants, indigenous people, children, and youth, especially those in vulnerable situations, have access to life-long learning opportunities

[68] The term junk science is used to describe spurious or fraudulent scientific data, research or analysis. It often conveys a pejorative connotation indicating that the research has been driven by political, ideological, financial or non- scientific motives. The term has been used in scientific discourse since at least the 1970s. In 1997, the term was used in an opinion by Justice John Paul Stevens of the U.S. Supreme Court ("An example of 'junk science' that should be excluded under the Daubert standard as too unreliable would be the testimony of a phrenologist purporting to prove a defendant's future dangerousness based on the contours of his skull."). *General Electric Company v. Robert K. Joiner*, No. 96-188, slip op. at 4 (U.S. Dec. 15, 1997).

[69] DEPCC, *supra* note 23, Art. 7.4.b.

that help them to acquire and update the knowledge, skills, values, and attitudes needed to respond to climate change and contribute to sustainable development.

3. Promote formal, non-formal, and informal education with regard to climate change challenges and solutions, and encourage retraining for professionals in line with these objectives.

4. Encourage educational institutions and educators to integrate these principles in their teaching activities from the pre-school to university levels.

5. Promote, in accordance with national laws, at all levels and in all forms of education, that the recognition of cultural, social, and gender diversity is valuable and is an important source of knowledge with which to promote dialogue and the exchange of knowledge indispensable to responding to climate change.

6. Support developing countries through educational and scientific capacity-building, as well as financial means and facilitation of environmentally sound technological development."[70]

The duty to promote scientific literacy is intimately connected to the duty to facilitate public participation in science affairs. Without scientific literacy, one cannot meaningfully participate in decision-making that necessitates the understanding of scientific phenomena.

We already discussed the normative basis for the right to scientific literacy. As to the normative content, the right to scientific literacy is an entitlement to attain a "familiarity with the enterprise and practice of science"[71] sufficient to adequately participate in and benefit from scientific progress. Scientific literacy is essential to participation in scientific progress because it provides the foundations to appreciate, actively contribute to, and enjoy scientific progress and its applications. Scientific literacy also empowers citizens to participate in the civic life of a democratic society.[72] Understanding scientific problems, appreciating the value of scientific knowledge, and the ability to assess collective responses to social problems enhance civic engagement. Scientific literacy is one of the best weapons against misinformation and

[70] *Id.,* Art. 11.

[71] National Academies of Sciences, Engineering, and Medicine (2016) SCIENCE LITERACY: CONCEPTS, CONTEXTS, AND CONSEQUENCES, National Academies Press, 1.

[72] CESCR, *General Comment 25, supra* note 5, ¶ 8, 10; J. M. Wyndham & M. Weigers Vitullo (2018) *Define the Human Right to Science*, SCIENCE 362(6418).

"misleading and pseudoscience-based practices,"[73] "which create ignorance and false expectations among the most vulnerable sectors of the population."[74]

Yet, what are the essential components of adequate scientific literacy? What degree of scientific literacy satisfies human rights standards? The conceptual foundations can be grounded on the work done by OECD in developing the Programme for International Student Assessment (PISA) Science Framework).[75] Established in 2000, PISA is an expert-driven, peer-reviewed evaluative framework designed to measure the capabilities and progress of 15-year-olds in 90 countries in reading, mathematics, and science.[76] According to the OECD's, "scientific literacy" is "the ability to engage with science-related issues, and with the ideas of science, as a reflective citizen."[77] More specifically, it entails

> "... an individual's [s]cientific knowledge and use of that knowledge to identify questions, [to] acquire new knowledge, [to] explain scientific phenomena, and draw evidence-based conclusions about science-related issues, [u]nderstanding of the characteristic features of science as a form of human knowledge and enquiry, [a]wareness of how science and technology shape our material, intellectual, and cultural environments, [and] [w]illingness to engage in science-related issues, and with the ideas of science, as a reflective citizen."[78]

The focus is on developing a *general* education in science for all young citizens, not just those on a path to earning a STEM degree. For these reasons, the PISA Science Framework sets outcomes highly relevant to determine human rights standards connected to everyone's right to participate in scientific progress.

The most recent iteration of the PISA Science Framework was published in May 2023 and focuses exclusively on science.[79] To that end, it outlines three competencies that, when

[73] CESCR, *General Comment 25, supra* note 5, ¶ 52.

[74] *Id.*, ¶ 44.

[75] OECD, *PISA 2025 Science Framework* [accessed June 28, 2023].

[76] OECD iLibrary, *PISA* [accessed June 28, 2023].

[77] OECD, *PISA 2009 Assessment Framework. Key competencies in reading, mathematics and science*, OECD, 2009.

[78] *Id.,* 128, box 3.2.

[79] OECD, *PISA 2025 Science Framework (Second Draft)* [accessed June 28, 2023].

manifested, demonstrate the achievement of scientific literacy.[80] The first is the ability to explain phenomena scientifically (i.e. to recognize, offer and evaluate explanations for a range of natural and technological phenomena).[81] The second is the competency to construct and design scientific inquiry and interpret scientific data and evidence critically (i.e. to appraise and evaluate ways of investigating questions scientifically and interpret and evaluate scientific data critically).[82] The third is the capacity to research, evaluate and use scientific information for decision-making (i.e. to obtain scientific information on a specific global, local, or personal science-related issue and evaluate its credibility, potential flaws, and implications for personal and communal decisions).[83]

These competencies require three types of knowledge, whose acquisition is thus necessary to achieve scientific literacy. The first is "content knowledge": "a knowledge of the facts, concepts, ideas and theories about the natural world that science has established."[84] The second type is "procedural knowledge": "a knowledge of the practices and concepts on which empirical enquiry is based such as repeating measurements to minimise error and reduce uncertainty, the control of variables, and standard procedures for representing and communicating data."[85] The third type is "epistemic knowledge": "an understanding of the role of specific constructs and defining features essential to the process of knowledge building in science."[86]

The PISA Framework also includes a component of science education that is vital to human rights analysis: science identity, which captures "the extent to which young people feel meaningfully connected to science, recognise themselves and feel recognised by others as science interested/competent, and engage with the sciences as critical consumers and decisionmakers in their daily lives."[87] This outcome, the PISA experts write, is "crucial for

[80] *Id.*, ¶ 1.

[81] *Id.*, 9, box 1; 21, box 3; ¶ 29-34.

[82] *Id.*, 9, box 1; 21, box 4; ¶ 35-47.

[83] *Id.*, 9, box 1; 23, box 5; ¶ 48-54.

[84] *Id.*, 10, box 2; 25-26, box 6; ¶ 74-79.

[85] *Id.*, 10, box 2; 27, box 7; ¶ 80-81.

[86] *Id.*, 10, box 2; 28-29, box 8; ¶ 82-86 ("Epistemic knowledge includes an understanding of the role in science of questions, observations, theories, hypotheses, models and arguments, values and issues that frame a question and drive scientific inquiry, recognition of the variety of forms of scientific inquiry, and the role of peer review and scientific consensus in establishing knowledge that can be trusted.").

[87] *Id.*, ¶ 88, parentheses omitted.

supporting agency and active citizenship in a rapidly changing world."[88] Although PISA's focus is on young people, the concept can be easily applied to everyone. For our analysis of the right to science, achieving science identity is the entitlement to scientific literacy that the right to participate in scientific progress guarantees. Scientific literacy permits the acquisition of a "sense of agency, attitudes, and values in relation to science,"[89] in short, of science identity. "If the knowledge and competencies of the sciences are not valued as a way of thinking and being in the world, science education has failed to achieve one of its major goals."[90] This statement rings particularly true in international law, which recognizes science as a human right. Possessing a way of thinking that values science is at the heart of sharing the benefits of scientific progress.

A particularly compelling dimension of science identity for a human rights analysis is the possession of certain epistemic beliefs about science. These beliefs include "a commitment to evidence as the basis of belief for explanations of the material world; being comfortable with uncertainty and the notion of risk; valuing evidence-based argument and debate as a means of establishing the validity of any idea; and a commitment to the scientific approach to enquiry when appropriate."[91] They also include "the capacity and confidence to be critical consumers of science; the disposition to use science as a part of their intellectual toolkit in making decisions that involve multiple forms of knowledge; a recognition of competing values and knowledge claims about science-related issues; a concern with issues of equity associated with science and technology development and its deployment, and presenting a considered reasoned stance on science-related issues that values scientific evidence."[92] These beliefs substantiate an essential benefit of science, which General Comment 25 frames as its role "in forming critical and responsible citizens who are able to participate fully in a democratic society."[93] A science identity formed around these epistemic beliefs enables everyone who possesses it to participate in scientific progress, even without becoming a scientist.

[88] *Id.*

[89] *Id.*, ¶ 89.

[90] *Id.*

[91] *Id.*, ¶ 101.

[92] *Id.*, ¶ 102.

[93] CESCR, *General Comment 25, supra* note 6, ¶ 8.

In sum, the right to participate in scientific progress entitles everyone to attain a degree of scientific literacy that enables them to acquire a science identity and epistemic beliefs, which endow them with a "sense of agency, attitudes, and values in relation to science"[94] and empower them with the capacity to understand, appreciate, and participate in scientific progress and enjoy its applications and, more broadly, in the life of a democratic society.

As to obligations, as we saw, States must respect the right to participate in scientific progress. Respecting it requires *inter alia* not interfering with or curtailing the enjoyment of the entitlements to scientific literacy. These entitlements include various freedoms, including the freedom to choose pathways to scientific literacy, to pursue further educational opportunities in science to possess the credentials and skills needed to become a professional scientist, to contribute to research, and to participate in science affairs.

States must also protect the right to participate in scientific progress against third-party actions.[95] Science literacy curricula must be "acceptable (e.g. relevant, culturally appropriate and of good quality) to students and, in appropriate cases, parents."[96] Compulsory scientific literacy must be protected by ensuring that national minimum education standards are met.[97] To that end, the State must monitor the national minimum educational standards by regulating and inspecting private schools to ensure compliance with these standards. This applies also to religious institutions. Scientific literacy must be protected more broadly by "ensuring that private persons and entities do not disseminate false or misleading scientific information."[98]

The duty to fulfil scientific literacy translates into the State's positive duty to enable everyone to acquire it. The CESCR makes clear that governments must, at minimum, ensure *basic* scientific literacy. CESCR's General Comment 25 identifies as a core obligation the duty to "ensure that people have access to the basic education and skills necessary for the comprehension and application of scientific knowledge."[99] The instrument further specifies that

[94] OECD, PISA 2025 Science Framework (Second draft), supra note 79, ¶ 89.

[95] CESCR, *General Comment 25, supra* note 6, ¶ 43.

[96] *Id.*

[97] ICESCR, *supra* note 11, Art. 13.3; CESCR (2019) *General Comment 13: The right to education (Art. 13)*, E/C.12/1999/10, ¶ 6(c).

[98] CESCR, *General Comment 25, supra* note 6, ¶ 43.

[99] *Id.*, ¶ 52.

these educational opportunities must "respect the best available scientific knowledge."[100] CESCR's General Comment also adds that States must "carefully design and implement quality scientific education programmes in order to allow all persons equal opportunities to gain a basic level of understanding and knowledge of the science and training needed to pursue careers in science."[101] In other words, States are expected to focus on basic scientific literacy. Attainment of basic scientific literacy is an obligation of result: ensuring that everyone has access to opportunities to acquire a basic level of scientific literacy and attainment. An essential step towards fulfilling the duty is including scientific literacy in national curricula at compulsory levels of education.[102] Thus, at the primary level, where scientific literacy is compulsory, States must ensure that national minimum education standards are met, both in public and private schools, including religious institutions.

At higher educational levels (i.e., secondary and tertiary education), ensuring scientific literacy is a matter of progressive realization.[103] At these levels, States must allocate sufficient resources to expanding the STEM curriculum through "adequate financing" to support scientific education.[104] The duty to ensure scientific literacy requires governments to invest also in human resources, particularly teachers, and the educational infrastructure. Teachers should be trained and have access to materials informed by the best scientific knowledge and other teaching resources. These are essential aspects of a "quality" education, quality being an essential element of the right. Educational programs are of sufficient "quality" when they ensure that students possess a degree of scientific literacy sufficient, at minimum, to understand what science is and how individuals can participate in and benefit from scientific progress. PISA provides States with valuable indicators to identify benchmarks and measure their efforts to secure basic scientific literacy.[105]

The duty to fulfil scientific literacy goes beyond opportunities to attain it in a formal educational setting. In addition to their formative years, citizens are entitled to lifelong learning opportunities to gain or expand their scientific literacy. Throughout people's lives, formal and informal

[100] *Id.*

[101] *Id.*, ¶ 27.

[102] ICESCR, *supra* note 10, Art. 13.2.a ("primary education shall be compulsory and available free to all").

[103] Some States may make education compulsory beyond the primary level. If so, their obligations are of result.

[104] CESCR, *General Comment 25, supra* note 6, ¶ 16.

[105] OECD iLibrary, *PISA, supra* note 76.

learning opportunities foster continuous development and improvement of the knowledge and skills needed to participate in scientific progress. These opportunities are crucial, particularly for vulnerable groups and groups directly affected by scientific progress in novel ways. They can serve as the basis for understanding how scientific progress affects them and activating themselves to protect their interests. Lifelong acquisition of scientific literacy can be accomplished by consuming educational materials, enrolling in adult classes, and attending cultural events focusing on disseminating science, science festivals, science outreach efforts, community-based initiatives, and national campaigns.

The right to scientific literacy is also a right to access educational opportunities on a non-discriminatory basis. According to CESCR's General Comment 25, States "should remove discriminatory barriers that impede persons from participating in scientific progress, for instance, by facilitating the access of marginalized populations to scientific education"[106] and tailor "scientific education and the products of science ... to the particularities of populations with special needs, such as persons with disabilities."[107] In other words, STEM education should be accessible to all and inclusive. The right would be violated if access to STEM education was restricted to people belonging to a specific ethnic, linguistic, or religious group. The rapid growth of scientific progress and the increased role that technology plays in everyday life in every corner of the planet requires persistent efforts to ensure that everyone, including those who have completed the educational cycle and groups traditionally suffering from an educational gap compared to other segments of the population, can comprehend how science and technology work if they are to fully enjoy their benefits. Therefore, governments should expand the range of opportunities the public must learn about science and its benefits to reach underserved populations.

The duties of States concerning science education go beyond basic scientific literacy because they also need to meet the entitlement of everyone to access the scientific professions. This obligation means that States must provide educational pathways to those who desire to pursue a career in the sciences. This is an obligation of means subject to progressive realization. By contrast, the duty to ensure that educational opportunities to become a scientist are *equally accessible* to everyone is one of immediate realization. CESCR's General Comment 25 instructs States "to allow all persons equal opportunities to gain a basic level of ... training needed to pursue careers in science, and to ensure access without discrimination to available

[106] CESCR, General Comment 25, supra note 6, ¶ 17.

[107] Id., ¶ 19.

employment in scientific research fields."[108] A critical dimension is female underrepresentation in STEM education. Data reported in the *UNESCO Science Report 2021* reveal that, globally, female students represent only one-third of the student population in the STEM fields.[109] By limiting the pipeline of women qualified to enter a profession in the sciences, this gender gap is also reflected in the distribution of the workforce. General Comment 25 addresses this problem by demanding that States "immediately eliminate barriers, which affect girls' and women's access to quality science education and careers."[110] The instrument also sheds light on the gender gap in scientific professions[111] and the limited access for persons with disabilities[112] and persons living in poverty.[113] The same problem plagues access to the scientific profession of other minorities and members of vulnerable groups, particularly the disabled community and indigenous populations.

I. Normative Takeaways

The main obligations resulting from the RtS that States have in connection with the duty to ensure literacy in science and climate change can be summarised as a duty to:

- Empower citizens by ensuring that the population possesses adequate scientific literacy to understand the problem posed by climate change and the science and technology dimensions of climate policy.

C. Duty to "Share and Disseminate Knowledge"

According to Art. 6.3 of the DEPCC,

> "Knowledge related to the causes, modalities and impacts of climate change and responses to it should be shared equitably and in a timely manner in order to increase

[108] CESCR, General Comment 25, supra note 6, ¶ 27.

[109] UNESCO (2021) UNESCO Science Report: The Race Against Time Towards Smarter Development, 131.

[110] Id., ¶ 31 (emphasis added).

[111] Data published by the UNESCO Institute for Statistics show that less than 30% of the world's researchers are women. The data can be found in UNESCO, Women in Science [accessed June 30, 2023].

[112] CESCR, General Comment 25, supra note 6, ¶ 34.

[113] Id., ¶ 38.

the adaptive and mitigating capacities of all, and to increase the resilience of people and ecosystems."

Also, according to Art. 6.4,

> "Developed States and other States, on a voluntary basis, as well as relevant actors should strive to strengthen timely cooperative action in the areas of technology development and transfer, support for the synthesis of relevant information and knowledge, capacity-building, and means and financial resources to developing countries....."

The RtS includes a right to access scientific knowledge.[114] We have noted that CESCR General Comment 25 defines the term "benefits" as encompassing "scientific knowledge and information directly deriving from scientific activity."[115] According to UNESCO, knowledge is also considered constitutive of "science."[116] The basis for a right to access scientific knowledge can also be found in Article 15.2 of the ICESCR, which commits States Parties to take the steps "necessary for ... the diffusion of science."[117] General Comment 25 further notes that "doing science does not only concern scientific professionals but also ... the dissemination of scientific knowledge"[118] and that the element of availability means that "scientific knowledge and its applications are protected and widely disseminated."[119] More explicitly, in General Comment 25 the CESCR identified eliminating unjustifiable barriers to "access by individuals

[114] UNESCO, Recommendation on Science and Scientific Researchers, supra note 22, ¶ 1(a)(ii); CESCR, General Comment 25, supra note 6, ¶ 4-5.

[115] *Id.*, ¶ 8.

[116] The 2017 UNESCO Recommendation on Science and Scientific Researchers, the latest international legal instrument to provide a definition of "science", defines it as: "The enterprise by which humankind, acting individually or in small or large groups, makes an organized attempt, through the objective study of observed phenomena and their validation through the exchange of findings and data and through peer review, to discover and master the chain of causalities, relationships or interactions; brings together in a coordinated way subsystems of knowledge through systematic reflection and conceptualization; and thus equips itself with the opportunity to use, for its own benefit, the understanding of processes and phenomena occurring in nature and society." UNESCO, Recommendation on Science and Scientific Researchers, supra note 50, ¶ 1(a)(i). It also adds that the term "the sciences" means: "... a complex of knowledge, facts and hypotheses, in which the theoretical element is susceptible of being validated in the short or long term, and to that extent includes the sciences dealing with social facts and phenomena." Id., ¶ 1(a)(ii).

[117] ICESCR, supra note 11, Art. 15.2.

[118] CESCR, General Comment 25, supra note 6, ¶ 10.

[119] Id., ¶ 16.

or particular groups to ... scientific knowledge" as a core obligation under the ICESCR.[120] It further integrated access to knowledge with the duty to respect by "eliminating ... arbitrary limitations on access to the Internet, which undermines access to and dissemination of scientific knowledge,"[121] with the duty to protect by adopting measures preventing interferences that "prevent ... access to knowledge,"[122] and with the duty to fulfill by adopting measures "providing access to the Internet and other sources of knowledge."[123] Such language clarifies that access to scientific knowledge is part and parcel of the RtS.

The right to access scientific knowledge features prominently in other authoritative instruments, including the 2012 *Report on the Right to Enjoy the Benefits of Scientific Progress and its Applications* by the then-Special Rapporteur on Cultural Rights, Farida Shaheed.[124] Various UNESCO standard-setting instruments recognize an entitlement to access scientific knowledge.[125] For instance, the *Recommendation on Science and Scientific Researchers* considers access to knowledge "a social and ethical requirement for human development [and] essential for realizing the full potential of scientific communities worldwide."[126] However, the most significant recognition is probably the one in the 2021 *Recommendation on Open Science*, which formally captures the emerging norms of open science.[127] Access to scientific knowledge is constitutive of the definition of open science,[128] is a core value of open science,[129] and is an area of action where governments are recommended to take concurrent action.[130]

[120] *Id.*, ¶ 52.

[121] *Id.*, ¶ 42.

[122] *Id.*, ¶ 43.

[123] *Id.*, ¶ 45.

[124] UN Human Rights Council, *Report of the Special Rapporteur in the field of cultural rights, Farida Shaheed: The right to enjoy the benefits of scientific progress and its applications*, A/HRC/20/26 (May 14, 2012), para. 28 ("The right to have access to scientific knowledge is fundamental to the realization of the right to science.").

[125] *See for example* UNESCO, *International Declaration on Human Genetic Data*, *supra* note 27, Art. 18(b), (c).

[126] UNESCO, *Recommendation on Science and Scientific Researchers*, *supra* note 22, ¶ 18(b).

[127] UNESCO, *Recommendation on Open Science*, *supra* note 24.

[128] *Id.*, ¶ 7 ("Open scientific knowledge").

[129] *Id.*, ¶ 13(c) ("equal access to scientific knowledge for both producers and consumers of knowledge").

[130] *Id.*, ¶ 20(e) ("Encourage funders, research institutions, journal editorial boards, learned societies, and publishers to adopt policies that require and reward open access to scientific knowledge.").

At the regional level, there is no express recognition of the right to access scientific knowledge. However, when language recognizes the right "to enjoy the benefits of scientific progress and its applications" appears, as it is the case in the Americas,[131] Arab world,[132] or Southeast Asia,[133] it is safe to conclude, based on the textual analysis of Article 15.1.b of the ICESCR, the instrument that inspired all regional ones, that a right to access scientific knowledge is guaranteed.

A similar argument can be made for the national constitutions echoing Article 15.1.b of the ICESCR, even though constitutions are interpreted according to domestic law, which may place more value on sources other than international law. Thus, in the European Union, specific policies addressing access to scientific knowledge have been adopted. For instance, the *Open Science Policy* strives to make scientific knowledge more accessible to citizens to enable their participation in science.[134] Horizon Europe, the research funding scheme of the EU, includes a requirement to make research outputs available in open access format.[135] The *Directive on Open Data and the Re- Use of Public Sector Information* require Member States to "mak[e] publicly funded research data openly available ('open access policies'), following the principle of 'open by default' and compatible with the FAIR [Findable, Accessible, Interoperable, Re-usable] principles."[136]

Of course, scientists are entitled to access scientific knowledge as part of the right to scientific progress and scientific freedom. However, because the entitlement to access scientific knowledge is a right of "everyone", the term "scientific knowledge" must be interpreted to mean something more than just "scientific knowledge" in a technical sense. In a technical sense, "scientific knowledge" consists of findings published after peer review. However, in the context of the right to benefit, the public can benefit by learning about science and scientific knowledge from a broader set of sources, including non-peer-reviewed sources. Accordingly, "scientific knowledge" must be understood as including at least three kinds of knowledge sources: (1)

[131] ADHR, *supra* note 2, Art. XIII; PSS, *supra* note 12, Art. 14.1.b.

[132] ArabCHR, *supra* note 13, Art. 42.

[133] ASEANDcl, *supra* note 14, Art. 32.

[134] EU, European Commission, *European Research Area* [accessed Jan. 26, 2023].

[135] EU, European Commission, Directorate General for Research and Innovation (2021) *Horizon Europe, Open Science: Early Knowledge and Data Sharing, and Open Collaboration*, Publications Office of the European Union.

[136] EU, *Directive 2019/1024 of the European Parliament and of the Council of 20 June 2019 on open data and reuse of* public *sector information*, PE/28/2019/REV/1, OJEU L 172, 26 June 2019, Art. 10.

scientific publications conveying formally defined scientific knowledge in the form of peer-reviewed findings, (2) publications that are scientific in nature knowledge (conveying peer-reviewed findings) but not peer-reviewed, and (3) other sources that are "scientific" in the senses that they produced as part of the knowledge produced process called "science" ("scientific outputs").

Access to "scientific knowledge" thus certainly includes everyone's ability to read scientific findings published in peer-reviewed publications, the gold standard in scientific knowledge artifacts. Yet, the benefit that non-specialists can extract from peer-reviewed publications is limited by the writing norms and styles of technical writing in the sciences. While entitled to access these publications, the public is also entitled to learn about scientific findings from more accessible sources, like publications that have not been peer-reviewed and that summarize or popularize science. Lastly, the public is entitled to access scientific outputs, including "original scientific research results, research data, software, source code, source materials, workflows and protocols, digital representations of pictorial and graphical materials and scholarly multimedia material."[137] Journal articles are typically limited to a certain word count, even in a digital format.

It is important to note that the entitlement to access scientific knowledge depends on the entitlement to scientific literacy, discussed in the last section of this paper, which contributes to the normative content of the right to participate in scientific progress. To benefit from scientific progress, the public must be equipped with the skills and knowledge necessary to make sense of scientific knowledge.

States have the duty to take steps for the diffusion of scientific knowledge. This positive duty includes ensuring access to the knowledge sources we discussed (i.e. scientific publications, scientific outputs, and non-peer reviewed artifacts conveying peer-reviewed findings). One of the critical issues with access to scientific knowledge is the fact that a significant share of scientific findings is published in outlets owned by commercial publishers. Usually, these publications are beyond a paywall that can only be removed by a substantial fee. To address the issues created by the reader-pays model, States — mostly developed ones — have made many publications available through public library subscriptions, or by subsidizing publishing costs so that no fee is charged to readers. General Comment 25 suggests States to "exert

[137] UNESCO, Recommendation on Open Science, *supra* note 24, ¶ 7.a.

every effort to ensure equitable and open access to scientific literature, data and content,"[138] particularly for "research findings and research data funded by States."[139]

The emergence of the "open access model" in the past two decades caused a shift in the business practices of commercial publishers. Under the open access model, publication fees are typically shifted from readers to authors in the form of article processing charges (APCs). When APCs are paid, publications become openly accessible and any reader with an internet connection can access them. While the open access model facilitates the enjoyment of the benefits of scientific progress, it is still not an answer to human rights demands because it creates new distortions on the supply side of scientific publications. APCs are substantial and often unaffordable to poorly funded scientists and institutions. The effect is discriminatory in favor of wealthier institutions, based mainly in developed countries. Granted, some publishers offer APC discounts or waivers to authors from less developed countries. However, the model is certainly far from being satisfactory.

Another step towards the goal of ensuring diffusion of scientific knowledge is to support the growth of the open science movement. Open science enables more access to knowledge and greater enjoyment of scientific progress because non-scientists can also access knowledge circulating among scientists. Open science and open access are steps toward universal access to scientific knowledge, but the path to that goal is still long and uncertain.

I. Normative Takeaways

The main obligations resulting from the RtS that States have in connection with the duty to ensure literacy in science and climate change can be summarized as a duty to:

- Disseminate scientific knowledge about climate change, focusing on scientific knowledge relating to adaptation and mitigation and the strategies to achieve both.

D. Duty to Ensure "Participation in Science Affairs"

Art. 4.1 of the DEPCC affirms that "[j]ustice in relation to climate change requires fair treatment and meaningful involvement of all people"[140] and that "relevant actors at all levels should work

[138] CESCR, General Comment 25, *supra* note 6, ¶ 49.

[139] *Id.*, ¶ 16.

[140] DEPCC, supra note 23, Art. 4.1.

together in a spirit of justice, global partnership, inclusion, and in particular in solidarity with the poorest and most vulnerable people."[141] The instrument then emphasizes the need to "take into account the contribution of women in decision-making [and] the needs of those at greatest risk, particularly the poorest and the most vulnerable."[142] States should also "facilitate and encourage public awareness, and participation in decision-making and actions by making access to information and knowledge" on climate change.[143] States should also cultivate scientific literacy and public participation by "rais[ing] awareness and promot[ing] literacy in science in all sectors and amongst their populations,"[144] and ensuring "access to life-long learning opportunities that help them to acquire and update the knowledge, skills, values, and attitudes needed to respond to climate change and contribute to sustainable development."[145]

Participation has been an integral dimension of the right to science since its onset. The ADHR proclaims that "[e]very person has the right ... to participate in the benefits that result from intellectual progress, especially scientific discoveries."[146] The language in the final text of the ADHR evolved thought drafts that also recognized the participatory dimension of the right. Earlier versions of the provision focused on "the right to share in the benefits accruing from the discoveries and inventions of science."[147] According to Article 27 of the UDHR, "everyone has the right to freely participate in the cultural life of the community, to share scientific advances and its benefits, and to get credit for their own work." Although Article 15.1.b of the ICESCR does not mention "participation" or "sharing in," according to General Comment 25, Article 15.1.b of the ICESCR includes everyone's right "to participate in scientific progress."[148]

Participatory considerations pervade the *Venice Statement on the Right to Enjoy the Benefits of Scientific Progress and its Applications*[149] and the various UNESCO standard-setting

[141] *Id*.

[142] *Id*., Art. 4.3.

[143] *Id*., Art 4.4.

[144] *Id*., Art. 7.4(b).

[145] *Id*., Art. 11.2.

[146] ADHR, *supra* note 2, Art. XIII.

[147] For an analysis of the drafting process of the American Declaration and a comparison between the final text, the 1945 Preliminary Draft and the 1947 Final Draft, see Romano, The Origins of the Right to Science, 45 (Box 2.1).

[148] CESCR, General Comment 25, *supra* note 6, ¶ 11.

[149] *Supra* note 5.

instruments. The *Venice Statement* underscores the fact that "a human rights-based approach requires that science and its applications are consistent with fundamental human rights principles such as non- discrimination, gender equality, accountability and participation, and that particular attention should be paid to the needs of disadvantaged and marginalized groups."[150] It also construes the "duty to fulfil" as including the duty to periodically review relevant policies "on the basis of a participatory and transparent process, with particular attention to the status and needs of disadvantaged and marginalized groups,"[151] "provide opportunities for public engagement in decision-making about science and technology and their development," and design science curricula to strengthen "the skills necessary to engage in scientific research."[152]

The 1999 UNESCO *Declaration on Science and the Use of Scientific Knowledge* calls on States to address imbalances in representation in Science, Technology, Engineering and Mathematics (STEM), in particular of women,[153] and to remove the barriers that "have precluded the full participation [in science] of other groups, of both sexes, including disabled people, indigenous peoples and ethnic minorities."[154] It also emphasizes the role of science education in fostering democracy and access to the benefits of scientific progress, and the need to "develop and expand science literacy in all cultures and sectors of society as well as reasoning ability and skills and an appreciation of ethical values, so as to improve public participation in decision-making related to the application of new knowledge."[155]

Although focusing on the inner workings of the scientific ecosystem, the UNESCO *Recommendation on Science and Scientific Researchers*, as revised in 2017, includes provisions that address participatory aspects of the scientific enterprise. These include ensuring the remediation of past inequalities and patterns of exclusions from careers in science and technology, particularly of women;[156] ensuring the broadest possible access to scientific

[150] *Id.*, ¶ 12(b).

[151] *Id.*, ¶ 16(a).

[152] *Id.*, ¶ 16(e)-(f),

[153] UNESCO, *Declaration on Science and the Use of Scientific Knowledge*, *supra* note 289, 45-49, ¶ 24, 42.

[154] *Id.*, ¶ 25.

[155] *Id.*, ¶ 34.

[156] See for example UNESCO, Recommendation on Science and Scientific Researchers, supra note 22, ¶ 13(a)-(c), 24(b)-(c), 33, 34(d).

literature and data;[157] strengthening public scientific literacy and culture, public trust in and support of science throughout society, and facilitating dialogue between the scientific community and society.[158]

The UNESCO standard-setting instruments in biomedicine address issues of participation narrowly, focusing on participation in research and the right to be informed of research results.[159] By contrast, the more recent standard-setting instruments contain rich analyses of participation in scientific progress. We already mentioned what the DEPCC has to say on the issue. Similarly, the 2021 *Recommendation on Open Science* defines terms, core values, and guiding principles intersecting participation.[160] Open science must include "open engagement of societal actors"[161] and "the effective reuse of the outputs of citizen and participatory science by other actors, including scientists."[162] The relevant core values are collective benefit,[163] diversity and inclusiveness,[164] and collaboration, participation and inclusion.[165] Relevant guiding principles are equal opportunity,[166] and collaboration, participation and inclusion.[167] Finally, it outlines areas of action aiming to facilitate participation in open science. These

[157] See for example *id.*, ¶ 13(c), 18(a)-(d), 21, 26, 35-38.

[158] See for example *id.*, ¶ 5(c).

[159] UNESCO, *Universal Declaration on the Human Genome and Human Rights*, *supra* note 25, Art. 5(c); UNESCO, *International Declaration on Human Genetic Data*, *supra* notes 26, 27, Art. 10.

[160] UNESCO, *Recommendation on Open Science*, *supra* note 24.

[161] *Id.*, ¶ II.10 (defining "expanded collaboration between scientists and social actors beyond the scientific community, by opening up practices and tools that are part of the research cycle and making the scientific process more inclusive and accessible to the inquisitive society at large, based on new forms of collaboration and work such as crowdfunding, crowdsourcing, and scientific volunteering").

[162] *Id.*

[163] *Id.*, ¶ III.13(b) ("The practice of science should be inclusive, sustainable, and equitable, including opportunities for science education and capacity building").

[164] *Id.*, ¶ III.13(d) ("open science should embrace... the general public and knowledge holders beyond the traditional scientific community, including indigenous peoples and local communities, and social actors from different countries and regions, as appropriate").

[165] *Id.*, ¶ III.14(d) ("collaboration at all levels of the scientific process, across geographic, linguistic, generational, and resource boundaries, should become the norm, and collaboration across disciplines should be promoted, along with the full and effective participation of social actors and the inclusion of the knowledge of marginalized communities in the resolution of problems of social importance").

[166] *Id.*, ¶ III.14(b).

[167] *Id.*, ¶ III.14(d).

include "the dissemination of scientific knowledge to ... the public at large;"[168] "[e]nabling open multi-stakeholder discussions on open science benefits and its real and apparent challenges;"[169] "[e]nhancing the inclusion of citizen and participatory science as integral parts of open science policies and practices at the national, institutional and funder levels;"[170] "[d]esigning models that allow co-production of knowledge with multiple actors and establishing guidelines to ensure the recognition of non-scientific collaborations;"[171] "[p]romoting the use of open educational resources ... to empower educators and learners to become co-creators of knowledge;"[172] disseminating "scientific information [to] build public trust in science while increasing the engagement of societal actors beyond the scientific community;"[173] implementing "new participatory methods and validation techniques to incorporate and value inputs from social actors beyond the traditional scientific community, including through citizen science, crowdsource-based scientific projects, citizen involvement in community-owned archival institutions, and other forms of participatory science;"[174] and "[d]eveloping participatory strategies for identifying the needs of marginalized communities and highlighting socially relevant issues to be incorporated into the science, technology and innovation (STI) research agendas."[175]

Finally, the 2021 *Recommendation on the Ethics of Artificial Intelligence*[176] provides the lengthiest analysis of participation in scientific progress. Intending to foster "multi-stakeholder, multidisciplinary and pluralistic dialogue and consensus building about ethical issues relating to AI systems,"[177] the instrument recommends fostering participation in scientific and

[168] *Id.*, ¶ IV.16(f).

[169] *Id.*, ¶ IV.16(h).

[170] *Id.*, ¶ IV.17(f).

[171] *Id.*, ¶ IV.17(g).

[172] *Id.*, ¶ IV.19(d).

[173] *Id.*, ¶ IV.19(e).

[174] *Id.*, ¶ IV.21(d).

[175] *Id.*, ¶ IV.21(e).

[176] UNESCO, *Recommendation on the Ethics of Artificial Intelligence*, *supra* note 25.

[177] *Id.*, Sec. II, ¶ 8(d).

technological progress by emphasizing AI literacy[178] and its "prerequisite skills,"[179] inclusiveness,[180] particularly in access to AI professions,[181] interconnectedness,[182] transparency and explainability,[183] awareness and literacy,[184] and multi-stakeholder and adaptive governance and collaboration.[185] It concludes by suggesting various participatory policy actions. These include ethical impact assessments that "facilitate citizen participation and address societal challenges... [and are] transparent and open to the public"[186] and "AI governance mechanisms [that] are inclusive, transparent, multidisciplinary, multilateral ... and multi-stakeholder."[187] On gender, the instrument recommends action to "increase the opportunities of girls' and women's participation in science, technology, engineering, and mathematics (STEM), including information and communication technologies (ICT) disciplines, preparedness, employability, equal career development and professional growth of girls and women"[188] as well as "encourage female entrepreneurship, participation and engagement in

[178] *Id*., Sec. IV, ¶ 101 ("AI literacy of the public at all levels and in all countries in order to empower people and reduce digital divides and digital access inequalities resulting from the widespread adoption of AI systems.").

[179] *Id*., Sec. IV, ¶ 102 ("Member States should promote the acquisition of "pre-requisite skills" for AI education, such as basic literacy, numeracy, coding and digital skills, and media and information literacy, as well as critical and creative thinking, teamwork, communication, social-emotional skills and AI ethics, especially in countries and in regions or areas within countries where there are notable gaps in the education of these skills.").

[180] *Id*., Sec. III.1, ¶ 19.

[181] *Id*., Sec. IV, ¶ 78, 91, 92.

[182] *Id*., Sec. III.1, ¶ 22-24.

[183] *Id*., Sec. III.2, ¶ 38-39.

[184] *Id*., Sec. III.2, ¶ 44 (recommending the promotion of "open and accessible education, civic engagement, training in digital skills and AI ethics, media and information literacy and training led jointly by governments, intergovernmental organizations, civil society, academia, the media, community leaders and the private sector, and taking into account existing linguistic, social and cultural diversity, to ensure effective public participation so that all members of society can make informed decisions about their use of AI systems and be protected from undue influence").

[185] *Id*., Sec. III.2, ¶ 47 ("The participation of different stakeholders throughout the life cycle of the AI system is necessary to adopt inclusive approaches to AI governance, enabling benefits to be shared by all and contributing to sustainable development [...] and to enable meaningful participation of marginalized groups, communities and individuals and, where appropriate, in the case of indigenous peoples, respect for self-governance of their data.").

[186] *Id*., Sec. IV, ¶ 53.

[187] *Id*., Sec. IV, ¶ 54.

[188] *Id*., Sec. IV, ¶ 88.

all stages of an AI system life cycle."[189] Educational initiatives action should "provide adequate AI literacy education to the public on all levels in all countries in order to empower people and reduce the digital divides and digital access inequalities resulting from the wide adoption of AI systems."[190]

The normative basis of the right to participate in scientific progress is also strengthened by its connection to other human rights. The right to education, which is enshrined in Article 16 of the UDHR and Articles 13 and 14 of the ICESR, supports an entitlement to scientific literacy and a science education. Furthermore, Articles 28 and 29 of the Convention on the Rights of the Child require States to provide access to scientific and technical knowledge and modern teaching methods.[191] Participation in citizen science projects connects to the same civic and political rights that contribute to the normative content of scientific freedom, and, arguably, in some cases overlaps with them when citizen scientists enjoy scientific freedom. Similarly, the right to participate in science affairs is reinforced by the right "to take part in the conduct of public affairs, directly or through freely chosen representatives."[192]

Internationally, at the regional level, three instruments have adopted language that echo Article 15.1.b of the ICESCR. These are Article 14 ("Right to the Benefits of Culture") of the Protocol of San Salvador,[193] Article 42 of the (Revised) Arab Charter on Human Rights,[194] and Article 32 of the ASEAN Human Rights Declaration.[195] The legal instruments adopted in the African and European systems, including those adopted by the Council of Europe, do not include provisions recognizing the right to participate in scientific progress.

[189] *Id.*, Sec. IV, ¶ 91.

[190] *Id.*, Sec. IV, ¶ 101.

[191] *Convention on the Rights of the Child*, adopted November 20, 1989, entered into force September 2, 1990, UNTS, Vol. 1577, 3.

[192] UN, *International Covenant on Civil and Political Rights (ICCPR*), adopted December 16, 1966, entered into force March 23, 1976, UNTS, Vol. 999, p. 171, Art. 25(a).

[193] *Supra* note 12, Art. 14.

[194] *Supra* note 13, Art. 42.

[195] *Supra* note 14, Art. 32.

Finally, domestically, at least three national constitutions include language expressly acknowledging the right to participate in scientific progress: of Lesotho,[196] Madagascar,[197] and Vietnam.[198] Nine more constitutions contain provisions that echo Article 15.1.b of the ICESCR in that they refer to sharing the benefits of scientific progress.[199]

As to the normative content, General Comment 25 affirms that "the right of everyone to take part in cultural life includes the right of every person to take part in scientific progress and in decisions concerning its direction."[200] It further explains that "decision" must be construed broadly to include "decisions concerning the orientation of scientific research or the adoption of certain technical advancements."[201] These decisions, the comment adds,

> "should be subjected to public scrutiny and citizen participation. As far as possible, scientific or technological policies should be established through participatory and transparent processes and should be implemented with accompanying transparency and accountability mechanisms."[202]

CESCR's General Comment 25 clearly indicates that the public is entitled to participate in the governance of scientific progress and its applications. It is an entitlement to public engagement in science affairs. "Public engagement" is an umbrella term grouping together various methods that create opportunities for the public to contribute to public affairs and decision-making. Engagement can be passive or active.[203] Passive engagement assigns to the public the role of recipient of information, as in the case of awareness campaigns. Passive methods of public

[196] Lesotho, Constitution of April 2, 1993 (last amended, 2018), Art. 35.1 ("strive to ensure that all citizens have the opportunity to participate freely in the cultural life of the community and to share in the benefits of scientific progress and its application").

[197] Madagascar, Constitution of April 8, 1998, Art. 26 ("All individuals have the right to participate in the cultural life of the community, in scientific progress and in the well-being resulting therefrom").

[198] Vietnam, Constitution of April 18, 1992 (last amended, 2013), Art. 40.3 ("The State shall provide favorable conditions for all to participate in and enjoy the benefits of scientific and technological activities.").

[199] These are the constitutions of Bolivia, Dominican Republic, Ecuador, Guatemala, Indonesia, Mongolia, Paraguay, Spain, and Tajikistan.

[200] CESCR, *General Comment 25*, *supra* note 6, ¶ 10.

[201] *Id.*, ¶ 55.

[202] *Id.*

[203] G. Rowe & L. J. Frewer (2000) *Public Participation Methods: A Framework for Evaluation*, SCI. TECHNOL. HUMAN VALUES 25(1).

engagement are unidirectional in the sense that they generate information flowing exclusively from experts or institutions to the public.

Active engagement can take the form of public consultation and public participation. Public consultations are initiated by a "sponsor" to collect input from members of the public to expand the informational basis of policy formulation or decisions.[204] Public consultation methods include citizens' panels, consultation documents, internet-based consultations, focus groups, open spaces, opinion polls, referenda, study circles, surveys, telepolling, and televoting. Public participation generates an exchange between members of the public and the sponsors to build an understanding shared by the public and the decision-makers. It entails "some degree of dialogue in the process that takes place (usually in a group setting), which may involve representatives of both parties in different proportions (depending on the mechanism concerned) or, indeed, only representatives of the public who receive additional information from the sponsors prior to responding."[205] Public participation methods include action plans, workshops, citizen juries, consensus conferences, deliberative opinion polls, negotiated rulemaking, planning cells, task forces, and town meetings with voting.

While human rights standards do not prescribe any specific method, participatory methods that assign an active role to the public must be prioritized. CESCR's General Comment 25 requires States to "promote ... a culture of active citizen engagement with science, particularly through a vigorous and informed democratic debate on the production and use of scientific knowledge, and a dialogue between the scientific community and society."[206] It also entitles indigenous peoples to consultations "whenever the State party or non-State actors conduct research, take decisions or create policies relating to science that have an impact on indigenous peoples or when using their knowledge."[207] General Comment 25 also mentions public engagement in relation to developing policies, strategies, and action plans relating to the right to science.[208]

[204] *Id.*, 255 (a "sponsor" is the "party that commissions the engagement initiative").

[205] *Id.*, 255-256.

[206] CESCR, *General Comment 25*, *supra* note 6, para. 54.

[207] *Id.*, ¶ 40.

[208] *Id.*, ¶ 52 (States should "[d]evelop a participatory national framework law on this right that includes legal remedies in case of violations, and adopt and implement a participatory national strategy or plan of action for the realization of this right").

It is also essential to recall that monitoring and anticipation of harm are also opportunities to realize the right to participate in science affairs. According to General Comment 25,

> "in controversial cases, participation and transparency become crucial because the risks and potential of some technical advances or some scientific research should be made public in order to enable society, through informed, transparent and participatory public deliberation, to decide whether or not the risks are acceptable."[209]

The public has "the right to information and participation in controlling the risks involved in particular scientific processes and its applications"[210] and States owe a corresponding duty to make "information concerning the risks and benefits of science and technology ... accessible without discrimination."[211] According to Article 4.4. of the DEPCC, "States and other pertinent actors should facilitate and encourage public awareness, and participation in decision-making" regarding measures to be taken to address climate change.[212]

As to obligations, the duty to fulfil the right to participate in the conduct of science affairs requires States to set up forms of public consultations, deliberations, or participatory governance mechanisms that ensure the active participation of the public in science affairs. They include public consultation (e.g., asking the public for input, feedback, or recommendations), public deliberation (e.g., involving the public in a way that can contribute to forming a shared understanding of the issues and meaningfully influence the outcome), and other forms of sustained involvement of the public in policymaking (e.g., granting permanent or semi-permanent representation of the public in the various aspects of decision-making processes including planning, implementation, monitoring, and assessment). The specific methods to be used depend on the intended objective goal of public engagement and the context in which participation is expected.

While a comprehensive catalog of methods that could be used is beyond the scope of this paper, the right to participate in science affairs must be fulfilled in at least three circumstances. The first is the case of decisions regarding allocating public funds to support research programs. Public funding is never sufficient to support all research activities in any State, not

[209] General Comment No. 25, *supra* note 6, ¶ 57.

[210] *Id.*, ¶ 56.

[211] *Id.*, ¶ 17.

[212] DEPCC, *supra* note 23, Art. 4.4.

even the wealthiest. Public funding allocation can also be used maliciously to marginalize groups or shut down certain lines of research. CESCR's General Comment 25 provides that in "the allocation of public resources, priority is given to research in areas where there is the greatest need for scientific progress in health, food and other basic needs related to economic, social, and cultural rights and the well-being of the population, especially with regard to vulnerable and marginalized groups."[213] Funding allocation choices also have a cascade effect as they affect the production of scientific knowledge and the possibility of developing applications. The second is the case of regulatory initiatives to limit the right to science and the rights of science, particularly prohibitions and restrictions to research. In connection to this, we must also recall the duty (of immediate realization) to avoid and repeal prohibitions and restrictions that contravene Articles 4 of the ICESCR and the ICCPR, particularly where they indicate that limitations must be acceptable "decisions affecting marginalized or vulnerable a democratic society." The third is the case of populations.[214]

Finally, States must ensure that the right to participate is protected from third-party influence in public consultation and participation. Particularly, they should target attempts by special interests to capture public consultations and other public fora where the public actively participates in science affairs.[215] Unless governments play an active role in creating an environment that enables participation, the pledge enshrined in the sentence "everyone has the right to ... share in scientific advancement and its benefits" risks becoming hollow.[216]

I. Normative Takeaways

The main obligations resulting from the RtS that States have in connection with the duty to ensure participation in science affairs, particularly in relation to climate change, can be summarized as a duty to:

[213] CESCR, *General Comment 25*, supra note 6, ¶ 52.

[214] Community advisory boards in the context of clinical trials are an example of a public participation mechanism. See L. E. Cox, et al. (1998) *Community Advisory Boards: Their Role in AIDS Clinical Trials. Terry Beirn Community Programs for Clinical Research on AIDS*, HEALTH SOC. WORK 23(4); G. Pancras, et al. (2020) *How Do Community Advisory Boards Fulfil Their Ethical Role in HIV Clinical Trials? A Protocol for a Systematic Review of Qualitative Evidence*, BMJ OPEN 10; A. DeLuca, et al. (2014) *The Evolving Role of Advocacy in Tuberculosis*, LANCET RESPIR. MED. 2(4).

[215] For an analysis of lobbying practices at the EU agency level, see S. Arras & J. Beyers (2020) *Access to European Union Agencies: Usual Suspects or Balanced Interest Representation in Open and Closed Consultations?,* J. COMMON MARK. STUD. 58(4).

[216] UDHR, *supra* note 10, Art. 27.1.

- Fully recognize the rights of scientists to participate in policy and public debates concerning climate policy;
- Set up mechanisms and for a for public discussions of climate policy aiming at involving representatives of a variety of groups and key stakeholders;
- Ensure broad participation, in terms of scientists and institutions, in the science-policy interfaces to address concerns that "data are frequently provided and analyzed by institutions that only represent UN members partially."[217]

E. Duty to "Align Policies with Best Scientific Available Knowledge"

According to Art. 7.1 of the Recommendation,

> "Decision-making based on science is critically important for meeting the mitigation and adaptation challenges of a rapidly changing climate. Decisions should be based on, and guided by, the best available knowledge from the natural and social sciences, including interdisciplinary and transdisciplinary science, and by taking into account, as appropriate, local, traditional and indigenous knowledge."

Although there is no express mention of the right to policies aligned with scientific evidence in international and regional treaties, the CESCR read it in Article 15 of the ICESCR. As General Comment 25 declares, "[a]dopt[ing] mechanisms aimed at aligning government policies and programmes with the best available, generally accepted scientific evidence" is a core obligation under the ICESCR.[218]

The UNESCO *Recommendation on Science and Scientific Researchers* acknowledges the duty to align policies with scientific evidence when it recommends that States "us[e] scientific and technological knowledge in decision-making and policies"[219] and "create the environment to ensure that scientific researchers, who give policy advice to policymakers and other public officials."[220] The *Recommendation on the Ethics of Artificial Intelligence* considers scientific

[217] C. Kőrösi & J. Cullmann (2023) *Science Needed Now, for Action*, SCIENCE 381(6663).

[218] CESCR, *General Comment 25*, *supra* note 6, ¶ 52.

[219] UNESCO, *Recommendation on Science and Scientific Researchers*, *supra* note 22, ¶5(g).

[220] *Id.*, ¶ 9.

evidence necessary for regulating AI technologies.[221] The right to policies aligned with scientific evidence does not appear yet in national constitutions.

What does it mean that policies must be aligned "with best available, generally accepted scientific evidence?"[222] To identify the standards, we must first define the terms "best," "available," "generally accepted," and "aligned." Because they are mentioned but not defined in General Comment 25, their meaning must be drawn from other legal and non-legal sources.

First, since "scientific evidence" means the factual or data-based component of scientific knowledge, including data and narratives presenting, discussing, analyzing, and drawing conclusions from data,[223] the CESCR's choice to use the term "evidence" rather than "knowledge" indicates the requirement to align policies to scientific knowledge's factual or data-based component but not to theories, hypotheses, and other nonfactual elements.

Second, scientific evidence becomes "available" when it formally enters the scholarly record. This happens when findings appear in a refereed scientific publication. Peer-reviewed publication is the gold standard of scientific knowledge production. Indeed, the DEPCC urges States to "promote accurate communication on climate change based on peer-reviewed scientific research."[224] That being said, nowadays, studies often appear on preprint repositories, such as arXiv, bioRxiv, medRxiv, or SSRN, which are platforms that publish research outputs before peer review. Should evidence published on these online platforms be considered "available" for the purpose of the RtS? A reasonable approach is that, ordinarily, pre-peer-review scientific outputs are not "available scientific evidence" because they lack the required validation of peer review. However, under exceptional circumstances (e.g. when no other evidence is available and policy action is necessary to preserve a human right), policies and programs can be aligned with pre-peer-review scientific outputs and adjusted as evidence becomes "available" after peer review.[225] The unacceptable alternative is to base those policies

[221] UNESCO, *Recommendation on the Ethics of Artificial Intelligence*, *supra* note 25, ¶ 86, 122, 131(d).

[222] CESCR, *General Comment 25*, *supra* note 6, ¶ 52, 54, 65.

[223] Romano & Boggio, *supra* note 8, ch. 2.3.4.1.

[224] DEPCC, *supra* note 23, Art. 7.4.c.

[225] C. Dunlop & C. Radaelli (2020) *The Lessons of Policy Learning: Types, Triggers, Hindrances and Pathologies*, POLICY POLIT. 46(2); C. Dunlop, E. Ongaro, & K. Baker (2020) *Researching COVID-19: A Research Agenda for Public Policy and Administration Scholars*, PUB. POLICY ADM. 35(4).

on no evidence, or to refrain from acting. A public emergency justifies lowering the evidentiary standards for policy alignment.[226]

Third, the adjective "best" is a mark of scientific quality. Two factors determine scientific quality. First, the evidence must be in studies that adhere to the conventional research integrity standards discussed above. Second, the evidence must be "reproduced," as in confirmed in multiple studies.[227]

The "best" evidence comes from studies whose internal and external validity have been verified by reproducing them.[228] Yet, this definition of "best" restricts the pool of studies that can be used to align policies and programs significantly because many studies do not undergo or cannot undergo the test of reproducibility.[229] Moreover, reproducibility is not a well-established norm in all scientific disciplines.[230] The movement towards open science and the norm that raw data must be deposited in public repositories may progressively alleviate some of the roots of

[226] The policies adopted during the COVID-19 pandemic are an excellent example of the use of pre-peer-review scientific results in policy and their replacement once peer-reviewed evidence is available. *See* Y. Yin, *et al*. (2021) *Coevolution of Policy and Science During the Pandemic*, SCIENCE 371(6525).

[227] We draw on S. N. Goodman, D. Fanelli & J. P. A. Ioannidis () *What Does Research Reproducibility Mean?*, SCI. TRANSL. MED. 8(341). They interpret "reproducibility" as a general term that refers to various approaches to confirming a study that others may call "replicability", "repeatability", "reliability", "robustness", and "generalizability". Reproducibility is measured in three dimensions: methods, results, and inferential ability. Reproducibility of methods conveys "the ability to apply, as accurately as possible, experimental and computational procedures, with the same data and tools, to obtain the same results ("reproducibility")" (*id.*, 2). Reproducibility of results aims to produce "corroborable results in a new study, having followed the same experimental methods" ("replicability") (*id.*, 2-3). Inferential reproducibility focuses on the inferences that can be drawn from the data. Inferences are reproducible if the conclusions drawn from an independent replication of a study or a reanalysis of the original study are of similar qualitative strength to those of the original study (*id.*, 4-5).

[228] For a comprehensive discussion of the variety of types and purposes of reproducibility, *see* F. Fidler & J. Wilcox (2021) *Reproducibility of Scientific Results*, THE STANFORD ENCYCLOPEDIA OF PHILOSOPHY, E. N. Zalta (ed.).

[229] Reproducibility is also context-dependent, meaning that replication is neither necessary nor sufficient to establish the validity of all research claims. *See* F. Steinle (2016) *Stability and Replication of Experimental Results: A Historical Perspective*, *in* REPRODUCIBILITY: PRINCIPLES, PROBLEMS, PRACTICES, AND PROSPECTS, H. Atmanspacher & S. Maasen (eds.), 60.

[230] The lack of incentives to engage in replication studies, the pressure to do new studies, and often the lack of access to war data mean that very few studies are validated. This problem, called the replication crisis or reproducibility crisis, plagues the sciences. It is the subject of an extensive literature dating back to the Open Science Collaboration's seminal paper: Open Science Collaboration (2015) *Estimating the Reproducibility of Psychological Science*, SCIENCE 349(6251) (based on a review of 100 studies in the field of psychology, the authors conclude that "a large portion of replications produced weaker evidence for the original findings"). J. Freese & D. Peterson (2017) *Replication in Social Science*, ANNU. REV. SOCIOL. 43; J. M. Chin & K. Zeiler (2021) *Replicability in Empirical Legal Research*, Ann. REV. LAW SOC. SCI. 17. Certain qualitative studies in the social sciences are not replicable in the proper sense.

limited reproducibility. However, other root causes also contribute to the fact that studies are not consistently reproduced.[231] Since all policies, including those with significant human rights impacts, must align with scientific evidence, adopting rigorous and selective standards is the correct human rights approach.

Rigor and selectivity also apply to the first quality standard defining the "best" scientific evidence: research ethics. When a study is retracted, it is extracted from the scholarly record. As such, it can no longer be considered "scientific evidence". Therefore, policies and programs based on that study must be realigned based on the "new" best evidence. The only permissible exception to the rigor and selectivity of "reproduced studies" is policy alignment to "reproducible studies" in the event no "reproduced study" exists. Under exceptional circumstances (e.g. when no other evidence is available and policy action is necessary to preserve a human right), the standard can be lowered from "reproduced" (i.e. the study underwent reproducibility tests) to "reproducible" (i.e. the study can be reproduced because the authors have made available all tools necessary to test its internal and external validity).[232] This way, a more comprehensive range of studies could be considered "best available evidence."

Fourth, General Comment 25 includes an additional requirement for using scientific evidence in policymaking: being "generally accepted." This terminology is not foreign to the international law discourse.[233] However, how a norm becomes "generally accepted" in international law bears little or no relevance to how evidence becomes "generally accepted" in the sciences. Scientists consider evidence to be generally accepted when there is consensus. Scientific consensus is said to be present when all, or almost all, scientists agree that a hypothesis, group of hypotheses, or a theory is proven, that it is a "scientific fact." Consensus emerges when findings or claims are confirmed in multiple studies and widely validated, but it certainly does not require unanimity. A seminal study on climate change conducted by Naomi Oreskes

[231] T. Miyakawa (2020) *No Raw Data, No Science: Another Possible Source of the Reproducibility Crisis*, MOL. BRAIN 13(24); M. AlQuraishi & P. K. Sorger (2016) *Reproducibility Will Only Come with Data Liberation*, SCI. TRANSL. MED. 8(339).

[232] To be included, studies "require, at a minimum, sharing analytical datasets (original raw or processed data), relevant metadata, analytical code, and related software." *See* Goodman, *supra* note 227, 1.

[233] A "general practice accepted as law," according to the ICJ Statute, is considered evidence of the existence of a rule of customary international law, one of the principal sources of international legal obligations. United Nations, Statute of the International Court of Justice, UNTS, Vol. 33, 993, Arty. 38.1.b. For the different ways in which international law interprets "generally accepted", *see* L. B. Sohn (1986) *Generally Accepted International Rules*, WASH. L. REV. 61.

of almost a thousand abstracts concluded that a consensus existed on the fact that human activities contribute to climate change after observing that 75% of the abstracts accepted, either explicitly or implicitly, held that view.[234]

Consensus implies general agreement not unanimity.[235] Some level of disagreement among scientists is compatible with consensus. Disagreement is natural in the sciences; it is part of its workings. It is an expression of the "organized skepticism" that Merton identified as a core norm of science.[236] Some level of contestation in scientific literature is inevitable, almost expected. However, consensus is reached when contestation is below the threshold that any residual contestation amounts merely to "benign contestation."[237] Contestation is no longer "benign" when it expresses "epistemic rivalries," that is, disagreement on the validity of the knowledge at stake. While "benign contestation" is compatible with consensus, "epistemic rivalries" are not. So, consensus is absent if residual contestation reveals a disagreement on core issues. Scientific consensus requires time to emerge because it results from a process of evidence accumulation. What about valid evidence not sufficiently mature for consensus? Should governments align their policies to the evidence before consensus is reached? Generally speaking, the answer is negative because evidence must be "generally accepted." However, under the same circumstances that justify lowering evidence standards for availability and reproducibility (i.e. no other evidence is available, and policy action is necessary to preserve a human right), policies may be aligned with methodologically sound, pre-consensus scientific evidence. However, this evidence must meet methodological criteria that are "generally accepted" for producing scientific knowledge: being grounded on already

[234] N. Oreskes (2004) *The scientific consensus on climate change*, SCIENCE 306(5702), 1686. The remaining 25% did not take a position. No article explicitly disagreed with the consensus position.

[235] For example, a review of studies on the scientific consensus around the anthropogenic climate change hypothesis shows that 97% of climate scientists agree with the science that climate change is occurring and that humans are contributing to it. *See* J. Cook, *et al*. (2016) *Consensus on Consensus: A Synthesis of Consensus Estimates on Human- Caused Global Warming*, ENVIRON. RES. LETT. 11(4).

[236] Organized skepticism involves a "methodological and institutional mandate" in which scholars in a discipline collectively engage in "detached scrutiny of beliefs in terms of empirical and logical criteria." See generally R. K. Merton (1973) The Sociology of Science: Theoretical and Empirical Investigations, University of Chicago Press, 277.

[237] The term identifies contestation at the margins of a knowledge claim around which there is consensus. U. Shwed & P. S. Bearman (2010) The Temporal Structure of Scientific Consensus Formation, AM. SOCIOL. REV. 75(6).

accumulated knowledge, using adequate methodology to gather data, and drawing reasonable inferences from data.[238]

To fulfill the duty to ensure that policies are aligned with best scientific evidence available, States must also "ensur[e] that private persons and entities do not disseminate false or misleading scientific information."[239] Regrettably, these days there is ample evidence that false and misleading information has a negative impact on human rights, particularly on the enjoyment of scientific progress.[240] General Comment 25 identifies adopting "mechanisms to protect people from the harmful consequences of false, misleading and pseudoscience-based practices, especially when other economic, social and cultural rights are at risk"[241] as a core obligation of States. General Comment 25 envisions these initiatives be folded into "a national plan of action to promote scientific progress and to disseminate its results and products to all persons, without discrimination,"[242] which should include "measures to facilitate access without discrimination to the applications of scientific progress, especially when these applications are needed for the enjoyment of economic, social and cultural rights[,] mechanisms to promote a culture of scientific inquiry, public trust and support for sciences in society, particularly through a vigorous and informed democratic debate on the production and use of scientific knowledge, and a dialogue between the scientific community and society[, and] mechanisms to protect the population from false, misleading and pseudoscience-based practices, especially when other economic, social and cultural rights are at risk."[243] These initiatives should also extend to the private sector, particularly social media, which States must control as part of the duty to protect. "To meet their obligations to protect against human rights abuses caused by companies," the

[238] According to this "methodological approach," scientific evidence is "generally accepted" when there is no disagreement among scientists about the appropriateness of the assumptions, methods, and conclusions drawn from the evidence. The emphasis is not on what is produced but on how it is produced, i.e., on the process scientists follow to generate evidence and to base policies on evidence that meets this standard.

[239] Id. False information or "fake news" is inaccurate statements of fact disseminated with the intent to mislead and cause harm. Misleading information is inaccurate statements of fact disseminated accidentally. See United Nations, Countering Disinformation [accessed July 21, 2023].

[240] J. D. West & C. T. Bergstrom (2020) *Misinformation in and about science*, PROC. NAT'L. ACAD. SCI. 118(15); H. Hopf, *et al.* (2019) *Fake Science and the Knowledge Crisis: Ignorance Can Be Fatal*, R. SOC. OPEN SCI. 6; B. Swire- Thompson & D. Lazer (2020) *Public Health and Online Misinformation: Challenges and Recommendations*, ANNU. REV. PUBLIC HEALTH 41; N. J. Temple (2001) *A Plague of False and Misleading Information*, *in* NUTRITIONAL HEALTH. STRATEGIES FOR DISEASE PREVENTION, N. J. Temple, *et al*. (eds.), Humana Press.

[241] CESCR, *General Comment* 25, *supra* note 6, ¶ 52.

[242] *Id.*, ¶ 87.

[243] *Id.*

UN Secretary-General noted, “States should apply a combination of legal and policy measures to require technology companies to respect human rights.”[244]

Another essential duty in this regard is to protect the enjoyment of the right to benefit from scientific progress from undue influence by third parties. This is a perennial problem with policymaking, particularly with risk assessment of applications, in areas of innovation that rely heavily on privately-funded or corporate research. Often, industry input is essential to policy development and regulatory actions because the evidence needed to assess risk is exclusively in their hands. Yet, it is well documented that in several sectors, from nutrition to fossil fuels, have been compromised by conflicts of interest and misleading claims about product safety. A textbook example is research in the field of nutrition.[245] “In a systematic review of systematic reviews on the link between sugar-sweetened beverages and weight gain,” Soares and colleagues “concluded that industry sponsorship was five times more likely not to show an association.”[246] It is well- known that the fossil fuel industry has also been marred.[247]

The strategies to capture the process are several — securing the membership of experts paid to advance the interest of private companies in risk assessment committees, funding studies that ignore or minimize risks of certain applications, destroying or hiding evidence of risk, and pressuring decision-makers. Some influencing strategies are more subtle than others. For instance, bias in research findings on the impact of sugars on nutrition is more likely driven by the industry’s choice “to support those scientists whose pre-existing opinions on the matter were more favorable to industry” rather than a crass *quid pro quo* exchange with scientists

[244] United Nations General Assembly, *Report of the Secretary-General, Combating Disinformation for the Promotion and Protection of Human Rights and Fundamental Freedoms*, A/77/287, 12 August 2022. The duty to protect in the face of digital technology is further developed in OHCHR (2021) *Bridging Governance Gaps in the Age of Technology - Key Characteristics of the State Duty to Protect*, A B-Tech Foundational Paper.

[245] N. Chartres, A. Fabbri, & L. A. Bero (2016) Association of Industry Sponsorship With Outcomes of Nutrition Studies: A Systematic Review and Meta-Analysis, JAMA INTERN. MED. 176(12); M. Bes-Rastrollo, et al. (2013) Financial Conflicts of Interest and Reporting Bias Regarding the Association between Sugar-Sweetened Beverages and Weight Gain: A Systematic Review of Systematic Reviews, PLOS MED. 10(12); L. I. Lesser, et al. (2007) Relationship between Funding Source and Conclusion among Nutrition-Related Scientific Articles, PLOS MED. 4(1).

[246] M. J. Soares, et al. (2019) Conflict of interest in nutrition research: an editorial perspective, EUR. J. CLIN. NUTR. 73.

[247] A classic study of the fossilfuel industry is N. Oreskes & E. M. Conway (2010) MERCHANTS OF DOUBT: HOW A HANDFUL OF SCIENTISTS OBSCURED THE TRUTH ON ISSUES FROM TOBACCO SMOKE TO GLOBAL WARMING, Bloomsbury Press.

accepting to be "paid" to come to a particular conclusion.[248] However, all strategies can potentially corrupt risk governance and produce less-than-optimal outcomes. If risks are not adequately assessed and applications receive a green light when they should not, the ability to benefit from scientific progress is weakened, if not undermined. One step that States must take is to set up policies and mechanisms to detect conflicts of interest of those participating in risk assessment and of the authors of any study used in these assessments. As General Comment 25 noted,

> "States should take measures to avoid the risks associated with the existence of conflicts of interest by creating an environment in which actual or perceived conflicts of interest are adequately disclosed and regulated, especially those involving scientific researchers who give policy advice to policy-makers and other public officials."[249]

Policies may include legislation to prevent conflict of interest for public servants, instruments focused on providing expertise and information to policymakers and regulatory bodies, codes of conduct or ethics, and even criminal law, where appropriate.[250] The DEPCC urges "States and pertinent actors" to,

> "[e]nsure effective climate policy and action through appropriate governance measures, by promoting transparency and preventing corruption....."[251]

Finally, and to repeat, States have a duty to align policies "with best available, generally accepted scientific evidence."[252] Earlier, we identified the evidence that meets this standard: reproduced scientific findings published upon peer review and around which consensus exists.[253] We also argued that under exceptional circumstances (i.e., no other evidence is available and policy action is necessary to preserve a human right), this standard can be lowered to methodologically sound and reproducible findings published in preprint repositories.

[248] *Id.*, 1213.

[249] CESCR, General Comment 25, *supra* note 6, ¶ 53.

[250] For best practices for dealing with conflicts of interest in the public sector, see World Bank (2005) PREVENTING AND MANAGING CONFLICTS OF INTEREST IN THE PUBLIC SECTOR: A GOOD PRACTICE GUIDE; H. Whitton & J. Bertók (2005) MANAGING CONFLICT OF INTEREST IN THE PUBLIC SECTOR: A TOOLKIT, OECD.

[251] DEPCC, *supra* note 23, Art.13.

[252] CESCR, General Comment 25, *supra* note 6, ¶ 52, 54, 65.

[253] See *supra* note 8.

How States must discharge the duty to align their policies to scientific evidence is primarily a question of "fulfilment," that is, adopting measures and establishing effective remedies to enjoy the right to policies fully aligned with scientific evidence. As the CESCR noted in General Comment 25, the duty to "[a]dopt mechanisms aimed at aligning government policies and programmes with the best available, generally accepted scientific evidence"[254] is a core obligation under the ICESCR.

"Science-policy interfaces" are probably the most appropriate mechanisms to fulfil this obligation. They are "social processes encompassing relations between scientists and other actors in the policy process that allow for exchanges, co-evolutions, and joint construction of knowledge to enrich decision-making."[255] They can be general or focused on a specific policy issue, local, national, or international. The DEPCC urges States to "build effective mechanisms to strengthen the interface between science and policy to ensure a strong knowledge base in decision-making."[256] A well- known example of international science-policy interface is the Intergovernmental Panel on Climate Change (IPCC).[257]

I. NORMATIVE TAKEAWAYS

The main obligations from the RtS that States have in connection with the duty to align policies with the best scientific available knowledge regarding climate change, can be summarized as a duty to:

[254] CESCR, General Comment 25, *supra* note 6, ¶ 52.

[255] S. van den Hove (2007) *A Rationale for Science-Policy Interfaces*, FUTURES 39(7), 815.

[256] DEPCC, *supra* note 23, Art. 7.4.d.

[257] The IPCC was established in 1988 by the World Meteorological Organization and the United Nations Environment Programme to provide policy makers with regular assessments of the scientific basis of climate change, its impacts and future risks, and options for adaptation and mitigation. Participation in the IPCC is open to all WMO and UN Member States, currently 195. The central decision-making body is the Panel. All member states can participate in the Panel's plenary sessions, which are held about twice a year. Scientists contribute by producing reports that provide a scientific basis for governments at all levels to develop climate-related policies. They also serve as a basis for negotiations at the Conference of the Parties to the United Nations Framework Convention on Climate Change. Assessment Reports cover all scientific, technical and socio-economic aspects caused by climate change. Special Reports are studies on a specific topic. Methodological Reports provide practical guidelines for the development of greenhouse gas inventories under the UNFCCC. Between 1990 and 2023, the IPCC has published six comprehensive Assessment Reports (approximately one every six years), 14 Special Reports and 6 Methodological Reports. The work of the IPCC is guided by a set of principles and procedures. IPCC reports are prepared by hundreds of scientists, drawn from a wide range of scientific fields, organized as Coordinating Lead Authors, Lead Authors, Contributing Authors, Review Editors and other roles. More than 3,000 scientists have been involved in writing IPCC reports since their inception. They receive no compensation for their work, relying instead on salaries from their home institutions or other work. *See generally* https://www.ipcc.ch/.

- Internationally
    - Keep supporting the leading science-policy interface (IPCC);
    - Request the IPCC to declare the job of Working Group I (WGI) on a "physical science basis" to be done and close it down. Focus the resources on WGII on "impacts, adaptation, and vulnerability" and WGIII on mitigation.[258]
- Domestically
    - Establish a new science-policy interface or support the existing science-policy interface working on climate policy at the local level;
    - Act on the knowledge available on the science-policy interfaces by adopting the recommendations of domestic and international science-policy interfaces, and aligning policies with scientific evidence

F. DUTY TO "ANTICIPATE, AVOID OR MINIMIZE HARM" AND TO ADOPT A "PRECAUTIONARY APPROACH"

According to Article 2 (prevention of harm) of the DEPCC:

> "States and all actors should take appropriate measures within their powers to:.... (b) anticipate, avoid or minimize harm, wherever it might emerge, from climate change, as well as from climate mitigation and adaptation policies and actions; (c) seek and promote transnational cooperation before deploying new technologies that may have negative transnational impacts."[259]

As the wording suggests, the duty to "anticipate, avoid or minimize harm from climate change" is one that imposes obligations not only on States but also on "other actors", which includes scientists. We will start by discussing the duties of States "to anticipate, avoid or minimize harm" first, and then we will move on to the duties of scientists in that regard.

I. DUTIES OF STATES

The RtS requires States to protect everyone from the harm of scientific progress. The history of the development of the RtS,[260] and a literal interpretation of its provisions tell us that.

[258] N. Oreskes (2021) IPCC, You've Made Your Point: Humans Are a Primary Cause of Climate Change, SCIENTIFIC AMERICAN.

[259] DEPCC, *supra* note 23, Art. 2.

[260] Romano & Boggio, *supra* note 8, Ch. 3, 4 and 5.

Moreover and intuitively, if States are to ensure everyone *benefits* from progress in science and technology, they must have a duty to ensure the development only of *beneficial* applications of scientific developments. Since climate change is caused by the scientific revolution that led to the Industrial Revolution, States have a duty to protect everyone from its negative effects. Furthermore, they also have a duty to protect everyone from the negative effects of any applications developed and deployed to contrast climate change.

The idea that scientific progress and its applications must benefit everyone is critical to the recognition of science as a human right. The RtS requires that the impacts of prospective applications are assessed before they are developed, and that only the prospective applications assessed to be beneficial are developed.[261] It requires States to evaluate the short-and long-term impact of applications. The obligation to monitor and anticipate impacts was already articulated by the UN General Assembly in 1975 in its Declaration on the Use of Scientific and Technological Progress in the Interests of Peace and for the Benefit of Mankind. Paragraph 6 reads as follows:

"All States shall take measures to extend the benefits of science and technology to all strata of the population and to protect them, both socially and materially, from possible harmful effects of the misuse of scientific and technological developments, including their misuse to infringe upon the rights of the individual or of the group, particularly with regard to respect for privacy and the protection of human personality and its physical and intellectual integrity."[262]

Monitoring and anticipation duties can be linked to the general international law obligation to prevent, the precautionary principle, and due diligence.[263] Precaution "requires the adoption of

[261] Impacts to be considered include, for example, those affecting present and future people, communities, society at large, nonhuman animals and the environment. "It is important that we all take action to safeguard and protect the Earth's terrestrial and marine ecosystems for present and future generations. The interaction of people and ecosystems is especially important, given the great dependence of one on the other." DEPCC, Art. 4.2. New applications must also be evaluated in terms of their actual or potential discriminatory impact. This requirement is distinct from the fair and equal access requirement. It focuses on how applications are designed. Only applications designed in a way that is not biased toward individuals or groups can be considered beneficial. "Fairness in relation to climate change requires fair treatment and meaningful participation of all people. In addressing climate change, relevant actors at all levels must work together in a spirit of fairness, global partnership, inclusiveness and, in particular, in solidarity with the poorest and most vulnerable people. A global commitment that mobilizes governments, international organizations, including the UN system, the private sector, civil society and other relevant actors can be beneficial." DEPCC, *supra* note 23, Art. 4.1.

[262] UNGA, Resolution 3384 (XXX), *Declaration on the Use of Scientific and Technological Progress in the Interests of Peace and for* the Benefit of Mankind, UN Doc. A/RES/30/3384, ¶ 6 (10 November 1975).

[263] For a theoretical discussion that situates anticipation in the broader international legal framework, *see* Y. Donders & M. Plozza (2023) *Look before You Leap: States' Prevention and Anticipation Duties under the Right to Science*, Amsterdam Law School Research Paper No. 2023-24, 4 (interpreting "anticipation" as "a general term that

measures of avoidance or, at least, of mitigation and reduction of risks of serious and irreversible harm, and this even when, under the current state of scientific knowledge, the occurrence of that harm is only probable and remains uncertain."[264] Prevention requires States to act when risks become scientifically certain. Their actions must avoid harm or at least mitigate and reduce the risk of harm. Due diligence qualifies the duties of precaution and prevention in the sense that unreasonable or undue negligence on the part of the State constitutes a breach of the two duties.[265]

Typically, States absolve their anticipatory obligations to determine and manage acceptable levels of innovation risk by creating risk governance mechanisms. States typically take two steps: pre- marketing regulatory approvals and post-marketing safety-monitoring oversight. However, risk governance mechanisms might also violate the RtS when they are too rigid. While General Comment 25 recognized the usefulness of the precautionary principle as a "tool" to evaluate "the risks and potential of some technical advances or some scientific research,"[266] a standard critique of using the precautionary principle in risk governance is that it forces regulators to exceed the side of caution. Aptly, in General Comment 25, the CESCR noted that the principle "should not hinder and prevent scientific progress, which is beneficial for humanity." As the CESCR pointed out, often, the precautionary principle is interpreted as a zero-risk tolerance standard.[267] This use of the precautionary principle infringes upon the right to benefit from scientific progress if it overrides any consideration of beneficial impacts of

can trigger obligations due to a cross-fertilization of tools, principles and rules from different fields of public international law"); S. Besson (*forthcoming* 2023) *Anticipation under the Human Right to Science: Concepts, Stakes and Specificities*, INT. J. HUM. RIGHTS.

[264] *Id,* 5.

[265] *Id.* Besson notes that negligence occurs when a State fails to act diligently in the face of avoidable and foreseeable harm in the circumstances. For an in-depth analysis, *see* S. Besson (2023) *Due Diligence in International Law*, BRILL. On the concept of due diligence in international law, *see* T. Koivurova & K. Singh (2022) *Due Diligence*, MAX PLANCK ENCYCLOPEDIA OF PUBLIC INTERNATIONAL LAW.

[266] CESCR, *General Comment no. 25, supra* note 6. *See also id.*, ¶ 22 ("Human rights impact assessments may be necessary to protect individuals from risky applications").

[267] C. Munthe (2020) *Precautionary Principle*, *in* INTERNATIONAL ENCYCLOPEDIA OF ETHICS; A. Stirling (2007) *Risk, Precaution and Science: Toward a More Constructive Policy Debate. Talking Point on the Precautionary Principle*, EMBO REP. 8, 314 ("Precaution does not automatically imply prohibitions and phase-outs, but requires deliberate and thorough attention to conflicting policy or technological pathways. Far from being in tension with science, precaution offers a way to be more restrained and rational with uncertainty, ambiguity, and ignorance [than traditional risk assessment].").

applications in the presence of a certain degree of risk of harm. Indeed, Article 3 (precautionary *approach*) of the DEPCC reads:

> "Where there are threats of serious or irreversible harm, a lack of full scientific certainty should not be used as a reason for postponing cost-effective measures to anticipate, prevent or minimize the causes of climate change and mitigate its adverse effects."[268]

When governments proceed with an excess of precaution, resulting in a missed opportunity to develop beneficial applications, the RtS might be violated. This could be the case of solar geoengineering.[269] The most commonly discussed solar geoengineering strategy involves spraying reflective aerosols into the atmosphere to beam sunlight away from the Earth, lowering global temperatures.[270] Solar geoengineering could reduce the amount of solar radiation that hits the planet, and reduce global rise in temperature. Then again, solar geoengineering is a contentious idea because it could backfire.[271] Solar geoengineering risks and side effects range from possible damage to the Earth's ozone layer to inadvertent changes in global precipitation patterns. Moreover, once started, it would be dangerous to stop unless enough carbon had been sucked out of the atmosphere to lower the Earth's temperatures below a safe threshold. A sudden halt to solar geoengineering could cause temperatures to skyrocket, potentially faster than life could adapt, a concept known as "termination shock."[272]

One could make two other examples of when hindering the development of an application of scientific knowledge may constitute an infringement of the RtS. One is the prohibition of beneficial applications already used in other jurisdictions. State A prohibits marketing an application approved in State B, even after intense regulatory scrutiny satisfying all precautionary requirements has been conducted in State B. Bans on GMO crops, assisted reproductive technologies, or hormone-blocking drugs facilitating the termination of a pregnancy, to name a few, fit the description. In the climate change context, a State restricting

[268] DEPCC, *supra* note 23, Art.3.

[269] (12 May 2021) *Give Research into Solar Geoengineering a Chance*, NATURE 593; J. Tollefson (2010) *Geoengineering Faces Ban*, NATURE 468.

[270] C. Harvey (8 January 2013) *Scientist Offers Novel Solution to Far-Fetched, Sun-Blocking Climate Fix*, E&E NEWS.

[271] In 2021, climate researchers halted a test of solar geoengineering technology in Sweden after objections from environmentalists and indigenous groups.

[272] C. Harvey (3 April 2023) *Geoengineering Is Not a Quick Fix for the Climate Crisis, New Analysis Shows*, E&E NEWS.

the development and deployment of applications that can mitigate climate change, such as carbon removal technology,[273] while other States have allowed it after intense regulatory scrutiny satisfying all precautionary requirements has been conducted, arguably would be in violation of its obligations under the RtS.

A second example is when legal or regulatory provisions inhibit innovation. This situation may arise, for instance, when patents on research tools[274] or fundamental technologies[275] are awarded. These patents give the holders significant control of downstream innovation as they empower them with the ability to effectively set the agenda of subsequent research. If patent holders decide not to grant licenses or to do so at unreasonable conditions, the effect may be that downstream innovation does not occur and beneficial applications are never developed. The argument can be made that these patents infringe upon the right to benefit from scientific progress.[276]

In any event, rather than a decision-making tool, the precautionary principle is just one of the tools in the toolbox of anticipation.[277] Anticipation is a broader normative umbrella under which precaution and prevention coexist with beneficence and the obligation to harness science as a force of good for the benefit of humanity. When scientific progress presents opportunities to be implemented in beneficial yet potentially harmful applications, any decision restricting the development of applications must be considered a limitation to be scrutinized based on the necessity and proportionality standards codified in Article 4 of the ICESCR.[278]

[273] F. Harvey (25 April 2023) Carbon Dioxide Removal: The Tech that is Polarising Climate Science, THE GUARDIAN.

[274] J. L. Contreras (2018) Is CRISPR Different? Considering Exclusivity for Research Tools, Therapeutics, and Everything In Between, AM. J. BIOETH. 18(12) (defining "research tools" as "basic scientific discoveries and techniques that can be used to develop a range of "downstream" diagnostics and therapies.").

[275] O. Feeney, et al. (2018) Patenting Foundational Technologies: Lessons From CRISPR and Other Core Biotechnologies, AM. J. BIOETH. 18(12), 37 (defining "core technologies" as those that "rarely produce a direct societal benefit, but are important tools for further research").

[276] A. Boggio & C. W. L. Ho (2018) The human right to science and foundational technologies, AM. J. BIOETH. 18(12).

[277] Stirling, supra note 267, 314 (noting that the precautionary principle "is not - nor can it claim to be - a complete decision rule at all" and indicating that the principle should be considered a general policy framework for policy formulation rather than a decision-making tool).

[278] "The States Parties to the present Covenant recognize that, in the enjoyment of the rights recognized by the State in accordance with the present Covenant, the State may subject such rights only to such limitations as are

The UNESCO World Commission on the Ethics of Scientific Knowledge and Technology (COMEST), which penned the DEPCC, noted that precautionary actions "should be chosen that are proportional to the seriousness of the potential harm, with consideration of their positive and negative consequences, and with an assessment of the moral implications of both action and inaction."[279] The principle of proportionality in particular rejects limitations to the core content of a right.[280] It also mandates that precautionary prohibitions be used only as measures of last resort when less restrictive measures are ineffective.[281] In most cases, applications should not be prohibited but deemed acceptable, even when there is potential harm, with a robust monitoring system and anticipation of impacts. Monitoring involves the assessment of present impacts as they happen. Anticipation is the contemplation of future impacts yet to happen. Beneficial monitoring and anticipation must be informed by "all cross-cutting human rights principles, such as transparency, nondiscrimination, accountability and respect for human dignity."[282] States should produce "technological and human rights impact assessments [to] help to identify potential risks early in the process and the use of scientific applications"[283] without "hinder[ing] and prevent[ing] scientific progress ... beneficial for humanity.[284]

Finally, the duty to develop beneficial applications includes assessing who will likely benefit or be harmed by these applications. States must ensure that applications are developed in ways that are not biased against certain groups or populations. Bias may be embedded in an application during its development. For instance, medical products may be biased when developed as a result of clinical research on research subjects disproportionately representing a subgroup within a population. As a result, a drug may work well for the subgroup included in

determined by law only to the extent consistent with the nature of these rights and solely for the purpose of promoting the general welfare in a democratic society." ICESCR, *supra* note 10, Art. 4.

279 World Commission on the Ethics of Scientific Knowledge and Technology (2005) *The Precautionary Principle,* 14, Box 2.

280 CECSR, *General Comment 25, supra* note 6, ¶ 21 ("limitations must respect the minimum core obligations of the right").

281 *Id.* (limitations "must be proportionate to the objective pursued. This means that, when there are several reasonably apt means of achieving the legitimate aim of the limitation, the one that least restricts economic, social and cultural rights must be chosen, and the burdens imposed on the enjoyment of the right must not outweigh the benefits of the limitation.").

282 *Id.*, para. 75.

283 *Id.*, para. 56.

284 *Id.*, para. 57.

the study and be less effective or even harmful to other subgroups. This is the case, for instance, when drugs are developed using mostly male subjects.[285] In the climate change context, the DEPCC stresses that "[j]ustice in relation to climate change requires fair treatment and meaningful involvement of all people."[286] "[M]easures [to anticipate, prevent or minimize the causes of climate change and mitigate its adverse effects] should take into account ... women ... since women are disproportionately affected by climate change while at the same time tending to have lower access to resources and yet play a vital role in achieving inclusive sustainable development. These measures should also take into account the needs of those at greatest risk, particularly the poorest and the most vulnerable."[287]

II. DUTIES OF SCIENTISTS

Scholars have conceptualized scientific responsibility by distinguishing between *external* and *internal* obligations.[288] Internal obligations concern scientists' respect for the norms and values of science. We will revert to that in the next section, under the heading "integrity in decision-making". External obligations refer to the impact of the activities of scientists. The *Declaration on Science and the Use of Scientific Knowledge* of the 1999 UNESCO World Conference on Science provides that "[t]he practice of scientific research and the use of knowledge from that research should always aim at the welfare of humankind, including the reduction of poverty, be respectful of the dignity and rights of human beings, and of the global environment, and take fully into account our responsibility towards present and future generations."[289] Thus, scientists, like States, have a duty to consider the impact of their activities on a wide range of

[285] There is compelling evidence of sex bias in drug development. A meta-analysis of 86 different drugs, including antidepressants, cardiovascular and anticonvulsant drugs, and analgesics, among others, all approved for marketing in the United States, has found clear evidence of a gender gap in drug dosing resulting in overmedication of women, which the authors argue needs to be addressed by better studying how sex affects efficacy. *See* I. Zucker & B. J. Prendergast (2020) *Sex Differences in Pharmacokinetics Predict Adverse Drug Reactions in Women*, BIOL. SEX DIFFER. 11(32).

[286] DEPCC, *supra* note 23, Art. 4.1.

[287] *Id.*, Art. 4.3.

[288] *See for example* H. Lenk (2022) *Responsibility in Science: The Philosophical View*, *in* THE RESPONSIBILITY OF SCIENCE, H. A. Mieg (ed.), 13; Rhodes, *Scientific Freedom and Responsibility in a Biosecurity Context*, *supra* note 6, 106-109; Wensley & King, *Scientific Responsibility for the Dissemination and Interpretation of Genetic Research*, *supra* note 6, 508. The distinction is also acknowledged in International Science Council, *A Contemporary Perspective on the Free and Responsible Practice of Science in the 21st Century*, *supra* note 5, 9-10. On the literature on the right to science, *see* Wyndham, *The Right to Science*, *supra* note 3, 211-30, 214.

[289] UNESCO, Records of the General Conference, 30th session, Paris, 26 October-17 November 1999, Vol. 1: Resolutions, 30 C/20, Annex I, *Declaration on Science and the Use of Scientific Knowledge*, 45-49, ¶ 39.

subjects, including individuals, communities, society broadly defined, non-human animals, the environment at large, presently and in the future.

Mapping the normative basis of the external duties of scientists (i.e. the duty to monitor and anticipate impacts) is complex. Some duties have a long tradition of recognition under international human rights law, and their normative basis is easily traced. This is the case, for instance, of the duty to respect the interests of research subjects and the requirements of ethical conduct. Their roots can be traced to the aftermath of World War II and the adoption of ten principles, in the so-called *Nuremberg Code*, setting the boundaries of permissible scientific research on human subjects.[290] In the following years, the principles were incorporated into international human rights instruments, including the UDHR, ICCPR and others. The "ten principles, which have since become known as the *Nuremberg Code*, are today regarded as international customary law.[291]

Other duties (monitoring and anticipating impacts) have emerged more recently and therefore are not as well-defined.[292] Yet, they permeate all RtS instruments. CESCR General Comment 25 includes a section featuring "the right to information and participation in controlling the risks involved in particular scientific processes and its applications", pointing to the precautionary principle as a tool to evaluate "the risks and potential of some technical advances or some scientific research."[293] It also reminds that international human rights law calls for a particular focus on how science and technology could impact oppressed and marginalized populations

[290] Nuremberg Military Tribunals, *Trials of War Criminals before the Nuremberg Military Tribunals under Control Council Law No. 10.* Nuremberg October 1946 - April 1949, U.S. Government Printing Office, 1949-1953, Vol. 2, 181-182. Nuremberg October 1946 - April 1949, U.S. Government Printing Office, 1949-1953, vol. 2, 181-182.

[291] M. S. Bryant (2023) *Nazi Eugenics, Euthanasia, and Medical Ethics Today*, *in* THE HOLOCAUST: REMEMBRANCE, RESPECT, AND RESILIENCE, M. Polgar & S. John (eds.) Pennsylvania State University.

[292] In her historical account of the emergence of these external responsibilities of science in North America, Heather Douglas concludes, based on analysis of the study of "official documents and structures of the scientific community," that the scientific community fully embraces "external responsibilities" in its scientific practices in the first decade of the 21st century. In 2010, Douglas writes: "No longer was freedom to set research agendas thought to be warranted only when one was also free from social responsibility for research impacts. Instead, freedom to do research was now thought to require taking responsibility for the impacts of research." *See* H. Douglas (2021) *Scientific Freedom and Social Responsibility*, *in* SCIENCE, FREEDOM, DEMOCRACY, P. Hartl & A. Tamas Tuboly (eds.), Routledge, 75-80, 68- 87. However, the roots are probably deeper, at least since Einstein warned of the dangers of atomic technology or the creation of the Bulletin of Atomic Scientists and the Doomsday Clock in 1947. Even the infamous eugenics movement can be seen as a misguided effort by scientists to control the repercussions of scientific progress. *See* e.g., A. Rutherford (2023) *Control: The Dark History and Troubling Present of Eugenics*, W.W. Norton & Company.

[293] CESCR, *General Comment 25*, *supra* note 6, ¶ 56-57. *See also id.*, ¶ 22 ("Human rights impact assessments may be necessary to protect individuals from risky applications").

and on impacts that breach the principle of non-discrimination.[294] In that context, the instrument indicates that the "evaluation of impacts" of scientific progress and new technologies on "specific groups"[295] is critical to ensure compliance with human rights standards.[296]Another dimension explored in CESCR General Comment 25 is the connection between assessing impacts and the participatory aspects of the right to science. "The right to information and participation in controlling the risks involved in particular scientific processes and its applications" implies a role to be played by scientists in facilitating "public scrutiny and citizen participation" in "decisions concerning the orientation of scientific research or the adoption of certain technical advancements."[297] Scientists are thus called upon to engage the public about how the scientific community monitors and anticipates impacts.

The UNESCO standard-setting instruments also include provisions on the duty of scientists to monitor and anticipate the impacts of their activities. The *Recommendation on Science and Scientific Researchers* parses this responsibility into various dimensions. Contemplation of impacts relates to the scientists' "ability to review a problem or situation in perspective and in proportion, with all its human implications,"[298] possessing the "skill" of "isolating the civic and ethical implications, in issues involving the search for new knowledge and which may at first sight seem to be of a technical nature only,"[299] engage in "vigilance as to the probable and possible social and ecological consequences of research and development activities, to communicate with others not only in scientific and technological circles but also outside those,"[300] and "willingness circles."[301] Furthermore, "researchers should seek to minimize

[294] *Id.*, ¶ 25, 32 (women), 40 (traditional knowledge and indigenous peoples).

[295] *Id.*, ¶ 28-40. Although this "impact assessment" appears in the section on women and girls, bearing in mind the spirit and structure of CESCR General Comment No. 25, the requirement to assess impact can be interpretively applied to all groups mentioned in paragraph 28, which reads: "Without prejudice to the duty of States to eliminate all forms of discrimination, particular attention should be paid to groups that have experienced systemic discrimination in the enjoyment of the right to participate in scientific progress and its applications and to enjoy its benefits, such as women, persons with disabilities, lesbian, gay, bisexual, transgender and intersex persons, indigenous peoples and persons living in poverty."

[296] *Id.*, ¶ 32.

[297] *Id.*, ¶ 55.

[298] UNESCO, *Recommendation on Science and Scientific Researchers*, *supra* note 22, para. 14(d)(iii).

[299] *Id.*, ¶ 14(d)(iv).

[300] *Id.*, ¶ 14(d)(v).

[301] *Id.*, ¶ 14(d)(vi).

impacts on living subjects of research and on the natural environment and should be aware of the need to manage resources efficiently and sustainably."[302]

Impacts of scientific progress feature prominently in the *Recommendation on the Ethics of Artificial Intelligence*. There, the term "impact" appears 37 times. As a framework for all actors involved in the life cycle of AI systems, the recommendation calls for "dealing responsibly with the known and unknown impacts of AI technologies on human beings, societies and the environment and ecosystems"[303] and for "the continuous assessment of the human, social, cultural, economic and environmental impact of AI technologies."[304] The actors involved in the life cycle of AI systems are also expected to participate in the ethical impact assessment and other processes or tools to monitor the impact of AI technologies on society.[305]

"[E]nhancing the societal impact of science and increasing the capacity of society as a whole to solve complex interconnected problems" is a guiding principle of the *Recommendation on Open Science*."[306]

Environmental concerns appear in right-to-science instruments. For instance, CESCR General Comment 25 requires considering the "risks for ... the environment.[307] The UNESCO *Recommendation on Science and Scientific Researchers* recommends scientists "integrat[ing] in their research and development work in an ongoing manner ... controls to minimize harm to each living subject of research and the environment, and consultations with communities where the conduct of research may affect community members."[308]

Finally, States, but also scientists, bear responsibilities vis-à-vis the interests of future generations. Intergenerational equity is encompassed in the legal concept of sustainability, which has strong normative roots in international law.[309] CESCR General Comment 25

302 *Id.*, ¶ 16(a)(ii).

303 UNESCO, *Recommendation on the Ethics of Artificial Intelligence*, *supra* note 25, para. 1.

304 *Id.*, ¶ 31.

305 *Id.*, ¶ 50-70.

306 UNESCO, Recommendation on Open Science, supra note 24, ¶ 14(a).

307 CESCR, General Comment 25, supra note 6, ¶ 57.

308 UNESCO, Recommendation on Science and Scientific Researchers, supra note 22, ¶ 16(a)(vii).

309 V. Barral (2012) *Sustainable development in international law: nature and functioning of an evolving legal norm*, EUR. J. INTL. LAW 23(2).

considers harm that is “inequitable to present or future generations” as “unacceptable.”[310] The UNESCO *Recommendation on Science and Scientific Researchers* indicates that governments must incorporate standards of “protection and enhancement of the cultural and material well-being of its citizens in the present and future generations”[311] in the “treatment of scientific researchers”[312] and their education and training.[313] Also, it recommends supporting research studying “the impact of science on future generations.”[314]

III. NORMATIVE TAKEAWAYS

The main obligations resulting from the RtS that States have in connection with the duty to “anticipate, avoid or minimize harm” and to adopt a “precautionary approach”, can be summarized as a duty to:

- Engage in anticipation driven by the knowledge available on the science-policy interfaces:
  - Assess the short- and long-term impacts of action and inaction in the area of climate innovation policy;
  - Ensure that the best scientific available knowledge drives anticipatory assessments
- Avoid lost opportunities for innovation:
  - Ensure that anticipatory assessments do not prevent studying potentially beneficial applications in trials and other small-scale experiments;
  - Ensure that anticipatory assessments do not prevent potentially beneficial applications from being developed;
  - Ensure that the positive and negative externalities of development are sufficiently understood to avoid “seemingly good investments backfir[ing] in other sectors.”[315]

[310] CESCR, General Comment 25, supra note 6, ¶ 56.

[311] UNESCO, Recommendation on Science and Scientific Researchers, supra note 22, ¶ 4.

[312] *Id.*

[313] *Id.*, ¶ 13(d).

[314] *Id.*, ¶ 19(a).

[315] Kőrösi & Cullmann, supra note 217.

- Contribute to the UN Sustainable Development Goals (SDG)[316] agenda by:
    - Setting ambitious goals on SDGs connected to climate policy (i.e., phasing out fossil fuel, which is linked in SDGs 7 and 13);
    - Facilitating the periodic review of the SDGs so that the goals can be adjusted to new evidence becoming available and other circumstances (i.e., crises);
    - Promoting and participate in the negotiation and adoption of treaties that would bind countries to specific goals and targets.[317]

5. Conclusion

Clearly, there is much that the RtS can contribute to the identification of the duties, not only of States but also of scientists and other relevant actors, in connection with the climate emergency. A wealth of soft law instruments of regional and global organizations — UN and UNESCO foremost — and a rapidly growing scholarly literature is finally bringing the normative content of the RtS into focus. The Inter-American Court of Justice, the International Court of Justice and the International Tribunal for the Law of the Sea should keep it in mind while preparing the advisory opinions concerning the climate change emergency pending before them in the fall of 2023. That would not only strengthen their conclusions, grounding them also on one of the oldest human rights, but it would also go a long way towards further clarifying and solidifying the normative content of this complex right that has much to offer. If properly understood and implemented, it has the promise of unlocking the full potential of science to better the human condition and our planet while ensuring the rights of present and future generations.

[316] UNGA (2015) Transforming our world: the 2030 Agenda for Sustainable Development, A/RES/70/1.

[317] F. Biermann, et al. (2023) Four Governance Reforms to Strengthen the SDGs, SCIENCE 381 (6663).

Climate Resilience: Why, When and How?

Professor V. Ramanathan[1]

1. Summary and Recommendations

Summary of Data: Climate change is no longer a problem that is in the distant future; it no longer is a problem that affects just those in the margins of society. It has become a disruptive phenomenon affecting all aspects of society, including social, economic, and agricultural systems, and disrupting terrestrial and marine ecosystems. The number of weather/climate/water-related disasters has increased five-fold during the last 50-year period.

Recommendations:

- We can no longer rely just on mitigation of climate change but must broaden the framework of climate actions to include adaptation and transformation. In this broader framework of Climate Resilience, social and natural systems must be transformed to become climate resilient.
- Climate resilience actions must consider two other interrelated major crises: Unsustainable loss of biodiversity; and unsustainable inequality among people and nations.
- Championing and enacting mitigation actions to reduce climate risks needs to be the primary objective of the wealthiest one billion population, while implementing climate adaptation measures must be the primary focus of the poorest three billion.
- The planet will most likely cross the 1.5°C warming threshold in 8 to 12 years (2030 to 2034). Limiting warming to 2°C or slightly lower is still an achievable goal. Adaptation measures need to plan for warming of at least 2°C.

A major effort focused on the poorest three billion people must be immediately initiated to adapt to the impacts of climate change and provide: 1) access to affordable clean energy and water; 2) help to farmers impacted by droughts and heat stress with improved governance and

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technical assistance to shift to drought-resilient agriculture; 3) integration of technological solutions with nature-based solutions; 4) improved access to health care to cope with mental as well as physical health effects.

2. Resilience: What is it?

Resilience has a wide spectrum of interpretations. IPCC goes on to define Resilience as follows:[2]

Resilience in this report is defined as the capacity of social, economic and ecosystems to cope with a hazardous event or trend or disturbance, responding or reorganizing in ways that maintain their essential function, identity, and structure as well as biodiversity in case of ecosystems while also maintaining the capacity for adaptation, learning and transformation.

IPCC elaborates on the above definition by stating: "Resilience as a system trait overlaps with concepts of vulnerability, adaptive capacity, and thereby risk, and resilience as a strategy overlap with risk management, adaptation, and also transformation."[3]

Climate resilience needs to be built on three pillars: First Pillar – Mitigation to reduce climate change risks; Second Pillar – Adaptation to reduce exposure and vulnerability to climate changes that are unavoidable; and Third Pillar – Transformation of society to develop the capacity to prepare and plan for mitigation and adaptation. This transformation needs to happen bottom-up from the level of an individual and a community to a national level.

3. Climate Resilience: Need for a New Framework to Address Climate Risks

- Climate change is no longer a problem that is in the distant future; it no longer is a problem that affects just those in the margins of society. It has become a disruptive phenomenon affecting all aspects of society, including social, economic, and agricultural systems and disrupting terrestrial and marine ecosystems. The number of

[2] Intergovernmental Panel on Climate Change (2022) CLIMATE CHANGE 2022: IMPACTS, ADAPTATION, AND VULNERABILITY, P. Arias, *et al*. (eds.).

[3] *Id.*

weather/climate/water-related disasters has increased five-fold during the last 50-year period.[4]

- Bending the warming curve quickly is a global imperative. Since we have delayed too long to bend the emissions curve, bending the warming curve requires more ambitious actions in addition to deep cuts in carbon emissions. Both the emissions and the warming curves are rising unsustainably. Fossil fuel emission of CO2 reached its highest value in 2021.
- The warming crossed the 1°C threshold around 2014. The planet is currently warming at an unprecedented rate and is very likely to amplify by 50% (from 1°C) and cross the 1.5°C threshold in 8 to 12 years, during 2030 to 2034.[5] This is likely to become the COVID moment for the climate crisis, affecting everyone on the planet directly or indirectly. Without deep emission cuts, the warming can cross the dangerous threshold of 2°C in about 25 years.[6] The velocity of changes is already posing severe constraints and limits on adaptation.[7] Currently, 50% of the world's population is subject to severe water shortages and 3.3 billion people live in countries with high climate vulnerability.[8]
- We can no longer rely just on mitigating climate change but must broaden the framework of our climate actions to include adaptation. In this broader framework of *Climate Resilience*, social and natural systems must be transformed to become climate resilient.

Finally, climate resilience actions must consider two other interrelated major crises: Unsustainable loss of biodiversity;[9] and unsustainable inequality among people and nations. There are amplifying feedback effects between the three crises, such that solving one of them will have co-benefits for the other two.

[4] World Meteorological Organization (2021) WMO Atlas of Mortality and Economic Losses from Weather, Climate and Water Extremes (1970–2019), WMO-No. 1267.

[5] Y. Xu, V. Ramanathan, & D. G. Victor (2018) *Global warming will happen faster than we think*, NATURE 564(7734).

[6] IPCC, CLIMATE CHANGE 2022; Xu, *Global warming will happen faster than we think*.

[7] IPCC, CLIMATE CHANGE 2022.

[8] *Id.*

[9] National Academies of Sciences, Engineering, and Medicine (2022) Biodiversity at Risk: *Today's Choices Matter*, The National Academies Press.

4. Climate Resilience: Criteria Setting Context

A. INEQUALITY

There is a vast inequality among the global population in terms of income, wealth, and access to energy, water, healthcare, and other resources. It is helpful for this discussion to divide the population into three groups:[10] The wealthiest 15% of the population, which is currently about 1 billion. I refer to this group as the Top One Billion (T1B). The poorest 40% of the population, which is about 3 billion, is referred to as Bottom Three Billion or B3B. In between the two, is the middle 45%, or about 4 billion, M4B. The uncertainty in these demographic statistics is at least 10%. For example, the 40% cited for B3B can range from 36% to 44%.

Per capita income of the poorest three billion, B3B, is less than $10/day (US dollars) and that of the middle 4 billion is between $10/day to $30/day, i.e., about 85% of the population earns less than $30/day.[11] The combined wealth of the B3B is about 2%, and that of the top one billion is 76%[12] The poorest three billion rely on primitive fuels (wood, dung and solid coal) and technologies (mud stoves, open burning, kerosene) for cooking, heating, and lighting.

The top one billion contribute about 50% or more of the climate warming pollution, such as CO2, methane and HFCs. On the other extreme, the 3 billion in the B3B contribute only about 7%. Among the 3 billion in B3B, the poorest 0.7 billion emit just 0.5% of the CO2 pollution.[13]

On the receiving end of the climate risks, climate change impacts are felt disproportionately by the B3B, living mostly in rural areas. Over the last forty years, extreme weather has led to a cumulative 606,000 mortalities and 4.1 billion displaced people.[14] Global warming has decreased the GDP of the bottom three billion by 17% to 31%.[15]

[10] V. Ramanathan (2014) *The Two Worlds Approach for Mitigating Air Pollution and Climate Change*, *in* Sustainable Humanity, Sustainable Nature, Or Responsibility, Proceedings of the Pontifical Academy of Sciences and Pontifical Academy of Social Sciences Workshop, ES 41.

[11] L. Chancel, T. Piketty, E. Saez, & G. Zucman (2022) World Inequality Report 2022, World Inequality Lab.

[12] *Id.*

[13] *Id.*

[14] United Nations Office for Disaster Risk Reduction (2016) The Human Cost of Weather-Related Disasters 1995-2015.

[15] A. Orttiz-Bobea, T. R. Ault, C. M. Carrillo, R. G. Chambers, & D. Lobell (2021) *Anthropogenic climate change has slowed global agricultural productivity growth*, NAT. CLIM. CHANGE 11.

Globally, agriculture productivity decreased by 21% due to climate change and climate pollution.[16] An extreme case is India, where the warming and fossil fuel-related air pollution decreased wheat yield by 34%.[17] One of the main reasons is that the warming (and related drying) impacts those (most of the B3B population) living in hotter areas more than those (more than half of T1B population) living in equitable climates. In short, climate impacts act as force multipliers of the underlying socio-economic-cultural forces that cause inequality.

Global climate mitigation actions must be championed and enacted by the T1B group to limit climate risks to manageable levels, even for the B3B and M4B groups; implementing climate adaptation measures (through T1Bs technological/financial support) must be the primary goal of the B3B.

B. NEAR AND LONG TERM

Our main concern is the 21st century, although climate changes, once initiated, can last thousands of years due to the millennial time scales of ice sheets and ocean circulation. The near term applies to the period until 2050 and the long term beyond 2050. This categorization of the time scales is motivated by the fact that unchecked warming can exceed the 2°C guard rail for catastrophic climate risks by 2050, and deep reductions to the emissions of CO2 and other heat-trapping gases to near-zero levels must happen by 2050. Beyond 2050, failure in drastic mitigation actions can lead to catastrophic/unmanageable warming levels of 3°C or more that could lead to the crossing of various tipping points in the social and natural systems.[18]

The primary goal is to limit the warming below 2°C by 2050 and beyond, which is still an achievable goal.

C. INERTIA IN THE SOCIAL AND THE NATURAL SYSTEMS

There are numerous sources of inertia which pose severe constraints on the efficacy of mitigation actions. Let us start with the inertia in the social system: 1) Time it takes for society to respond to scientific findings; 2) Time it takes for policy makers to respond to societal

[16] N. S. Diffenbaugh & M. Burke (2019) *Global warming has increased global economic inequality*, PROC. NAT'L. ACAD. SCI. 116(20).

[17] J. Burney & V. Ramanathan (2014) *Recent climate and air pollution impacts on Indian agriculture*, PROC. NAT'L. ACAD. SCI. 111(46).

[18] IPCC, CLIMATE CHANGE 2022; Xu, *Global warming will happen faster than we think*.

concerns; 3) Time to adapt available technologies and develop new ones for reducing emissions and the time for global scaling. Inertia from the above three sources can range from ten to fifty years. Next comes the inertia in the natural systems.

Once emitted, heat trapping gases stay in the atmosphere for about a decade (methane and HFCs) to several decades (CFCs) to a century (nitrous oxide) and even longer (carbon dioxide). The ocean-land-atmosphere system has thermal inertia such that about 1/2 to 2/3 of the projected warming (that results from today's emissions) is delayed by about 10 to 15 years and the remaining 1/3 to 1/2 will unfold over multi-decadal to longer time scales.

Because of these sources of inertia, the crossing of the 1.5°C warming in the next 8 to 12 years is mostly assured irrespective of the mitigation actions that are being contemplated currently.

We can still limit the warming below 2°C, provided we start bending the emissions curve in the next five years, which requires the entire global society to pull simultaneously on three levers.

5. Building Climate Resilience: The Three Pillars

A. The First Pillar: Mitigation

We have waited too long to make deep cuts. The T1B must reduce their own emissions and provide financial as well as technological assistance for the rest of the world to follow their example.

Bending the warming curve below 2°C by 2050 requires society to pull on three levers as illustrated above:[19]

1. The Short-lived climate pollutants (methane, HFCs, surface and lower atmosphere ozone & Black Carbon soot) lever. With available technologies and current air-pollution governance mechanisms, we can cut the emissions of these pollutants by 40% to 100% within 25 years and cut the rate of warming by half.

[19] V. Ramanathan, M. L. Molina, D. Zaelke, & N. Borgford-Parnell (2020) *Well Under 2°C: Ten Solutions for Carbon Neutrality and Climate Stability*, *in* HEALTH OF PEOPLE, HEALTH OF PLANET AND OUR RESPONSIBILITY, Springer International Publishing; V. Ramanathan, Y. Xu, & A. Versaci (2021) *Modelling human–natural systems interactions with implications for twenty-first-century warming*, NAT. SUSTAIN. 5.

2. The Decarbonization lever. We must bring down the fossil fuel-related emissions of CO_2 close to zero before 2050. This is the most important step for keeping the warming below 2°C for the rest of the century and beyond.
3. The Atmospheric Carbon Extraction (ACE) lever. The blanket of carbon dioxide is already too thick (it weighs 1.1 trillion tons already and we are emitting about 40 billion tons every year). From now to 2050, we must extract as much as 300 billion tons of CO_2 out of the air and thin the heat-trapping blanket sufficiently.

B. The Second Pillar: Adaptation

The first step is to reduce vulnerability and exposure to weather extremes and other severe risks, such as sea level rise and ocean acidity that are already occurring. Biodiversity loss and degradation of coastal and other ecosystems caused by climate change are also major risks. The next step, much more daunting, is to develop plans for future climate changes. To give but one example of its daunting nature, with unchecked emissions, the warming will progressively increase from 1.5°C to 2°C to 3°C etc. during the 21st century. Should adaptation planners, target 1.5°C, 2°C or 3°C or more? My best guess is that we should plan for 2°C warming for the time being and update it as needed, in about five to ten years from now.

While mitigation starts with and relies on top-down policies, adaptation measures require a different approach. It must start at the individual to local community level and integrate scientific knowledge with knowledge of local cultures and local governance mechanisms. Adaptation also must rely on top-down actions on a national to global level to deal with long-term risks such as sea level rise, ocean acidity and biodiversity loss. Several sectors are impacted with agriculture and infrastructure topping the list.

A major effort focused on marginalized and vulnerable populations, especially the B3B, must be immediately initiated to adapt to the impacts of climate change. It must provide: 1) access to clean energy and drinkable water for all; 2) help to farmers suffering from droughts and heat stress around the world with improved water and land governance, enhanced water storage and technical assistance to shift to drought-resilient agriculture; 3) integration of technological solutions with nature-based solutions; 4) climate change poses grave threats to human health, including mental health. Improved access to health care for the B3B and M4B should be prioritized.

C. The Third Pillar: Transformation

The third pillar of resilience is transformation of society and ecosystems. Transformation, instead of incremental transitions, can change the fundamental attributes of natural and social systems. To give but one example, growth in GDP is strongly coupled with energy generation and consumption. Transformation would involve decoupling energy consumption from economic growth, by increasing energy efficiency, reducing energy waste, and reducing the carbon intensity of energy consumption. On the social side, behavioral changes for reducing consumption and working for the common good are going to be essential attributes for climate risk reductions. Another example is a socio-economic transformation that will enable equitable access to renewable energy and natural resources for all and preserve the ecosystem and biodiversity for generations to be born. Such singular transformations require massive education of everyone from children to senior citizens, so that they will collectively support drastic and bold actions by their religious, cultural, social, and political leaders.

I will conclude with the most formidable challenge of all, which is uncertainty. There is uncertainty in societal will to bend the emissions curve; uncertainty in the magnitude of the future warming and resultant impacts, due to the multitude of feedbacks between and within the human and natural systems. Compounding all these uncertainties is the uncertainty in the optimal responses by society. We have an obligation not to let uncertainty paralyze us to inaction. Since uncertainty can go both ways (i.e., make it much worse or much better), use the uncertainty to catalyze rapid actions. It is going to require multiple iterations where we learn in the field by experimentation to sort out better actions.[20] Climate scientists have a special role to help society navigate through the uncertainties, provided scientists and scientific institutions form alliances with governments, private sector, faith-based institutions, and NGOs who are on the front lines of climate actions.

[20] C. F. Sabel & D. G. Victor (2022) Fixing the Climate: *Strategies for an Uncertain World*, Princeton University Press.

The Amazon Near a Tipping Point

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1. The Amazon Forest Acts Like a Big Engine of the Climate System

The Forest and Land Use Declaration, a notable achievement of the 26th UNFCCC Conference of the Parties (COP26), emphasized the crucial interconnection of forests, biodiversity, and sustainable land practices in the pursuit of worldwide Sustainable Development Goals (SDG), affirming the pivotal significance of tropical forests as a nature-based solution to addressing both climate change and biodiversity loss.[2]

Tropical rain forests[3] are the most extensive tropical ecological zone in the world, occupying 13.4% of the global ice-free land surfaces and 25% of all tropical ecological zones.[4] It is also the richest place in species, harboring more than half of the globe's biodiversity and is a major terrestrial carbon sink,[5] removing about 7.6 $GtCO_2e$ a year (2001–2019).[6] Tropical rainforest distribution, composition, and functioning evolved over 140 million years, responding to changing patterns of climate, soils, and atmospheric CO_2 concentrations across geological timescales following a global pattern of warming and cooling.[7] Currently, these exuberant

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[2] V. H. A. Heinrich, et al. (2023) *The carbon sink of secondary and degraded humid tropical forests*, NATURE 615.

[3] Tropical humid broadleaf forest (THBF) biome from: D. M. Olson, et al. (2001) *Terrestrial Ecoregions of the World: A New Map of Life on Earth: A new global map of terrestrial ecoregions provides an innovative tool for conserving biodiversity*, BIOSCI. 51(11).

[4] J. P. Ometto, et al. (2022) *Cross-Chapter 7: Tropical Forests*, in CLIMATE CHANGE 2022: IMPACTS, ADAPTATION, AND VULNERABILITY, P. Arias, et al. (eds.); L. S. Borma, et al. (2022) *Beyond Carbon: The Contributions of South American Tropical Humid and Subhumid Forests to Ecosystem Services*, REV. GEOPHYS. 60(4).

[5] Ometto, supra note 4.

[6] N. L. Harris, et al. (2021) *Global maps of twenty-first century forest carbon fluxes*, NAT. CLIM. CHANGE 11.

[7] C. Jaramillo (2019) *Chapter 6: 140 Million Years of Tropical Biome Evolu*tion, in THE GEOLOGY OF COLOMBIA, Vol. 2, J. Gomez & A. O. Pinilla-Chacon (ed.), Servicio Geológico Colombiano; Y. Malhi & J. Grace (2000) Tropical forests and atmospheric carbon dioxide, TRENDS ECOL. EVOL. 15(8); Y. Malhi, et al. (2021) *Chapter 6:*

forests occur under wet equatorial (Af) and tropical monsoon (Am), with an annual mean temperature of 25°C and precipitation greater than 1,500 mm yr^{-1} well distributed across the year.[8] Unlike temperate forests, its presence confers to the environment a daily cooling effect, with temperatures dropping by an average of 2.4°C both during daytime and nighttime.[9]

The Amazonian forest is the greatest tropical rainforest in the world, covering over ca 700 Mha in South America, representing ca. 40% of the South American continent. In the Amazon biogeographic province, 74% of its natural vegetation corresponds to forests which cover vast regions of Brazil, southern Venezuela, and eastern Colombia, extends to the eastern slopes of the northern and central Andes from Colombia to Bolivia, as French Guiana, Guyana, and Suriname.[10] With an estimated 55,000 plants[11] and 5,637 animals' vertebrates,[12] the Amazon forest holds ca 13% of the world's biodiversity. Amazon biodiversity has evolved across hundreds of million years, becoming a center and source of biodiversity for the whole Neotropical zone.[13] The Amazon Region is home to over 47 million people, including roughly 2.2 million Indigenous individuals. In addition, there are millions of residents in local communities within the Amazon who depend to varying extents on the forest's resources. These resources provide these communities with essential elements such as shelter, sustenance, fiber, security, and cultural and spiritual significance.[14]

The Amazon's remarkable biodiversity and complex forest structure play a pivotal role in sustaining the stability of crucial ecosystem processes. Biogeochemical processes like carbon sequestration, air purification, and decomposition, as well as biophysical processes such as

Biogeochemical cycles of the Amazon, in AMAZON ASSESSMENT REPORT 2021 ["AAR 2021"], C. Nobre, et al. (eds.).

[8] Y. Zhao, et al. (2005) *Impacts of present and future climate variability on agriculture and forestry in the humid and sub-humid tropics*, CLIM. CHANGE 70; Borma, supra note 4.

[9] Y. Li, et al. (2015) *Local cooling and warming effects of forests based on satellite observations*, NAT. COMMUN. 6.

[10] J. S. Albert, et al. (2023) *Human impacts outpace natural processes in the Amazon*, SCIENCE 379(6630).

[11] R. Moraes, et al. (2021) *Chapter 4: Biodiversity and Ecological Functioning in the Amazon*, in AAR 2021.

[12] Personal communication, R. Mittermeier and A. B. Rylands.

[13] Jaramillo, supra note 7; J. M. Guayasamin, et al. (2021) *Chapter 2: Evolution of Amazonian Biodiversity*, in AAR 2021.

[14] S. Athayde, et al. (2021) *Viewpoint: The far-reaching dangers of rolling back environmental licensing and impact assessment legislation in Brazil*, ENVIRON. IMPACT ASSESS. REV. 94; Borma, supra note 3.

thermal regulation and rainfall recycling, and the control of the rainy season's duration, collectively yield a range of ecosystem services that confer both regional and global benefits to people.[15] Through photosynthesis, Amazonian rainforests suck up and store between 150-200 GtC[16] and sequester ca. 430 to 650 MtC annually.[17] By doing this, the forests help keep the air cleaner and prevent the planet from getting too warm. The Amazon Forest also acts like a big engine in the climate system, consisting in one of three special places in the intertropical zone (along with Central Africa and Southeast Asia) where hot air goes up carrying energy as water vapor, making it acts as a giant fan helping to move the water from the forest and sends it into the air through a process called evapotranspiration. Then, when that water turns into clouds or rain, it releases heat into the air, cooling local surface temperatures, effectively moderating the diurnal and seasonal temperature ranges,[18] thus compensating for part of the heating produced by the greenhouse gases.[19] A medium- sized tree, with a canopy diameter of 5 meters, injects 68 to 88 liters of water vapor to the atmosphere daily (considering evapotranspiration rates between 3.5 to 4.5 liters a day),[20] producing an air cooling of approximately 2200 watts, equivalent to a 7500 Btu/h (British Thermal Unit/hour) air conditioning unit.[21] A large tree of 10 meters canopy ratio would almost double this rate.

The substantial evapotranspiration occurring in the Amazon region is essential for several key processes. The deep root system of Amazonian trees helps the tree to draw water from the deeper soil layers, ensuring the production of humidity and its release into the atmosphere,[22] increasing cloud production and guarantees 35% to 80% of precipitation within the ecosystem,[23]

[15] Borma, *supra* note 4.

[16] Malhi, *Ch. 6: Biogeochemical cycles of the Amazon*, *in* AAR 2021.

[17] R. J. W. Brienen, *et al.* (2015) *Long-term decline of the Amazon carbon sink*, NATURE 519.

[18] A. Huang, X. Xu, G. Jia, & R. Shen (2022) *Asymmetrical cooling effects of Amazonian protected areas across spatiotemporal scales*, ENVIRON. RES. LETT. 17(5).

[19] I. D. Artaxo, *et al*. (2022) *Tropical forests are crucial in regulating the climate on Earth*, PLOS CLIMATE 1(8).

[20] M. H. Costa & J. A. Foley (1999) *Trends in the hydrologic cycle of the Amazon Basin*, J. GEOPHYS. RES. ATMOS. 104(D12).

[21] Science Panel for the Amazon (2023) *Diálogo entre Saberes por uma Amazônia que Queremos*, Science Panel for the Amazon, Agência Bori, Nexo Políticas Públicas.

[22] D. C. Nepstad, et al. (1994) *The role of deep roots in the hydrological and carbon cycles of Amazonian forests and pastures*, NATURE 372.

[23] J. A. Marengo, et al. (2018) *Changes in Climate and Land Use Over the Amazon Region: Current and Future Variability and Trends*, FRONT. EARTH SCI. 6.

causing cooling of the Earth's surface and minimizing the effects of interannual droughts and heat waves.[24]

With a recycling ratio ranging from 24% to 35% and with annual precipitation exceeding evapotranspiration (2190 mm vs. 1220 mm, in average),[25] Amazon forests guarantee replenishment of groundwater, the world's greater river discharge (220,000 m^3 per second, 16–22%) and an increase in dry-season evapotranspiration rates, critical for the onset of the rainy season.[26] Additionally, its role in rainfall recycling makes the Amazonian forests serve as a critical moisture source for downstream regions contributing to the release of water vapor towards regions like the Andes, Central Brazil, and the La Plata basin through the so-called atmospheric rivers.[27] These interconnected mechanisms are essential for sustaining warm and humid climates, which, in turn, are indispensable for the preservation of the Amazonian rainforest. Consequently, the Amazon Forest commands significant attention in our collective efforts to combat climate and biodiversity crises, which may pose huge social and ecological impacts. These dual crises erode the invaluable contributions of nature to human wellbeing, livelihoods, economies, and sustainable developmental prospects.[28]

2. Deforestation, Forest Degradation, and Climate Changes in the Amazon

From 1990 to 2020, the world accumulated the concerning loss of more than 420 million hectares of forests due to deforestation, an area roughly matching the size of the European

[24] M. E. Arias, et al. (2018) *Decoupling the effects of deforestation and climate variability in the Tapajós river basin in the Brazilian Amazon*, HYDROL. PROCESS. 32(11); M. Llopart, et al. (2018) *Land Use Change over the Amazon Forest and Its Impact on the Local Climate*, WATER 10(2); V. M. Pavão, et al. (2017) *Impacto da Conversão da Cobertura Natural em Pastagem e Área Urbana sobre Variáveis Biofísicas no Sul do Amazonas*, REV. BRAS. METEOROL. 32(3).

[25] M. H. Costa, et al. (2021) Chapter 7: Biogeophysical Cycles: Water *Recycling, Climate Regulation*, in AAR 2021.

[26] A. T. Leite-Filho, et al. (2019) *Effects of Deforestation on the Onset of the Rainy Season and the Duration of Dry Spells in Southern Amazonia*, J. GEOPHYS. RES. ATMOS. 124(10).

[27] Supra note 24; J. M. Arraut, et al. (2012) *Aerial Rivers and Lakes: Looking at Large-Scale Moisture Transport and Its Relation to Amazonia and to Subtropical Rainfall in South America*. J. CLIM. 25(2); D. C. Zemp, et al. (2017) *Self- amplified Amazon forest loss due to vegetation-atmosphere feedbacks*, NAT. COMMUN. 8(14681); W. Weng, et al. (2018) *Aerial and surface rivers: Downwind impacts on water availability from land use changes in Amazonia*, HYDROL. EARTH. SYST. SCI. 22(1).

[28] H. O. Pörtner, *et al*. (2023) *Overcoming the coupled climate and biodiversity crises and their societal impacts*, SCIENCE 380(6642).

Union. Remarkably, 90% of this significant loss occurred in tropical regions.[29] The Amazon Forest lost 56 million hectares of its forests between 1985 to 2021, which roughly represents 13% of the world's loss.[30] Previously to 1985, Amazon had lost a large amount of forests starting in the 1970s. Presently, estimates indicate that more than one hundred million hectares have been deforested over the last 50 years (15.5%). There is secondary forest regrowth in close to 60 million hectares in the Brazilian Amazon over abandoned pastures.[31] Notably, ca. 62% of the Amazon Forest is located in Brazil, which also experienced the most significant forest loss between 1985 and 2021, amounting to 52 million hectares. In 2021, 89% of the Amazon region was covered by natural vegetation and 11% was converted to anthropogenic land uses through a process of urbanization, development of extractive activities, agroindustry and infrastructure.[32] Over the last 36 years, 96% (55 million hectares) of deforested areas in the Amazon Forest were converted into agricultural lands, representing an expansion of pasturelands in the region.[33] It is crucial to highlight that in addition to livestock farming in the natural forests of the Amazon there is association with multiple forms of clandestine and illegal economies such as timber, land grabbing and gold.[34] Beyond deforestation, the Amazon suffers enormous impacts from forest degradation by human-induced disturbance, namely logging, fuelwood collection, edge effect, and fire, which reached 17% of the total forest area by 2017.[35]

Despite distinguishing climate-induced from land use-driven changes is challenging,[36] Amazon climate change is already a reality.[37] While the global mean temperature increased 0.98°C,

[29] Ometto, *supra* note 4.

[30] *Mapbiomas*.

[31] Instituto Nacional de Pesquisas Espaciais (2021) *Monitoramento do Uso e Cobertura da Terra nas Áreas Desflorestadas da Amazônia Legal—TerraClass Amazônia*, São José dos Campos: São Paulo, Brazil.

[32] *Supra* note 30.

[33] *Id.*

[34] S. Hecht, *et al.* (2021) *Chapter 14: Amazon in Motion: Changing politics, development strategies, peoples, landscapes, and livelihoods*, *in* AAR 2021.

[35] E. L. Bullock, *et al*. (2020) *Satellite-based estimates reveal widespread forest degradation in the Amazon*, GLOB. CHANG. BIOL. 26(5).

[36] E. Castellanos, *et al*. (2022) *Chapter 12: Central and South America, in* CLIMATE CHANGE 2022.

[37] J. A. Marengo, *et al*. (2021) *Chapter 22: Long-term variability, extremes and changes in temperature and hydro meteorology in the Amazon region*, *in* AAR 2021.

the mean warming trends for the whole Amazonia was 1.02 ± 0.12°C between 1979 and 2018.[38] Monthly maximum temperatures have increased by 0.04–0.06°C in most of the Amazon region.[39] Long-term observations (over the last 20 years) indicate that the atmosphere over the Amazon rainforest is becoming drier due to global warming, biomass burning, and land use changes.[40] The dry season length in southern Amazonia has already increased by four to five weeks since 1979, particularly in deforested areas.[41] The Amazon has also experienced extreme climate events, such as the historically intense droughts recorded in 1906, 1912, 1926, 1964, 1986, 1992, 1998, 2005, 2010, and 2015–2016, 2023.[42]

Fires are becoming increasingly intense and frequent, exacerbated during years of anomalous droughts, such as El Niño years and/or warmer-than-normal North Atlantic tropical sea surface temperatures, which elevate tree mortality, carbon emissions and impact on agricultural productivity.[43] Moreover, in heavily deforested areas, the rainy season starts late and is more likely to be interrupted.[44] The interaction between warmer and drier regional climate increases fire activity and deforestation is foreseen to lock large parts of the Amazon forests in open degraded vegetation states, with limited capability of regrow.[45]

[38] L. V. Gatti, *et al*. (2021) *Amazonia as a carbon source linked to deforestation and climate change*, NATURE 595.

[39] P. E. Da Silva, *et al*. (2019) *Precipitation and air temperature extremes in the Amazon and northeast Brazil*, INT'L J. CLIMATOL. 39(2).

[40] A. Barkhordarian, *et al*. (2019) *A Recent Systematic Increase in Vapor Pressure Deficit over Tropical South America*, SCI. REP. 9(15331).

[41] Leite-Filho, *supra* note 26; Marengo, *supra* note 37.

[42] A. Nobre, *et al.* (2016) *Land-use and climate change risks in the Amazon and the need for a novel sustainable development paradigm*, PROC. NAT'L. ACAD. SCI. 113(39); World Meteorological Organization (2023) WMO GLOBAL ANNUAL TO DECADAL CLIMATE UPDATE.

[43] J. A. Marengo, *et al.* (2022) *Increased climate pressure on the agricultural frontier in the Eastern Amazonia–Cerrado transition zone*, SCI. REP. 12(1).

[44] Leite-Filho, *supra* note 26.

[45] M. Hirota, et al. (2021) *Chapter 24: Resilience of the Amazon Forest to Global Changes: Assessing the Risk of Tipping Points*, in AAR 2021; M. Drüke, et al. (2021) *Climate-induced hysteresis of the tropical forest in a fire-enabled Earth system model*, EUR. PHYS. J. SPEC. TOP. 230.

3. Impacts of Land Use and Climate Change on Biodiversity, GHG Emissions, and Human Wellbeing

The interplay between land use, notably deforestation and degradation, with climate change is expected to heighten Amazon forest threats, escalating fires, and forest degradation. Climate change will exacerbate current regional challenges, leading to severe food and water insecurity due to prolonged droughts, increased threats of floods to both people and infrastructure, and a higher incidence of epidemics, such as Malaria. These compounding risks will place significant strain on public stability.[46] Additionally, there's an imminent risk of large-scale landscape transformations with forest biome dieback in the Amazon.[47]

Deforestation and degradation are responsible for a cascading effect on species richness and biomass.[48] In the Amazon, tree species richness may decline 19–36% due to deforestation by 2050.[49] These trends indicate a loss of the forest's resilience in responding to disturbances.[50] Boulton et al. (2022) corroborated this pattern by utilizing a stability indicator linked to the duration of vegetation recovery following extreme drought-induced disturbances.[51] Their study unveiled a concerning finding: during the period from 1991 to 2016, approximately 75% of the Amazon rainforest displayed diminished resilience, particularly in drier areas adjacent to human-influenced zones.

Extensive deforestation in regions like the Amazon, which heavily relies on the recycling of rainfall, triggers a series of events. These events include reduced water recycling into the atmosphere, resulting in decreased local cloud cover and precipitation. Consequently, this leads to a decrease in overall water availability in the system and an increase in solar radiation.[52] On average, the conversion of one hectare of forest into agricultural land is

[46] Albert, *supra* note 10; Castellanos, *supra* note 36.

[47] Nobre, *supra* note 42.

[48] C. Vancutsem, *et al*. (2021) *Long-term (1990–2019) monitoring of forest cover changes in the humid tropics*, SCI. ADV. 7(10).

[49] V. H. F. Gomes, *et al*. (2019) *Amazonian tree species threatened by deforestation and climate change*, NAT. CLIM. CHANGE 9.

[50] Hirota, *supra* note 45.

[51] C. A. Boulton, T. M. Lenton, & N. Boers (2022) *Pronounced loss of Amazon rainforest resilience since the early 2000s*, NAT. CLIM. CHANGE 12(3).

[52] E. Salati & P. B. Vose (1984) *Amazon basin: a system in equilibrium*, SCIENCE 225 (4658).

estimated to result in a reduction of 0.5 million liters of water evaporated annually, which does not precipitate any more in the Amazon during a dry season.[53]

Studies suggest that the atmosphere at the surface of forests can be 2°C cooler and more humid than deforested areas.[54] The southern and eastern regions of the Amazon have experienced the most pronounced impacts from regional climate shifts due to elevated rates of deforestation, increased wildfire occurrences, and natural seasonal climatic variations. The transition region between the Cerrado (tropical savanna) and Amazon biomes in the eastern Amazon basin is experiencing 20 to 30 percent decrease in precipitation, temperatures are 2 to 3 degrees Celsius warmer and the forest has become a carbon source.[55] This area has warmed by 0.38 ± 0.15°C per decade in the transition from dry to wet season between 1981 and 2020, accompanied by a significant increase in the number of dry days by 3 to 4 days per decade.[56]

As we peer into the future, projections indicate that the Amazon is likely to experience even higher temperatures and increased aridity until the close of this century. Deforestation in the Amazon can lead to the eastern region warming by more than 3°C, a decrease of up to 40% in rainfall from July to November, and a delay in the onset of the rainy season (0.12 to 0.17 days per percent for every 1% increase in deforestation).[57] With 40% of the Amazon area deforested, annual precipitation in the Amazon basin would be reduced by 5% to 10%.[58] The reduction in moisture recycling after forest removal results in longer dry seasons in the southern Amazon and diminishes the moisture flow to the eastern region.[59] For example,

[53] A. Staal, *et al*. (2020) *Feedback between drought and deforestation in the Amazon*, ENVIRON. RES. LETT. 15(4).

[54] Arias, *supra* note 24.

[55] Gatti, *supra* note 38.

[56] Marengo, *supra* note 37; Marengo, *supra* note 43.

[57] Leite-Filho, *supra* note 26.

[58] Zemp, *supra* note 27.

[59] J. Agudelo, et al. (2019) *Influence of longer dry seasons in the Southern Amazon on patterns of water vapor transport over northern South America and the Caribbean*, CLIM. DYN. 52.

Strand et al. (2018) estimate that soybean or beef production in certain regions could be reduced, resulting in losses of up to $9 per hectare per year due to decreased rainfall.[60]

This scenario paints a troubling picture, with the potential for more than 150 days each year surpassing the 35°C threshold—twice the annual average of the previous two decades, which may push the Amazon beyond the human physiological limit.[61] These regional temperature increases would also have significant implications for agriculture and cattle ranching productivity in the Amazon. Several studies suggest that productivity losses resulting from climate change could render some agricultural production systems unviable, such as the double-cropping systems mentioned above.[62] According to Abrahão and Costa (2018),[63] double-cropping systems located in the Amazon-Cerrado transition area may experience a 17% decline by 2050, while some regions like MATOPIBA (a political term encompassing productivity losses in the Brazilian states of Maranhão, Tocantins, Piauí, and Bahia) could see a reduction of 61%, jeopardizing their sustainability.[64]

Carbon emissions in the tropics are strongly associated with deforestation to convert natural forests into agricultural uses (farming and cultivation).[65] The significant expansion of degraded areas in the Amazon over the past two decades has contributed to approximately 50% of emissions from deforestation.[66] Due to land use and climate changes, the Amazon basin as a whole already operates as a net carbon source of 0.29 ± 0.40 Gt C yr^{-1} (or 1.1 Gt CO_2e yr^{-1}), rather than a carbon sink.[67] The clearing of the forest followed by biomass burning can account

[60] J. Strand, et al. (2018) *Spatially explicit valuation of the Brazilian Amazon Forest's Ecosystem Services*, NAT. SUSTAIN. 1.

[61] B. F. Alves de Oliveira, M. J. Bottino, P. Nobre, & C. A. Nobre (2021) *Deforestation and climate change are projected to increase heat stress risk in the Brazilian Amazon*, COMMUN. EARTH ENVIRON. 2(1).

[62] D. Arvor, et al. (2014) *Spatial patterns of rainfall regimes related to levels of double cropping agriculture systems in Mato Grosso (Brazil)*, INT'L. J. CLIMATOL. 34(8); G. F. Pires, et al. (2016) *Increased climate risk in Brazilian double cropping agriculture systems: Implications for land use in Northern Brazil*, AGRIC. FOR. METEOROL. 228–229.

[63] G. M. Abrahão & M. H. Costa (2018) *Evolution of rain and photoperiod limitations on the soybean growing season in Brazil: The rise (and possible fall) of double-cropping systems*, AGRIC. FOR. METEOROL. 256–257.

[64] Pires, supra note 62.

[65] Castellanos, supra note 36.

[66] T. O. Assis, et al. (2020) *CO_2 emissions from forest degradation in Brazilian Amazon*, ENVIRON. RES. LETT. 15(10).

[67] Gatti, supra note 38.

for 11–70% of deforestation emissions, primarily released during the southern dry season.[68] The extreme climate events, increasingly more frequent in the Amazon, such as El Niño and warmer-than-normal North Atlantic tropical sea surface temperatures, exacerbate carbon emissions by fire and forest degradation.[69] For instance, during the severe drought year (El Niño-Southern Oscillation – ENSO) in 1997-1998, the forest area burned by wildfires (3.9×10^6 ha) was 13 times larger than the area burned during the average precipitation year (0.2×10^6 ha), and twice the size of the annual deforestation area, resulting in a total of 0.049 to 0.329 Gt of dead tree biomass.[70] The incidence of wildfires during the 2015–2016 drought increased by 36% compared to the previous 12 years, and killed approximately 2.5 billion trees, releasing ca. 500–1000 Mt of carbon dioxide (CO_2) into the atmosphere.[71] The increase in deforestation and degradation over the years of 2019 and 2020 made carbon emissions reach the magnitude of El Niño events, but unlikely was driven by the dismantling of public policies in Brazil addressed to combat and control deforestation intertwined by a discourse encouraging illegal land use practices.[72]

Lovejoy and Nobre (2018) argue that the severity of the droughts in 2005, 2010, and 2015-16 (as well as the 2020 drought) may represent the first signs of ecological tipping points operating on a planetary scale.[73] In this context, Indigenous peoples and local communities of the Amazon play a critical role in climate mitigation. In 2016, Indigenous Territories and Protected Natural Areas stored a significant portion of the region's carbon (ca 58%) which contributed only 10% to the net change in carbon.[74]

[68] G. R. van der Werf, et al. (2009) *Estimates of fire emissions from an active deforestation region in the southern Amazon based on satellite data and biogeochemical modelling*, BIOGEOSCI. 6(2); L. E. O. C. Aragão, et al. (2018) *21st Century drought-related fires counteract the decline of Amazon deforestation carbon emissions*, NAT. COMMUN. 9(536).

[69] L. V. Gatti, et al. (2023) *Increased Amazon carbon emissions mainly from decline in law enforcement*, NATURE 621.

[70] A. Alencar, D. Nepstad, & M. C. Vera Diaz (2006) *Forest understory fire in the Brazilian Amazon in ENSO and non-ENSO years: Area burned and committed carbon emissions*, EARTH INTERACT 10.

[71] E. Berenguer, et al. (2021) *Tracking the impacts of El Niño drought and fire in human-modified Amazonian forests*, PROC. NAT'L. ACAD. SCI. 118(30); Aragão, supra note 68.

[72] *Supra* note 69.

[73] T. E. Lovejoy & C. Nobre (2018) *Amazon's Tipping Point,* SCI. ADV. 4(2).

[74] W. S. Walker, *et al*. (2020) *The role of forest conversion, degradation, and disturbance in the carbon dynamics of Amazon indigenous territories and protected areas*, PROC. NAT'L. ACAD. SCI. 117(6).

In the event that CO_2 is released from the Amazon Forest biomass into the atmosphere, it would result in a substantial increase in CO_2 concentration, estimated at around 85 ppm. This increase would push the atmospheric CO_2 concentration from 415 ppm to 500 ppm and raise the average global temperature from 1.2°C to 1.7°C above preindustrial levels.[75] When we take into account climate projections derived from the current generation of general circulation models (GCMs), which predict an average global temperature increase of approximately 3.3°C by the end of the 21st century,[76] the potential consequences of such warming become even more alarming.

The capability of the forest to recover after disturbance might take centuries and is limited by reduced rainfall and the feedback of forest loss and intensification of regional droughts.[77] While the heightened levels of CO_2 in the atmosphere are often viewed as a potential growth stimulant for forests, it's important to note that canopy leaves in tropical forests could also encounter a critical temperature threshold due to elevated carbon levels, which might have a moderating effect on the increase in photosynthesis.[78]

The escalating population of cattle in the Amazon, reaching 83 million in 2022 across the entire Brazilian Amazon biome,[79] has introduced an additional threat to climate mitigation efforts. Public policies in Brazil have successfully reduced carbon emissions in the Amazon by an impressive 83%. However, emissions from livestock accounted for 25% of national emissions, totaling 601 MtCO2e in 2021, approximately 68.3% of the total of the agricultural sector.[80] While methane's atmospheric lifetime is 10 times shorter than CO_2, it has a potential to cause global warming approximately 25 times greater.[81] In 2021, methane emissions from the agricultural sector accounted for 70.6% of the country's total methane emissions. Thus, actions aimed at mitigating emissions are essential to reduce the impact of Brazilian agriculture on

[75] Albert, *supra* note 10.

[76] Intergovernmental Panel on Climate Change (2021) CLIMATE CHANGE 2021: THE PHYSICAL SCIENCE BASIS, V. Masson-Delmotte, et al. (eds.),

[77] Drüke, *supra* note 45; Staal, *supra* note 53; Zemp, *supra* note 58.

[78] L. A. Cernusak, *et al*. (2013) *Environmental and physiological determinants of carbon isotope discrimination in terrestrial plants*, NEW PHYTOL. 200(4); Drüke, *supra* note 45.

[79] Instituto Brasileiro De Geografica E Estatística (2022) *Produção Pecuaria Municipal*.

[80] System for Estimating Greenhouse Gas Emissions (SEEG).

[81] O. Boucher, et al. (2009) *The indirect global warming potential and global temperature change potential due to methane oxidation*, ENVIRON. RES. LETT. 4(4).

greenhouse gas production. Methane emissions in the Legal Amazon, from enteric fermentation and manure management, account for approximately 55% of the total methane emissions in the Brazilian agricultural sector. Additionally, the cattle herd in the Legal Amazon.

4. Global and Amazon Tipping Points

Tipping points are critical thresholds in a system which, when crossed, can lead to a significant change in the system's state, often with the understanding that the change is irreversible. Tipping elements refer to subsystems of the Earth system that can undergo a qualitative state change due to small perturbations. Understanding tipping points in the climate system is essential to comprehend the risks associated with different degrees of global warming and changes in land use. This understanding is crucial for preventing the Amazon rainforest, one of the Earth's key tipping elements, from reaching a tipping point.[82]

This section presents the facts and evidence that are pushing the Amazon closer to a tipping point. Firstly, climate change drivers are introduced, including global warming, the El Niño-Southern Oscillation (ENSO), and the Atlantic Meridional Overturning Circulation (AMOC). Secondly, land- use change drivers are briefly addressed (*see* **section 2**), which include deforestation, forest degradation, and wildfires. Finally, it presents the synergistic interactions resulting from the combination of global climate change and land-use changes in the Amazon, including the lengthening of the dry season, increased vapor pressure deficit, and changes in species composition.

A. Climate Change Vector: The Planet is Warming and Droughts are Becoming More Frequent and Intense in the Amazon

Global warming is a concerning reality. Between 2011 and 2020, the global average surface temperature increased by approximately 1.09°C compared to the period from 1850 to 1900. This increase has a confidence interval ranging from 0.95°C to 1.20°C.[83] It is important to emphasize that there is compelling evidence that global warming is primarily attributed to greenhouse gas emissions resulting from human activities.[84]

[82] T. M. Lenton, et al. (2008) *Tipping elements in the Earth's climate system*, PROC. NAT'L. ACAD. SCI. 105(6); Castellanos, supra note 36; Nobre, supra note 42.

[83] Castellanos, *supra* note 36.

[84] IPCC, *supra* note 76.

Global warming is more pronounced on land surfaces compared to ocean surfaces. The temperature variation over land ranged from 1.34°C to 1.83°C, with an average of 1.59°C, while over oceans, the variation ranged from 0.68°C to 1.01°C, with an average of 0.88°C. For each year between 2023 and 2027, the global average surface temperature is projected to vary between 1.1°C to 1.8°C compared to the period from 1850 to 1900.[85]

During the ENSO, the surface water temperatures of the equatorial Pacific Ocean warm, leading to increased evaporation and cloud formation over the Pacific.[86] This phenomenon influences the atmospheric circulation (Walker Circulation), shifting the Walker cell eastward. This results in upward motion over the central and eastern Pacific, causing negative anomalies of subsiding motion in the Amazon.[87] These changes primarily affect precipitation in the northern and eastern regions of the Amazon due to reduced atmospheric convection and convective cloud formation.[88]

While the occurrence of El Niño is a natural phenomenon typically spaced at intervals of 20 years, there are indications that its frequency may increase linearly with the rise in global average temperature.[89] In the past three decades, El Niño events occurred in 1991/1992, 1993, 1994/1995, 1997/1998, 2015/2016, and 2023.[90] The El Niño event in November 2015 resulted in a significant temperature anomaly of 2.5°C over the Amazon.[91] Mathematical models have indicated that under high greenhouse gas emission scenarios, precipitation over the Amazon could decrease from 5 mm per day compared to the pre-industrial period to 2 mm

[85] WMO, *supra* note 42.

[86] L. S. Borma & C. A. Nobre (2013) SECAS NA AMAZÔNIA: CAUSAS E CONSEQUÊNCIAS, São Paulo: Oficina de Textos.

[87] C. A. S. Cavalcanti, S. M. S. Costa, & S. R. Freita (2013) *O efeito do aerossol na formação de nuvens – o caso das secas de 2005 e 2010*, *in* SECAS NA AMAZÔNIA: CAUSAS E CONSEQUÊNCIAS.

[88] G. Sampaio (1999) *El Niño e você: o fenômeno climático*, São José dos Campos: Transtec Editorial.

[89] IPCC (2023) AR6 SYNTHESIS REPORT: CLIMATE CHANGE 2023, P. Arias, *et al.* (eds.).

[90] Sampaio, *supra* note 88; J. C. Jiménez-Muñoz, *et al.* (2016) *Record-breaking warming and extreme drought in the Amazon rainforest during the course of El Niño 2015–2016*, SCI. REP. 6(33130); WMO, *supra* note 42.

[91] Jiménez-Muñoz, *id*.

per day by the year 2100.[92] Therefore, El Niño has led to higher temperatures and more intense and prolonged droughts in the Amazon.[93]

Another oceanic phenomenon that plays a significant role in the climate of the Amazon is the warming of surface waters in the northern tropical Atlantic Ocean. This phenomenon occurs when the northeast trade winds weaken. The increase in ocean surface temperature is directly linked to reduced rainfall in the northwestern and western regions of the Amazon.[94]

The rise in global temperatures leads to the melting of glaciers and ice sheets in the northern hemisphere. This has altered the salinity and density of ocean waters. Freshwater runoff into the Atlantic Ocean becomes less prone to sinking, thus disrupting the circulation rate in the Atlantic, a phenomenon that has been observed since 1950. The weakening of the AMOC has possibly led to warmer waters in the North Tropical Atlantic. Consequently, this has resulted in more intense and frequent droughts in large parts of the Amazon.

In conclusion, the evidence presented underscores the alarming reality of global warming and its profound impact on the Amazon region. Rising temperatures and changing oceanic patterns are clear indicators of the climate crisis. Global warming of 3°C to 4°C could represent a tipping point that would lead to a significant decline in the Amazon rainforest, with a key forcing mechanism being El Niño events causing more frequent droughts in the region.[95] It is imperative that immediate and sustained efforts are made to mitigate greenhouse gas emissions and address the complex interplay of factors that threaten the Amazon rainforest.

B. Vector of Land Use Changes: Deforestation, Degradation, and Forest Fires

Another factor accelerating the "*savannization*" process in the Amazon is land use changes. Deforestation, degradation, and forest fires have extended the dry season, raised temperatures, increased tree mortality, and released significant amounts of carbon into the atmosphere. Deforestation in the Amazon results in a reduction of forest biomass, causing

[92] R. A. Betts, *et al*. (2004) *The role of ecosystem-atmosphere interactions in simulated Amazonian precipitation decrease and forest dieback under global climate warming*, THEOR. APPL. CLIMATOL. 78.

[93] Jiménez-Muñoz, *supra* note 90.

[94] Cavalcanti, *supra* note 87.

[95] Nobre, *supra* note 42.

climatic alterations by modifying the surface energy and water balance.[96] The long-wave solar radiation reflected by the surface (albedo) is approximately 5% higher in pasture areas,[97] while evapotranspiration rates are between 20% and 41% lower compared to the forest.[98] As a result, both average and temperature fluctuations increase, while cloud cover and precipitation decrease.[99]

Furthermore, the Amazon faces a critical tipping point if deforestation rates exceed 40%, regardless of global climate changes.[100] Forest degradation is equally concerning, resulting in a two to threefold increase in tree mortality rates[101] and a significant three to sixfold reduction in seed and fruit production compared to intact forests.[102] Additionally, during drought episodes, tree mortality due to fire-related injuries experiences a dramatic increase, ranging from 219% to a staggering 462%.[103] These alarming trends emphasize the urgent need to address and mitigate deforestation, degradation, and forest fires in the Amazon.

C. Synergistic Interaction Between Global Climate Change and Land Use Changes in the Amazon

Three critical tipping elements are interconnected with the tipping point of the Amazon. The melting of ice caps in Greenland, the weakening of the AMOC, and the ENSO phenomenon. The abnormal warming of surface waters in the equatorial Pacific and North tropical Atlantic

[96] J. H. C. Gash & C. A. Nobre (1997) *Climatic effects of Amazonian deforestation: some results from ABRACOS*, BULL. AM. METEOROL. SOC. 78(5).

[97] A. D. Culf, G. Fisch, & M. G. Hodnett (1995) *The albedo of Amazonian forest and ranch land*. J. CLIM. 8(6).

[98] C. von Randow, *et al*. (2004) *Comparative measurements and seasonal variations in energy and carbon exchange over forest and pasture in South West Amazonia*, THEOR. APPL. CLIMATOL. 78(1).

[99] Gash, *supra* note 96.

[100] G. Sampaio, *et al*. (2007) *Regional climate change over eastern Amazonia caused by pasture and soybean cropland expansion*, GEOPHYS. RES. LETT. 34(17); L. F. Salazar, C. A. Nobre, & M. D. Oyam (2007) *Climate change consequences on the biome distribution in tropical South America*, GEOPHYS. RES. LETT. 34(9).

[101] W. F. Laurance, *et al*. (2000) *Rainforest fragmentation kills big trees*, NATURE 404(6780); S. D'Angelo, *et al*. (2004) *Inferred causes of tree mortality in fragmented and intact Amazonian forests*, J. TROP. ECOL. 20(2).

[102] E. R. Hooper & M. S. Ashton (2020) *Fragmentation reduces community-wide taxonomic and functional diversity of dispersed tree seeds in the Central Amazon*, ECOL. APPL. 30(5).

[103] P. M. Brando, *et al*. (2014) *Abrupt increases in Amazonian tree mortality due to drought–fire interactions*, PROC. NAT'L. ACAD. SCI. 111(17).

oceans leads to drought in the Amazon. Reduced rainfall caused by El Niño episodes and warming of the North tropical Atlantic Ocean increases the forest's vulnerability to forest fires.

I. Looking at a Longer, Drier, and Hotter Dry Season

The potential lengthening of the dry season in the southern Amazon has been linked to deforestation and subsequent regional climate changes.[104] Field studies have observed a temperature increase of 0.4°C per decade[105] and a temporal trend of the maximum cumulative water deficit of -1.1 mm/year across the entire Amazon region.[106] In fact, Leite-Filho et al. (2019) correlated a delay in the onset of the rainy season of 0.12 to 0.17 days for every 1% of deforestation, estimating that the rainy season may be delayed by one week with accumulated deforestation between 50% and 60%.[107] These findings highlight the significant impact of deforestation on regional climate and the lengthening of the dry season in the Amazon.

Furthermore, the lengthening of the dry season in the Amazon may also be linked to a significant increase in aerosols from the smoke resulting from forest fires. These aerosols are tiny particles that play a role in cloud formation. However, these aerosols have a dual effect: on one hand, they act as cloud condensation nuclei, promoting the formation of water droplets. On the other hand, these droplets can be so small that they cannot develop into rain. Additionally, the smoke also blocks a portion of the solar radiation reaching the Amazon's surface, making the atmosphere more stable and hindering the vertical development of moist air masses near the surface. This phenomenon reduces cloud formation and, consequently, the occurrence of rainfall.[108]

[104] C. A. Nobre, P. J. Sellers, & J. Shukla (1991) *Amazonian Deforestation and Regional Climate Change*, J. CLIM. 4(10).

[105] C. A. de Almeida, *et al*. (2016) *High spatial resolution land use and land cover mapping of the Brazilian Legal Amazon in 2008 using Landsat-5/TM and MODIS data*, ACTA AMAZ. 46(3).

[106] A. Esquivel-Muelbert, *et al*. (2019) *Compositional response of Amazon forests to climate change*, GLOB. CHANG. BIOL. 25(1).

[107] Leite-Filho, *supra* note 26.

[108] C. A. S. Coelho, *et al*. (2012) *Climate diagnostics of three major drought events in the Amazon and illustrations of their seasonal precipitation predictions*, METEOROL. APPL. 19(2).

Indeed, the lengthening of the dry season in the southern Amazon has been observed since the 1980s.[109] The extension of the dry season is primarily associated with a delay in its end date. When analyzing daily rainfall data in the Southern Amazon region, an increase ranging from 6.5 ± 2.5 days per decade in the period from 1979 to 2010[110] to 12.5 ± 2.5 days per decade in the period from 1979 to 2020[111] has been identified. This indicates that the dry season in southern Amazon has extended by approximately four to seven weeks between 1980 and 2020. If this trend continues, extending the dry season beyond 5-6 months over the next three decades, it may no longer be able to sustain a closed-canopy, humid forest.

II. THE INCREASE IN VAPOR PRESSURE DEFICIT (VPD) AFFECTS THE PHYSIOLOGY OF THE FOREST

The increase in temperature over terrestrial vegetation areas leads to a reduction in relative humidity, consequently causing an increase in vapor pressure deficit (VPD). Deforestation effects and reduced evapotranspiration intensify VPD. This induces the closure of plant cells (stomata) responsible for gas exchange between the plant and the atmosphere. Studies have shown that in years with high VPD in the Amazon, sap flow is reduced by 35 to 70%, leading to increased vegetation mortality.[112] This occurs because the rising VPD induces stomatal closure to counteract the VPD-mediated evaporative water loss from plants.

The increase in VPD in the Amazon is more pronounced in the southern and eastern regions, primarily observed during the dry season in the months of August, September, and October. This increase is directly related to reduced air humidity but is also associated with deforestation and forest fires.[113] The rise in VPD is the primary adverse consequence of climate change in the Amazon, impacting gross productivity.[114] This suggests a future with less forest cover in the Amazon in regions where VPD is increasing. The globally important carbon sink of intact,

[109] Leite-Filho, *supra* note 26; Marengo, *supra* note 37; R. Fu, *et al*. (2013) *Increased dry-season length over southern Amazonia in recent decades and its implication for future climate projection*, PROC. NAT'L. ACAD. SCI. 110(45).

[110] Fu, *id*.

[111] Marengo, *supra* note 37.

[112] C. G. Fontes, *et al*. (2018) *Dry and hot: the hydraulic consequences of a climate change–type drought for Amazonian trees*, PHIL. TRANS. R. SOC. B 373(1760).

[113] Barkhordarian, *supra* note 40.

[114] C. C. Smith, *et al.* (2021) *Old-growth forest loss and secondary forest recovery across Amazonian countries*, ENVIRON. RES. LETT. 16(8).

old- growth tropical humid forests has declined 30% from the 1990s to the 2000s because recent productivity increases have plateaued, compounded by a sustained long-term rise in tree mortality.[115]

III. Transition to a Degraded 'Savanna-Like' State: Impacts of Climate Change, Deforestation, and Forest Fires on Species Composition

Changes in species composition (**Figure 1**) are influenced by natural processes, but human activities are accelerating this process in the Amazon.[116] An example is the increased density of species in the Vismia genus, such as *Vismia guianensis* (Aubl.) Choisy and *Vismia Japurensis* Reichardt, in response to forest fires.[117] Esquivel-Muelbert and co-authors (2019) reported a recruitment rate of 3.4% per year in the Cecropia genus, which is common in disturbed Amazonian lands and central Brazilian savannahs.[118] In some abandoned pastures, the babassu palm has become predominant, representing between 12% and 50% of regenerating vegetation cover.[119] Therefore, these findings highlight the increase in species adapted to dry climates and recurring forest fires, while there is a reduction in the recruitment of species adapted to wet climates.[120]

[115] Brienen, *supra* note 7.

[116] R. Condit (1995) *Research in large, long-term tropical forest plots*, TRENDS ECOL. EVOL. 10(1); R. D. Mesquita, *et al.* (2015) *Amazon Rain Forest Succession: Stochasticity or Land-Use Legacy?*, BIOSCI. 65(9).

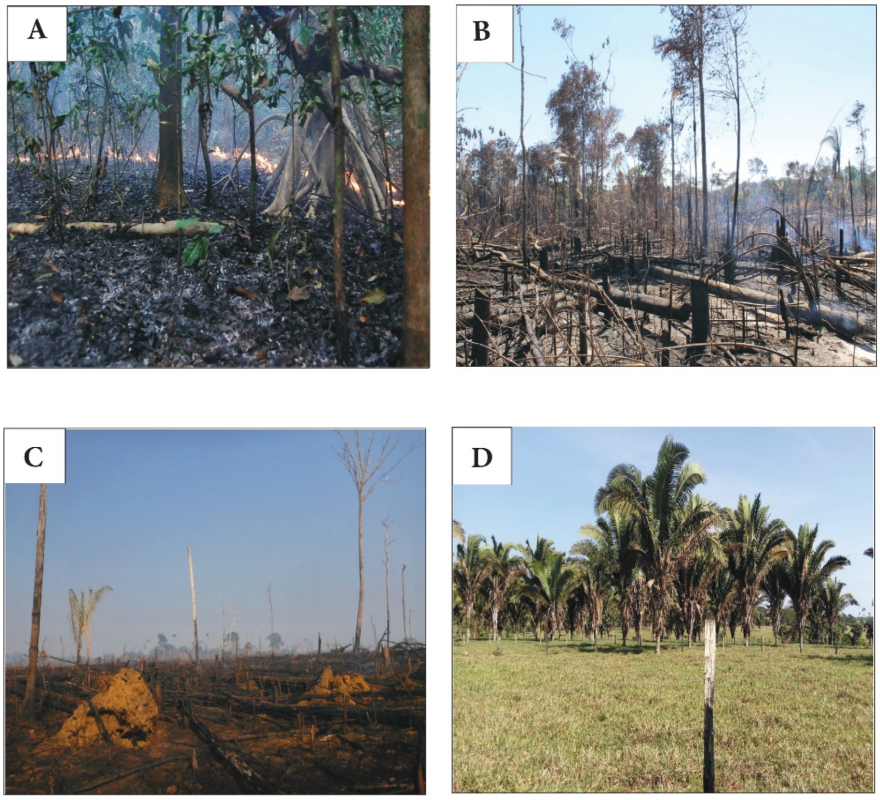
[117] Mesquita, *id*.

[118] Esquivel-Muelbert, *supra* note 106.

[119] B. Feigl, *et al.* (2006) *Biological Survey of a Low-Productivity Pasture in Rondônia State, Brazil*, OUTLOOK AGRIC. 35(3); G. P. Rocha, D. L. Vieira, & M. F. Simon (2016) *Fast natural regeneration in abandoned pastures in southern Amazonia*, FOR. ECOL. MANAGE. 370.

[120] Mesquita, *supra* note 116; Esquivel-Muelbert, *supra* note 106.

Figure 1. Changes in the Composition of Species in the Southern Amazon



A: In the initial fire, the fire slowly advances along the ground, forming a fire line (photo by Erika Berenguer). B, C, and D (Babaçu Palms): As forest fires repeat, the forest's structure undergoes more profound transformations, with better-adapted species gradually assuming dominance (photo by Diego Oliveira Brandão).

The Amazon's response to the synergistic interactions between global climate change and land use changes is closely tied to its distinct environmental and societal dynamics. The increasing temperatures, coupled with reduced rainfall due to deforestation, present multifaceted challenges. Agriculture in the region could experience decreased crop yields and potential harm to livestock. Furthermore, this altered climate may impact the Amazon's capacity to store carbon within its remaining forests, influencing the global carbon cycle.

5. Nature-Based Solutions

A. Protect and Restore Forests While Promoting a New Sociobioeconomy of Healthy Standing Forests and Flowing Rivers

Nature-based solutions in the Amazon are vital for addressing a myriad of interconnected challenges. The combination of large-scale deforestation in the Amazon and global warming is predicted to lead to unsustainable levels of heat stress for millions of people in the region by the end of the 21st century, along with increased aridity, reduced soil moisture, and a substantial increase in the number of hot days throughout the century.[121] To steer away from such a dystopian future, it is essential to adopt nature-based solutions in South America which prioritize protecting native vegetation through measures like protected areas and payment for ecosystem services (PES), while stimulating a new sociobioeconomy model for the region that combines human activities that maintain productive and conserved multifunctional landscapes and cultural diversity, while promoting economic and social added value to the Amazon's biodiversity and agrobiodiversity.[122]

Protected areas within the Amazon basin, including various conservation units encompassing both full protection and sustainable use, cover a quarter of the region. When Indigenous Territories are included, they collectively represent more than half of the Amazon (52%).[123] These areas have been established due to historical conservation policies and the recognition of Indigenous Peoples' rights in the Amazon. These protected areas and Indigenous Territories play a pivotal role in preserving the region's rich biodiversity and ecosystems. They act as strongholds against deforestation and forest degradation, thereby preventing the release of massive amounts of carbon into the atmosphere (25.5 Gt of carbon retained in forest biomass).[124] This is crucial for global climate mitigation efforts.[125] Additionally, Indigenous Territories act as barriers protecting Amazonian forests from the encroachment of agriculture and other land-use changes. Recognizing the intricate and symbiotic relationship between Indigenous, traditional, and extractive communities and the natural environment is essential in decision-making processes. This understanding should form an integral part of efforts to reduce conflicts, promote equity, and enhance wellbeing by safeguarding the territorial rights of Indigenous Peoples and Local Communities.[126]

[121] Marengo, *supra* note 37.

[122] R. Garrett, *et al.* (2023) *Supporting Sociobioeconomies of healthy standing forests and flowing rivers in the Amazon*, Science Panel for the Amazon, Policy Brief.

[123] C. Josse, *et al*. (2021) *Chapter 16: The state of conservation policies, protected areas, and Indigenous territories, from the past to the present*, *in* AAR 2021.

[124] Walker, *supra* note 74.

[125] P. Moutinho, *et al.* (2022) *The role of Amazonian Indigenous Peoples in fighting the climate crisis*, Policy Brief, Science Panel for the Amazon.

[126] H. T. Barretto Filho, *et al.* (2021) *Chapter 31: Strengthening land and natural resource governance and management: Protected areas, Indigenous lands, and local communities' territories*, *in* AAR 2021.

Preventing further deforestation in the Amazon is a top priority to prevent unfavorable climate conditions and a potential social collapse, particularly affecting vulnerable populations. However, given the ongoing land use and climate changes, merely halting deforestation is insufficient. There is an urgent need to promote extensive restoration in deforested and degraded areas and protect secondary forests.[127] The Amazon offers significant restoration potential under deforested areas and degraded lands to support the creation of an Arc of Restoration. It is estimated that 50 million hectares are available for forest restoration in the Amazon. Protected areas alone provide over 0.8 million hectares for natural regeneration, while undesignated lands, particularly those cleared since 2015, could offer more than 1.8 million hectares. 45% of deforestation between 2008 and 2021 primarily occurred on private lands in the Brazilian Amazon. Reforestation on approximately 6 million hectares of private lands would be required to meet compliance with the Brazilian Forest Code.[128] Moreover, restoring degraded farmland across the Brazilian Amazon could apply to an extensive area exceeding 24 million hectares. These restoration opportunities extend to other Amazonian countries as well.[129]

These restoration efforts would demand approximately twenty billion dollars to be achieved. PES through forest protection initiatives have been shown to be a promising approach to mitigate climate change, conserve forest ecosystems, and increase the portfolio of economic alternatives. Indigenous lands allow nations to focus these resources where significant emission reductions are most likely to be observed by carefully assessing the impact and counterfactuals of Indigenous Lands (TIs),[130] strengthening the adaptation and resilience of social-ecological systems, and reduce the vulnerability of Indigenous communities to climate change.[131] However, the perception of failure to mitigate carbon emissions and support people's livelihoods act as a barrier in investors' perception and should be overcome. Schemes

[127] Smith, *supra* note 114.

[128] G. Camara, *et al*. (2023) *Impact of land tenure on deforestation control and forest restoration in Brazilian Amazonia*, ENVIRON. RES. LETT. 18(6).

[129] J. Barlow, *et al*. (2022) *Transforming the Amazon through 'Arcs of Restoration'*, Policy Brief, Science Panel for the Amazon.

[130] B. Garcia, L. Rimmer, L. C. Vieira, & B. Mackey (2021) *REDD+ and forest protection on indigenous lands in the Amazon*, REV. EUR. COMP. INT. ENVIRON. LAW 30(2).

[131] *Supra* note 35; K. Baragwanath, E. Bayi, & N. Shinde (2023) *Collective property rights lead to secondary forest growth in the Brazilian Amazon*, PROC. NAT'L. ACAD. SCI. 120(22).

which focus on multiple ecosystem service at the same time that consider both cash and in-kind contributions may reduce the probability of failure in PES projects.[132]

Moreover, the Amazon needs a complete paradigm shift, which replaces the current predatory model of development with a new sociobioeconomy model based on intact forests and unpolluted rivers.[133] This visionary approach hinges on core principles: the appreciation of preserved forests, free-flowing rivers, and the pivotal role of Amazonian communities in protecting these ecosystems while envisioning a new regional socio-economic model. The Amazonian bioeconomy aims to cultivate an economy harmonized with the unique context of the Amazon. It relies on sustainable supply networks for biodiversity products that integrate ethical-normative values into the interaction between humans and nature. A green Amazonian economy not only offers economic growth opportunities but also seeks to alleviate poverty, reduce social inequalities, and enhance resilience against extreme climatic events. This transformative model has the potential to generate over 2 million jobs throughout Brazil by 2030, with a strong emphasis on family-based agroforestry systems.[134] A new Socio-Bioeconomy of Healthy Standing Forests and Flowing Rivers can be more profitable than business as usual economies that drive deforestation. Standing forests and agroforestry systems can be at least four to six times (400– 600 US$) more lucrative than cattle grazing (ca. 100 US$).[135]

However, overcoming the persistent economic and social challenges in the Amazon that have perpetuated the divide between economic and social development requires substantial investments. These investments should focus on science, education, the establishment of technological centers of excellence in the Amazon, and the development of sustainable and socially inclusive infrastructure. Additionally, industrial policies should encourage innovative business initiatives that depart from current forest and river exploitation practices and instead

[132] N. Grima, S. J. Singh, B. Smetschka, & L. Ringhofer (2016) *Payment for Ecosystem Services (PES) in Latin America: Analysing the performance of 40 case studies*, ECOSYST. SERV. 17.

[133] Garrett, *supra* note 122.

[134] V. Romeiro, *et al*. (2020) A NEW ECONOMY FOR A NEW ERA: *ELEMENTS FOR BUILDING A MORE EFFICIENT AND RESILIENT ECONOMY IN BRAZIL*, São Paulo, Brasil: WRI Brasil; Costa, *supra* note 25.

[135] C. M. Peters, A. H. Gentry, & R. O. Mendelsohn (1989) *Valuation of an Amazonian rainforest*, NATURE 339(6227); F. A. Barbosa, *et al.* (2015) *Cenários para a pecuária de corte amazônica*, IGC & UFMG (ed.); WWF Brasil (2020) AVALIAÇÃO FINANCEIRA DA RESTAURAÇÃO FLORESTAL COM AGROFLORESTAS NA AMAZÔNIA; P. Gasparinetti, *et al.* (2022) *Economic Feasibility of Tropical Forest Restoration Models Based on Non-Timber Forest Products in Brazil, Cambodia, Indonesia, and Peru*, FORESTS 13(11).

create value-added production chains based on Amazonian Forest products.[136] Technological advancements, such as traceability, the development of environmentally friendly products, and strengthened legal protections for knowledge and patents, offer promising avenues for transforming production methods in the Amazon. However, the active engagement of diverse stakeholders, including government bodies, local institutions, and, critically, local communities, is essential for the success of this transformation. Sustainable and inclusive economic alternatives that align with the conservation of Amazonian ecosystems can reinforce local governance and empower Amazonian communities, counteracting decades of degrading economic activities in the region.[137]

To achieve this goal, it is also crucial to implement public policies, management systems, and practices that encourage emissions-free methane and carbon livestock farming in the Amazon. This approach should be grounded in eliminating deforestation and forest degradation while promoting the restoration of multifunctional forests. These forests can enhance biodiversity, and contribute to carbon capture, soil protection, and environmental cooling, all while ensuring a sustainable source of income and improving the quality of life for local communities. This approach will aid both in climate change mitigation and adaptation to ongoing changes.

Enhancing adaptation amidst climate change necessitates overcoming barriers like limited farmer education, site-specific knowledge, and financial constraints. While nature-based and hybrid infrastructure solutions show promise, more progress is needed. Indigenous and local knowledge are vital for bolstering resilience and reducing vulnerability.[138] Government policies and actions that could potentially contribute to deforestation are intricately tied to the amplification of their root causes. These fundamental causes encompass unresolved land tenure issues, illegal land allocations, pardons for illegal deforestation activities, exemptions from reforestation obligations for deforested areas, the declassification of protected regions, the weakening of regulatory bodies, approval of major infrastructure projects in the Amazon without adequate impact mitigation strategies, reduced funding for environmental agencies, and the erosion of programs and strategies dedicated to curbing deforestation.

[136] I. Nobre & C. Nobre (2020) *'Amazon 4.0' project: Defining a third way for the Amazon*, FUTURIBLES 434(1); R. Abramovay, *et al*. (2021) *Chapter 30: Opportunities and challenges for a healthy standing forest and flowing rivers bioeconomy in the Amazon*, *in* AAR 2021.

[137] *Id.*

[138] *Supra* note 36.

B. Maximizing Agroforesty through Bioindustrialization

Agroforestry systems using native species have the potential to drive a new economic cycle in the Amazon. To achieve this, investments in technologies for processing raw products into industrialized items will be necessary. These investments are crucial for adding value to products from Amazonian ecosystems, including those derived from forest and river restoration efforts.[139] In fact, the selling price of raw products can increase from 2 to 5 times when basic industrial infrastructure is available, such as dehydration, pulping, pressing, refrigeration, and pasteurization equipment.[140]

RECA and CAMTA—agroforestry cooperatives in the Brazilian Amazon-- are examples of how social organization and technology aligned with conservation can increase income in the Amazon.[141] RECA was founded in 1987 and currently involves more than 300 farming families supplying over two thousand tons of non-timber forest products annually. CAMTA began industrializing products from agroforestry systems in 1987 and currently employs 170 direct workers and engages 1800 farming families. RECA and CAMTA primarily produce fruit pulp, dried seeds, and vegetable oils, and due to the use of industrial technologies, the majority of agroforestry farmers have reached the middle-class status.

However, there is a significant lack of technologies with the potential to add value to primary products from agroforestry systems in the Amazon. Studies that mapped processing facilities for five widely used non-timber forest products in the Amazonian economy identified only 55 municipalities with the infrastructure capable of transforming primary products into industrialized products with some level of added value. This was observed when 532 municipalities were evaluated, indicating that 90% of Brazilian Amazon municipalities completely lack basic technological infrastructure to add value to regional products.[142]

[139] I. Nobre & C. A. Nobre (2018) *The Amazonia third way initiative: the role of technology to unveil the potential of a novel tropical biodiversity-based economy*, *in* LAND USE: ASSESSING THE PAST, ENVISIONING THE FUTURE, L. C. Loures, IntechOpen.

[140] D. O. Brandão (2023) *Desmatamento na Amazônia e influência nos produtos florestais não-madeireiros de uso econômico local*, São José dos Campos: Instituto Nacional de Pesquisas Espaciais.

[141] Associação dos Pequenos Agrossilvicultores do Projeto Reca e Cooperativa Agropecuária e Florestal do Projeto RECA, *Quem Somos* [accessed 24 August 2023]; Cooperativa Agrícola Mista de Tomé-Açu, *Conheça nossa história* [accessed 24 August 2023].

[142] D. O. Brandão, L. E. S. Barata, I. Nobre, & C. A. Nobre (2021) *The effects of Amazon deforestation on non-timber forest products*, REG. ENVIRON. CHANGE 21.

There is still limited knowledge regarding the implementation costs of processing facilities for Amazonian products. An example of a company with more modest technology was established at a cost of USD 100,000.[143] This factory was equipped with machinery for de-pulping, drying, grinding, distilling, and filtering oils and fats from native species, structured to absorb agroforestry production from 300 families living in nearby communities. It is estimated that the factory can generate an annual revenue of USD 200,000 when operating at full production capacity.[144] When further investments in technology are made, results become more promising, as seen with CAMTA, which has become a significant exporter of tropical fruits to countries such as Japan, Israel, the United States, and French Guiana. The CAMTA example has been disseminated in countries like Brazil, Bolivia, and Ghana.[145]

The feasibility study conducted by the Amazonia 4.0[146] project reveals that the potential for value addition through industrialization can be even more significant. For instance, cocoa production is traded for approximately USD 2 per kilogram of seeds, while fine chocolate can reach values between USD 20 and 40 per kilogram. The proportion of cocoa in chocolate varies from a minimum of 25% of total solids to 70% for darker chocolate.[147] This implies that the added value of the seed in the production of fine cocoa chocolate can be more than 10 times higher compared to the simple sale of seeds.

C. How to Induce Low Carbon Livestock Farming

The over 20 million hectares of degraded pastures in the Amazon are the result of an extensive and low-tech cattle farming model. This pattern began to establish itself in the 1970s, often driven by policies that encouraged the occupation of low-cost and low-infrastructure lands. However, common mistakes in the establishment and management of these pastures have contributed to their early degradation, including the inappropriate choice of forage species for

[143] IDESAM (2020) *Miniusina de óleos vegetais: mais geração de renda aos comunitários da RDS do Uatumã*.

[144] *Id.*

[145] OCB Pará (22 May 2022) *CAMTA reinaugura parque fabril*.

[146] Amazonia 4.0, *Laboratórios Criativos da Amazônia*.

[147] Ministério da Saúde, Agência Nacional de Vigilância Sanitária (2005) RESOLUÇÃO-RDC No 264.

the region.[148] This livestock management model has had a significant impact on greenhouse gas emissions, making the Brazilian Amazon one of the world's major emitting regions.

The expansion in the number of cattle heads present in 532 municipalities within the boundaries of the Brazilian Amazon is significant (Figure 2). The quantity increased by 630% over the period between 1985 and 2022 (Table 1). This represented an absolute increase of 72 million cattle heads, rising from 11 million in 1985 to 83 million in 2022. The states of Mato Grosso, Pará, and Rondônia account for 67 million cattle heads. Table 1 presents the details of the absolute and percentage variation by states during the period from 1985 to 2022. Figure 3 provides an overview of common situations found in pasture areas in Amazonas, which are also prevalent in other regions of the Brazilian Amazon.

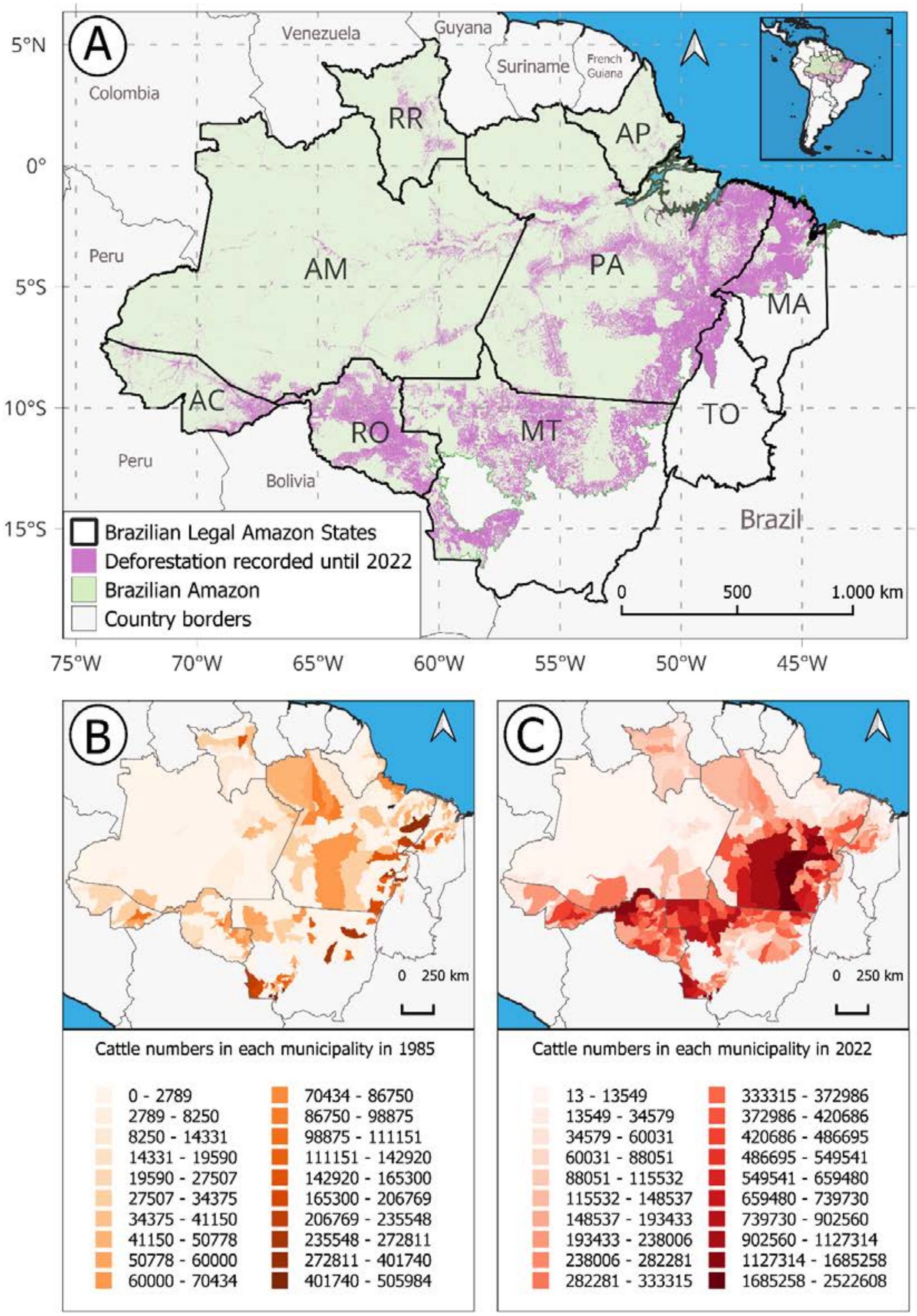
Table 1. Cattle Heads Evolution in Brazilian Amazon from 1985 to 2022

Brazilian Amazon States	Municipality (County)	Total Cattle Heads in 1985	Total Cattle Heads in 2022	Percentual Growth	Absolute Growth
Acre (AC)	22	349,150	4,635,381	1228%	4,286,231
Amazonas (AM)	62	427,504	1,558,283	265%	1,130,779
Amapá (AP)	16	48,370	53,691	11%	5,321
Maranhão (MA)	98	1,733,584	4,917,840	184%	3,184,256
Mato Grosso (MT)	88	3,233,981	24,928,632	671%	21,694,651
Pará (PA)	143	3,378,894	24,771,459	633%	21,392,565
Rondônia (RO)	52	764,299	17,688,225	2214%	16,923,926
Roraima (RR)	15	305,155	1,133,502	271%	828,347
Tocantins (TO)	36	1,152.,700	3,430,984	198%	2,278,284
Total	532	11,393,637	83,117,997	630%	71,724,360

Source: IBGE (2022)

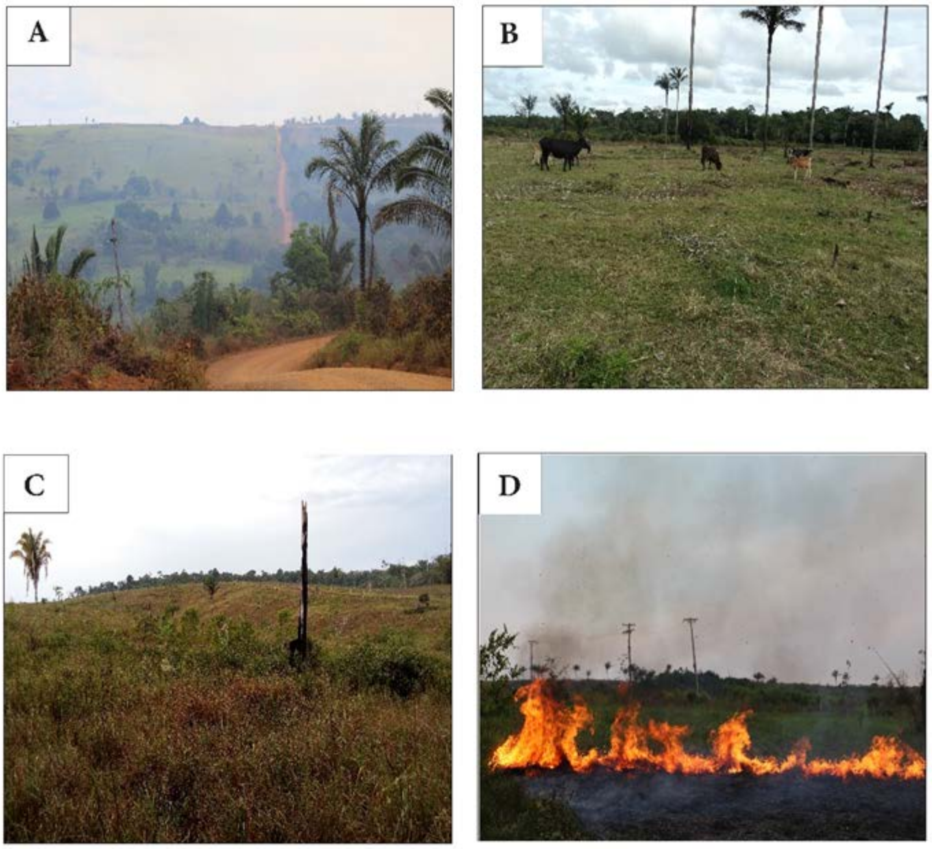
[148] M. B. Dias-Filho (2015) *Estratégias para recuperação de pastagens degradadas na Amazônia brasileira*, Embrapa Agropecuária Oeste.

Figure 2. Brazilian Amazon Deforestation and Cattle Numbers



A. Brazilian Amazon deforestation recorded until 2022. B. Cattle numbers in each municipality in 1985. C. Cattle numbers in each municipality in 2022. Source data: A, INPE (2023); B and C, IBGE (2022).

Figure 3. Impacts in the Amazon



A. Pasture overview. B. Overgrazing, where the quantity of cattle exceeds the carrying capacity of the pasture. C. Undergrazing, characterized by the presence of cattle below the carrying capacity of the pasture. D. Uncontrolled fire, often observed in degraded pastures. Photographs by Diego Oliveira Brandão.

The analysis of methane emissions must consider an energy perspective. It is widely recognized that the increase in energy consumption by animals is directly related to the rising demand for food, which in turn contributes to methane emissions. Studies indicate that a significant portion, ranging from 2–12%, of the gross energy consumed by ruminant animals is dissipated in the form of methane.[149] This loss is related to various factors, including the genetic characteristics of the animals, the quantity and quality of food in the diet, and the digestibility of the food.[150]

[149] L. A. Z. Machado, E. B. Correa, & F. M. Vargas Junior (2011) *Integração lavoura-pecuária-floresta. 3. Escolha dos animais e formação de lotes*, Embrapa Agropecuária Oeste.

[150] G. A. Sene, *et al*. (2019) *Práticas estratégicas com vistas à mitigação dos gases do efeito estufa na produção de bovinos a pasto*, *in* NOVOS DESAFIOS DA PESQUISA EM NUTRIÇÃO E PRODUÇÃO ANIMAL, Pirassununga: 5D Editora.

To address the challenge of achieving net-zero emissions in livestock farming, various strategies and practices are being explored on how to induce net-zero livestock farming. However, there are challenges in achieving this goal, considering Brazil's commitments under the Paris Agreement on Climate Change. In addition to pasture management and the energy consumption of animals, emissions also depend on specific characteristics such as gender, age, and the location of the herd. Therefore, to mitigate livestock emissions, a comprehensive approach is required, involving the adoption of innovative technologies and management practices.[151]

In this section, various approaches will be explored on how to induce net-zero livestock farming. These approaches include the development of more productive and climate-resilient animals, early slaughter, livestock intensification, and the presence of native trees in pastures. It will be demonstrated how the implementation of these practices not only aims to reduce greenhouse gas emissions but also leads to significant increases in meat and milk productivity, contributing to a positive shift in direct land uses.

Breeds undergoing genetic improvement are focused on achieving faster weight gain and better adaptation to thermal stresses.[152] The Senepol breed (**Figure 4**) was introduced in Brazil in the year 2000 and is currently recognized for its highest genetic potential in enhancing the profitability of meat production in the Amazon region. This translates to producing more meat in less space and time.[153] However, genetic improvement in the context of Amazonian livestock farming has received limited attention. Some possibilities have pointed to weight gains ranging from 1 kg/day to 1.5 kg/day, allowing for slaughter between 18 and 24 months, after reaching a weight of 300 kg of carcass or more. This signifies a reduction of at least 12 months in the current average slaughter time and up to a 2.9-fold increase in productivity, with more animals per hectare.[154]

[151] M. Liu, *et al*. (2021) *A New Divergence Method to Quantify Methane Emissions Using Observations of Sentinel-5P TROPOMI*, GEOPHYS. RES. LETT. 48(18); E. D. Assad, *et al*. (2021) POTENCIAL DE MITIGAÇÃO DE GASES DE EFEITO ESTUFA DAS AÇÕES DE DESCARBONIZAÇÃO DA PECUÁRIA ATÉ 2030, Observatório de Bioeconomia, Escola de Economia de São Paulo, & Fundação Getúlio Vargas.

[152] L. Flori, *et al*. (2012) *A quasi-exclusive European ancestry in the Senepol tropical cattle breed highlights the importance of the slick locus in tropical adaptation*, PLOS ONE 7(5).

[153] G. R. O. Menezes, *et al*. (2015) DIVERSIDADE GENÉTICA DA RAÇA SENEPOL NO BRASIL POR MEIO DE ANÁLISE DE PEDIGREE, Embrapa Gado de Corte.

[154] Flori, *supra* note 152.

Figure 4. Livestock Race Senepol

Source: Embrapa Gado de Corte, by João Costa Jr. Date: 24 July 2015.

Early slaughter is a solution capable of reducing methane emissions from enteric fermentation and waste emissions by 33%. Typically, the lifespan of cattle is 36 months, resulting in emissions of 6,700 kgCO_2e per animal. By adopting already available pasture improvement technologies, cattle can reach the slaughter age at 24 months, reducing their lifespan by 12 months and emissions by 2,220 kgCO_2e per animal. Considering that the Brazilian Institute of Geography and Statistics (IBGE) recorded 83 million cattle in 532 municipalities located in the Brazilian Amazon, the potential reduction in kgCO_2e per animal is estimated at 185 billion kgCO_2e for the entire cattle herd.

The presence of trees in pastures enhances the system's resilience to droughts, extreme heat, and wildfires, making it more adaptable to climate change.[155] Technological benefits include increased organic matter, reduced disease and weed pressure, improved animal welfare due to shade, and enhanced nutrient cycling (Figure 5). Native trees such as Inga edulis Mart., Hymenaea courbaril L., and Dipteryx odorata (Aubl) Willd also provide protein-rich food for the animals.[156] Livestock production can increase by up to 30% without resorting to deforestation when

[155] Assad, *supra* note 151.

[156] G. C. Carrero (2016) *Sistemas silvipastoris com pastejo rotacional: alternativas sustentáveis para a produção pecuária na Amazônia*, Gestão e Governança Local para a Amazônia Sustentável, PQGA/IBAM.

native trees are incorporated into pastures. However, implementing tree-integrated pastures presents challenges for farmers who are more accustomed to conventional grazing practices.

Figure 5. Crop-livestock integration system, Don Aro farm, Machadinho D'Oeste, Brazil

Source: redeilpf.org.br. Date of access: 28 September 2023.

6. Concluding Remarks

The Amazon Forest, the world's largest and most biodiverse tropical forest, plays a vital role in providing essential ecosystem services and adding global climate regulation. However, it has suffered an alarming loss of more than 100 million hectares (14.5%) in the last five decades due to an economic model that incentivizes low-profit pasture expansion, fostering illegal activities like timber harvesting, land grabbing, and gold mining. The proliferation of cattle farming has resulted in pasture degradation, elevated CO_2, and methane emissions. Land use and climate changes are pushing the Amazon toward a critical tipping point, endangering its regional and climate-regulating functions. Warming temperatures, frequent severe droughts, prolonged dry seasons, and species loss further exacerbate these challenges. These interconnected factors increase the risk of the Amazon transitioning into degraded vegetation states with limited regrowth potential, posing severe threats to food security and the wellbeing of forest-dependent communities. Prolonged droughts, heightened flood risks, and increased epidemic occurrences jeopardize millions of lives. The consequences encompass reduced agricultural productivity, escalated epidemic risks, substantial carbon emissions, compromising social-ecological system resilience, and heightened vulnerability among Indigenous Peoples and Local Communities to climate and land use changes impacts. Consequently, safeguarding the Amazon Forest assumes paramount importance in our collective endeavors to address the climate and biodiversity crises, both of which entail substantial social and ecological consequences. These dual crises undermine nature's invaluable contributions to human wellbeing, livelihoods, economies, and sustainable development prospects. To address these challenges, a paradigm shift is imperative, replacing the current predatory development model with a new socio-bioeconomic approach grounded in the preservation and restoration of forests and the value of Indigenous Peoples and local community knowledge. While numerous obstacles exist, the Amazon also offers inspiring examples that demonstrate the feasibility of a more environmentally sustainable and socially equitable future.

Toward an Amazon Green Deal: *The Urgent Need for an Innovative Sociobioeconomy and Regenerative Livestock Farming to Prevent the Amazon Tipping Point*

Eduardo Assad, Julia Arieira, Diego Oliveira Brandão, and Carlos A. Nobre[1]

Highlights

✓ Deforestation and forest degradation are historically associated with the expansion of pasture areas and the growing number of cattle in the Legal Amazon in the last five decades, making agricultural activity in a broad sense, along with real estate speculation and timber smuggling, the most responsible for all Brazilian climate pollution.

✓ Reducing greenhouse gas emissions from deforestation, degradation, fires, and livestock production in the Legal Amazon is critical for keeping the temperature below *tipping points* and the ecosystem services that depend on the standing forest, such as rain recycling, environmental cooling, and food provision.

✓ The Legal Amazon is home to 43% of Brazil's cattle herd, highlighting its national relevance in livestock production. Among the 808 municipalities in the Legal Amazon, 537 face serious problems of pasture degradation, resulting in high CO_2 and methane emissions, as well as low stocking capacity.

✓ About 55% of total methane emissions in the Brazilian agricultural sector originate in the Legal Amazon due to enteric fermentation and waste management.

✓ Solving these challenges depends in large part on political and business actions, including national and international commitments to eliminate deforestation, restrict meat exports

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associated with deforestation, and promote public policies that encourage sustainable production models.

✓ Actions that encourage the adoption of regenerative, low-emission, high-carbon removal agricultural practices, especially at the national level and in the Amazon, have the potential to drastically reduce net emissions from livestock, even neutralizing them, through the growth of regenerative livestock farming and the increase of Agroforestry Systems.

✓ Studies indicate that the recovery of degraded pastures and the intensification of cattle ranching can reduce the time it takes to slaughter animals to 24 months, reducing methane emissions by about 33% in the Legal Amazon.

✓ The implementation of integrated systems, such as Integrated Crop-Livestock-Forest, emerges as an essential mechanism to increase agricultural and livestock production in the region, allowing doubling grain production and increasing livestock production by 30%, without resorting to deforestation.

✓ Agroforestry Systems are highly recommended in the Amazon region, promoting the production of fruits and native woods, as well as the intercropping of grains with livestock, making agricultural systems more resilient to climate change.

✓ It is imperative that Brazil establishes a Green Deal for the Amazon, with an urgent commitment to adopt an innovative socio-economic approach, centered on preserving forests and promoting regenerative and carbon-neutral livestock farming. This can be achieved through initiatives that encourage regional development, through education for technological innovation and adding value to forest products, strengthening local entrepreneurship for the benefit of indigenous and local communities.

1. Introduction

The Amazon rainforest covers 40% of South America and is the largest and most biodiverse rainforest biome on the planet (ca. 13% of global biodiversity).[2] Its high biodiversity plays a critical role in maintaining the resilience of Amazonian ecosystems, providing resistance to

[2] G. Zapata-Ríos, *et al.* (2021) *Chapter 3: Biological diversity and ecological networks in the Amazon*, *in* AMAZON ASSESSMENT REPORT 2021 [“AAR 2021”], C. Nobre, *et al.* (eds.); R. Mittermeier & A. B. Rylands, personal communication.

natural or human-induced disturbances, while maintaining their basic functions.[3] Amazon forests store between 150 and 200 billion tons of carbon above and below ground and sequester 1.2 billion tons of carbon dioxide per year.[4] In addition, they recycle rainfall by throwing in the order of 1,220 mm. year^{-1} ± 15% of water vapor into the atmosphere through evapotranspiration from the forest. This ecosystem service is important because it cools the Earth's surface (*cooling effect*) and contributes to the transport of moisture to other regions outside the Amazon Basin, such as the Andes and La Plata Basin.[5] As the largest tropical terrestrial carbon sink on the planet, the more than 5 million km^2 of Amazon rainforest is a crucial part of global efforts to keep global warming below 2.0°C.[6]

Figure 1. Boundaries of the Amazon biome in Brazil (green) and the geopolitical boundary of the Legal Amazon formed by nine Brazilian states

Data source: INPE (2023) Banco de Dados de queimadas.

[3] L. S. Borma, *et al*. (2022) *Beyond Carbon: The Contributions of South American Tropical Humid and Subhumid Forests to Ecosystem Services*, REV. GEOPHYS. 60(4).

[4] Y. Malhi, *et al*. (2021) *Chapter 6: Biogeochemical cycles of the Amazon*, *in* AAR 2021.

[5] M. H. Costa, *et al*. (2021) *Chapter 7: Biogeophysical Cycles: Water Recycling, Climate Regulation*, *in* AAR 2021.

[6] Intergovernmental Panel on Climate Change (2021) CLIMATE CHANGE 2021: THE PHYSICAL SCIENCE BASIS, V. Masson-Delmotte, *et al.* (eds.).

Most of the Amazon biome is found on Brazilian lands, covering an area of 4.1 M km^2 (**Figure 1**). This corresponds to just over 60% of the entire biome, attributing to Brazil a great responsibility in the management of this territory. With a focus on territorial management, the Brazilian State delimited a political and socio-geographical division called the Brazilian Legal Amazon. This region corresponds to 59% of the Brazilian territory, consisting of nine states: Acre, Amazonas, Amapá, Maranhão (just West of the 44° Meridian), Mato Grosso, Pará, Rondônia, Roraima, and Tocantins. This region has a human population of around 29 million people, 80% of which is urban and encompasses the Indigenous Peoples of the Amazon (ca. 300,000 Indigenous people).[7] The 5 M km^2 of Legal Amazon is covered not only by the Amazon biome, but also by the Cerrado, a tropical savanna biome that differs substantially in vegetation structure, biodiversity, soil attributes, and climatic conditions.[8]

The occupation of the Amazon through the expansion of farmlands and an infrastructure to support commodity economies (e.g., roads, urbanization) has been the focus of Brazilian policies since the 1960s.[9] These policies caused pressures for land use that resulted in the loss of more than one hundred million hectares over the last 50 years (15.5%).[10]

It is estimated that more than 60% of all deforested land in the region has been converted to pasture[11] and that 60% of pasture lands in the biome are in a greater or lesser state of soil degradation.[12] The expansion of cattle ranching over the natural forests of the Amazon is associated with multiple forms of clandestine and illegal economies, such as timber, land grabbing, and gold mining.[13] 32% of undesignated public lands in the Brazilian Amazon (18.6 million hectares) were deforested by the end of 2020 and self-declared as private properties

[7] J. Albert, *et al*. (2021) *The multiple viewpoints for the Amazon: geographic limits and meanings*, The Amazon We Want.

[8] G. Durigan & J. A. Ratter (2016) *The need for a consistent fire policy for Cerrado conservation*, J. APPL. ECOL. 53(1); Borma, *supra* note 3.

[9] S. Hecht, *et al.* (2021) *Chapter 14: Amazon in Motion: Changing politics, development strategies, peoples, landscapes, and livelihoods*, *in* AAR 2021; E. Berenguer, *et al*. (2021) *Tracking the impacts of El Niño drought and fire in human-modified Amazonian forests*, PROC. NAT'L. ACAD. SCI. 118(30).

[10] Instituto Nacional De Pesquisas Espaciais (2023) *Coordenação Geral De Observação Da Terra*, Programa De Monitoramento Da Amazônia e Demais Biomas, Desmatamento: Amazônia Legal; *Mapbiomas*.

[11] INPE & EMBRAPA (2018) TerraClass, Mapeamento do uso e da Cobertura da terra na Amazônia Legal.

[12] M. Dick, *et al.* (2021) *Environmental impacts of Brazilian beef cattle production in the Amazon, Cerrado, Pampa, and Pantanal biomes*, J. CLEAN. PROD. 311(127750).

[13] Hecht, *supra* note 9.

in the national registry, indicating the process of land grabbing as a major driver of deforestation in the Brazilian Amazon.[14] In 2020, of the 58,878 deforestation alerts by satellite monitoring and 838,189 ha of deforested area in the legal Amazon, 99.88% and 99.43%, respectively, showed signs of irregularity or illegality.[15] Such an economic model based on neo-extractivism, with minimal diversification of production and aimed at the commodity market, benefits a few and burdens millions, through environmental degradation, loss of biodiversity and forest services of climate regulation, which drive social inequality, poverty, threats to the right to land and good living of Indigenous Peoples and local communities.[16]

Brazil is the seventh largest emitter of greenhouse gases (GHG) in the world, attributed to emissions resulting from changes in land use (in particular deforestation) and livestock.[17] Livestock farming has been widely considered a major emitter of methane (CH_4) globally and a major driver of climate change.[18] On the other hand, the loss of the approximately 119 billion tons of carbon stored in the trees of the Amazon would be equivalent to 15 years of the current global anthropogenic emissions of GHG into the atmosphere.[19] The increase in GHG emissions and its consequent changes in climate could reduce the yield of agricultural crops produced in the Amazon, such as soybeans, by up to 44% by 2050.[20]

The concomitant pressures on the Amazon rainforest caused by climate change, deforestation, frequent fires, result in more forest loss by positive feedback mechanisms. Mathematical models estimate that up to 50% of its original area could be lost by 2050, especially in the Southern and Eastern regions of the forest, surpassing a tipping point for the

[14] C. Azevedo-Ramos, *et al.* (2020) *Lawless land in no man's land: The undesignated public forests in the Brazilian Amazon*, LAND USE POLICY 99.

[15] *Mapbiomas*.

[16] Hecht, *supra* note 9; B. S. Soares-Filho, *et al.* (2006) *Modelling conservation in the Amazon basin*, NATURE 440(7083).

[17] SEEG (2023) *Análise das Emissões de Emissões de Gases de Efeito Estufa e suas Implicações Para as Metas Climáticas do Brasil 1970-2021*, Observatório do Clima; Brasil Ministry of Science, Technology and Innovations (2021) FOURTH NATIONAL COMMUNICATION OF BRAZIL TO THE UNITED NATIONS FRAMEWORK CONVENTION ON CLIMATE CHANGE.

[18] M. Liu, *et al*. (2021) *A New Divergence Method to Quantify Methane Emissions Using Observations of Sentinel-5P TROPOMI*, GEOPHYS. RES. LETT. 48(18); Intergovernmental Panel on Climate Change (2022) CLIMATE CHANGE 2022: IMPACTS, ADAPTATION, AND VULNERABILITY, P. Arias, *et al*. (eds.).

[19] Soares-Filho, *supra* note 16.

[20] D. M. Lapola, *et al.* (2011) *Impacts of climate change and the end of deforestation on land use in the Brazilian Legal Amazon*, EARTH INTERACT. 15(16).

Amazon.[21] This tipping point represents a significant change in the functioning of the humid tropical forest ecosystems that dominate the region, leading to other vegetation states, similar to degraded vegetation and with affinities with tropical savanna climate.[22] The intensification of climate cycles, evidenced by the increase in the frequency, duration (4-5 weeks longer) and severity of droughts in the Amazon in the last two decades (e.g., 2005, 2010 and 2015-16, 2020), and the average warming of 1°C verified in the last 40 years in the Amazon[23] may represent an abrupt disturbance in carbon cycles,[24] being the first indications of how close we are from the Amazon tipping point.[25]

Reducing GHG emissions from deforestation and degradation is critical to keep forest carbon stocks and maintain temperature below tipping points. This will contribute to avoid irreversible changes in regional and global climate systems,[26] the impacts of which will rapidly spread across socioeconomic and ecological systems.[27] On the other hand, mitigation of livestock emissions should be implemented with innovative technologies and management practices.[28] There are major challenges to be faced by Brazil to achieve net-zero emissions in accordance with its self- determined commitments to the Paris Agreement on Climate Change. The time is ripe for these challenges with the current Brazilian government and the recent Amazon

[21] C. A. Nobre, *et al.* (2016) *Land-use and climate change risks in the Amazon and the need of a novel sustainable development paradigm*, PROC. NAT'L. ACAD. SCI. 113(39).

[22] *Id*; C. A. Nobre, P. J. Sellers, & J. Shukla (1991) *Amazonian Deforestation and Regional Climate Change*, J. CLIM. 4(10); M. Hirota, *et al.* (2021) *Chapter 24: Resilience of the Amazon Forest to Global Changes: Assessing the Risk of Tipping Points*, *in* AAR 2021.

[23] J. A. Marengo, *et al*. (2021) *Chapter 22: Long-term variability, extremes and changes in temperature and hydro meteorology in the Amazon region*, *in* AAR 2021; L. V. Gatti, *et al.* (2021) *Amazonia as a carbon source linked to deforestation and climate change*, NATURE 595.

[24] Malhi, *supra* note 4.

[25] T. E. Lovejoy & C. Nobre (2018) *Amazon's Tipping Point,* SCI. ADV. 4(2).

[26] T. M. Lenton, *et al*. (2008) *Tipping elements in the Earth's climate system*, PROC. NAT'L. ACAD. SCI. 105(6); Nobre, *supra* note 21.

[27] D. I. A. McKay, et al. (2022) *Exceeding 1.5°C global warming could trigger multiple climate tipping points*, SCIENCE 377(6611); O. Banerjee, et al. (2022) *Can we avert an Amazon tipping point? The economic and environmental costs*, ENVIRON. RES. LETT. 17(12).

[28] Liu, supra note 18; E. Assad, C. G. Estevam, C. Z. Lima, & T. P. Pinto (2021) *Potencial de mitigação de gases de efeito estufa das ações de descarbonização da pecuária até 2030*, Observatório de Bioeconomia, Escola de Economia de São Paulo, Fundação Getúlio Vargas.

Summit[29] of the eight Amazon countries with contribution of civil society, but this will require an Amazon Green Deal from all of society.

This paper presents historical data on the change in land use and agriculture in the Legal Amazon over 32 years and its consequent GHG emissions at the national and regional levels. An analysis of the impacts of cattle ranching in the Amazon on methane emissions is presented from the perspective of the increase in the number of cattle in the region from 1990 to 2021. This scenario of changes in the Amazon is used to propose some climate mitigation and adaptation measures, considering the need to keep the forest standing and reduce the vulnerability of local and Indigenous populations in the region.

2. Deforestation and Land Use Change in the Legal Amazon

A. Deforestation and Degradation in the Legal Amazon

In the Legal Amazon, 75.7% of the region is covered by ombrophilous and seasonal forests that occur in both the Amazon and Cerrado biomes. Non-forest formations occupy 4.2% of the territory and consist of open vegetation with a predominance of shrubs and herbaceous plants, typical of the savannas.[30] Agriculture occupies 17.6% of the region, 78% of which is pasture (68 million hectares (Mha)) and 18% agriculture. Agriculture in the region has a predominance of temporary crops (99%), mostly soybean (82%; 13 Mha).

The Amazon Forest lost 56 million hectares of its forests between 1985 to 2021, which roughly represent 13% of the world's loss.[31] Previously to 1985, Amazon had lost a large area of forests starting in 1970s. Presently, estimates indicates that more than one hundred million hectares have been deforested over the last 50 years (15.5%). Forest cover has reduced by about 12% in these 32 years. 11% of the forests were converted to pasture areas and 1% to soybean plantations (**Figure 2**).[32]

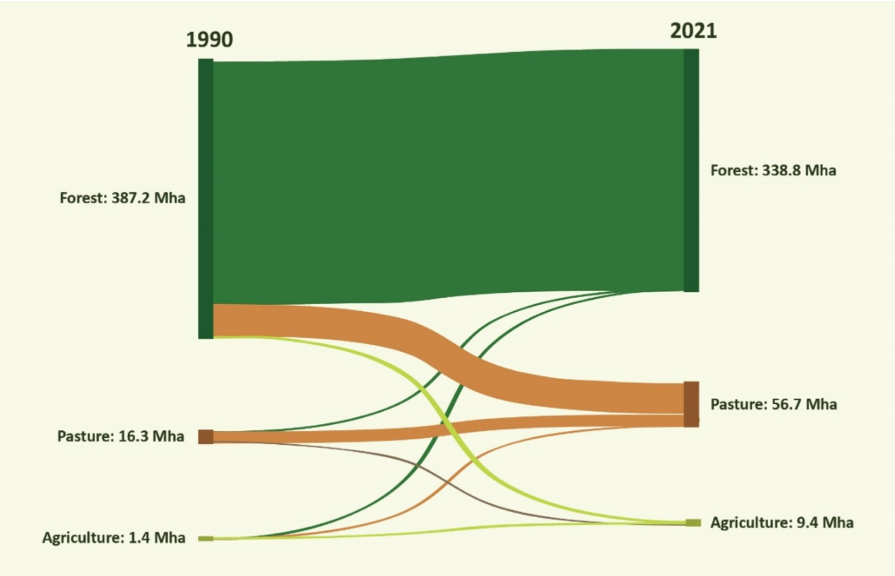
[29] Ministério das Relações Exteriores (8 August 2023) *Declaração Presidencial por ocasião da Cúpula da Amazônia – IV Reunião de Presidentes dos Estados Partes no Tratado de Cooperação Amazônica*, Nota à Imprensa No 331.

[30] *Supra* note 15.

[31] *Id*.

[32] *Id*.

Figure 2. Senchi diagram showing transitions between land covers between 1990 and 2021



Source: *Mapbiomas*.

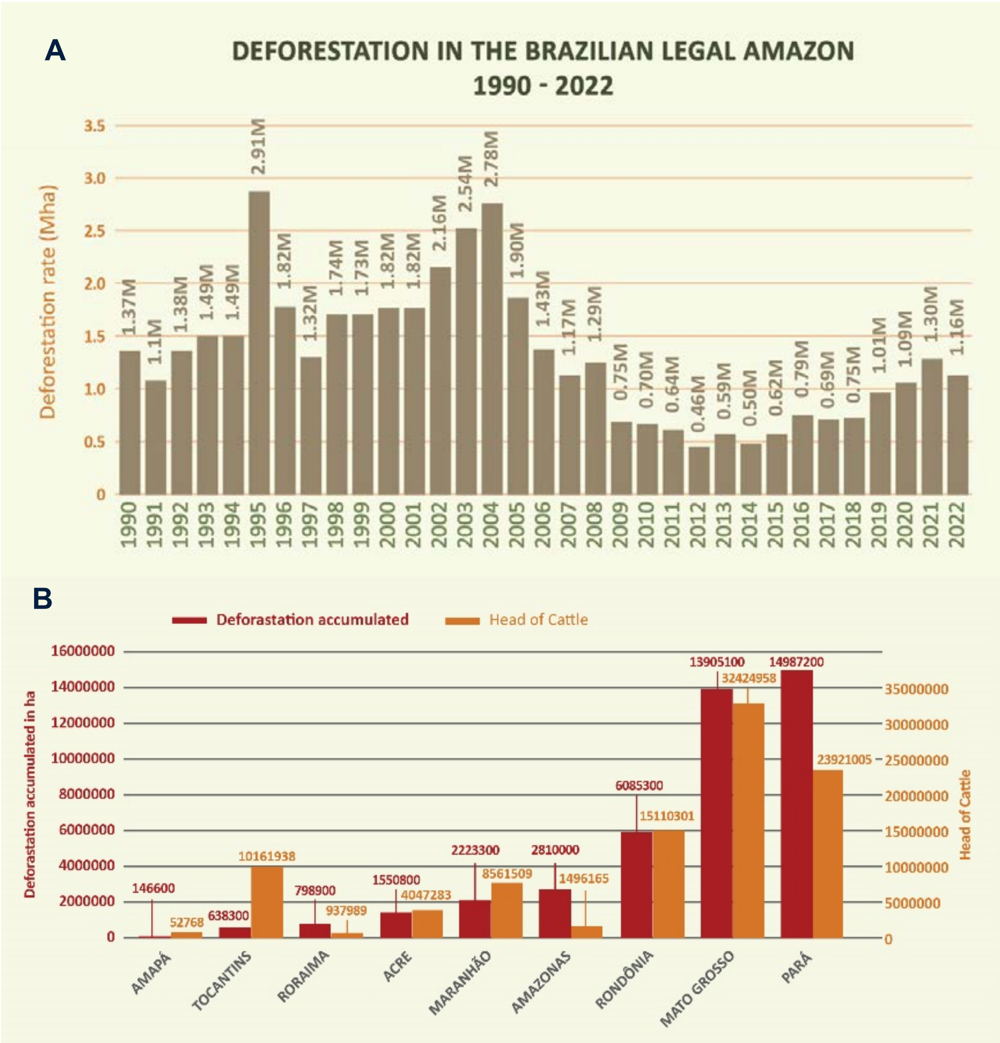
In 2021, the deforestation rate was 1.3 Mha, an increase of 22% since 2019 (**Figure 3A**). From 2021 to 2022, deforestation decreased by 12%. The 84% reduction in deforestation in the Amazon from 2004 to 2012 is attributed to forest conservation policies in Brazil through the increase in protected areas and actions plans for the Prevention and Control of Deforestation in the Legal Amazon (PPCDAm) initiated in the second half of the 2000s.[33]

The states in the Legal Amazon with the largest deforested areas from 1990 to 2021 were Pará (15 Mha), Mato Grosso (13.9 Mha), and Rondônia (6.1 Mha). Mato Grosso and Pará, states that accumulated the largest number of cattle in 2021 (56 million; 58% of a total of 96.7 million heads), accounted for 87% of deforestation (**Figure 3B**, details of the evolution of cattle ranching in **section 2B**). Tocantins, although it is the second state with the lowest absolute deforestation (638,000 hectares), is the fourth largest in number of cattle. It is worth remembering that 91% of the state is in the Cerrado biome, therefore with a reduced forest area. An important fact is that much of the deforestation in the Brazilian Amazon occurs within undesignated public lands, such as a process of irregular occupation of public lands known as land grabbing. From 1997 to 2018, a total of about 2.6 million hectares of forested area were

[33] J. Assunção, C. Gandour, & R. Rocha (2015) *Deforestation slowdown in the Brazilian Amazon: prices or policies?*, ENVIRON. DEV. ECON. 20(6); Instituto Nacional De Pesquisas Espaciais (2013) *Projeto PRODES - Monitoramento da floresta Amazônica Brasileira por satélite*; C. Sanquetta, et al. (2020) *Estoque de Carbono e Remoção de CO_2 em Jovens Estandes de Restauração de Floresta em Rondônia*, FLORESTA 50(1).

lost on these lands.[34] Before the 1990s, from 1975 to 1986, the total deforestation in the Legal Amazon was 21 Mha (4.36%), with Amazonas state having lost 731,000 hectares of its natural cover (<0.22%), Pará 7 Mha (1.44%) and Mato Grosso 6.4 Mha (1.30%).

Figure 3. Deforestation accumulated in the Legal Amazon from 1990 to 2022



A. Deforestation accumulated in the Legal Amazon from 1990 to 2022. B. in the nine states that compose the Legal Amazon region (red bar). Differences in the number of cattle heads per state per state is also shown (orange bar). Data source: INPE, 2023a; IBGE 2021a.

[34] Azevedo-Ramos, supra note 14.

The degradation of the Amazon rainforest is as critical as deforestation. Fire, edge effects and timber extraction caused 36 Mha of the Amazon biome to show some stage of degradation (5.5%) between 2001 and 2018.[35] This area corresponds to 112% of total area deforested in this same period. The combination between logging and forest fires led the Brazilian Amazon to emit 2.7 billion tons of CO_2 between 2007 and 2015, almost half of the emissions from deforestation in the same period (5.1 billion tons).[36]

Pasture field clearing, deforestation and other types of forest degradation and fragmentation in general initiate forest fires in the Amazon.[37] According to INPE's data on the number of fire,[38] there were 75,021 fires[39] in the Legal Amazon in 2021 (**Figure 4**). This year, the state of Pará accounted for 30.5% of the fires, followed by the state of Amazonas (19.8%). It is worth mentioning that deforestation rates are not always directly associated with the highest number of fires, such as Amazonas, which was the fourth state with the highest deforestation rate in 2021 (7%), but the second with the highest number of fires in the year.

The exploitation of timber in the Amazon causes degradation of the forest by altering its structure and microclimate, increasing the deposit of organic matter on the soil and decomposition. The mapping of logging in the Brazilian Amazon carried out by SIMEX (Logging Monitoring System) identified 377,624 hectares of logging from August 2020 to July 2021, with 38% of this area (i.e., 142,428 hectares) having been exploited in an unauthorized manner by the environmental authorities. Of these, about 72% are within rural properties with an Environmental Rural Registry (CAR, in Portuguese).[40] Mato Grosso was the state with the largest area for logging between August 2020 and July 2021 (73.4%), followed by Pará (15.1%) and Rondônia (4.3%). In this context, it is important to note that undesignated public lands were the most exploited in the region, whether through legal and authorized means

[35] D. Lapola, et al. (2023) *The drivers and impacts of Amazon forest degradation*, SCIENCE 379(6630).

[36] T. O. Assis, et al. (2020) *CO2 emissions from forest degradation in Brazilian Amazon*, ENVIRON. RES. LETT. 15(10).

[37] Y. Malhi, et al. (2009) *Exploring the likelihood and mechanism of a climate-change-induced dieback of the Amazon rainforest*, PROC. NAT'L. ACAD. SCI. 106(49); A. Cano-Crespo, D. Traxl, & K. Thonicke (2021) *Spatio-temporal patterns of extreme fires in Amazonian forests*, EUR. PHYS. J. SPEC. TOP. 230(14).

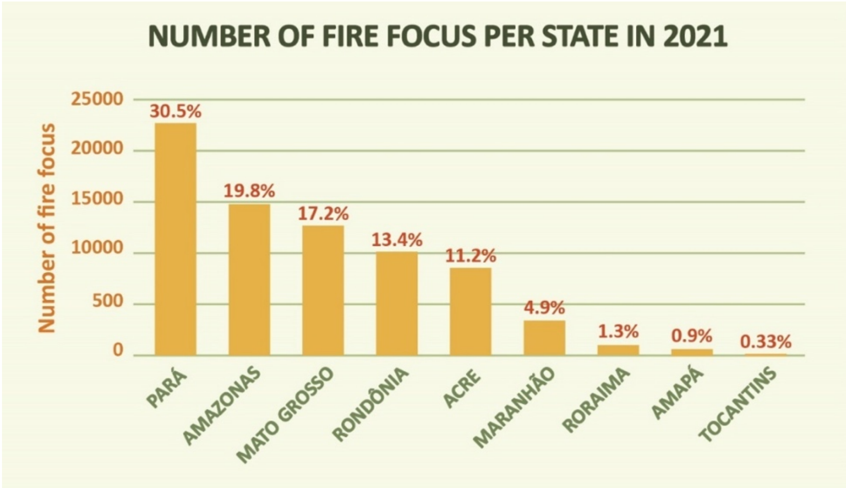
[38] INPE (2023) Banco de Dados de queimadas.

[39] INPE, Database of fires [accessed 10 September 2023].

[40] Logging Monitoring System (Simex), Mapping logging in the Amazon - August 2020 to July 2021, Belém: Imazon, Idesam, Imaflora and ICV.

(corresponding to 82.6%, i.e., 311,996 hectares), or illegally (covering 72%, i.e., 102,003 hectares). It is noteworthy that Indigenous territories constitute the second land category with the highest incidence of logging, with most of it occurring in an unauthorized manner and, therefore, illegally (representing 11% of the total, i.e., 16,211 hectares).

Figure 4. Number of fire focus counted by the States of the Legal Amazon in 2021



Data source: INPE, *Database of fires*.

B. Evolution of Agriculture in the Legal Amazon from 1990 to 2021

Over the last few decades, Brazilian soybean and cattle ranching have experienced significant growth in the states of the Legal Amazon. Through the absolute numbers of soybean planted area and cattle herd registered in Municipal Agricultural and Livestock Production in 1990, 2009, 2014 and 2021,[41] it is possible to observe the evolution in each federative unit and in the Legal Amazon (**Table 1**; **Table 2**).

Soybean production in the Legal Amazon is concentrated in the state of Mato Grosso (MT), where the soybean planted area increased from 1,552,910 hectares in 1990 to 10,461,712 hectares in 2021. Mato Grosso maintained the largest planted area in 1990, 2009, 2014 and 2021, although its proportion in relation to the total area in the Legal Amazon decreased to 96.9%, 86.5%, 82.2% and 75.4%, respectively. Tocantins and Maranhão stand out, with more than 1 million hectares of soybean planted, followed by Maranhão and Pará, with 753,000 and 400,000 hectares, respectively. Roraima, Amapá, Acre and Amazonas recorded soybean planted areas of less than 100 thousand hectares by 2021 (**Table 1**). In total, the soybean

[41] Instituto Brasileiro de Geografica Estatística (2021) *Produção agrícola municipal: culturas temporárias e permanentes*.

planted area in the Legal Amazon grew from 1.6 million hectares in 1990 to 13.9 million hectares in 2021, an increase of 769%.

Table 1. Evolution of soybean planted area in hectares in states of Legal Amazon between 1990 and 2021

	Soybean Planted Area (hectares)			
STATE (UF)	**1990**	**2009**	**2014**	**2021**
Mato Grosso (MT)	1,552,910	5,831,468	8,628,608	10,461,712
Tocantins (TO)	30,120	315,560	719,356	1,171,308
Maranhão (MA)	15,305	409,402	677,540	1,023,541
Pará (PA)	0	71,410	243,171	753,781
Rondônia (RO)	4,640	111,426	195,180	400,459
Roraima (RR)	0	1,400	16,000	57,277
Amapá (AP)	0	0	17,220	6,715
Acre (AC)	0	50	400	6,185
Amazonas (AM)	0	204	0	3,000
Legal Amazon	**1,602,975**	**6,740,920**	**10,497.475**	**13,883.978**

Data source: Instituto Brasileiro De Geografica E Estatística (2021) *Produção agrícola municipal: culturas temporárias e permanentes*.

In the context of the evolution of the cattle herd in the nine states of the Legal Amazon in the time intervals analyzed (**Table 2**, **Figure 5**), the total number of cattle was 27 million in 1990. By 2009, that number had grown to 75 million, representing an absolute increase of 48 million head or 181%. In the subsequent period, from 2009 to 2014, the herd continued to increase, reaching a total of 82 million. In 2021, the total herd reached 97 million, registering an additional 15 million head increase compared to 2014 or 18%. The absolute change of 70 million between 1990 and 2021 represented an increase of 263%.

It is clear that the area occupied by cattle in the Legal Amazon has grown significantly over these three decades, especially in the states of Mato Grosso and Pará. Mato Grosso also stands out as the state with the largest cattle herd among the time intervals analyzed. From 1990 to 2021, there was a notable increase of more than 23 million head (**Table 2**). Consequently, the herd expanded from 9,041,258 head of cattle in 1990 to 32,424,958 in 2021, representing an increase of 258%. Throughout this period, the size of the cattle herd fluctuated between 33.5% and 36.6% of the total herd present in the Legal Amazon. The following Table 2 represents the absolute evolution of cattle herd size in the nine states of the Legal Amazon.

Table 2. Absolute evolution of cattle herd size in the states of the Legal Amazon between 1990 and 2021

	cattle herd size			
STATES (UF)	**1990**	**2009**	**2014**	**2021**
Mato Grosso (MT)	9,041,258	27,357,089	28,592,183	32,424,958
Pará (PA)	6,182,090	16,856,561	19,911,217	23,921,005
Rondônia (RO)	1,718,697	11,532,891	12,744,326	15,110,301
Tocantins (TO)	4,309,160	7,605,249	8,062,227	10,161,938
Maranhão (MA)	3,900,158	6,885,265	7,758,352	8,561,509
Acre (AC)	400,085	2,511,285	2,799,673	4,047,283
Amazonas (AM)	637,299	1,350,816	1,405,208	1,496,165
Roraima (RR)	345,650	475,380	735,962	937,989
Amapá (AP)	69,619	104,977	167,529	52,768
Legal Amazon	**26,604,016**	**74,679,513**	**82,176,677**	**96,713,916**

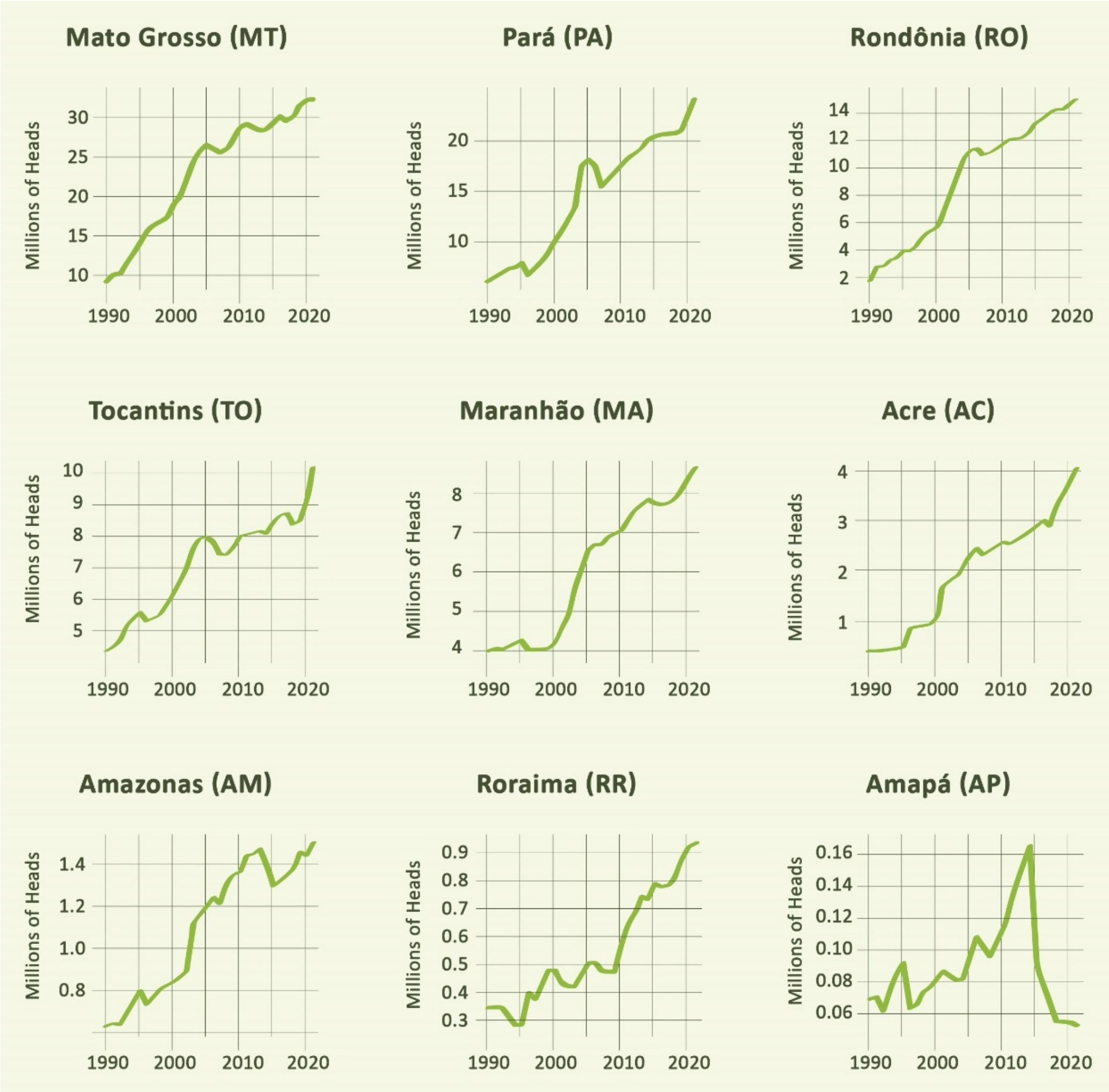
Data source: IBGE (2022) *Produção Agrícola Municipal*.

The states of Pará, Rondônia, Tocantins and Maranhão rank below Mato Grosso in terms of the number of cattle in the legal Amazon. Pará went from 6 million head of cattle in 1990 to 24 million in 2021, which represents an increase of almost 18 million head, equivalent to a growth of 287%. Rondônia grew from 1.7 million to 15 million head of cattle in the same period, representing a growth of 779%. Tocantins grew from 4.3 million to 10 million head, an increase of 119% between 1990 and 2021. The sum of the cattle herds from these four states together increased from 16 million in 1990 to 58 million in 2021, representing an increase of 275%.

The herds in the states of Acre, Amazonas, Roraima and Amapá sum 7% of total heard of the Legal Amazon. Acre increased from 400 thousand head of cattle in 1990 to 4 million in 2021, representing a 912% increase over the period. Amazonas also recorded a significant increase, going from 637 thousand head of cattle in 1990 to 1.5 million in 2021, representing an increase of 135%. Roraima had 345 thousand head of cattle in 1990 and this number rose to 937 thousand in 2021, a growth of 171%. Amapá presented a peculiar dynamic (**Figure 5**), increasing from 69 thousand head of cattle in 1990 to 167 thousand in 2014 and then reducing to 53 thousand in 2021, being 24% lower compared to 1990. Due to its low herd size, Amapá has been traditionally a large importer of animals from other Amazonian states such as Pará.[42] In all, the number of combined head of cattle in these four states grew from 1.7 million to 6.5 million, or 282%, between 1990 and 2021.

[42] E. Arima, P. Barreto, & M. Brito (2005) PECUÁRIA NA AMAZÔNIA: TENDÊNCIAS E IMPLICAÇÕES PARA A CONSERVAÇÃO, Belém: Imazon.

Figure 5. Size of the cattle herd in the Legal Amazon between 1990 and 2021



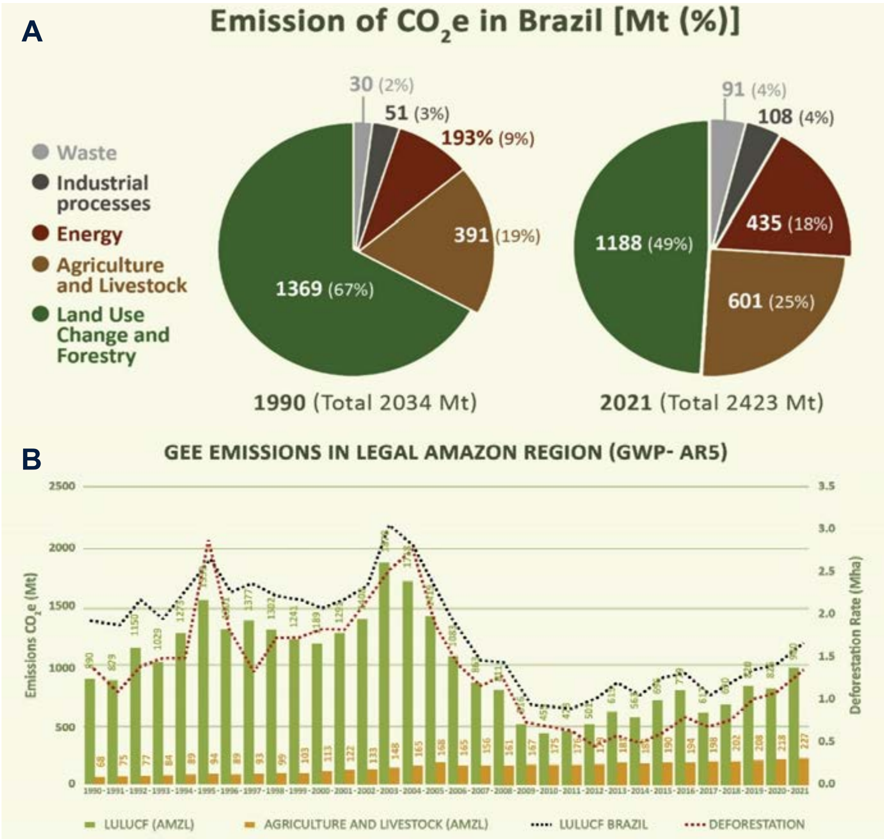
Data source: [https://sidra.ibge.gov.br/pesquisa/ppm/quadros/brasil/2021.](https://sidra.ibge.gov.br/pesquisa/ppm/quadros/brasil/2021)

3. Greenhouse Gas Emissions from Land Use, Land-Use Change, and Forestry and Cattle Ranching in the Legal Amazon

A. Greenhouse Gas Emissions from Land Use, Land-Use Change, and Forestry (LULUCF)

The land use change and forestry sector are responsible for reporting total emissions and GHG emissions related to changes in above- and below-ground biomass and organic matter stocks. This also includes emissions from soil liming in recently deforested lands and emissions from forest residue burning.[43] The land use change and forestry sector are responsible for most of Brazil's emissions (1.188 million tons (Mt)), followed by the agricultural (agriculture & livestock) sector (601 Mt) (**Figure 6A**). GHG emissions in Brazil increased by 16% from 1990 to 2021. While LULUCF emissions have decreased in these 32 years, emissions from agriculture have almost doubled. Of the total 2.4 billion gross tons of CO_2 equivalent emitted in 2021 by Brazil, more than 51% was emitted by the land use sector (approximately 1.2 billion gross tons of CO_2). Adding emissions from deforestation and other changes in land use with those from the agricultural sector, it is concluded that these activities in a broad sense account for 74% of all Brazilian climate pollution.

Figure 6. GHG emissions in Brazil, in 1990 and 2021



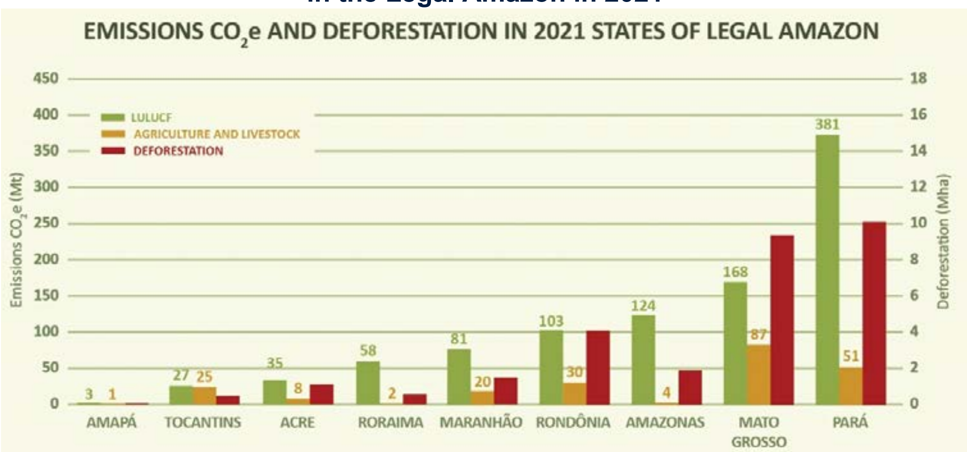
A. GHG emissions in Brazil, in 1990 and 2021, by economic sector. B. Evolution of GHG emissions between 1990 and 2021, for the land use, land use change and forestry (LULUCF) and agricultural sectors in the Legal Amazon and Brazil. Rates of deforestation over time seems to follow emissions by LULUCF in the Legal Amazon. Data source: SEEG, 2023 Platform.

[43] Sistema de Estimativa de Emissão de Gases de Efeito Estufa (2020) Setor Mudança de Uso do Solo e Florestas, Nota Metodológica SEEG 7 Setor Mudança de Uso do Solo e Florestas (IPAM & IMAZOM, Eds.).

About 40% (980 Mt CO_2e) and 9% (227 Mt CO_2e) of Brazilian emissions in 2021 were attributed to changes in land use and agriculture in the Legal Amazon, respectively. On the other hand, while emissions from LULUCF increased by 9% (90 Mt CO_2e) from 1990 to 2021, reflecting a huge variability between different periods, emissions from agriculture rose by 70% more or less uniformly (159 Mt CO_2e) (**Figure 6B**). The relationship between deforestation and GHG emissions is so close in Brazil that the variation in LULUCF emissions in the country follows the rate of deforestation in the Amazon region.[44] In 2018, deforestation in the Amazon accounted for approximately 59% of GHG emissions from land-use change, and 25.7% of the country's annual emissions.[45]The 84% reduction in deforestation in the Legal Amazon from 2004 to 2012 resulted in a decrease of more than 240% in the sector's gross CO_2 equivalent emissions. The agricultural sector, on the other hand, continued to increase its emissions by 8%, mainly driven by the increase in the cattle herd. The contribution of LULUCF emissions from the Legal Amazon to LULUCF emissions in Brazil rose from 65% to 82% from 1990 to 2021.

The state of Pará emitted the most by the LULUCF sector in 2021, releasing about 381 million tons of GHG into the atmosphere (**Figure 7**). Mato Grosso was the state that emitted the most in the same year by the agricultural sector, with 87 million tons. Amazonas, although the third largest emitter of the Legal Amazon by LULUCF (124 Mt CO_2e), had lower deforestation than Rondônia, the fourth largest emitter state due to land use changes. Mato Grosso, Pará and Amazonas accounted for almost 67% of emissions.

Figure 7. Differences in GHG emissions from LULUCF and agricultural sectors among all states in the Legal Amazon in 2021



Deforestation data is used for visual comparisons. Data source: SEEG Platform, 2023.

44 SEEG, supra note 44.

45 *Id.*

Although emissions from degradation are not yet computed in national inventories, studies show that net emissions due to forest degradation contributed to 16.2% of 5.4 Gt CO_2 emitted from 2007 to 2016.[46] Total emissions from forest fires in the Brazilian Amazon during drought years such as 2015 (989 ± 504 Mt CO_2 per year) are more than half of the emissions resulting from forest clearing.[47] This shows the importance of including degradation, especially by fires, in national inventories.

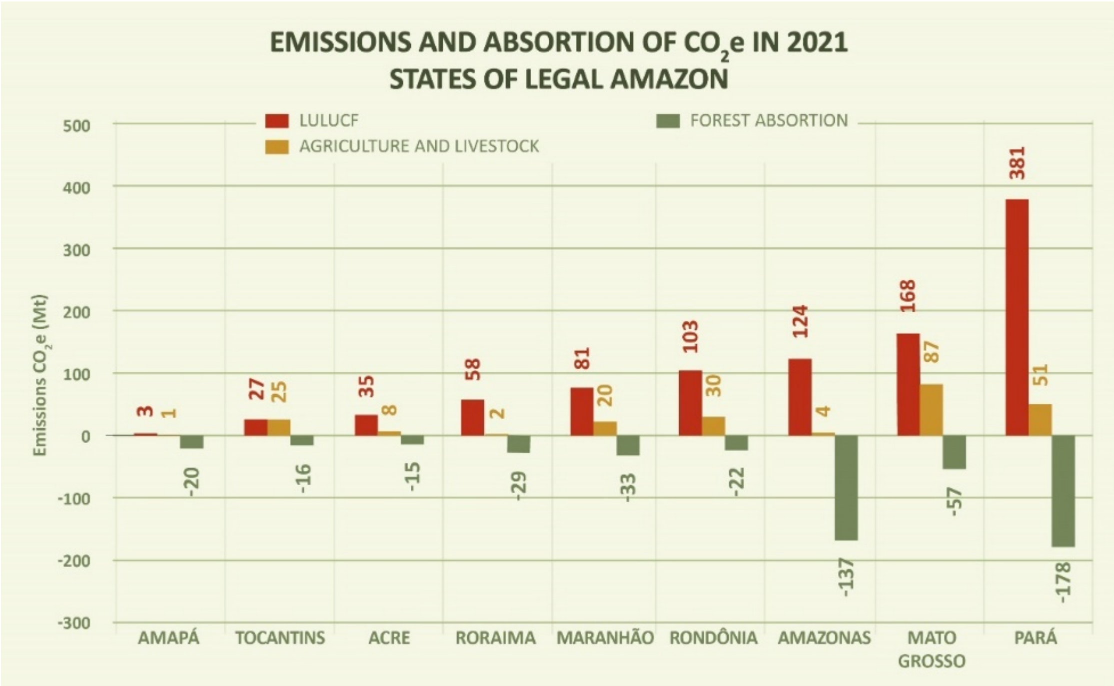
The Amazon Rainforest plays an essential role in sequestering carbon from the atmosphere through photosynthesis, removing part of the carbon emitted by different human activities (agriculture, energy, changes in land use, etc.). In 2021, forests absorbed about 666 Mt CO_2e, with 81% of this sequestration occurring within the Legal Amazon. Most of the removal (58%) occurs from areas of native vegetation in protected areas (conservation units and Indigenous territories), with the rest of the removals coming from the growth of secondary vegetation as occurs in abandoned pastures, which are equivalent to 42% (-277 Mt CO_2e).[48] Amapá and Amazonas were the only states where carbon emissions from LULUCF and agricultural sectors were completely offset through carbon sequestration by the forest (**Figure 8**). Pará and Mato Grosso were the states with the highest GHG removal in 2021, but due to their high LULUCF emissions, the state continues to be a source of GHG into the atmosphere. Even if emissions from land-use change are zero, the removal of carbon equivalent by the forests of Mato Grosso, Tocantins and Rondônia is not enough to balance emissions due to agricultural activity. This underscores the need to reduce Brazilian GHG emissions through both actions to combat deforestation and degradation in the Legal Amazon, and investments in low-GHG cattle ranching and restoration of unproductive pastures.

[46] Assis, supra note 38.

[47] L. E. O. C. Aragão, et al. (2018) *21st Century drought-related fires counteract the decline of Amazon deforestation carbon emissions*, NAT. COMMUN. 9(536).

[48] SEEG (2023) ANÁLISE DAS EMISSÕES DE EMISSÕES DE GASES DE EFEITO ESTUFA E SUAS IMPLICAÇÕES PARA AS METAS CLIMÁTICAS DO BRASIL 1970-2021, Observatório do Clima.

Figure 8. GHG (CO_2e) emissions from land use changes, and agricultural sectors in the nine states of the Legal Amazon

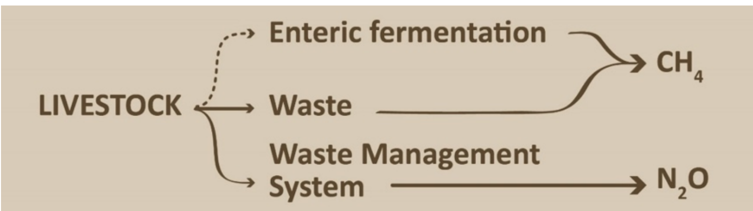


Carbon dioxide removal by land-use change refers to the amount of carbon gases fixed by vegetation growth and is presented with negative values. Data source: SEEG, 2023 platform.

B. Methane Emissions from Cattle Ranching in the Legal Amazon

Animal production systems in the Amazon, especially ruminant production, contribute significantly to GHG emissions (Figure 9). Among the sources of emissions from these systems, the enteric fermentation process stands out, which occurs in the digestive tract of ruminants and results in the production and release of methane gas. Animal waste management and storage systems also affect methane (CH_4) and nitrous oxide (N_2O) emissions, which are generated during waste decomposition. In addition, losses of ammonia (NH_3) and nitrogen oxides (NO_x) by volatilization, as well as losses of nitrogen by leaching and runoff in manure management systems and soils, cause indirect GHG emissions.

Figure 9. General scheme of GHG emissions by type of gas in livestock



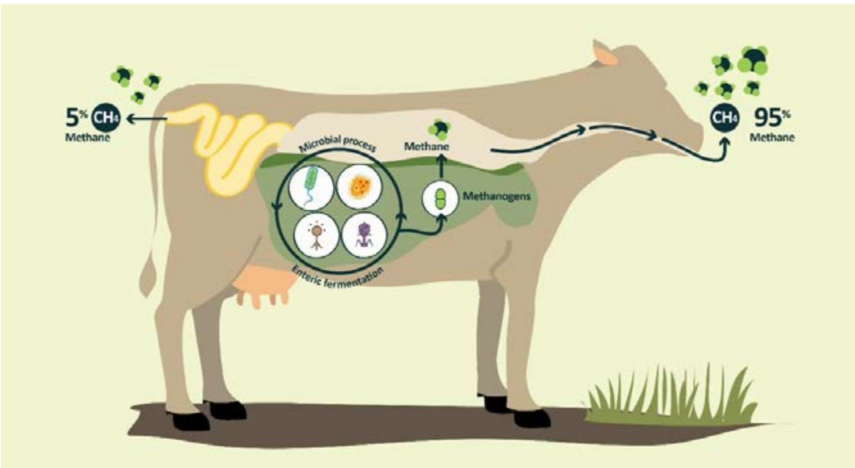
Data source: Adapted from Estevam et al., 2023.

Methane is in second place as the gas that contributes most to the warming of the planet through the absorption of radiation in the atmosphere, second only to carbon dioxide.[49] While the lifetime of methane in the atmosphere is 10 times shorter than carbon dioxide, it has about 25 times the potential to cause global warming.[50] In 2021, the methane emitted by the agricultural sector was equivalent to 70.6% of the total methane emission in the country. Thus, actions aimed at mitigating emissions are necessary to reduce the impacts of Brazilian agriculture on the production of greenhouse gases.

I. ENTERIC FERMENTATION

Enteric fermentation occurs in one of the stages of digestion of ruminant herbivorous animals, such as cattle, buffaloes, sheep and goats (**Figure 10**). The digestive process of these animals results in the generation of hydrogen gas (H_2), which is used by methanogenic bacteria to reduce carbon dioxide, resulting in the formation of **methane** gas, which is then expelled via eructation into the atmosphere. Monogastric (non-ruminant) herbivorous animals, such as horses and pigs, also emit methane, however, in smaller amounts, as they do not ferment the food ingested during digestion.[51]

Figure 10. Methane gas release process via enteric fermentation in cattle



Source: Adapted from New Zealand Agricultural Greenhouse Gas Research Centre, *The science of methane*.

[49] C. A. Zotti & V. T. Paulino (2009) *Metano na produção animal: Emissão e minimização de seu impacto*, Instituto de Zootecnia, APTA & SAA.

[50] O. Boucher, P. Friedlingstein, B. Collins, & K. P. Shine (2009) *The indirect global warming potential and global temperature change potential due to methane oxidation*, ENVIRON. RES. LETT. 4(4).

[51] E. D. Assad, S. C. Martins, L. A. M. Cordeiro, & B. A. Evangelista (2019) *Sequestro de carbono e mitigação de emissões de gases de efeito estufa pela adoção de sistemas integrados*, Embrapa Cerrados.

In the context of the tropicalization of the methodology for calculating GHG emissions, it is important to consider the particularities of animal production systems, taking into account local conditions such as animal categories, age, management condition, purpose of production and digestibility rates. GHG emissions are influenced by factors such as animal diet composition, forage quality, rumen microorganisms, genetics, herd management, production environment.

The IPCC guidelines provide standard emission factors (*default*), that is, average emissions from an animal, considering the type of herd and its location, at the continental level, and also by generalized category of production system (beef or milk). The documents also provide technical guidelines for the specific calculation of cattle emission factors, considering the specificities of the animal diet and management conditions. However, this level of accuracy applies to controlled operations, with a high level of information and data organization, conditions found in some technical production units. For emission calculations and inventories at the regional and national level, the application of the specific emission factor calculation methodology becomes impractical.

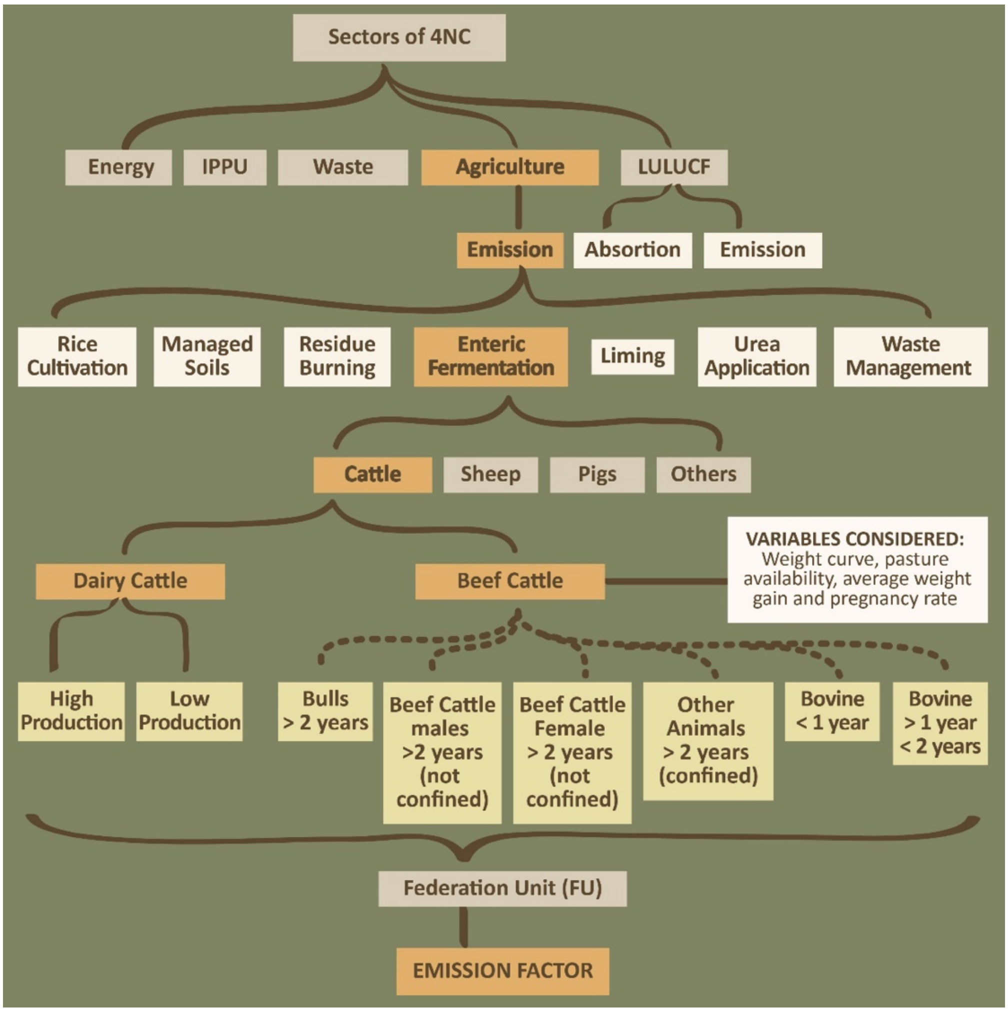
Brazil has specific emission factors for the calculation of emissions from enteric fermentation of national cattle, at the Tier 2 information level. The values that were used in the accounting of the emissions disclosed in the National GHG Inventory were obtained through scientific research carried out in the country, and, therefore, adequate for the Brazilian reality. The data, segregated by animal category, breeding system (beef or milk), sex, age and state of the federation, can be accessed in the sectoral reference reports of the national communication.

Figure 11 shows the flow of the methodological rationale used by the Sectoral Reference Report (RRS)[52] to quantify and establish enteric fermentation emission factors for the different classes of animals. In the case of pigs, sheep and other categories (buffaloes, goats, horses, mules and donkeys), the same default enteric methane emission factors were considered, pre-established for each animal class grouping, indicated by the IPCC.[53]

[52] Ministry of Science Brazil (2020) FOURTH NATIONAL COMMUNICATION OF BRAZIL TO THE UNFCCC.

[53] IPCC (2006) GUIDELINES FOR NATIONAL GREENHOUSE GAS INVENTORIES, H. S. Eggleston, et al. (eds.), Institute for Global Environmental Strategies.

Figure 11. Flow of categories considered for emission factors in Enteric Fermentation according to the Fourth National Communication of Brazil (4NC) to the UNFCCC



Data source: Adapted from Estevam et al. (2023).

When comparing the default values of IPCC emission factors (Tier 1) with those obtained at the national level, it is possible to observe a significant difference between the Tiers and categories of animals. For example, for beef cattle (bulls), the emission factor is 71 kg CH_4.animal^{-1} year^{-1}, while for beef cattle - males older than 2 years - not confined, the values vary from 63 to 72, depending on the federation unit (state). The Tier 1 values of the IPCC Guidelines[54] consider only an average value (default) for the age classes of beef cattle, as can be seen in **Table 3** below.

[54] *Id.*

Table 3. Comparison of emission factors from enteric fermentation for cattle, according to IPCC and Fourth National Communication of Brazil to the United Nations Framework Convention on Climate Change

EMISSION FACTOR (YEAR 2016)	Kg CH_4 animal^{-1} year^{-1}	
Class	IPCC (Tier 1)	4 NC (Tier 2)*
Beef cattle – Bulls	56	71
Beef cattle Males over 2 years of age, not confined		63 - 72*
Females older than 2 years of age, not confined		73 - 79
Beef cattle – Under 1 year of age		34
Beef cattle between 1 and 2 years of age		52
Low-producing dairy cattle	78	81 - 93*
High-producing dairy cattle	103	60 - 96
Feedlot cattle > 2 years of age	58	60 - 67

*Values defined by Brazilian State

One point of attention is related to the methane emission values of dairy cattle, segmented by the IPCC into the high and low productivity classes. However, the definitions of high and low productivity diverge from the Brazilian classification. According to the IPCC, a high-yielding dairy cow produces, on average, 3,400 kg of milk head^{-1} year^{-1}. On the other hand, low-yielding cows produce 1,250 kg of milk per head^{-1} year^{-1}, and intermediate production cows produce 2,050 kg of milk per head^{-1} year^{-1}, emitting an average of 87 kg CH_4 animal^{-1} year^{-1}. In the case of Brazil, the milk productivity limit value of 2,000 kg of milk per head^{-1} year^{-1} is accepted as a dividing mark between the population of high and low production cows. In other words, while the IPCC considers a production of 2050 kg as intermediate, in the Brazilian system it is considered as high.

In this sense, the IPCC also defines average values of emission factors for beef cattle, according to high and low productivity classification, which vary between 55 and 58 kg CH_4 animal^{-1} year^{-1}, with high productivity compared to semi-confinement or intensive confinement conditions. In this case, it is considered for comparative purposes with the Brazilian rearing system, the national intensive confinement system.

It is important to note that enteric fermentation is the class that presents the highest representativeness in relation to livestock emissions, especially with regard to methane emissions. Therefore, it is crucial that the choice of emission factor to be used is the most representative of the actual conditions.

Methane emissions should be analyzed from an energy perspective, in which the higher the animal's energy expenditure, the greater the demand for food, i.e., the greater the methane emission. According to the literature, it is considered that about 2% to 12% of the gross energy consumed by ruminant animals is lost in the form of methane, representing a significant loss of energy in the agricultural production system.[55]

This loss is related to factors involving the genetic characteristics of the animals, as well as variables related to the quantity and quality of food available for consumption, types of carbohydrates, digestibility of food, and other resources used in their nutrition.[56] Therefore, emission factors are related to specific characteristics of herd type, sex, age, management and location. Mitigation strategies through the improvement and manipulation of animal diets take into account the reduction of methane emissions, while seeking to increase productivity, especially through improvements in pasture conditions and in the nutritional composition offered to animals.[57]

II. DETERMINATION OF METHANE EMISSIONS IN THE LEGAL AMAZON BY CATEGORY OF CATTLE

Despite the unavailability of the number of cattle divided into categories for the Amazon, in 2021, it was possible to estimate the cattle population in six categories (Table 4), based on the 2006 Agricultural Census, which had these data. Based on the total number of animals, the calculation of the proportion of animals per category (PC%) was made using the equation:

$$PC = \frac{Number\ of\ Cattle\ Herd\ per\ Category}{Total\ Number\ of\ Cattle\ Herd}\ x\ 100$$

Table 4. Proportion of animals per category (PC%) in the Brazilian region

Categories	Adopted Nomenclature	PC %
Bovine < 1 year	< 1 year	21.8
Bovine > 1 year < 2 years	1-2 year	26.8
Bulls	bulls	2.8
Beef Cattle Female > 2 years (not confined)	female 2 years+ nc	32.3
Beef cattle males >2 years (not confined)	males 2 years+ nc	15.7
Other Bovine > 2 years (confined)	2years + conf	0.6

nc = no confined; conf = confined.

[55] L. A. Z. Machado, E. B. Correa, & F. M. Vargas Junior (2011) Integração lavoura-pecuária-floresta. 3. Escolha dos animais e formação de lotes, Embrapa Agropecuária Oeste.

[56] G. A. Sene, et al. (2019) *Práticas estratégicas com vistas à mitigação dos gases do efeito estufa na produção de bovinos a pasto*, in NOVOS DESAFIOS DA PESQUISA EM NUTRIÇÃO E PRODUÇÃO ANIMAL, 5D Editora.

[57] Machado, supra note 58.

By adjusting the herd by animal category, the determination of CH_4 emissions only, not considering N_2O, allows us to establish some indicators:

- The emission of methane in the Legal Amazon, through enteric fermentation and waste management, represents around 55% of total methane emissions in the Brazilian agricultural sector. The cattle herd in the legal Amazon represents 43% of the Brazilian cattle herd.
- Of the 808 municipalities in the Legal Amazon, 537 are in the condition of severely degraded pastures, that is, high CO_2 emissions, low stocking capacity, and, therefore, high methane emissions.

Data on methane emissions can be found in **Table 5** below.

Table 5. Methane emissions from cattle ranching in the Legal Amazon

YEAR	HEAD OF CATTLE BEEF AND MILK – LEGAL AMAZON										
2021	MT	PA	RO	TO	MA	AC	AM	RR	AP	TOTAL number of cattle head	%
	32,424,958.00	23,921,005.00	15,110,301.00	10,161,938.00	8,561,509.00	4,047,283.00	1,496,165.00	937,989.00	52,768.00	96,713,916.00	43% of the herd
	ENTERIC FERMENTATION CH_4 - EMISSION FACTOR 0.063*										
	MT	PA	RO	TO	MA	AC	AM	RR	AP	TOTAL TON CH_4	%
	2,042,772.35	1,507,023.32	951,948.96	640,202.09	539,375.07	254,978.83	94,258.40	59,093.31	3,324.38	6,092,976.71	41% of CH_4 emissions from agriculture
	METHANE: WASTE MANAGEMENT - EMISSION FACTOR 0,0016*										
	MT	PA	RO	TO	MA	AC	AM	RR	AP	TOTAL TON CH_4	
	51,879.93	38,273.61	24,176.48	16,259.10	13,698.41	6,475.65	2,393.86	1,500.78	84.43	154,742.27	
Total CH_4	2,094,652.29	1,545,296.92	976,125.44	656,461.19	553,073.48	261,454.48	96,652.26	60,594.09	3,408.81	**6247718.97	
Total CO_2										174,936,131.26	

Source: Adapted from IV National Inventory of GHG Emissions/Removals, Brasil-MCTI (2021).

4. Innovative Sociobioeconomy to Prevent the Amazon Tipping Point

The economic development model in the Amazon has resulted in the conversion of 15% of the natural areas since 1975, much of it converted into unproductive pastures, focused on extensive breeding and with low use of technologies. This model has resulted in environmental and social degradation, placing Brazil as one of the largest GHG emitters in the world, and the northern region of Brazil, with one of the worst social development indices.[58] This model has also posed a threat to the Amazon's climate system, pushing it dangerously to the brink of irreversible change, which will result in the loss and degradation of its forests and biodiversity, and of ecosystem services vital to the well-being of people living inside and outside the Amazon.

[58] Instituto Brasileiro de Geografia e Estatística (2015) Pesquisa Nacional por Amostra de Domicílios, Principais resultados; Sidra Brasil, supra note 34.

To move away from such an undesirable future, it is necessary to adopt a new sociobioeconomic model for the region, which *'combine activities that maintain productive and conserved multifunctional landscapes and cultural diversity, while promoting economic and social added value to the Amazon's biodiversity'*.[59]

To achieve this goal, it is essential to implement public policies, management systems and practices that encourage cattle ranching in the Amazon that is net-zero emissions of methane and carbon. This approach must be based on eliminating deforestation and forest degradation, while promoting the restoration of forests. These forests will be able to increase biodiversity, contribute to carbon capture, soil protection and cooling the environment, while ensuring a sustainable source of income and improving the quality of life for local communities, thus helping both, to mitigate climate change and adapt to ongoing changes.

A. Induce Net Zero Livestock Farming through a Regenerative Agriculture

I. Strategy to Reduce Methane Emissions

Livestock stands out as a significant source of GHG emissions. However, it is important to analyze livestock activities considering different management systems and practices. It is of paramount importance to consider the emissions from livestock activity not only attributing them to individual animals, but rather understanding the system as a whole. When analyzing Brazilian cattle ranching, and especially in the Legal Amazon, we must keep in mind that the animals are raised, mostly, on pastures. Data from ANUALPEC indicate that 93% of the national herd is managed on pastures, and 30% of the herd raised on pasture is finished (fattened) in a confined environment.[60] Thus, unlike the feedlot production systems of the northern hemisphere, Brazil has a system focused on extensive breeding.

In addition, the climatic characteristics of tropical regions bring specificities in relation to emissions associated with waste management processes, use of natural resources, and agricultural practices. When the production system is properly managed, it is possible to neutralize emissions and even remove atmospheric carbon at rates higher than the emissions generated by animals, that is, transform production systems into carbon sinks. Efficient and

[59] R. Garrett, et al. (2023) *Supporting Sociobioeconomies of healthy standing forests and flowing rivers in the Amazon*, Science Panel for the Amazon, Policy Brief.

[60] Anuário da Pecuária Brasileira (2022) *Abate de Bovinos no Brasil*, in ANUÁRIO DA PECUÁRIA BRASILEIRA 2022.

sustainable management can play a key role in reducing emissions from livestock, making it a more environmentally balanced activity and contributing to climate change mitigation.

The development of cattle ranching in the Legal Amazon should be based on stopping deforestation and on the recovery of the approximately 23.5 million hectares of degraded pastures in the region. Of this total, 5 million are severely degraded pastures with heavy CO_2 emissions.[61]

The rapid expansion of beef cattle ranching in the Amazon region was based on basically extensive cattle ranching (with low use of technology), subsidized by a generous governmental policy of tax incentives, developed on abundant, cheap land devoid of adequate infrastructure. This more extensive model of initial cattle ranching development, typical of agricultural frontier regions at the time, was also a consequence of the lack of pasture management technologies and the few options for suitable forage for planting in the Amazon. As a result, serious errors in pasture formation and management were often made, resulting in the short productive life span of these areas.[62]

Due to the inability to maintain productive pastures over time, production targets were, with few exceptions, achieved at the expense of abandoning unproductive (degraded) pastures and the formation of new pastures in primary forest areas. With technological advances based on incentives from Low Carbon Agriculture[63] financing, this immense area of degraded pastures can adopt techniques to decarbonize agriculture and gradually reverse the situation from degraded pastures to recovered pastures, thus allowing to increase pasture productivity and meat supply, without deforestation. Based on meat production in the Legal Amazon in 2010, which was 2.7 million tons, it was projected that the implementation of high-tech regenerative practices by 2022 would lead to an optimization in meat production, resulting in an annual increase of 5.6 million tons (equivalent to about R$ 30 billion, based on the price of cattle in 2010) in degraded pastures with greater agronomic potential. The investment in these practices would be around 2.1 billion dollars over 10 years and should be focused on the states

[61] *See* Atlas das Pastagens (Atlas of Pastures): https://atlasdaspastagens.ufg.br/.

[62] M. B. Dias-Filho (2015) *Estratégias para recuperação de pastagens degradadas na Amazônia brasileira*, Embrapa Agropecuária Oeste.

[63] Embrapa, ABC Sector Plan – Sector Plan for Mitigation and Adaptation to Climate Change for the Consolidation of a Low-Carbon Economy in Agriculture.

of Mato Grosso, Pará and Rondônia.[64] On the other hand, in the study by Carlos et al. (2022),[65] the cost of recovering degraded pastures in the Amazon would be 4.5 billion dollars, considering pastures in a severe stage of degradation.

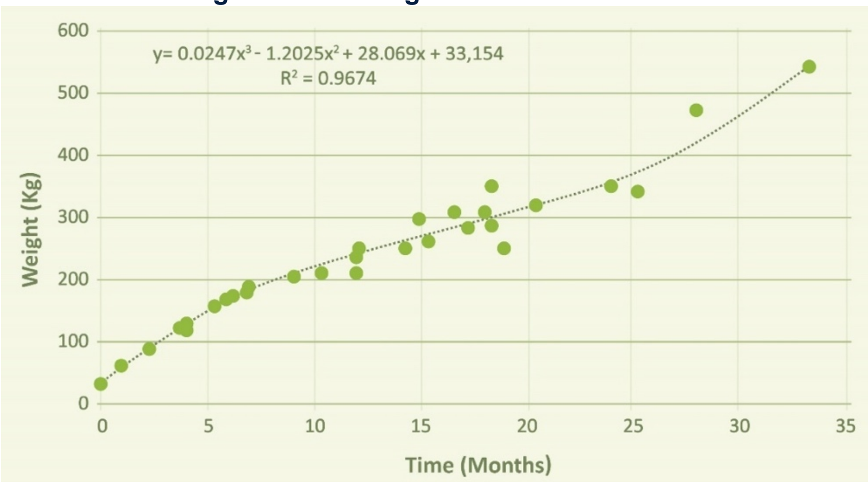
In addition to the traditional forms of pasture recovery (fertilization and liming), in the Amazon biome the following are also being observed: i) insertion of forage legumes (such as forage peanuts) in intercropping with forage, which promote greater nitrogen input to the soil due to biological nitrogen fixation (BNF) and, consequently, reduce the use of nitrogen fertilizers by up to 60%, in addition to being highly palatable to livestock; and ii) insertion of the crop component, promoting the adoption of crop-livestock integration only in the first two years of the system, to increase soil fertility.

With these characteristics, the average emission by enteric fermentation and emission of manure from cattle during their lifespan of 36 months is 6,700 Kg CO_2e animal^{-1}. By adopting the pasture improvement technologies available today, this same animal can reach a slaughter age of 24 months, reducing CH_4 emissions and consequently CO_2 equivalent by 12 months. At the end of 24 months, the animal will have emitted 4,480 Kg CO_2e animal^{-1}, providing a CH_4 emission reduction of 33%. In other words, it is possible to intensify the productivity of livestock, reducing the time it takes to slaughter the animal, and optimizing the use of the soil. The end result would be: there is no need to deforest to increase livestock production in the Legal Amazon. The growth curve of cattle in Brazil, with an average lifespan of 36 months, is represented in **Figure 12**. These changes in livestock farming at the national level would result in total net carbon removal of 1,223.6 Mt CO_2e, averaging 94.1 Mt CO_2e year^{-1} by 2030.

[64] P. Barreto & D. S. Silva (2012) Como desenvolver a economia rural sem desmatar a Amazônia?.

[65] S. M. Carlos, et al. (2022) Custos da Recuperação de Pastagens Degradadas nos Estados e Biomas, Observatório de Conhecimento e Inovação em Bioeconomia, Fundação Getúlio Vargas, FGV-EESP.

Figure 12. Cattle growth curve in Brazil



Agricultural reference report, subsector – enteric fermentation. Data source: Brasil-MCTI, 2021.

II. Intensification of Livestock, Early Slaughter and Heat Tolerance through Genetic Improvement and Management with Native Trees

In Brazil's specific case, the growth of production may have an even higher increase since the growth of exports has placed the country as one of the main agricultural producers in the world. Concomitant with the increase in demands, the environmental, economic, and social impacts of global climate change are one of the greatest challenges facing humanity today. Thus, current production systems will increasingly have to continue to evolve to ensure production growth and adapt to climate change, while preserving ecosystem services more effectively.

Recent studies have emphasized that while changes in average climate conditions may affect agricultural productivity and require adaptation policies, a large part of agricultural crop losses and food security risks are expected to be associated with interannual variations in climatic conditions and the occurrence of extreme weather events (persistent droughts, heavy precipitation events, persistent rainfall, occurrence of floods, frosts, high temperatures, heat waves, etc.). Alves de Oliveira et al. (2021),[66] for example, demonstrated that in scenarios of high carbon emission and forest loss resulting from the Amazon tipping point, wet-bulb temperatures could reach extremely high levels, exceeding 40 °C on 25 days per year, by the end of this century in the Amazon Basin region. These temperatures exceed the average (28.14 °C) and maximum temperature (31.90 °C) considered ideal (i.e., ~27 °C) for the well-

[66] B. F. Alves de Oliveira, M. J. Bottino, P. Nobre, & C. A. Nobre (2021) *Deforestation and climate change are projected to increase heat stress risk in the Brazilian Amazon*, COMMUN. EARTH ENVIRON. 2(1).

being of cattle. This highlights the need to provide shade, whether natural or artificial, for grazing, as discussed by Storti et al. (2019).[67]

Some breeds existing in Brazil have part of these characteristics, but most have difficulties in adapting and tolerating heat, and at the same time maintaining productive efficiency, especially in the Amazon. Some scenarios can be studied and compared according to a proposal, which would be to seek heat-tolerant breeds, which allow early slaughter with greater carcass efficiency, reaching 330 kg in up to 20 months. Breeds that are on the path of genetic improvement seeking not only weight gain, but also early slaughter and adaptation to heat stresses,[68] according to genetic test fields, indicate that the gain can be from 1 $Kg.day^{-1}$ to 1.5 $kg.day^{-1}$. In the worst situation, the animal can be slaughtered at 24 months and in the best situation at 18 months. This means a reduction of at least 12 months in the current average slaughter time, and up to 2.9 times of productivity gain, i.e., more animals per hectare, with carcass weight for slaughter of 300 kg, and tolerant to high temperatures with pasture production.

Implementing an intensified system with *Brachiaria*, at a cost of about $800 per hectare per year, has the potential to generate net negative emissions of approximately 4 to 5 tons of CO_2 per hectare annually. The effort to recover 40 hectares of degraded pastures in terms of carbon is nullified by avoiding 1 hectare of deforestation, requiring an investment of $32,000 per year.[69]

III. INTEGRATED PRODUCTION SYSTEMS (OFF-SEASON)

Right at the beginning of the occupation of the Brazilian savannas within the Legal Brazilian Amazon, with the introduction of soybean planting, the cultivars had a long cycle and had a productivity of around 1.7 tons ha^{-1}.[70] In 2016 by IBGE,[71] the average yield in the savanna reached from 2.9 t ha^{-1} to 3.26 t ha^{-1}. Such official results indicate an average productivity gain of more than 170%, i.e., more than 4% per year. Planting was “single”, that is, a single crop per year, which meant using, with the practices of soil preparation, fertilization, planting and

[67] A. A. Storti, M. R. B. de Mattos Nascimento, C. U. de Faria, & N. A. M. da Silva (2019) *Índices de estresse térmico para touros jovens Nelore criados em ambiente tropical*, ACTA. SCI. VET. 47(1).

[68] L. Flori, et al. (2012) *A quasi-exclusive European ancestry in the Senepol tropical cattle breed highlights the importance of the slick locus in tropical adaptation*, PLOS ONE 7(5).

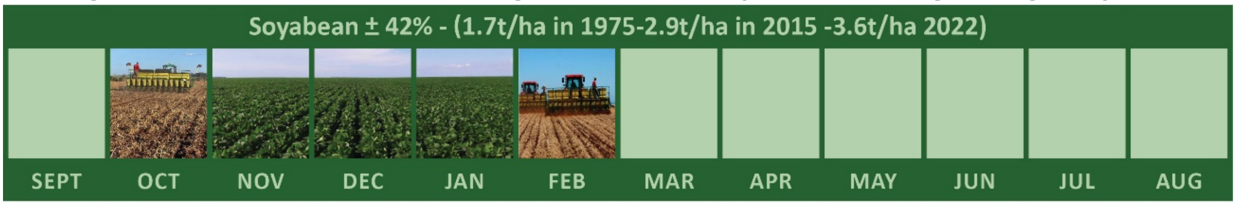
[69] C. A. Nobre, et al. (2023) *Nova Economia da Amazônia*, World Resources Institute.

[70] N. E. Arantes & P. I. M. Souza (1993) Cultura da soja nos cerrados. Simposio sobre a cultura da soja nos Cerrados, Piracicaba: Potafos.

[71] IBGE (2022) Produção Agrícola Municipal.

harvesting, 42% of the useful time of the agricultural property. After harvesting, the soil was exposed and in the other 58% of the useful time, there were greenhouse gas emissions, erosion, low water infiltration, etc. This practice has rapidly expanded to the Amazon biome, providing soy production at very low latitudes, which in the early 1970s was unimaginable. The problem today is no longer to produce soybeans in the Amazon, but rather what production model is used. Figure 13 below illustrates an example of how soil management was done.

Figure 13. Useful time used in the agricultural property in the planting of single soybeans



Data source: L. Embrapa Cerrados Viela (personal communication).

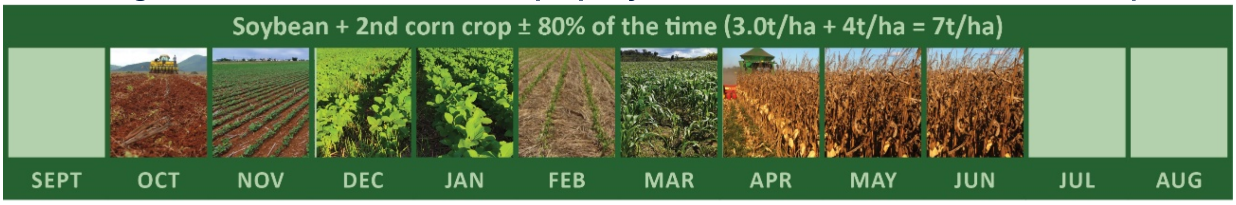
In the case of corn, the cultivars have a longer cycle and the time of use was 50%, with yields starting from 1.8 t ha^{-1} in 1975 (average values of the IBGE) in southern Brazil and reaching an average of 5.77 t ha^{-1} in 2016,[72] a gain of more than 320% in productivity, that is, close to 8% per year, as illustrated in Figure 14.

Figure 14. Useful time of use of a property in the Cerrado only with corn planting

Data source: L. Embrapa Cerrados Viela (personal communication).

As with soybeans, the other 50% of the property's useful time was exposed, emitting greenhouse gases, accentuating erosion and reducing water infiltration into the soil (Figure 15).

Figure 15. Useful time of use of a property in the Cerrado with the off-season crop



Data source: L. Embrapa Cerrados Viela (personal communication).

[72] *Id.*

With the integration of production systems with the introduction of off-season crops, the time of use of the property rises to 80%, which in addition to diversifying production, keeps the soils covered for longer, avoiding soil losses and increasing the water infiltration capacity. The combination of soybean and corn allows a national average productivity of around 7 tons of grains ha^{-1}, and growing at rates higher than 3 to 4% per year. However, experts warn that the continued soybean-corn production system is not sustainable in the long term. To reverse this cycle of problems, one of the solutions lies in diversification. Diversified production systems promote the improvement of the physiological and biological conditions of the soil, assist in the management of pests and diseases, and ensure better economic results. It is in this productive design that the integration of crops, livestock and crops, livestock, and forests comes into play in the medium and long term. These are the main systems recommended in ABC Agriculture (i.e., Low Carbon Agriculture).

Advancing in the integration of systems, there is the option of soybeans and off-season corn and livestock. It is an excellent system, which in addition to allowing a complete soil cover, can in several situations,[73] reduce erosion by 99.7% and water losses by 94%, in addition to allowing a gain of 105 kg of meat per carcass equivalent. The effects of mitigation are known and this is a system adapted to tropical situations with agricultural production almost all year round, in addition to allowing the gain of 105 kg per carcass equivalent ha^{-1}, as illustrated in Figure 16.

Figure 16. Integrated system: Crops (harvest + off-season) and livestock

Data source: L. Embrapa Cerrados Viela (personal communication).

IV. THE BENEFITS OF INTEGRATED CROP-LIVESTOCK-FORESTRY (ICLF)

Agroecosystems of the 21st century must be able to maximize the quantity of high-quality agricultural products and conserve the system's resources. Sustainable agricultural development depends on actions that address the following aspects: a) the conservation of biodiversity and environmental services; (b) reduction of pollution/contamination of the

[73] D. M. S. Resck (1986) Effect of crop residues and liming on soil physical and chemical properties of Tropical and Temperate soils, PhD thesis, Purdue University.

environment and man; (c) soil and water conservation and improvement; d) integrated management of insect pests, diseases and weeds; e) reduction of anthropogenic pressure in the occupation of fragile ecosystems and environments; f) adaptation to new market demands.[74]

By definition, ICLF is a strategy that aims at sustainable rural production, which integrates agricultural, livestock and forestry activities carried out in the same area, in intercropping, in succession or rotational, and seeks synergistic effects between the components of agroecosystems, contemplating environmental adequacy, economic viability and valuing people.[75] Many of the benefits of agricultural integration and the consequent intensification of production and rationalization of the use of resources have been demonstrated year after year and described in the literature.[76] However, the positive characteristics, generally associated with ICLF, are not sufficient to reach conclusions regarding the environmental performance of establishments or the contributions of production systems to the sustainability of rural territories, according to the different contexts of adoption.

Different technological levels were adopted in the experiments observed by Rodrigues et al. (2017),[77] from complete agrosilvopastoral integration to simple succession of degraded pastures - crops intercropped with grass - reformed pasture (ICL). In any case, the implementation of these integration practices invariably implied significant increases in grain productivity and weight gain for a greater number of animals, favoring the indicators of changes in direct land uses. The crop- livestock-forest integration system is the most complete and efficient integrated system advocated by ABC Agriculture.

In general, the ICLF systems used in Brazil are composed of: corn, soybean, rice and beans for grain production and *Brachiaria* for forage production, adding the tree components eucalyptus, pine, teak and more recently paricá and mahogany.

In the Amazon region, it is strongly recommended the adoption of SAF Agroforestry systems, which in addition to allowing the production of fruits and wood of native species, are also

[74] L. C. Balbino, et al. (2011) *Evolução tecnológica e arranjos produtivos de sistemas de integração lavoura-pecuária-floresta no Brasil*, PESQUI. AGROPECU. BRAS. 46(10).

[75] *Id*.

[76] I. Barros, C. R. Martins, G. S. Rodrigues, & A. V. Teodoro (2016) Intensificação ecológica da agricultura. Aracaju: Embrapa Tabuleiros Costeiros, Embrapa Tabuleiros Costeiros.

[77] G. S. Rodrigues, et al. (2017) Avaliação de impactos ambientais de sistemas de integração lavoura-pecuária-floresta conforme contexto de adoção, Jaguariúna: Embrapa Meio Ambiente.

adapted at the beginning of the implementation to the production of grains intercropped with livestock. The presence of trees in agricultural systems increases their resilience in the face of climate change. Systems such as crop-livestock-forest integration and livestock-forest integration are examples. Trees create favorable microclimates, making these systems better able to cope with droughts, extreme heat, and fires.[78] In addition, some native trees, such as *Inga edulis*, *Hymenaea courbaril*, and *Dipteryx odorata*, not only fix nitrogen in the soil, but also provide shade and protein-rich food for animals.[79]

The main technological benefits of SAF systems are:

- Improvement of the physicochemical and biological attributes of the soil due to the increase of organic matter;
- Minimization of the occurrence of diseases and weeds;
- Increased animal welfare, as a result of thermal comfort;
- Greater efficiency in the use of inputs and expansion of the positive energy balance;
- Possibility of application of various systems and production units (large, medium and small properties);
- Reduction in the opening of new areas;
- Improvement in water recharge and quality;
- Promotion of biodiversity and favoring new niches and habitats for pollinators and natural enemies of insect pests and diseases;
- Intensification in nutrient cycling.

The biggest difficulty is to transfer the technology from integrated systems, which involve the planting of trees. Rural producers have more ability to work with pastures and crops, but it is necessary to make an effort to transfer technology.

[78] E. D. Assad, et al. (2022) Adaptation and resilience of agricultural systems to local climate change and extreme events: an integrative review, PESQUI. AGROPECU. TROP. 52.

[79] G. C. Carrero (2016) Sistemas silvipastoris com pastejo rotacional: alternativas sustentáveis para a produção pecuária na Amazônia, Gestão e Governança Local para a Amazônia Sustentável, PQGA/IBAM.

B. Promoting a Sociobioeconomy of Forests and Agroforestry

I. Restoration to Reduce Pressure on the Natural Forest and Foster the Sociobioeconomy

There is an area of more than 50 million hectares with the potential to be restored in the Amazon.[80] This includes 24 million hectares of low-yielding pastures. Undoubtedly, it is possible to eliminate deforestation and forest degradation in the Amazon, while promoting the growth of a sociobioeconomy of healthy standing forests and agroforestry. In fact, estimates from the National Institute for Space Research (INPE) suggest that about 20% of the deforested area has been left abandoned, totaling about 160,000 km^2 in the Brazilian Amazon region. In this context, the adoption of regenerative agricultural practices and the restoration of previously deforested and degraded lands emerge as viable measures to reduce pressure on the forest while producing agricultural and forestry resources.

The economic exploitation of standing forest resources reveals substantial potential that surpasses conventional approaches to deforestation (**Figure 17**). In some parts of the Amazon, studies have shown that Agroforestry systems are more profitable than cattle ranching (**Figure 17A**) or soybean cultivation (**Figure 17B**). In terms of profitability, one hectare of pasture yields US$ 50 to 100 per year,[81] while soybean cultivation yields US$ 100 to 300, being negative in some years in several regions of the Amazon.[82] In fact, Agroforestry systems with the management of açaí (*Euterpe precatoria*), cocoa (*Theobroma cacao*), cupuaçu (*Theobroma grandiflorum*), cassava (*Manihot esculenta*) and other species can generate from $300 to $700 per year (**Figure 17C, D**).[83]

[80] J. Barlow, et al. (2022) *Transforming the Amazon through 'Arcs of Restoration'*, Policy Brief, Science Panel for the Amazon.

[81] F. A. Barbosa, et al. (2015) *Cenários para a pecuária de corte amazônica*, IGC & UFMG (ed.).

[82] C. M. Oliveira, A. C. Santana, & A. K. O. Homma (2013) *Os custos de produção e a rentabilidade da soja nos municípios de Santarém e Belterra, estado do Pará, Ciências Humanas e Sociais*, ACTA AMAZ. 43(1); R. R. Rocha (2020) *Evaluation of conventional soybean production costs: a case study in the municipality of Nova Mutum (Brazil)*. Meio Ambiente.

[83] WWF Brasil (2020) AVALIAÇÃO FINANCEIRA DA RESTAURAÇÃO FLORESTAL COM AGROFLORESTAS NA AMAZÔNIA.

Figure 17. Standing Forest Resources

A. Degraded pastures, B. Soybean cultivation, C. Agroforestry system, and D. Standing forest.

A large-scale forest restoration strategy should be linked to measures to acquire primary production from Agroforestry systems. Such a strategy would require efforts to strengthen associations and cooperatives to acquire all timber and non-timber products from production systems. Such measures are already common in Brazil for agricultural species such as orange, corn, soybean, and cattle. However, they are less frequent in regard to native Amazon species, such as açaí, Brazil nut and cocoa, and are carried out by social organizations such as the Association of Small Agroforesters of the Reca Project (RECA) and the Mixed Agricultural Cooperative of Tomé-Açu (CAMTA).

In terms of timber management, the production of native wood obtained from the recovery of degraded lands has been shown to be economically feasibility.[84] Brazil nut (*Bertholletia excelsa*), andiroba (*Carapa guianensis*), and paricá (Schizolobium *parahyba amazonicum*) showed a cost/benefit ratio of 2.26 and an Internal Rate of Return of 21.7% per hectare after a 30-year cycle. However, the economic efficiency of wood production can be optimized by increasing productivity through genetic selection and investments in innovation in the timber sector, which is still dominated by low-skilled activities.[85]

Similarly, the collection of non-timber forest products (NTFP) through sustainable extractivism and agroforestry system management has generated around $2 billion per year throughout the Amazon.[86] Fruits, seeds and roots of açaí (*Euterpe* spp), cocoa (*T. cacao),* Brazil nut (*B. excelsa*), cupuaçu *(T. grandiflorum*) and cassava (*M. esculenta)* are among the main products traded in the region. In the municipalities of Pará alone, it is estimated that around $1 billion per year is estimated.[87] However, most NTFPs are traded without any technological processing, contributing to the low value added in the region.[88]

In addition to the timber products and NTFP already mentioned, there are other species with high economic potential in the Amazon. Some of these include buriti (*Mauritia flexuosa* L.), copaiba (*Copaifera* spp), cubiu (*Solanum sessiliflorum*), cupuaçu (*T. grandiflorum*), guaraná (*Paullinia cupana*), jaborandi (*Pilocarpus microphyllus*), murici (*Byrsonima* spp), taperebá (*Spondias mombin*), tucumã (*Astrocaryum aculeatum*) and tururi (*Manicaria saccifera*). In addition to plant products, species of microalgae and freshwater porifera native to the Amazon are recognized by scientists as having high economic potential. Microalgae act in the production of biodegradable polymers, and porifera (*Metania reticulata*) draw attention due to

[84] S. Brienza-Júnior, et al. (2008) *Recuperação de áreas degradadas com base em sistema de produção florestal energético-madeireiro: indicadores de custos, produtividade e renda*, AMAZÔNIA: CI. & DESENV. 4(7).

[85] *Id*.

[86] IBGE (2021) Produção da extração vegetal e da silvicultura.

[87] F. A. Costa, et al. (2021) *Bioeconomia da sociobiodiversidade no Estado do Pará*, Brasília: The Nature Conservancy, Banco Interamericano de Desenvolvimento (BID), Natura.

[88] *Id*.; ICMBIO, 2019; Instituto Chico Mendes de Conservação da Biodiversidade (2019) Catálogo dos produtos da sociobiodiversidade do Brasil ofertados pelos povos e comunidades tradicionais em unidades de conservação federais.

their bioactivity against diseases such as malaria, in addition to acting as filter feeders with the ability to retain metals from mining activities.[89]

II. Bio-Industrialization at the Service of the Peoples of the Amazon

Products from Agroforestry systems using native trees can drive a new economic cycle in the Amazon. To achieve this, investments in processing technological will be required to transform primary products into industrialized items with higher added value.

The Amazon 4.0 Initiative,[90] aimed at boosting innovation in the region for the good of its local populations, proposes as one of the essential pillars for a new sociobioeconomy of healthy standing forests, investments in biofactories of biodiversity products and the implementation of the Amazon Institute of Technology (AmIT), inspired by the renowned Massachusetts Institute of Technology (MIT). AmIT aims to promote innovation and decentralized education, with research and teaching centers throughout the Pan-Amazon. Its approach encompasses topics such as water, forests, socio- biodiversity, altered landscapes, green infrastructure, and sustainable urbanism that will support regional entrepreneurship. A highlight is the integration of knowledge and practices from Indigenous Peoples and local communities, ensuring a holistic perspective.[91]

Investing in technology is essential to add value to the products of Amazonian ecosystems, including those from the restoration of forests and rivers.[92] The selling price of primary products can increase by 2-5 times. For example, fresh *unpeeled* seeds of Brazil nut (*B. excelsa)* ranged from $2 to $4 per kilogram, while dehydrated seeds (after pre-processing) are sold for $15. Andiroba seeds (*Carapa* spp.) were priced between $0.4 and $2.3 per kilogram, and the oil extracted from the seeds reached values between $7 and $12. Açaí fruits (*Euterpe* spp.) were sold for $0.4 to $0.5 per kilogram, with pulp sold for $2 to $3 and oil for $76. These examples

[89] M. L. Lopes-Assad (2023) Amazônia Brasileira: Produtos Nativos para a Sustentabilidade do Desenvolvimento Regional, Observatório de Conhecimento e Inovação em Bioeconomia, Fundação Getúlio Vargas - FGV-EESP, São Paulo, SP, Brasil.

[90] See Amazônia 4.0: https://amazonia4.org/lca/.

[91] Id.

[92] I. Nobre & C. A. Nobre (2018) *The Amazonia third way initiative: the role of technology to unveil the potential of a novel tropical biodiversity-based economy*, in LAND USE: ASSESSING THE PAST, ENVISIONING THE FUTURE, L. C. Loures, IntechOpen.

illustrate the potential for adding value by investing in basic industrial infrastructure, such as dewatering, pulping, pressing, refrigeration, and pasteurization equipment.[93]

RECA[94] and CAMTA[95] are examples of how social organization and technology aligned with forest conservation can increase the income of local communities and small farmers. RECA was founded in 1987 and currently has the involvement of more than 300 farming families, who supply more than two thousand tons of non-timber forest products per year. CAMTA began the industrialization of products originated in Agroforestry systems in 1987, and currently has 170 direct employees and 1800 farming families that supply primary products for industrialization. These social organizations mainly produce fruit pulp, dehydrated seeds, and vegetable oils, and due to bio-industrialization, most farmers in Agroforestry systems have reached the middle class.

However, there is a significant lack of enterprises with technologies to add value to the products from Agroforestry systems in the Amazon. Studies that mapped the agro-industries of five non- timber forest products widely used in the Amazonian economy identified only 55 municipalities (county) that have technological infrastructure capable of transforming primary products into products with some level of added value. This was observed when 532 municipalities were assessed, which indicates that 90% of the Brazilian Amazon totally lack basic technological infrastructure to add value to regional products.[96]

There is still little knowledge about the costs of setting up factories for processing Amazonian products. An example of a more modest factory was implemented at a cost of USD 100 thousand.[97] This factory is capable of absorbing all the agroforestry production of more than 300 families living in local communities. The factory had equipment and machines for pulping, drying, grinding, distilling and filtering oils and fats of native species. It is estimated that the infrastructure is capable of processing three tons of fixed oils and 90 liters of essential oil per

[93] D. O. Brandão (2023) *Desmatamento na Amazônia e influência nos produtos florestais não-madeireiros de uso econômico local*, São José dos Campos: Instituto Nacional de Pesquisas Espaciais.

[94] Reca Amazônia, Quem somos.

[95] See Cooperativa Agrícola Mista de Tomé-Açu: https://www.camta.com.br/index.php/en/.

[96] D. O. Brandão, L. E. S. Barata, I. Nobre, & C. A. Nobre (2021) *The effects of Amazon deforestation on non-timber forest products*, REG. ENVIRON. CHANGE 21.

[97] IDESAM (2020) Miniusina de óleos vegetais: mais geração de renda aos comunitários da RDS do Uatumã.

month, generating an estimated annual revenue of around USD 200 thousand, using its entire production capacity.[98]

When more investments are made in industrialization, the results become more promising. Due to the investments made in technologies, CAMTA has become an important exporter of tropical fruits to countries such as Japan, Israel, the United States, and French Guiana.[99] This experience has motivated new investments, such as those made in 2022, which totaled R$ 20 million in refrigeration infrastructure, cold room for fruits, fruit packaging room, expansion of the freezing tunnel, certification, improvement of production equipment, creation of new production lines, acquisition of forklifts, effluent treatment machines, ice breaker, new line for açaí washing, pasteurizer and power generators. The example of CAMTA has been disseminated within Brazil, as in other countries such as Bolivia and Ghana.[100]

An intermediate-cost factory, situated between the modest factory[101] and CAMTA's infrastructure,[102] is estimated at USD 1.2 million.[103] The factory, structured by the Amazônia 4.0 (www.amazon4.org) project, aims to produce fine chocolate from cocoa and cupuaçu, but also allows adaptation to other production chains.[104] The central idea of the Amazônia 4.0 project is to demonstrate the feasibility of a new sociobioeconomy through bio-industrialization in rural and urban communities in the Amazon. The investment is related to the technologies used in production, which include a genomics laboratory, a futuristic design inspired by Indigenous huts, broadband internet connectivity, modular materials for expansion, 3D printers for food and packaging, water treatment systems, and energy self-sufficiency. However, there is still a lack of cases of enterprises in the Amazon with technological characteristics typical of Industry 4.0, combining nature-based science and innovations with the traditional knowledge of Indigenous Peoples and local communities.

[98] *Id.*

[99] OCB PARA (2022) CAMTA reinaugura parque fabril.

[100] *Id.*

[101] IDESAM, supra note 100.

[102] Supra notes 97, 101.

[103] Supra note 92.

[104] *Id.*

The knowledge acquired through the Amazônia 4.0 project reveals that the potential for added value by industrialization can be even more expressive. For example, cocoa production is usually sold for approximately USD 2 per kilogram of seeds, while fine chocolate can reach values between USD 20 and 40 per kilogram. Traditionally, the proportion of cocoa present in chocolate ranges from at least 25% of total solids to 70% for the darkest chocolate.[105] This implies that the added value of the seed in the production of fine cocoa chocolate can be more than 10 times higher compared to simply selling the seeds.

III. Incentives for Science, Technology and Innovation (ST&I)

Some other requirements for strengthening the bioeconomy of standing forests include innovation, science and technology measures, financial compensation for reducing deforestation and forest degradation, fishing and fish farming, ecotourism, payment for environmental services, and the installation of sustainable infrastructure. These options can help reduce pressure on the forest and ensure its long-term conservation. In this context, for a more detailed understanding of each of these economic demands of standing forests, the following paragraphs will synthetically address each of them, including some challenges to their implementation at scale.

Mechanisms that offer financial compensation for the reduction of deforestation and forest degradation are necessary in the standing forest bioeconomy. For example, the international mechanism known as REDD+ (Reducing Emissions from Deforestation and Forest Degradation) has been implemented in the Amazon, which is consistent with the decisions of the United Nations Framework Convention on Climate Change (UNFCCC), including the Paris Agreement and the Cancun Safeguards. However, the challenges of financial resource distribution, the pressure exerted by selective logging, illegal mining, and land grabbing[106], and the lack of effective public policies are some of the main challenges faced in the region for the success of REDD+ projects.[107]

Fishing and fish farming are vital activities for food security, providing protein and fat for local and regional populations. The main fishing resources include a variety of species, such as curimatã, jaraqui, tambaqui, dourada, filhote, mapará, pacu, surubim, tucunaré and arapaima.

[105] Ministério da Saúde, Agência Nacional de Vigilância Sanitária (2005) RESOLUÇÃO-RDC No 264.

[106] I. Vieira (13 January 2023) *A ameaça da "grilagem" do carbono florestal na Amazônia*, LIBERAL AMAZON.

[107] R. Abramovay, et al. (2021) *Chapter 30: Opportunities and challenges for a healthy standing forest and flowing rivers bioeconomy in the Amazon*, in AAR 2021.

However, overfishing and bycatch pose one of the main threats to the region's aquatic biodiversity. Another threat is contamination by heavy metals, such as mercury, from illegal mining. This contamination mainly affects Indigenous and riverine communities, who depend on fishing as a source of protein.[108]

The immense socio-biodiversity of the Amazon places it in a privileged position in the context of ecotourism.[109] In fact, nature is considered a decisive factor for travelers' choice of destination, both for domestic and foreign tourism. However, the Amazon is not on the list of most visited destinations globally, indicating that the potential of the Amazon is undertapped. Studies indicate that the main challenges for tourism in the Amazon are to reconcile the reality of commercial capitalism and local communities with their traditional forms of subsistence and social relations, as well as to control the disorderly growth of tourism to avoid problems for nature and local communities.[110]

In turn, Payment for Environmental Services (PES) is a voluntary transaction in which a payer provides financial resources or another form of remuneration to an environmental service provider. Environmental services promote the maintenance, recovery, or improvement of ecosystem services, which are the benefits that ecosystems offer to society. The Amazon provides an extensive array of essential ecosystem services, but economically quantifying their attribution also presents significant challenges. This includes accounting for variations in land use and ecological systems among different regions,[111] and others, such as equitably distributing benefits and ensuring effective and long-lasting positive effects. It is necessary to address these challenges in an integrated and collaborative manner to ensure that PES can effectively contribute to the economy of the standing forest.[112]

A new sociobioeconomy of healthy standing forests and flowing rivers in the Amazon requires infrastructure similar to that found in sustainable cities, including renewable energy sources.

[108] *Id.*

[109] J. L. Gazoni & I. L. G. Brasileiro (2018) *Tourism as an instrument of forest protection in the Amazon: a multivariate analysis*, REV. BRAS. PESQ. TURISMO 12(3).

[110] Abramovay, supra note 110.

[111] J. Strand, et al. (2018) *Spatially explicit valuation of the Brazilian Amazon Forest's Ecosystem Services*, NAT. SUSTAIN. 1(11).

[112] Abramovay, supra note 110.

The economic feasibility of photovoltaic systems in Brazil is proven,[113] and technological advances are rapidly decreasing the costs of solar panels. The cost per watt of energy produced fell from $79.67 in 1977 to $0.36 in 2014.[114] Similarly, energy storage equipment, such as lithium batteries, has reduced costs by 400% between 2010 and 2020.[115] With the economic feasibility of solar panels and batteries, a future powered by renewable and low-carbon energy becomes possible in the Brazilian Amazon, where approximately 155,000 rural households still do not have access to the electricity grid.[116]

Therefore, ST&I, financial compensation for the reduction of deforestation and forest degradation, fishing and fish farming, ecotourism, payment for environmental services, sustainable infrastructure are all important strategies to strengthen a standing forest economy in the region. These measures are essential to move the Amazon away from the tipping point, and are implemented in the long term. Public and private organizations have a key role to play in establishing these sustainable economic activities, working in partnership with Indigenous Peoples and local communities to ensure responsible management of natural resources and territories.

5. Conclusions

Over the last few decades, the expansion of pastures and the increase in the number of cattle in the Legal Amazon have been intrinsically linked to deforestation and forest degradation, making agricultural activity the main source of climate pollution in Brazil. Reducing GHG emissions from deforestation, degradation, and livestock production in the Legal Amazon is a critical need to prevent the regional climate from reaching unbearable extremes due to the loss of essential ecosystem services provided by the forest, such as rainfall recycling, surface cooling, and food security.

The Legal Amazon is home to 43% of Brazil's cattle herd, highlighting its importance in national livestock production. However, 537 of the 808 municipalities in the Legal Amazon face serious

[113] Instituto De Pesquisas Econômica Aplicada (2018) *Viabilidade econômica de sistemas fotovoltaicos no Brasil e possíveis efeitos no setor elétrico*, Brasília: Rio de Janeiro.

[114] P. Diamandis (2014) *Solar Energy Revolution: A Massive Opportunity*, FORBES.

[115] *Id*.

[116] A. S. Sánchez, E. A. Torres, & R. A. Kalid (2015) *Renewable energy generation for the rural electrification of isolated communities in the Amazon Region*, RENEW. SUSTAIN. EN. REV. 49.

problems of pasture degradation, resulting in high CO_2 and methane emissions, as well as low stocking capacity. About 55% of total methane emissions in the Brazilian agricultural sector originate in the Legal Amazon, due to enteric fermentation and inadequate waste management. Solving these challenges depends on political and business actions, including national and international commitments to eliminate deforestation, restrict meat exports associated with deforestation, and promote public policies that encourage sustainable production models.

Encouraging the adoption of regenerative and low-carbon agricultural practices, especially in the Amazon, has the potential to drastically reduce net emissions from livestock, even neutralize them, through the growth of regenerative livestock farming and the increase of Agroforestry Systems (AFS). The recovery of degraded pastures and the intensification of cattle ranching can reduce the time it takes to slaughter animals to 24 months, reducing methane emissions by about 33% in the Legal Amazon. In addition, the implementation of integrated systems, such as Crop-Livestock- Forest, emerges as an essential mechanism to increase agricultural and livestock production in the region, allowing doubling grain production and increasing livestock production by 30%, without resorting to deforestation. AFS are highly recommended in the Amazon region and can serve as a model for pasture areas within private properties, promoting the sustainable production of fruits and native wood, as well as the intercropping of grains with livestock, making agricultural systems more resilient to climate change.

In light of this, it is imperative that Brazil establish a Green Deal for the Amazon, as an urgent commitment to reduce deforestation and degradation, and foster regional development through a new sociobioeconomy of healthy standing forest and flowing rivers. This great challenge needs to be encouraged with investments in the education of its population, at basic and technical levels, for technological innovation and integration of scientific and traditional knowledge, which results in creative and participatory solutions to reduce the impacts of conventional livestock farming and the creation of markets for value-added products from the standing forest, and for the guarantee of benefits to its Indigenous and local population.

A Primer on the Importance of Reducing Short-lived Climate Pollutants for the Inter-American Court of Human Rights

Drew Shindell[1]

Purpose and Summary

Short-lived climate pollutants (SLCPs) are climate forcers many times more powerful than carbon dioxide but with a much shorter residence times in the atmosphere. Many of them are also air pollutants that are harmful to people, ecosystems, and agricultural productivity. The contribution of SLCPs to anthropogenic climate change, alongside their impact on air quality, means that they pose a direct threat to human lives and while simultaneously undermining other ecosystem services that support human life.

Because short-lived climate pollutants can be removed from the atmosphere in periods ranging from days to 15 years, reducing their emissions can make quick headway on slowing global warming. These pollutants can be significantly reduced using technologies available today, and actions to reduce them have the potential to deliver significant additional benefits for human health, crop yields, and economies.

Speed is crucial in the fight against climate change. The planet has already warmed more than 1°C. According to the International Panel on Climate Change (IPCC), warming above 1.5–2°C would have devastating consequences. The only way to avoid passing this threshold – and the most dangerous impacts of climate change – is by reducing short-lived climate pollutants together with deep and persistent cuts in carbon dioxide (CO_2).

Background on the Climate & Clean Air Coalition Scientific Advisory Panel

The Climate and Clean Air Coalition is the only global effort that unites governments, civil society, and private sector, committed to improving air quality and protecting the climate in the

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next few decades by reducing SLCPs. The Coalition supports the achievement of transformative actions, policies, and regulations that lead to substantial reductions in these pollutants. The Coalition's Scientific Advisory Panel members are international experts who advise the Coalition on scientific matters related to short-lived climate pollutants, air pollution, and near-term climate change.

The Short-Lived Climate Pollutants (SLCPs) and their Impacts

SLCPs and co-emitted pollutants have important impacts on our climate system and the quality of our air. Methane, Black Carbon (BC), and ozone (O_3) are the most important contributors to current global warming after carbon dioxide (CO_2).[2] Together, SLCPs are the largest contributors to global warming after carbon dioxide. They are responsible for up to 45% of global warming to date (gross warming due to all warming agents),[3] contribute to the 7-10 million annual premature deaths from outdoor air pollution,[4] and cause 110 million tonnes of crop losses each year.[5]

Figure 1. The SLCPs

[2] S. Szopa, *et al.* (2021) *Chapter 6: Short-lived climate forcers*, *in* CLIMATE CHANGE 2021: THE PHYSICAL SCIENCE BASIS, V. Masson-Delmotte, *et al.* (eds.).

[3] *Ibid*.

[4] World Health Organization (2016) *Air pollution: A global assessment of exposure and burden of disease*; R. Burnett, *et al.* (2018) *Global estimates of mortality associated with long-term exposure to outdoor fine particulate matter*, PROC. NAT'L. ACAD. SCI. 115(38); K. Vohra, *et al.* (2021) *Global mortality from outdoor fine particle pollution generated by fossil fuel combustion: Results from GEOS-Chem*, ENVIRON. RES. 195(110754).

[5] D. Shindell, *et al.* (2012) *Simultaneously Mitigating Near-Term Climate Change and Improving Human Health and Food Security*, SCIENCE 335(6065).

Outdoor air pollution is the leading environmental cause of premature deaths worldwide, and it is the leading cause of all types for women & children in many developing nations. It is also important in developed nations, for example, the United States suffered approximately 135,000 premature deaths; 180,000 non-fatal heart attacks; 150,000 hospitalizations for respiratory & cardiovascular disease; 130,000 emergency room visits for asthma; 18,000,000 lost workdays and 11,000,000 missed school days annually as a result of poor air quality around 2010.[6]

Agricultural effects of SLCPs are not simply proportional to induced climate change as damages related to climate such as higher temperatures and extreme rainfall are partially offset for CO_2 by fertilization whereas they are not offset for HFCs or BC. For methane, climate-related damages are not only not offset by substantial CO_2 fertilization, but they are in fact augmented via ozone production, as ozone toxic to plants as well as people. Examples in the literature include this comparison.

Table 1. Projected Additional Yield (millions tons/yr) for Low vs High Emissions

CO_2	~165
Methane	~800
HFCs	~250

A. Methane & Tropospheric Ozone

Methane is a powerful greenhouse gas, with a warming effect 86 times stronger than CO_2 over 20 years. According to the Sixth Assessment Report (AR6) of the Intergovernmental Panel on Climate Change,[7] methane has caused 0.51°C of warming of the total observed 2010–2019 warming relative to 1850-1900. Over 60% of methane is emitted human activities such as leakage from natural gas systems and livestock production.

Methane is a key precursor of tropospheric ozone, a major air pollutant and greenhouse gas. Tropospheric, or ground level, ozone is not directly emitted, but is formed by the interaction of sunlight with methane and emissions from vehicles, fossil fuel power plants, and other

[6] N. Fann, *et al.* (2012) *Estimating the national public health burden associated with exposure to ambient PM2.5 and ozone*, RISK ANAL. 32(1).

[7] Intergovernmental Panel on Climate Change (2021) *Summary for Policymakers*, *in* CLIMATE CHANGE 2021.

industries. Globally, increased methane emissions are responsible for half of the observed rise in tropospheric ozone levels.

Tropospheric ozone, a major component of smog, can worsen bronchitis and emphysema, trigger asthma, and permanently damage lunch tissue. Every year, tropospheric ozone is responsible for about 1 million premature respiratory deaths globally. Overall, methane's impacts on climate change and public health contributes to a yearly loss of roughly 400 million hours of work globally due to extreme heat.

Tropospheric ozone is a highly reactive oxidant that significantly reduces crop productivity as well as the uptake of atmospheric carbon by vegetation. Its effects on plants include impeded growth and seed production, reduced functional leaf area and accelerated ageing. Studies have shown that many species of plants are sensitive to ozone, including agricultural crops, grassland species and tree species. These effects damage important ecosystem services provided by plants, including food security, carbon sequestration, timber production, and protection against soil erosion, avalanches, and flooding. The Global Methane Assessment found that every million tonnes of methane emissions contribute to losses of 145,000 tonnes of wheat, soybeans, maize and rice.

B. Black Carbon

Also known as soot, black carbon is product of incomplete combustion of fossil fuels, biofuels and biomass. It is typically emitted along with organic carbon and carbon monoxide. It is associated with large adverse health impacts, warming, disruption of traditional rainfall patterns, increases melting rate of snow and ice.

The climate impacts of black carbon are highly regionalised. For example, black carbon in the lower atmosphere has been shown to disturb rainfall and regional circulation patterns, such as the Asian Monsoon, with effects on regional precipitation that is disproportionately large relative to its effect on global mean annual average temperatures.[8] In glaciated and the polar regions, black carbon darkens the surface of snow and ice, increasing the absorption of sunlight and exacerbating melting.

[8] *See e.g.*, Chandra's papers as in her Bangkok presentation, X. Xie, *et al.* (2020) *Distinct responses of Asian summer monsoon to black carbon aerosols and greenhouse gases*, ATMOS. CHEM. PHYS. 20(20); D. Shindell, *et al.* (2023) *The important role of African emissions reductions in projected local rainfall changes*, NPJ CLIM. ATMOS. SCI. 6(1).

Black carbon is a component of fine particulate matter ($PM_{2.5}$). $PM_{2.5}$ is a one of the leading environmental causes of ill health and premature death. In 2019, long-term exposure to $PM_{2.5}$ contributed to more than 4 million deaths globally.[9]

C. HYDROFLUOROCARBONS (HFCS)

HFCs are entirely human-made. They are primarily produced for use in refrigeration, air-conditioning, insulating foams, and aerosol propellants, with minor uses as solvents and for fire protection.

Most HFCs are contained within equipment, so emissions are the result of wear, faulty maintenance, or leakage at the end of a product's lifetime. Though HFCs represent a small fraction of current greenhouse gas emissions, their potential to warm the atmosphere is hundreds to thousands of times greater than that of CO_2.

While emissions of HFCs are currently small, they were projected to rise and reach levels equivalent to 7 to 19% of CO_2 emissions by 2050 prior to the Kigali Agreement.[10] There is still the possibility of accelerating their phaseout beyond Kigali, as well as a need to see that Agreement followed through. These pollutants are present in the atmosphere for a few days up to a few years.[11]

Why Timing Matters: SLCP Mitigation Contribution to Climate and Development Goals

Because short-lived climate pollutants are present in the atmosphere for a much shorter period than carbon dioxide, they can be removed from the atmosphere much more quickly. They therefore provide the strongest plausible leverage to reduce the rate of warming over the next few decades.[12] The speed at which SLCPs can be removed from the atmosphere presents an

[9] Health Effects Institute (2020) STATE OF GLOBAL AIR 2020, Special Report, Health Effects Institute.

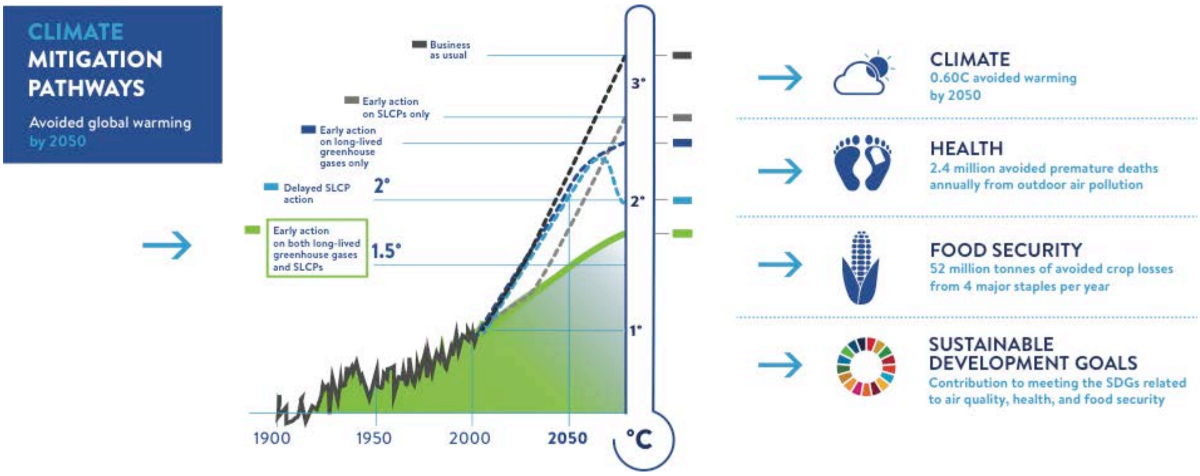
[10] United Nations Environment Programme and World Meteorological Organization (2011) INTEGRATED ASSESSMENT OF BLACK CARBON AND TROPOSPHERIC OZONE.

[11] Szopa, *Ch. 6: Short-lived climate forcers*, *in* CLIMATE CHANGE 2021.

[12] United Nations Environment Programme & Climate & Clean Air Coalition (2021) GLOBAL METHANE ASSESSMENT: BENEFITS AND COSTS OF MITIGATING METHANE EMISSIONS; G. B. Dreyfus, *et al.* (2022) *Mitigating climate disruption in time: A self-consistent approach for avoiding both near-term and long-term global warming*, PROC. NAT'L. ACAD. SCI. 119(22).

opportunity not only for quick, coordinated action to address global warming but also to achieve immediate benefits for development and human health.

Figure 2. Warming Trajectories Associated with Various SLCP and Long-lived Greenhouse Gas Controls



Although there are many paths, we can take to reach the Paris Agreement temperature targets, the path we choose will determine if we will avoid an irreversible climate crisis. Simultaneous mitigation of short-lived climate pollutants and CO_2 is the best possible scenario for achieving the Paris Agreement target. Delayed action on CO_2 or SLCP control measures will have significant, and potentially irreversible, negative impacts on temperature, cumulative sea-level rise, and human well-being (**Figure 2**).

Fast and immediate action on short-lived climate pollutants can avoid 0.6°C of warming by 2050. It will also avoid over 50% of predicted warming in the Arctic by 2050 and significantly reduce the risk of triggering dangerous climate tipping points, like the release of carbon dioxide and methane from thawing Arctic permafrost. Because some processes of the climate system, especially melting of the large land ice sheets of Greenland and Antarctica, have a nearly unstoppable momentum once begun, even with aggressive CO_2 and SLCP mitigation two-thirds of predicted sea-level rise is likely to be inevitable. But early mitigation could reduce its rate by up to one half, which would reduce vulnerability by giving coastal communities and low-lying states additional time to adapt.[13]

[13] A. Hu, *et al*. (2013) *Mitigation of short-lived climate pollutants slows sea-level rise*, NAT. CLIM. CHANGE 3.

There are also multiple health, social and development benefits to action to reduce short-lived climate pollutants. These benefits can be perceived almost immediately where action has been taken. These include dramatic reductions in indoor air pollution in developing countries resulting from increased access to modern energy instead of traditional use of biofuels or coal for cooking and/or heating (indoor air pollution also kills millions prematurely every year).[14]

Early mitigation of SLCPs *helps to meet SDGs* and, within the goal of climate action (based on Shindell *et al.* 2017):[15]

- Reduces damages due to climate change over the next few decades, including those dependent upon the pace of climate change such as biodiversity losses.
- Slows amplifying feedbacks such as snow/ice-albedo that are highly sensitive to BC.
- Reduces the risk of potential non-linear changes such as release of carbon from permafrost or ice sheet collapse.
- Increases the chance of staying below 2°C through mid-century.
- Reduces long-term cumulative climate impacts.
- Reduces costs of meeting temperature targets.
- Stimulates progress toward the long-term 2°C target through achievement of near-term benefits.

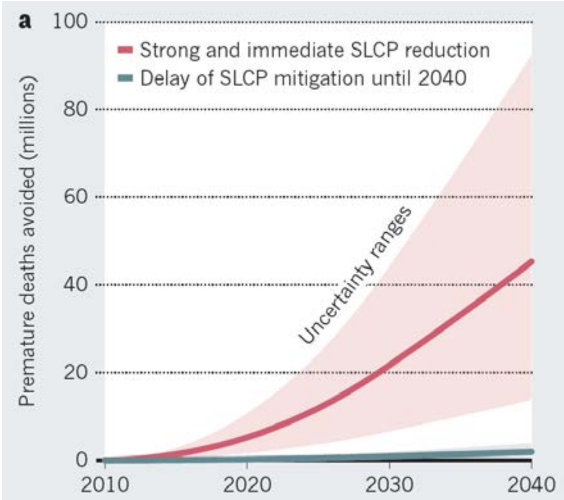
Comparing strong and immediate reductions in SLCPs against waiting 20 years, Schmale *et al.* (2014) reported that immediate action would avoid ~45 million premature deaths (**Figure 3**) and ~1 billion tonnes rice, wheat, soy & maize relative to delayed action.[16]

[14] WHO, *Air pollution: A global assessment of exposure and burden of disease*.

[15] D. T. Shindell, *et al*. (2017) *A climate policy pathway for near- and long-term benefits*, SCIENCE 356(6337).

[16] J. Schmale, *et al*. (2014) *Clean up our skies*, NATURE 515.

Figure 3. Premature Deaths Avoided with SLCP Reductions



How to Get SLCP Reductions

A. Methane & Tropospheric Ozone

While the amount of methane in the atmosphere is increasing at record-high rates, the Global Methane Assessment described how there are technical targeted control measures available today that could reduce methane emissions by 30% of projected 2030 anthropogenic emissions (or ~120 Mt per year).[17] Methane mitigation is very likely the strategy with the most potential to decrease warming in the next 20 years. Most of the methane mitigation from technical control measures over the next decade come from the fossil fuel sector (reducing intended and inadvertent emissions during extraction, storage and long-distance transport of coal, and oil and gas). Waste and rice production also provide opportunities via improved waste management and alternate growing techniques, while reductions from the livestock sector are less consistent across available analyses and many require behavioural measures as well.

Current targeted solutions alone, however, are not enough to achieve 1.5°C consistent mitigation by 2030. To achieve that, additional measures must be deployed, which could reduce 2030 methane emissions by another 15%, about 60 Mt/yr. Examples include decarbonization measures – such as a transition to renewable energy and economy-wide energy efficiency improvements. Behavioural change measures and innovative policies such

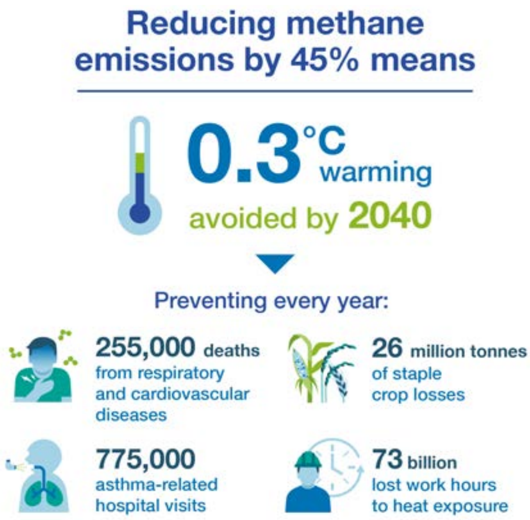
[17] UNEP & CCAC, GLOBAL METHANE ASSESSMENT.

as reducing food waste and loss, improving livestock management, and the adoption of healthy diets, are particularly important to prevent emissions from agriculture.

Benefits would be 0.3°C avoided warming by the 2040s, preventing 255,000 premature deaths from respiratory and cardiovascular diseases, 775,000 asthma-related hospital visits, 26 million tonnes of staple crop losses and 73 billion lost work hours due to heat exposure (Figure 4). Avoided warming and labor losses occur in the 2040s, other impacts are annual values beginning in 2030 that would continue thereafter.

More than 60% of the strategy control measures have low or negative costs. The greatest potential for negative cost abatement is in the oil and gas subsector where captured methane adds to revenue instead of being released to the atmosphere.

Figure 4. Benefits of Methane Emissions Cuts



B. Black Carbon

As described in detail in UNEP & WMO (2011) and Shindell *et al.* (2012), there are many existing options to reduce emissions of black carbon and co-emissions (e.g. Organic Carbon, Carbon Monoxide).[18] These include:

- Adding particle filters to diesel vehicles
- Replacing coal in residential stoves

[18] UNEP & WMO, INTEGRATED ASSESSMENT; Shindell, *Simultaneously Mitigating Near-Term Climate Change*.

- Replacing residential wood burning in Industrialized countries
- Switching to clean-burning cookstoves in developing countries
- Modern brick kilns
- Modern coke ovens
- Banning the open burning of agricultural waste
- Replacement of kerosene lamps

Conclusions

Reducing SLCPs is important to:

- those already suffering from the impacts of climate change
- preventing biodiversity loss
- providing additional time for adaptation
- realize the associated health, agricultural and economic benefits

Tackling both near-term and long-term climate change is critical:

- Near-term for our & our children's generations
- Long-term for our children's & grandchildren's generations

Mitigating climate disruption in time: A self-consistent approach for avoiding both near-term and long-term global warming

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Mitigating climate disruption in time: A self-consistent approach for avoiding both near-term and long-term global warming

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The ongoing and projected impacts from human-induced climate change highlight the need for mitigation approaches to limit warming in both the near term (<2050) and the long term (>2050). We clarify the role of non-CO_2 greenhouse gases and aerosols in the context of near-term and long-term climate mitigation, as well as the net effect of decarbonization strategies targeting fossil fuel (FF) phaseout by 2050. Relying on Intergovernmental Panel on Climate Change radiative forcing, we show that the net historical (2019 to 1750) radiative forcing effect of CO_2 and non-CO_2 climate forcers emitted by FF sources plus the CO_2 emitted by land-use changes is comparable to the net from non-CO_2 climate forcers emitted by non-FF sources. We find that mitigation measures that target only decarbonization are essential for strong long-term cooling but can result in weak near-term warming (due to unmasking the cooling effect of coemitted aerosols) and lead to temperatures exceeding 2 °C before 2050. In contrast, pairing decarbonization with additional mitigation measures targeting short-lived climate pollutants and N_2O, slows the rate of warming a decade or two earlier than decarbonization alone and avoids the 2 °C threshold altogether. These non-CO_2 targeted measures when combined with decarbonization can provide net cooling by 2030 and reduce the rate of warming from 2030 to 2050 by about 50%, roughly half of which comes from methane, significantly larger than decarbonization alone over this time frame. Our analysis demonstrates the need for a comprehensive CO_2 and targeted non-CO_2 mitigation approach to address both the near-term and long-term impacts of climate disruption.

climate mitigation | short-lived climate pollutants | fossil fuel radiative forcing | near-term warming | non-CO_2 climate effects

Significance

This study clarifies the need for comprehensive CO_2 and non-CO_2 mitigation approaches to address both near-term and long-term warming. Non-CO_2 greenhouse gases (GHGs) are responsible for nearly half of all climate forcing from GHG. However, the importance of non-CO_2 pollutants, in particular short-lived climate pollutants, in climate mitigation has been underrepresented. When historical emissions are partitioned into fossil fuel (FF)- and non-FF-related sources, we find that nearly half of the positive forcing from FF and land-use change sources of CO_2 emissions has been masked by coemission of cooling aerosols. Pairing decarbonization with mitigation measures targeting non-CO_2 pollutants is essential for limiting not only the near-term (next 25 y) warming but also the 2100 warming below 2 °C.

Global warming is causing climate disruption today. At about 1.1 °C warming above preindustrial temperature (1), these impacts are being felt sooner and more intensely than previously projected (2). The frequency and intensity of climate and weather extremes have increased due to human-induced climate changes (1), and impacts such as displacements due to extremes are expected to grow with additional global warming (2).

We make a distinction between near-term warming and long-term warming: Near-term warming refers to the warming from now until 2050, while long-term refers to the period beyond 2050. This distinction omits the "mid-term (2041 to 2060)" recently introduced in the Intergovernmental Panel on Climate Change's (IPCC) Sixth Assessment Report (AR6) (1). When the focus is on long-term, decarbonization to reach net-zero carbon dioxide emissions should be the foremost goal. However, a new set of issues has emerged because of the link between warming and extreme weather (3) and the risk of crossing uncertain tipping points that increase with additional warming (1, 4).

Every region is experiencing extreme weather impacts from climate change (2, 5). The number of potentially fatal humid heat events doubled between 1979 and 2017 (6), while heat-related mortality in people over 65 y increased 53.7% (7). Such fatal humid heat events are expected to become common in the tropics at global average temperatures above 1.5 °C (8, 9). Increases in humid heat also reduce labor productivity, with current losses of annual gross domestic product up to 6% in tropical countries (7) and nonlinear increases under warming (10). Actions that limit warming to close to 1.5 °C would "substantially reduce projected losses and damages related to climate change in human systems and ecosystems, compared to higher warming levels, but cannot eliminate them all (*very high confidence*)" (2).

The critical need to curb near-term warming and limit warming to well below 2 °C requires broadening the zero carbon dioxide emissions approach, which focuses on mitigating the long-term warming, with other approaches that can quickly reduce the near-term warming by including non-CO_2 warming pollutants as an additional major

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Reviewers: V.M.-D., Laboratoire des Sciences du Climat et de l'Environnement; and V.R., US National Oceanic and Atmospheric Administration/Geophysical Fluid Dynamics Laboratory.

The authors declare no competing interest.

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focus of climate mitigation actions. The science of non-CO_2 warming pollutants dates back to 1975 with the discovery of the supergreenhouse effect of chlorofluorocarbons (CFCs) (11) followed by the addition of methane (CH_4) and nitrous oxide (N_2O) in 1976 (12). A comprehensive review of non-CO_2 warming agents by a United Nations–commissioned group in 1985 (13) concluded that non-CO_2 greenhouse gases (GHGs) were contributing as much as CO_2 to warming and projected that for the period between 1980 and 2030 non-CO_2 gases were likely to continue contributing as much as CO_2 to warming. These findings and projections have been confirmed by the most recent IPCC reports (14–17). We summarize these in the next section.

Independently, a series of studies that began in the 1970s concluded that fossil fuels (FFs), while contributing to global warming through CO_2 emissions, were also leading to global dimming and resulting cooling by increasing atmospheric aerosol particles (18, 19). While the overall aerosol effect is strongly negative due to emissions of sulfates, nitrates, and some organics that primarily reflect sunlight, there are other aerosols such as black carbon (BC) and brown carbon that absorb sunlight and thus contribute to global warming. The findings of the three decades of studies have been confirmed by the most recent IPCC report, which concludes that as of 2019 the net radiative forcing from cooling aerosols is around –1.5 Wm^{-2} (excluding about +0.38 from the aerosol-radiation forcing from BC and its effect on surface albedo). The CO_2 radiative forcing is 2.16 Wm^{-2} and radiative forcing due to non-CO_2 GHGs and BC is 2.10 Wm^{-2} (15).

Despite the general recognition of the role of non-CO_2 pollutants in climate mitigation, their contribution to warming as well as their potential for near-term cooling has been underappreciated in part due to inconsistencies between representation of climate forcing between IPCC Working Group I (WGI: Physical Scientific Basis), which includes all pollutants, and Working Group III (WGIII: Mitigation of Climate Change), which focuses on CO_2 and the subset of GHGs covered under the Kyoto Protocol, hence excluding halogenated gases covered by the Montreal Protocol and both warming and cooling aerosols that are primarily coemitted with CO_2 from FF usage. As we discuss in the next section, since FF combustion is the primary source of CO_2 emissions and also the source of some non-CO_2 pollutants, the extent to which decarbonization strategies to reduce FF emissions also reduce non-CO_2 emissions is ambiguous in many mitigation studies due to study design, leading some to question the benefits of early and fast targeted action in reducing non-CO_2 emissions (20).

The focus on CO_2 underpins the concept of carbon budget, which has been used to construct decarbonization pathways to meet specified long-term warming levels (21). While it has long been known that the coincidental cancelling of non-CO_2 warming and aerosol cooling was unlikely to persist due to differences in their sources and residence times (22), few carbon-budget-based studies have included the tight linkage between CO_2 mitigation and reduction in cooling aerosol emissions until recently (23).

Many publications and reports by scientific agencies (24–32) highlighted the role of non-CO_2 for rapid near-term climate mitigation, specifically short-lived climate pollutants (SLCPs)—methane (CH_4), BC, hydrofluorocarbons (HFCs), and tropospheric ozone (O_3)—but these have not captured the attention of global mitigation actions, which still focuses largely on CO_2 emissions.

There are two primary objectives of this study: first, clarifying the role of non-CO_2 GHGs (short-lived and long-lived) and aerosols (warming and cooling) in the context of the need for near-term and long-term climate mitigation, and second, clarifying the net effect of the FF phaseout in decarbonization, which involves both cooling due to cutting CO_2 emissions and warming due to unmasking of cooling aerosols coemitted by FF use. Unless otherwise stated, we rely on forcing values in the IPCC WGI reports published in 2021 and 2013.

Contributions to Radiative Forcing: CO_2 vs. Non-CO_2 GHGs (Excluding Aerosols)

Previous reports of IPCC WGI have consistently found that CO_2 and non-CO_2 GHG and GHG precursor emissions contribute close to equal shares (52 to 57% for CO_2 and 43 to 48% for non-CO_2 GHG) to climate forcing in radiative forcing terms when excluding aerosols (*SI Appendix*, Table S1). These results are reproduced in Fig. 1 *A* and *B*. In contrast, IPCC WGIII states in the Fifth Assessment Report (AR5) that "CO_2 emissions from fossil fuel combustion and industrial processes contributed about 78% of the total GHG emission increase from 1970 to 2010, with a similar percentage contribution for the period 2000–2010 . . . . Annually, since 1970, about 25% of anthropogenic GHG emissions have been in the form of non-CO_2 gases" (33). A similar statement was made by WGIII in the Fourth Assessment Report (AR4). However, these statements are inconsistent with WGI science and contribute to confusion for several reasons:

- First, GHG emissions considered by WGIII only include CO_2 (from FF use and forestry and other land use, [FOLU]), CH_4, N_2O, and HFCs and omit nonmethane tropospheric ozone precursors, CFCs, hydrochlorofluorocarbons (HCFCs), and other ozone-depleting substances covered by the Montreal Protocol (*SI Appendix*, Fig. S1). Taking into account these omitted non-CO_2 climate forcers using the EDGARv5.0 emissions database (34) for CO (as a proxy for nonmethane O_3 precursors) and National Oceanic and Atmospheric Administration and AGAGE (35) network data for CFC/HCFC/halon emissions, the average non-CO_2 GHGs and GHG precursors share over 1970 to 2010 is 39% (instead of the 25% quoted in WGIII reports) using the 100-y global warming potential (GWP_{100}) metric and 59% using GWP_{20}.
- Second, presenting the increase in emissions between two years (1970 and 2010) provides limited if not misleading insights into the actual forcing and climate impacts. We offer two examples, all of which adopt IPCC WGI estimates. 1) For the years 1993, 1998, 2005, 2011, and 2019, the percentage of CO_2 forcing (from all sources) compared with the total GHGs forcing ranges from 52 to 57% (*SI Appendix*, Table S1). The non-CO_2 GHGs contribute the balance of 43 to 48% (*SI Appendix*, Tables S1 and S2). 2) The contribution of the CO_2 forcing from just FFs to the total GHGs forcing is 38% for 2011 and 43% for 2019. The basic inference is that the WGIII finding of "CO_2 emissions from fossil fuel combustion and industrial processes contributed about 78% of the total GHG emission increase from 1970 to 2010" cannot be used to infer the contribution of CO_2 or FFs to either the radiative forcing or the resulting climate changes.

In short, the conclusion by WGIII that CO_2 from FF combustion contributed 78% of the total GHG emissions increase from 1970 to 2010 significantly underrepresents the nearly equal contribution of non-FFs as well as that of non-CO_2 GHGs to the total radiative forcing, which are described in the next two sections. Revisiting this historical accounting puts

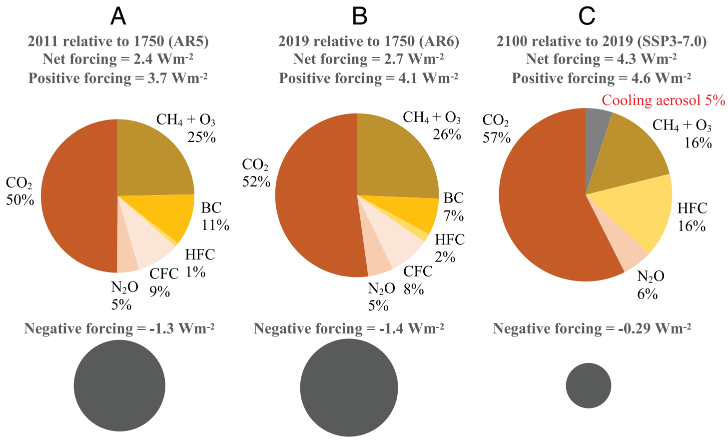

Fig. 1. Positive radiative forcing from long-lived GHGs (orange), short-lived GHGs, GHG precursors, and BC (aerosol–radiation interaction and snow albedo effects only) (yellow) and negative forcing from individual aerosol direct effects (aerosol–radiation interaction) and the total aerosol indirect effects (aerosol–cloud interaction) (separate gray pie) in (*A*) 2011 relative to 1750, from AR5 (14) and (*B*) 2019 relative to 1750, from AR6 (15). (*C*) The forcing at 2100 relative to 2019, under SSP3-7.0 emissions (49). Note the negative forcing due to assumed BC and CFC reduction and the positive forcing due to decline of cooling aerosols. Area of each pie chart is scaled to positive or negative forcing. See *SI Appendix*, Fig. S5 for bar chart version and *SI Appendix*, Table S6A for data.

into perspective the role of non-CO_2 emissions in the current global warming and serves as a reminder of the need to consider all sources of climate forcing when assessing mitigation strategies.

This comparison of WGI and WGIII approaches also further underscores the importance of separately accounting for short- and long-lived pollutant emissions, as discussed by Daniel et al. (36) and recently called for by Allen et al. (37). Reporting these pollutants separately allows for consideration not only of potential effects of mitigation measures by source and implications for coemissions but also an assessment of temperature impact on multiple time horizons of interest (1). With 1.5 °C expected to be crossed in the early 2030s (1, 38), Abernethy and Jackson (39) have advocated for choosing time horizons for GHG aggregation metrics consistent with temperature goals, specifically supporting the use of GWP_{20} over the GWP_{100}. A similar argument can be made in the context of the urgency to slow warming in the near term (2). In addition, common usage of aggregation metrics (e.g., GWP, GWP*, and global temperature potential) excludes very short-lived climate pollutants that are not well-mixed, such as aerosols and GHG precursors, but that can have significant implications for future warming (40, 41).

Contributions to Radiative Forcing: FFs vs. Non-FFs (Including Aerosols)

Here we clarify the historical contributions to present-day radiative forcing from FF and non-FF sources. Many heat-trapping gases and particles originate from both FF and non-FF sources, while others such as N_2O and halocarbons are primarily associated with non-FF sources. First, we calculate the relative share of emissions from FF and non-FF sources for GHGs alone, summing historical emissions pollutant by pollutant between 1850 and 2015 for each GHG based on source (42) and for future (after 2015) emissions using the FF coemission factors from Shindell and Smith (43) as described in *SI Appendix*. These shares are then applied to the total present-day radiative forcing in 2011 as in IPCC AR5 WGI (14) and 2019 as in IPCC AR6 WGI (15). Fig. 2 and *SI Appendix*, Table S2 show that for historical forcing (1750 to 2019) GHG from FF sources contributes about 53% of the total current GHG forcing, approximately the same as GHG forcing due to non-FF sources. However, if GHG emissions were to cease, residual forcing from long-lived GHG, predominantly FF CO_2, would dominate as shorter-lived pollutants would be rapidly removed.

Next, we consider warming and cooling aerosols. For forcing estimates related to aerosols, we distinguish effective radiative forcing (ERF) due to aerosol-radiation interaction (ERF_{ari}) for individual species from aerosol–cloud interaction (ERF_{aci}) considered separately as a lump-sum "indirect" forcing term associated with total aerosol emissions (*SI Appendix*). Previous studies have shown that the coemission of aerosols from FF combustion can result in warming or cooling with distinct temporal and spatial patterns (27, 44). Many studies have identified the importance of cooling aerosols—primarily sulfates (with SO_2 as the precursor), nitrates (NO, NO_2, and NH_3), and organic carbon—in masking GHG warming (1, 14). Fig. 1 shows the relative contributions of warming GHG, GHG precursors, and BC in comparison to the cooling from cooling aerosols relying on radiative forcing from historical emissions in recent IPCC reports, and how the relative contributions evolve in a reference scenario (SSP3-7.0) in 2100 relative to 2019.

The net forcings for all CO_2 and non-CO_2 FF (Fig. 2*A*) and non-FF non-CO_2 (Fig. 2*B*) sources are based on Hoesly et al. (42) for the period through 2015. For 2016 to 2019, we use the Shared Socioeconomic Pathways (SSP) scenario and adopt Shindell and Smith's (43) values for the coemission factors. We obtain similar results using radiative forcing values from AR6 WGI (*SI Appendix*, Table S3). For the radiative forcing from CO_2 emitted by FF as well as non-FF sources and non-CO_2 emitted by just FF, nearly half of the positive forcing (2.5 Wm^{-2}) in 2019 is masked by negative forcing of cooling aerosols (–1.1 Wm^{-2}), resulting in a net positive forcing of 1.4 Wm^{-2}. The forcing of cooling aerosols from non-FF non-CO_2 sources is only –0.2 Wm^{-2} compared to a positive forcing of 1.4 Wm^{-2}. Thus, the net forcing from non-FF non-CO_2 sources is 1.2 Wm^{-2} in 2019, or 45% of total net forcing when aerosols are included. The contribution to the net forcing from FFs (CO_2 and other

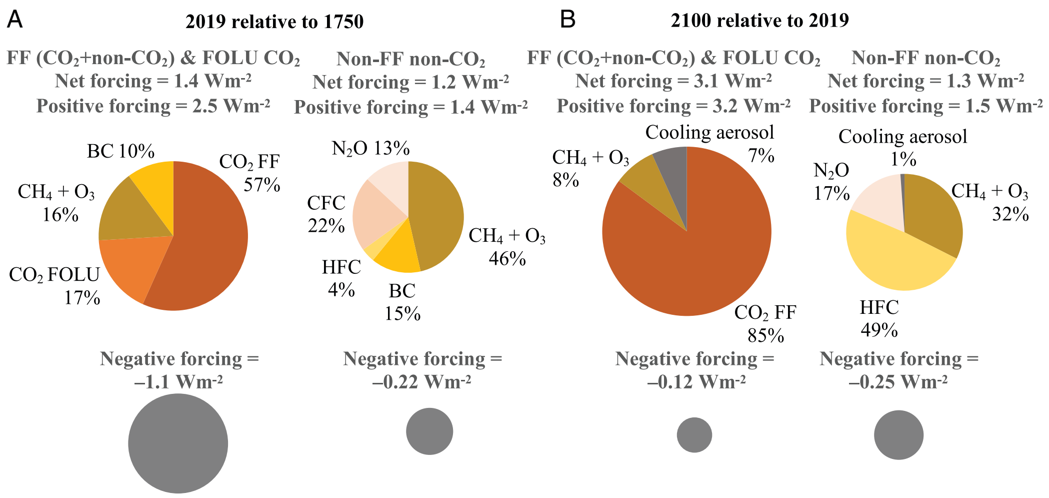

Fig. 2. (*A*) Contributions to 2019 radiative forcing from emissions by FF (CO_2+non-CO_2) sources and CO_2 from land-use changes (Forestry and Other Land Use, FOLU CO_2) compared with emissions from non-FF non-CO_2 sources based on ref. 42 and coemission factors from ref. 43 from this study, with similar results using radiative forcing values from AR6 WGI (*SI Appendix*, Table S3). (*B*) Contribution to the 2100 radiative forcing (relative to 2019) based on future emissions in SSP3-7.0 (49) partitioned by source using coemission factors from ref. 43. Area of each pie chart is scaled to positive or negative forcing. Data in *SI Appendix*, Table S6*B*.

GHGs) is 39% when aerosols are included and from non-FF sources is 61%.

The picture depicted above changes in the projection through 2100 under the limited climate policy SSP3-7.0 scenario. By 2100, around 70% of net forcing relative to 2019 is due to FF and other CO_2 emissions, emphasizing the importance of adopting decarbonization together with strategies targeting non-CO_2 to address near-term and long-term warming.

Contributions to Warming: CO_2 vs. Non-CO_2 and FFs vs. Non-FFs

The tendency to group CO_2 and non-CO_2 together irrespective of emission sources has contributed to a frequent misperception that CO_2, which comes predominantly from FF burning, is the only important contributor to observed warming. This misperception is understandable: Our model shows that out of the 1.01 °C warming simulated for 2015, CO_2 has contributed 0.98 °C (*SI Appendix*, Table S4). Thus, one can indeed claim that to the first order the observed global warming of ∼1 °C is primarily due to CO_2. However, a closer look reveals that the magnitude of warming by non-CO_2 GHGs coincidentally cancels the cooling by all (FF & non-FF sources) aerosols (45–47) (*SI Appendix*, Fig. S2). Indeed, our model shows that the combined cooling effects of aerosols including the indirect effects via enhancing cloud albedo (–1.15 °C) has masked an amount of warming that is almost equal to the total non-CO_2 warming of 1.17 °C. This leads to a facile but false assumption that most non-CO_2 forcings have canceled one another and will continue to do so in the future and obscures the significance of the residence time of the pollutants for both short- and long-term climate mitigation.

Uncovering the flaw in this reasoning requires correctly attributing the masking from cooling aerosols. Ignoring sources and aerosols, CO_2 would appear to contribute about 55% of GHG warming (*SI Appendix*, Table S4). Considering only FF sources, *SI Appendix*, Table S4 shows that the warming from FF emissions (GHGs and BC) of 1.07 °C in 2015 is mostly masked by cooling of 0.88 °C from cooling aerosols that are coemitted with FF emissions. In contrast, while the warming from non-FF emissions (GHGs and BC) is equivalent in magnitude at 1.08 °C, only 0.26 °C is masked by coemitted cooling aerosols. This analysis reveals that about 80% of warming realized in 2015 is attributable to non-FF sources due to masking by cooling aerosols coemitted from FF sources. As these aerosols fall out of the atmosphere, the future net warming contribution from FF sources under SSP3-7.0 begins to dominate by the 2060s due to the longer residence time of CO_2.

Accurately attributing past warming is key to mitigation actions going forward. As decarbonization measures reduce FF use they also reduce the coemitted cooling aerosols (primarily sulfates) and unmask the warming from accumulated GHGs in the atmosphere. In the following section we describe the implications of such unmasking for near- and long-term mitigation potential of decarbonization and clarify the essential role of strategies targeting non-CO_2 pollutants in limiting warming through 2050.

Mitigation Strategies in Time: Decarbonization and Targeted Mitigation

Reducing CO_2 emissions by shifting from FF to low-carbon energy sources is underway and needs to accelerate to achieve net-zero CO_2 emissions by midcentury or sooner consistent with the Paris temperature target (48). While getting to net-zero CO_2 emissions is critical and essential for stabilizing long-term warming, it also reduces coemitted cooling aerosols and causes weak near-term warming, which can be offset by reductions in non-FF pollutants (43). Few studies, however, have specifically quantified the contribution of measures targeting non-CO_2 independent from FF usage, such as the 16 measures in the 2011 UNEP/WMO Assessment (31).

Our analysis disentangles CO_2, SLCPs, and cooling aerosols by asking the following question: Under an aggressive climate mitigation scenario (such as the marker version of SSP1-1.9), what is the avoided warming due to decarbonization alone (i.e., reduction in FF usage) and when paired with non-decarbonization-related mitigation targeting non-CO_2 pollutants? We answer this question by explicitly accounting for the associated reductions in coemitted pollutants including cooling aerosols from each mitigation approach. As described in *SI Appendix*, we use SSP scenarios (49) and apply coemissions factors to partition emissions of individual pollutants into FF-related and non-FF-related (43). We consider three cases (Table 1): As a reference case we adopt the limited climate policy high-emission scenario SSP3-7.0, a middle case with only decarbonization-driven emissions reductions, and a "decarb+targeted" case including mitigation measures that go beyond decarbonization to target SLCPs and other non-CO_2 pollutants (based on SSP1-1.9). We construct the "decarb-only" case by partitioning the reduction in emissions in the "decarb+targeted" case relative to the baseline case into decarbonization-driven and other targeted measures. Our approach differs from ref. 43 in that we use the SSP3-7.0 scenario to quantify the nondecarbonization mitigation potential from methane and BC. This includes mitigation measures targeting the ~10% of methane emissions from abandoned coal mines and wells due to fugitive emissions that are not directly affected by decarbonization-driven reductions in FF use (*SI Appendix*).

All emission pathways including total and individual forcing were converted to temperature trajectories using the energy balance climate model RXM (*SI Appendix*), which has been validated in our earlier studies with climate models used in IPCC assessments (27, 30, 50, 51) and observed warming trends for the 20th century (*SI Appendix*, Fig. S3). Both the equilibrium and the transient climate sensitivity of the RXM model used in our study is within a few percent of the central values recommended in AR6. Our results for the avoided warming in the "decarb+targeted" case (*SI Appendix*, Table S5) are consistent with the results for methane, ozone precursor, and HFC abatement reported in AR6 WGI (52), which also used SSP3-7.0 as a reference case and SSP1-1.9 as the mitigation case, but do not account for source partitioning. With RXM we find avoided warming of 0.3 °C by 2040 from SLCP mitigation compared to 0.1 to 0.4 °C in AR6. The impact of SLCP reductions in 2100 is 0.5 to 1.3 °C in AR6, compared to 1.7 °C in our scenarios, which likely reflects the more stringent HFC and N_2O reductions in our adapted mitigation scenario. Our methane mitigation benefit of ~0.2 °C by 2050 is smaller than the ~0.3 °C in a recent assessment based on similar abatement (38), suggesting that the sensitivity of RXM to methane is lower than that in the three-dimensions composition-climate models (but well within uncertainties) (*SI Appendix*).

Aggressive decarbonization to achieve net-zero CO_2 emissions in the 2050s (as in the decarb-only scenario) results in weakly accelerated net warming compared to the reference case, with a positive warming up to 0.03 °C in the mid-2030s and no net avoided warming until the mid-2040s due to the reduction in coemitted cooling aerosols (Fig. 3*A*). By 2050, decarbonization measures result in very limited net avoided warming (0.07 °C), consistent with Shindell and Smith (43), but rise to a likely detectable 0.25 °C by 2060 and a major benefit of 1.4 °C by 2100 (*SI Appendix*, Table S5).

In contrast, pairing decarbonization with mitigation measures targeting CH_4, BC, HFC, and N_2O (not an SLCP due to its longer lifetime) independent from decarbonization are essential to slowing the rate of warming by the 2030s to under 0.3 °C per decade (Table 1 and Fig. 3*B*), similar to the 0.2 °C to 0.25 °C per decade warming prior to 2020 (38, 53). Recent studies suggest that rate of warming rather than level of warming controls likelihood of record-shattering extreme weather events (54, 55).

By 2050, the net avoided warming from the targeted non-CO_2 measures is 0.26 °C, almost four times larger than the net benefit of decarbonization alone (0.07 °C) (*SI Appendix*, Table S5). These results are calculated using an average BC forcing at present of 0.33 Wm^{-2} relative to preindustrial (direct and snow albedo; *SI Appendix*), which is consistent with the AR6 range (0.30 ± 0.2 Wm^{-2} for ERF_{ari} and 0.38 Wm^{-2} including snow albedo effects) (56). Combining all targeted non-CO_2 measures results in a net avoided warming in 2060 of 0.43 °C. Pairing decarbonization measures with targeted measures can achieve 0.25 °C in total avoided warming, a level that is likely to be detected (57) over a decade earlier (~2047) than

Table 1. Simulated warming rates and other key metrics under reference, decarbonization only, and decarb+targeted scenarios

Scenario	Warming rate, °C/decade (2020–2040)	Year when warming rate drops below 0.25 °C/decade	Year of peak warming rate	Year when crossing 1.5 °C warming	Year when crossing 2 °C warming	Warming in 2030 relative to 1850–1900, °C	Warming in 2050 relative to 1850–1900, °C
Reference: Limited climate policy, high emission (SSP3-7.0)	0.36 (0.34–0.38)	—	—	2031–2033	2045–2046	1.5 (1.4–1.5)	2.2
Decarbonization-driven: Scenario using decreasing FF primary energy as in SSP1-1.9 and associated emission factors to calculate decline in FF-related emissions compared to reference	0.37 (0.35–0.39)	2049–2052	2030	2030–2032	2045–2046	1.5 (1.4–1.5)	2.1
Decarbonization and Targeted measures: Aggressive climate policy, low emission (based on SSP1-1.9)	0.31 (0.29–0.32)	2035–2037	2023	2030–2033	—*	1.5 (1.4–1.5)	1.85 (1.8–1.9)

The range of years reflects the uncertainty in present-day forcings of BC and cooling aerosols.
*Peak temperature of 1.9 °C in 2060s before declining to 1.7 °C in 2100.

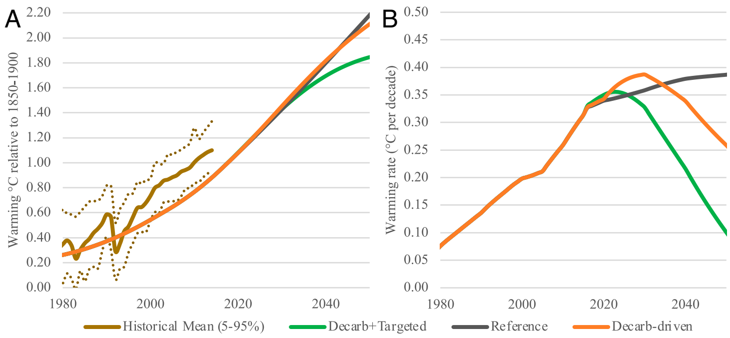

Fig. 3. (*A*) Historical and future temperature projections through 2050 calculated using the RXM energy balance model based on emissions scenarios from the SSP database (49) for reference scenario (SSP3-7.0), decarbonization-driven mitigation scenario (this study), and an "decarb+targeted" scenario including aggressive decarbonization and targeted SLCP mitigation (adapted from SSP1-1.9). Historical curve (past simulated warming) is from figure SPM8.a (47, 64). (*B*) Rate of warming (degrees Celsius per decade) in the reference SSP3, decarbonization only, and "decarb+targeted" mitigation cases.

decarbonization alone (2060; *SI Appendix*, Table S5). The avoided warming due to decarbonization begins to exceed that due to the targeted measures only after 2080 (*SI Appendix*, Fig. S4).

Only about 30% of the avoided warming from CH_4 over the period 2020 to 2040 is related to decarbonization measures (*SI Appendix*, Table S5). The larger portion of CH_4 reduction due to targeted measures may be due to a slower rate of reduction in natural gas usage in the marker SSP1-1.9 scenario (60% down in 2050 relative to 2015) compared with decrease in coal combustion (more than 90% down). Consistently, about two-thirds of non-CH_4-induced ozone mitigation is also due to non-CO_2 targeted measures rather than a direct consequence of decarbonization. These results are also consistent with UNEP/WMO (31), which found that measures to reduce methane and BC emissions cut warming in 2030 by half compared with a reference case and that aggressive CO_2 reductions, in themselves, did little to mitigate warming in the first 20 to 30 y, in part due to unmasking of coemitted cooling aerosol.

Fig. 3*A* shows that combining targeted mitigation strategies with decarbonization keeps warming below 2.0 °C, while decarbonization alone breaches 2.0 °C in 2045 in our scenario. Moreover, decarbonization alone increases the warming rate in the near term (Table 1). Notably, the warming rate in the decarbonization scenario would not drop below the current rate of warming until the 2040s (Fig. 3*B*). Pairing decarbonization with measures targeting SLCP slows the rate of warming a decade or two earlier than decarbonization alone.

Consideration of Uncertainties

The largest uncertainties in our analysis relate to the mitigation pathways chosen, both the reference limited climate policy scenario and the low-emission mitigation scenarios. While current CO_2 emissions commitments track closer to SSP2-4.5, the key insight of our study is not about additionality in terms of new policy measures. Rather, our study seeks to distinguish between mitigation policy focused on FF decarbonization alone versus decarbonization plus targeted measures. For this reason, we selected as a reference the high-emission scenario SSP3-7.0 and as a low-emission scenario SSP1-1.9, which are the same end-member scenarios as assessed in AR6 WGI (52).

The second major source of uncertainty is the nearly threefold uncertainty in climate sensitivity. All of the projected warming numbers presented here should be interpreted as median value with 50% probability. A third source of uncertainty relates to our use of constant FF coemission factors in constructing the decarbonization-driven scenario. Since this partitioning approach is most valid in the near term, we focus our analysis on the period through 2050. A fourth source of uncertainty relates to our limited understanding of the role of aerosols in climate forcing and feedbacks in future projections due to the following aspects: 1) the assumption of mixing of various aerosol species, especially the potential enhancement of BC forcing when accounting for the mixing with other reflective aerosols (58), 2) the future changes of background cloud field due to the slow feedback process to GHG warming (59, 60), and 3) the future changes of background aerosols from natural sources such as dust and sea salt due to climatic changes affecting the emission processes related to soil condition and wind stress over ocean surface and related cloud impacts (e.g., ref. 61).

Conclusions

This study clarifies as well as establishes the need for a comprehensive and inclusive CO_2 and non-CO_2 mitigation approach with distinct decarbonization and SLCP targets to address both the near-term and long-term impacts of climate disruption. A review of IPCC reports leads to the inference that non-CO_2 GHGs are responsible for nearly half of all current climate forcing from GHGs. When accounting for aerosols and coemissions by source, the inference from our analyses is that about 80% of the realized warming as of 2015 is attributable to non-FF sources due to FF GHG emissions being masked by coemission of short-lived cooling aerosols. However, the importance of non-CO_2 pollutants, in particular SLCPs, and their role in climate mitigation has been underappreciated due to misperception arising from inconsistencies between IPCC WGI and WGIII reports. The tendency to attribute impact to pollutants rather than sources and to group all non-CO_2 together regardless of emissions sources has further entrenched this misperception due to coincidental cancelling of warming and cooling pollutants and the false impression that they will continue to cancel out in the future. When historical emissions are partitioned into FF- and non-FF-related sources, we find that nearly half of the forcing from FF and other CO_2 emissions has been masked by coemission of cooling aerosols. As a result, close to half of net radiative forcing, as of now, is attributable to non-FF sources of methane, F-gases, BC, and N_2O. However, this is likely to change in the future as decarbonization policies reduce FF emissions of both warming GHGs and cooling aerosol.

By 2100, absent climate policy, FF will be the largest source (about 70%, mostly due to CO_2) for global warming and resulting impacts on planet and society. Even in the shorter term, FF emissions are the largest source of air pollution particles and ozone, which contribute to premature mortality of over 8 million people per year (45, 62). Tropospheric ozone also leads to crop losses of 100 million tons or more (63). As we have repeatedly emphasized in this study, achieving net-zero carbon dioxide emissions by 2050 is essential to limit global warming below 2 °C beyond 2050.

Pairing decarbonization with targeted SLCP mitigation measures is essential to simultaneously limit both near-term warming and long-term warming below 2 °C and thus reduce risks from crossing tipping points. Importantly, these two strategies are complementary and not interchangeable. Absent deep cuts in non-CO_2 emissions, CO_2 abatement alone is unable to keep warming below even the 2 °C threshold by 2050. Decarbonization measures alone achieve about a third of potential avoided warming from methane mitigation by 2050, less than half of SLCP mitigation potential, and none of the reductions from measures targeting N_2O. Nor can cutting methane emissions this decade replace the need for net-zero carbon dioxide by 2050 to stabilize the climate this century. Similarly, deeper CO_2 reductions this decade do not replace the need for methane and other SLCP reductions to slow warming in the near term. Aggregation metrics such as GWP and GWP* are designed in terms of warming impacts over multiple decades and are seldom used in ways that account for the important differences between strategies that can reduce warming in the near term.

Adopting a comprehensive mitigation approach that pairs rapid decarbonization with "strong, rapid and sustained reductions in CH_4 emissions" (1) as recommended in the Global Methane Assessment (32) and additional targeted SLCP mitigation responds to the call from WGII for urgent action to slow warming in the near term (2). For example, over 100 countries joined the Global Methane Pledge in November 2021, committing to a collective goal of reducing global anthropogenic methane emissions by at least 30% below 2020 levels by 2030. If achieved, this target, which is consistent with the reduction in the "decarb+targeted" scenario analyzed here, would avoid 0.2 °C by 2050 (*SI Appendix*, Table S5).

Data Availability. All study data are included in the article and/or *SI Appendix*.

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Climate tipping points — too risky to bet against

Timothy M. Lenton, Johan Rockström, Owen Gaffney, Stefan Rahmstorf, Katherine Richardson, Will Steffen & Hans Joachim Schellnhuber

Comment

Climate tipping points — too risky to bet against

Timothy M. Lenton, Johan Rockström, Owen Gaffney, Stefan Rahmstorf, Katherine Richardson, Will Steffen & Hans Joachim Schellnhuber

The growing threat of abrupt and irreversible climate changes must compel political and economic action on emissions.

Politicians, economists and even some natural scientists have tended to assume that tipping points[1] in the Earth system — such as the loss of the Amazon rainforest or the West Antarctic ice sheet — are of low probability and little understood. Yet evidence is mounting that these events could be more likely than was thought, have high impacts and are interconnected across different biophysical systems, potentially committing the world to long-term irreversible changes.

Here we summarize evidence on the threat of exceeding tipping points, identify knowledge gaps and suggest how these should be plugged. We explore the effects of such large-scale changes, how quickly they might unfold and whether we still have any control over them.

In our view, the consideration of tipping points helps to define that we are in a climate emergency and strengthens this year's chorus of calls for urgent climate action — from schoolchildren to scientists, cities and countries.

The Intergovernmental Panel on Climate Change (IPCC) introduced the idea of tipping points two decades ago. At that time, these 'large-scale discontinuities' in the climate system were considered likely only if global warming exceeded 5 °C above pre-industrial levels. Information summarized in the two most recent IPCC Special Reports (published in 2018 and in September this year)[2,3] suggests that tipping points could be exceeded even between 1 and 2 °C of warming (see 'Too close for comfort').

If current national pledges to reduce greenhouse-gas emissions are implemented — and that's a big 'if' — they are likely to result in at least 3 °C of global warming. This is despite the goal of the 2015 Paris agreement to limit warming to well below 2 °C. Some economists, assuming that climate tipping points are of very low probability (even if they would be catastrophic), have suggested that 3 °C warming is optimal from a cost–benefit perspective. However, if tipping points are looking more likely, then the 'optimal policy' recommendation of simple cost–benefit climate-economy models[4] aligns with those of the recent IPCC report[2]. In other words, warming must be limited to 1.5 °C. This requires an emergency response.

Ice collapse

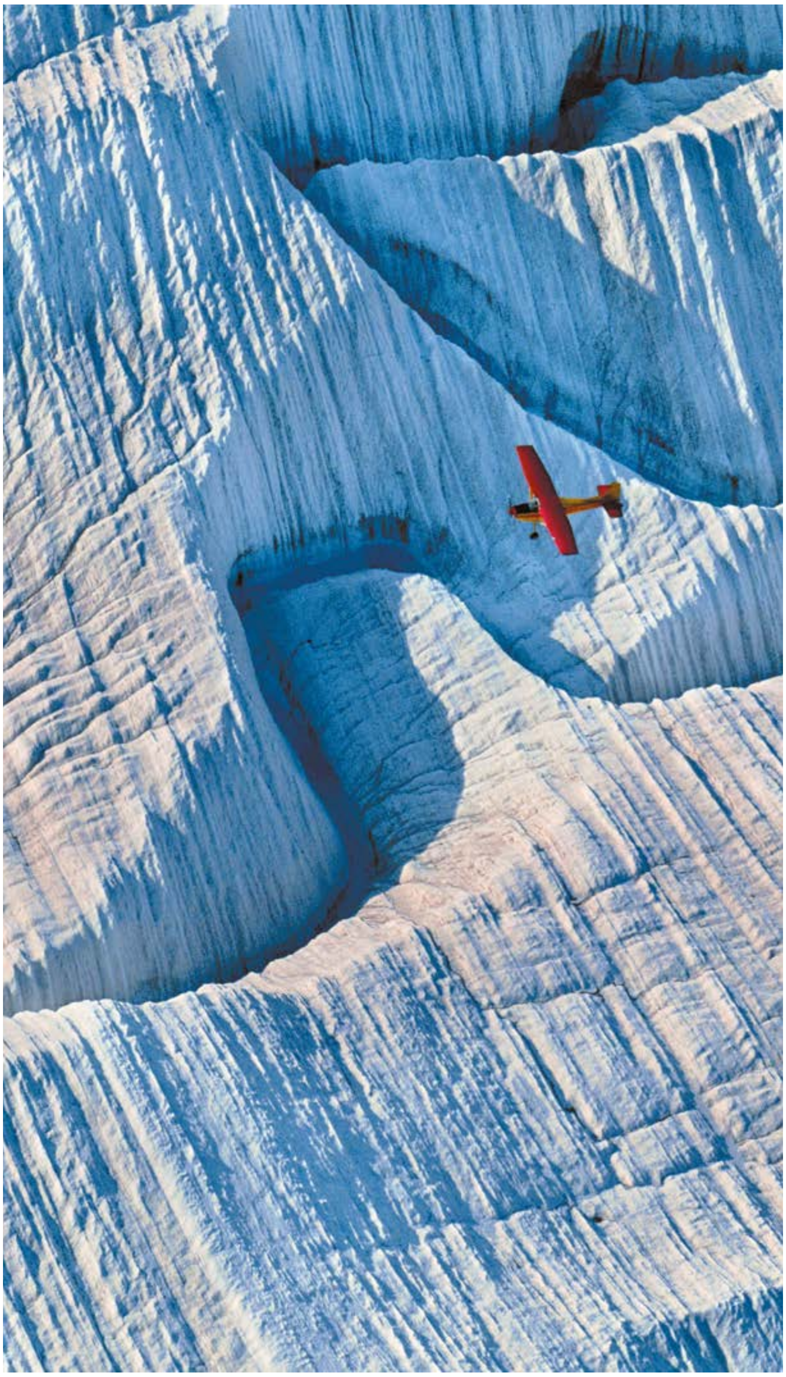
We think that several cryosphere tipping points are dangerously close, but mitigating greenhouse-gas emissions could still slow down the inevitable accumulation of impacts and help us to adapt.

Research in the past decade has shown that the Amundsen Sea embayment of West Antarctica might have passed a tipping point[3]: the 'grounding line' where ice, ocean and bedrock meet is retreating irreversibly. A model study shows[5] that when this sector collapses, it could destabilize the rest of the West Antarctic ice sheet like toppling dominoes — leading to about 3 metres of sea-level rise on a timescale of centuries to millennia. Palaeo-evidence shows that such widespread collapse of the West Antarctic ice sheet has occurred repeatedly in the past.

The latest data show that part of the East Antarctic ice sheet — the Wilkes Basin — might be similarly unstable[3]. Modelling work suggests that it could add another 3–4 m to sea level on timescales beyond a century.

The Greenland ice sheet is melting at an accelerating rate[3]. It could add a further 7 m to sea level over thousands of years if it passes a particular threshold. Beyond that, as the elevation of the ice sheet lowers, it melts further, exposing the surface to ever-warmer air. Models suggest that the Greenland ice sheet could be doomed at 1.5 °C of warming[3], which could happen as soon as 2030.

Thus, we might already have committed future generations to living with sea-level rises of around 10 m over thousands of years[3]. But that timescale is still under our control. The rate of melting depends on the magnitude of warming above the tipping point. At 1.5 °C, it could take 10,000 years to unfold[3]; above 2 °C it could take less than 1,000 years[6].



FRANS LANTING/NAT. GEO. IMAGE COLLECTION

An aeroplane flies over a glacier in the Wrangell St Elias National Park in Alaska.

Researchers need more observational data to establish whether ice sheets are reaching a tipping point, and require better models constrained by past and present data to resolve how soon and how fast the ice sheets could collapse.

Whatever those data show, action must be taken to slow sea-level rise. This will aid adaptation, including the eventual resettling of large, low-lying population centres.

A further key impetus to limit warming to 1.5 °C is that other tipping points could be triggered at low levels of global warming. The latest IPCC models projected a cluster of abrupt shifts[7] between 1.5 °C and 2 °C, several of which involve sea ice. This ice is already shrinking rapidly in the Arctic, indicating that, at 2 °C of warming, the region has a 10–35% chance[3] of becoming largely ice-free in summer.

"The clearest emergency would be if we were approaching a global cascade of tipping points."

Biosphere boundaries

Climate change and other human activities risk triggering biosphere tipping points across a range of ecosystems and scales (see 'Raising the alarm').

Ocean heatwaves have led to mass coral bleaching and to the loss of half of the shallow-water corals on Australia's Great Barrier Reef. A staggering 99% of tropical corals are projected[2] to be lost if global average temperature rises by 2 °C, owing to interactions between warming, ocean acidification and pollution. This would represent a profound loss of marine biodiversity and human livelihoods.

As well as undermining our life-support system, biosphere tipping points can trigger abrupt carbon release back to the atmosphere. This can amplify climate change and reduce remaining emission budgets.

Deforestation and climate change are destabilizing the Amazon – the world's largest rainforest, which is home to one in ten known species. Estimates of where an Amazon tipping point could lie range from 40% deforestation to just 20% forest-cover loss[8]. About 17% has been lost since 1970. The rate of deforestation varies with changes in policy. Finding the tipping point requires models that include deforestation and climate change as interacting drivers, and that incorporate fire and climate feedbacks as interacting tipping mechanisms across scales.

With the Arctic warming at least twice as quickly as the global average, the boreal forest in the subarctic is increasingly vulnerable. Already, warming has triggered large-scale insect disturbances and an increase

ALEXIS ROSENFELD/GETTY

Bleached corals on a reef near the island of Moorea in French Polynesia in the South Pacific.

in fires that have led to dieback of North American boreal forests, potentially turning some regions from a carbon sink to a carbon source[9]. Permafrost across the Arctic is beginning to irreversibly thaw and release carbon dioxide and methane – a greenhouse gas that is around 30 times more potent than CO_2 over a 100-year period.

Researchers need to improve their understanding of these observed changes in major ecosystems, as well as where future tipping points might lie. Existing carbon stores and potential releases of CO_2 and methane need better quantification.

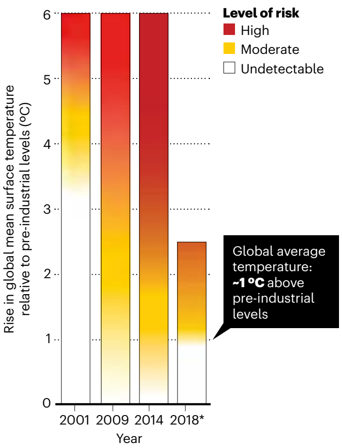
The world's remaining emissions budget for a 50:50 chance of staying within 1.5 °C of warming is only about 500 gigatonnes (Gt) of CO_2. Permafrost emissions could take an estimated 20% (100 Gt CO_2) off this budget[10], and that's without including methane from deep permafrost or undersea hydrates. If forests are close to tipping points, Amazon dieback could release another 90 Gt CO_2 and boreal forests a further 110 Gt CO_2 (ref. 11). With global total CO_2 emissions still at more than 40 Gt per year, the remaining budget could be all but erased already.

Global cascade

In our view, the clearest emergency would be if we were approaching a global cascade of tipping points that led to a new, less habitable, 'hothouse' climate state[11]. Interactions could happen through ocean and atmospheric circulation or through feedbacks that increase greenhouse-gas levels and global temperature. Alternatively, strong cloud feedbacks could cause a global tipping point[12,13].

TOO CLOSE FOR COMFORT

Abrupt and irreversible changes in the climate system have become a higher risk at lower global average temperature rise. This has been suggested for large events such as the partial disintegration of the Antarctic ice sheet.



*The 2018 IPCC *Special Report: Global Warming of 1.5 °C* focuses on the temperature range up to 2.5 °C.

SOURCE: IPCC AND J. B. SMITH *ET AL. PROC. NATL ACAD. SCI. USA* **106**, 4133–4137 (2009)

We argue that cascading effects might be common. Research last year[14] analysed 30 types of regime shift spanning physical climate and ecological systems, from collapse of the West Antarctic ice sheet to a switch from rainforest to savanna. This indicated that exceeding tipping points in one system can increase the risk of crossing them in others. Such links were found for 45% of possible interactions[14].

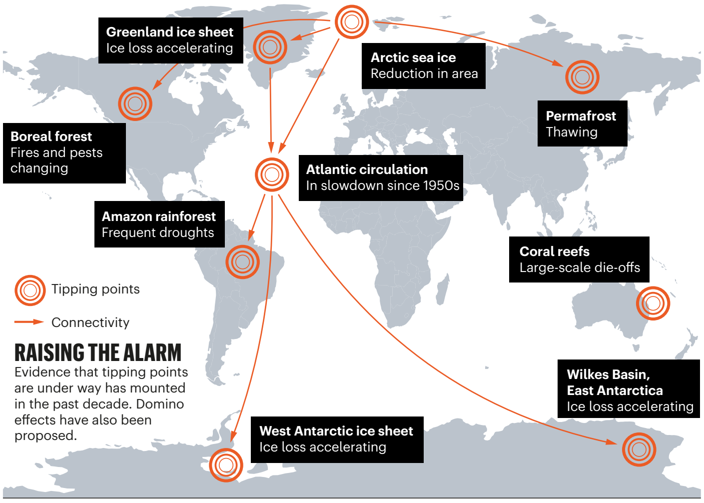
In our view, examples are starting to be observed. For example, Arctic sea-ice loss is amplifying regional warming, and Arctic warming and Greenland melting are driving an influx of fresh water into the North Atlantic. This could have contributed to a 15% slowdown[15] since the mid-twentieth century of the Atlantic Meridional Overturning Circulation (AMOC) , a key part of global heat and salt transport by the ocean[3]. Rapid melting of the Greenland ice sheet and further slowdown of the AMOC could destabilize the West African monsoon, triggering drought in Africa's Sahel region. A slowdown in the AMOC could also dry the Amazon, disrupt the East Asian monsoon and cause heat to build up in the Southern Ocean, which could accelerate Antarctic ice loss.

The palaeo-record shows global tipping, such as the entry into ice-age cycles 2.6 million years ago and their switch in amplitude and frequency around one million years ago, which models are only just capable of simulating. Regional tipping occurred repeatedly within and at the end of the last ice age, between 80,000 and 10,000 years ago (the Dansgaard–Oeschger and Heinrich events). Although this is not directly applicable to the present interglacial period, it highlights that the Earth system has been unstable across multiple timescales before, under relatively weak forcing caused by changes in Earth's orbit. Now we are strongly forcing the system, with atmospheric CO_2 concentration and global temperature increasing at rates that are an order of magnitude higher than those during the most recent deglaciation.

Atmospheric CO_2 is already at levels last seen around four million years ago, in the Pliocene epoch. It is rapidly heading towards levels last seen some 50 million years ago – in the Eocene – when temperatures were up to 14 °C higher than they were in pre-industrial times. It is challenging for climate models to simulate such past 'hothouse' Earth states. One possible explanation is that the models have been missing a key tipping point: a cloud-resolving model published this year suggests that the abrupt break-up of stratocumulus cloud above about 1,200 parts per million of CO_2 could have resulted in roughly 8 °C of global warming[12].

Some early results from the latest climate models – run for the IPCC's sixth assessment report, due in 2021 – indicate a much larger climate sensitivity (defined as the temperature response to doubling of atmospheric CO_2) than in previous models. Many more results are pending and further investigation is required, but to us, these preliminary results hint that a global tipping point is possible.

To address these issues, we need models that capture a richer suite of couplings and feedbacks in the Earth system, and we need more data – present and past – and better ways to use them. Improving the ability of models to capture known past abrupt climate changes and 'hothouse' climate states should increase



RAISING THE ALARM
Evidence that tipping points are under way has mounted in the past decade. Domino effects have also been proposed.

SOURCE: T. M. LENTON *ET AL.*

confidence in their ability to forecast these.

Some scientists counter that the possibility of global tipping remains highly speculative. It is our position that, given its huge impact and irreversible nature, any serious risk assessment must consider the evidence, however limited our understanding might still be. To err on the side of danger is not a responsible option.

If damaging tipping cascades can occur and a global tipping point cannot be ruled out, then this is an existential threat to civilization. No amount of economic cost–benefit analysis is going to help us. We need to change our approach to the climate problem.

Act now

In our view, the evidence from tipping points alone suggests that we are in a state of planetary emergency: both the risk and urgency of the situation are acute (see 'Emergency: do the maths').

We argue that the intervention time left to prevent tipping could already have shrunk towards zero, whereas the reaction time to achieve net zero emissions is 30 years at best. Hence we might already have lost control of whether tipping happens. A saving grace is that the rate at which damage accumulates from tipping – and hence the risk posed – could still be under our control to some extent.

The stability and resilience of our planet is in peril. International action – not just words – must reflect this.

EMERGENCY: DO THE MATHS

We define emergency (E) as the product of risk and urgency. Risk (R) is defined by insurers as probability (p) multiplied by damage (D). Urgency (U) is defined in emergency situations as reaction time to an alert (τ) divided by the intervention time left to avoid a bad outcome (T). Thus:

$$E = R \times U = p \times D \times \tau / T$$

The situation is an emergency if both risk and urgency are high. If reaction time is longer than the intervention time left ($\tau / T > 1$), we have lost control.

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Correction

The figure 'Too close for comfort' in this Comment incorrectly synthesized and interpreted information from the IPCC. The graph labelled the temperatures as absolute, rather than rises; misrepresented the levels of risk; misinterpreted information as coming from a 2007 IPCC report; extrapolated the focus of a 2018 report; and was not clear about the specific sources of the information. The graphic has been extensively modified online to correct these errors.

Quantifying the human cost of global warming

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Quantifying the human cost of global warming

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Check for updates

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The costs of climate change are often estimated in monetary terms, but this raises ethical issues. Here we express them in terms of numbers of people left outside the 'human climate niche'—defined as the historically highly conserved distribution of relative human population density with respect to mean annual temperature. We show that climate change has already put ~9% of people (>600 million) outside this niche. By end-of-century (2080–2100), current policies leading to around 2.7 °C global warming could leave one-third (22–39%) of people outside the niche. Reducing global warming from 2.7 to 1.5 °C results in a ~5-fold decrease in the population exposed to unprecedented heat (mean annual temperature ≥29 °C). The lifetime emissions of ~3.5 global average citizens today (or ~1.2 average US citizens) expose one future person to unprecedented heat by end-of-century. That person comes from a place where emissions today are around half of the global average. These results highlight the need for more decisive policy action to limit the human costs and inequities of climate change.

Despite increased pledges and targets to tackle climate change, current policies still leave the world on course for around 2.7 °C end-of-century global warming[1–5] above pre-industrial levels—far from the ambitious aim of the Paris Agreement to limit global warming to 1.5 °C. Even fully implementing all 2030 nationally determined contributions, long-term pledges and net zero targets, nearly 2 °C global warming is expected later this century[1,2,5]. Calls for climate justice highlight the vital need to address the social injustices driven by climate change[6]. But what is the human cost of climate change and who bears it? Existing estimates tend to be expressed in monetary terms[7], tend to recognize impacts on the rich more than those on the poor (because the rich have more money to lose) and tend to value those living now over those living in the future (because future damages are subject to economic discounting). From an equity standpoint, this is unethical[8]—when life or health are at stake, all people should be considered equal, whether rich or poor, alive or yet to be born.

A growing body of work considers how climate variability and climate change affect morbidity[9] or mortality[10–13]. Here, we take a complementary, ecological approach, considering exposure to less favourable climate conditions, defined as deviations of human population density with respect to climate from the historically highly conserved distribution—the 'human climate niche'[14]. The climate niche of species integrates multiple causal factors including combined[15] effects of physiology[16] and ecology[17]. Humans have adapted physiologically and culturally to a wide range of local climates, but despite this our niche[14] shows a primary peak of population density at a mean annual temperature (MAT) of ~13 °C and a secondary peak at ~27 °C (associated with monsoon climates principally in South Asia). The density of domesticated crops and livestock follow similar distributions[14], as does

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gross domestic product, which shares the same independently identified[14,18] primary temperature peak (~13 °C). Mortality also increases at both high and low temperatures[10–12], consistent with the existence of a niche.

Here, we reassess the human climate niche, review its mechanistic basis, link it to temperature extremes, and calculate exposure outside the niche up to present and into the future under different demographic scenarios and levels of global warming. Exposure outside the niche could result in increased morbidity, mortality, adaptation in place or displacement (migration elsewhere). High temperatures have been linked to increased mortality[12,13], decreased labour productivity[19], decreased cognitive performance[20], impaired learning[21], adverse pregnancy outcomes[22], decreased crop yield potential[9], increased conflict[23–25], hate speech[26], migration[27] and infectious disease spread[9,28,29]. Climate-related sources of harm not captured by the niche include sea-level rise[30,31].

Reassessing the niche

First, we re-examined how relative population density varies with MAT. Our previous work[14] considered the 2015 population distribution under the 1960–1990 mean climate as a baseline (Extended Data Fig. 1). Here, we use the 1980 population distribution (total 4.4 billion) under the 1960–1990 mean climate (Fig. 1a; '1980') as the reference state. This is a more internally consistent approach, particularly as recent population growth biases towards hotter places. Applying a double-Gaussian fitting, the primary temperature peak is now larger and at a slightly lower temperature (~12 °C), in better agreement with reconstructions from 300, 500 and 6,000 years BP (Extended Data Fig. 1). The 1960–1990 interval was globally ~0.3 °C warmer than the 1850–1900 'pre-industrial' level, but closer to mean Holocene temperatures that supported civilizations as we know them (because 1850–1900 was at the end of the Little Ice Age). The smoothed double-Gaussian function fit (Fig. 1a; '1980 fitted') is referred to from hereon as the 'temperature niche'. An updated 'temperature–precipitation niche' (additionally considering mean annual precipitation; MAP) was also calculated and considered in sensitivity analyses. It shows a marked drop in population density[14,32] below 1,000 mm yr^{-1} MAP. The temperature niche captures a key part of this effect because its minimum at 19–24 °C is associated with dry subtropical climates (Extended Data Fig. 2). However, the temperature niche overestimates population density at very low MAP (notably in temperate deserts) and at high MAP (Supplementary Fig. 1). Hence, projections with the temperature niche are more conservative than those with the temperature–precipitation niche. By either definition, the niche is largely that of people dependent on farming. The niche of hunter-gatherers is probably broader[33–36], as it is not constrained by the niches of domesticated species. This hypothesis is supported by the broader distribution of population density with respect to temperature reconstructed[16] from the ArchaeoGLOBE dataset for 6,000 years BP (when a smaller fraction of total population depended on farming; Extended Data Fig. 1b).

Mechanisms behind the niche

The human climate niche is shaped by direct effects of climate on us and indirect effects on the species and resources that sustain or afflict us. Direct climate effects include health impacts and changes in behaviour. Human perceptions of thermal comfort evolved[37] to keep us near optimal conditions of 22–26 °C, with well-being declining[38] above 28 °C. Behavioural changes include altering clothing, changing environment (including to indoor environments) and altering work patterns[39]. These can buffer individual exposure to temperature extremes but still affect collective well-being via effects on work. Sometimes uncomfortable conditions are unavoidable. High temperatures can decrease labour productivity[19], cognitive performance[20] and learning[21], produce adverse pregnancy outcomes[22], and increase mortality[10–12]. Exposure to temperatures >40 °C can be lethal[40], and lethal temperature decreases as

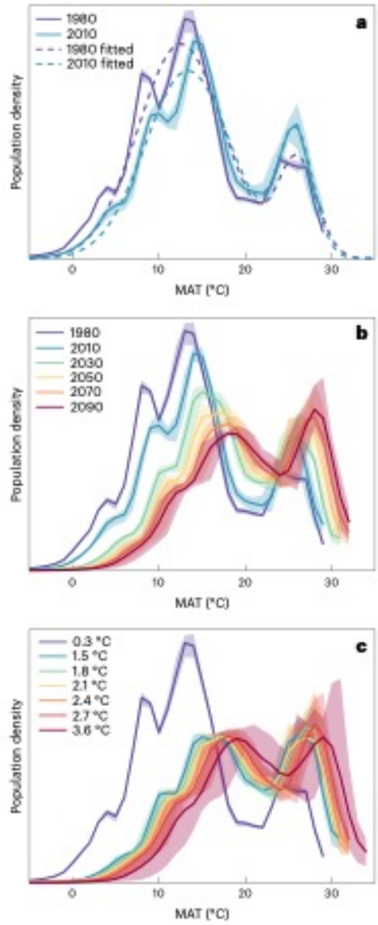

Fig. 1 | Changes in relative human population density with respect to MAT. **a**, Observed changes from the reference distribution for 1980 population (4.4 billion) under 1960–1990 climate (0.3 °C global warming), to the 2010 population (6.9 billion) under 2000–2020 climate (1.0 °C global warming), together with smooth fitted functions ('1980 fitted' is defined as the temperature niche). **b**, Observed and projected future changes in population density with respect to MAT following SSP2-4.5 leading to ~2.7 °C global warming and peak population 9.5 billion (see Extended Data Table 1 for global warming and population levels at each time). **c**, Projected population density with respect to MAT for a future world of 9.5 billion people under different levels of global warming (1.5, 1.8, 2.1, 2.4, 2.7 and 3.6 °C), contrasted with the reference distribution (0.3 °C, 1980 population). Data are presented as mean values with the shaded regions corresponding to 5th–95th percentiles.

humidity increases[12,40]. At wet-bulb temperature (WBT) >28 °C, the effectiveness of sweating in cooling the body decreases, and WBT ~35 °C can be fatal[41,42] especially for more vulnerable individuals[43] (as the body can no longer cool itself). High temperatures can also trigger conflict[23–25] or migration[27] to lower temperature locations.

Indirect effects of climate occur where climate influences the distribution and abundance of species or resources that sustain or afflict humans. Warmer, wetter conditions tend to favour vectors of human disease[9,28,29,44]. The majority of the world's population remains directly dependent on access to freshwater and lives within 3 km of a surface freshwater body[14,32,45]. Around 2 billion people depend on subsistence agriculture and thus the climate niche(s) of their crops. A further 120 million pastoralists depend on their domesticated animals, which as mammals have similar physiological limits to humans[40,46]. Despite a globalized food market, most countries pursue food security through localized production. This couples the rest of us to the climate niches of the crops and livestock we consume, which are similar to the niche of humans[14]. High temperatures decrease crop yield potential[9] and warming is spreading key crop pests and pathogens[47,48]. Major rainfed crops (maize, rice, wheat) are already migrating[49], somewhat mitigated by increases in irrigation[49]. This and the historical constancy of the niche (Extended Data Fig. 1a) suggest technological advancement has limited potential to expand the human climate niche in future.

Calculating exposure

For projections, we assume the temperature niche remains unaltered, and provide three calculations of exposure outside of it: (1) exposure to unprecedented heat; (2) total exposure due to temperature change only; or (3) total exposure due to temperature and demographic change (see Methods). (1) The simplest approach[14] just considers 'hot exposure'—that is, how many people fall outside the hot edge of the temperature niche. This is calculated[14] for a given climate and population distribution as the percentage of population exposed to MAT ≥29 °C, given that only 0.3% of the 1980 population (12 million) experienced such conditions in the 1960–1990 climate. (2) Total exposure due to temperature change alone[14] considers all areas where temperature increases to a value supporting lower relative population density according to the temperature niche. To calculate this[14] (Extended Data Fig. 3), we apply the niche to create a spatial 'ideal distribution' of relative population density under a changed climate that maintains the historical distribution with respect to temperature. This is contrasted with the spatial 'reference distribution' of population density with respect to the 1960–1990 climate. The difference between the two distributions integrated across space gives the percentage of population exposed outside the niche due to climate only. (3) Demographic change can also expose an increased density of population to a less favourable climate. To provide an upper estimate of population exposure (in %) due to both temperature and demographic change (Extended Data Fig. 3), we integrate the difference between the projected spatial 'assumed distribution' of population density with respect to temperature and the 'ideal distribution'.

Linking average temperature to other thermal metrics

MAT has the advantage of data availability for characterizing and projecting the human climate niche—it can be easily derived from observational data, reanalysis or climate model output. However, other metrics with less available data have been proposed to better capture thermal tolerance of humans, including mean maximum temperature[46] (MMT) and WBT[40]. Reassuringly, we find that MAT is very highly correlated with both annual MMT and mean annual WBT (Supplementary Fig. 2). Given the importance of extremes, we also considered how the number of days with maximum temperature >40 °C or with WBT >28 °C varies with MAT (Extended Data Fig. 4). Potentially lethal[40] exposure to maximum temperature >40 °C starts to increase markedly above MAT ~27 °C, reaching an average of over 75 days a year at MAT ~29 °C (half the longest time experienced in the present world), and almost all locations with MAT ≥29 °C experience a substantial number of days with maximum temperature >40 °C (Extended Data Fig. 4a). Physiologically challenging exposure to WBT >28 °C starts to increase at MAT >22 °C and exceeds an average of 10 days per year at MAT ≥29 °C (Extended Data Fig. 4b). Together these results show that MAT provides a good proxy for characterizing thermal tolerance, with MAT ≥29 °C providing a reasonable measure of unprecedented heat exposure, although it does not capture all exposure to temperature extremes.

Changes up to present

We find that noticeable changes in the distribution of population density with respect to temperature have occurred due to temperature and demographic changes from 1980 to 2010 (Fig. 1a). Considering the 2010 population distribution (total 6.9 billion) under the observed 2000–2020 climate, global warming of 1.0 °C (0.7 °C above 1960–1990) has shifted the primary peak of population density to a slightly higher temperature (~13 °C) compared with 1980, and the bias of population growth towards hot places has the increased population density at the secondary (~27 °C) peak. Greater observed global warming in the cooler higher northern latitudes than the tropics is visible in the changes to the distribution (Fig. 1a). Hot exposure (MAT ≥29 °C) tripled in percentage terms to 0.9 ± 0.4% (mean ± s.d.; 62 ± 26 million people), 9 ± 1% of the global population have been exposed outside the niche due to temperature change alone and 10 ± 1% from temperature plus demographic change (Fig. 2). Thus, global warming of 0.7 °C since 1960–1990 has put 624 ± 70 million people in less favourable temperature conditions, with demographic change adding another 77 million.

Future exposure

To estimate future exposure, we use an ensemble of eight climate model outputs (Supplementary Table 1) and corresponding population projections from four Shared Socioeconomic Pathways[50] (SSPs; Extended Data Table 1)—scenarios of socioeconomic global changes and associated greenhouse gas emissions up to 2100. The 'middle of the road' (SSP2-4.5) pathway provides a useful reference scenario because it produces end-of-century (2081–2100) average global warming of 2.7 (range 2.1–3.5) °C corresponding to the 2.7 (2.0–3.6) °C expected under current policies[1], and it captures population growth towards a peak of ~9.5 billion in 2070 (then declining to ~9.0 billion in 2100). Global warming and population growth combine to shift relative population density to higher temperature (Fig. 1b). Hot exposure (Fig. 2a,d) becomes significant by 2030 at 4 ± 2% or 0.3 ± 0.1 billion as global warming reaches 1.5 °C, and it increases near linearly to 23 ± 9% or 2.1 ± 0.8 billion in 2090 under 2.7 °C global warming. The number of people left outside the niche due to temperature change alone (Fig. 2b,e) reaches 14 ± 3% or 1.2 ± 0.2 billion by 2030, more than doubling to 29 ± 5% or 2.7 ± 0.5 billion in 2090. The number of people left outside the niche from temperature plus demographic change (Fig. 2c,f) reaches 25 ± 2% or 2.0 ± 0.2 billion by 2030, and 40 ± 4% or 3.7 ± 0.4 billion by 2090.

Variation across the SSPs

The other three SSPs produce a wide range of global warming (2081–2100) from ~1.8 (1.3–2.4) °C to ~4.4 (3.3–5.7) °C and span a wide range of human development trajectories, from population peaking at ~8.5 billion then declining to ~6.9 billion in 2100 to ongoing growth to ~12.6 billion in 2100 (Extended Data Table 1). Both global warming and demographic change alter the distribution of relative population density with respect to temperature (Extended Data Fig. 5). By 2090, hot exposure reaches 8–40% or 0.6–4.7 billion across scenarios (Fig. 2a,d). The number of people left outside the niche due to temperature change only reaches 18–47% or 1.3–4.7 billion (Fig. 2b,e). Adding in demographic change increases this to 29–53% or 2.2–6.5 billion (Fig. 2c,f). Estimates of exposure outside the combined temperature–precipitation niche are roughly 20% greater than for the temperature niche alone (Extended Data Fig. 6). The 'fossil-fuelled development' (SSP5-8.5) pathway exposes the greatest proportion of the population to unprecedented heat or being pushed out of the niche due to climate change alone, but the 'regional rivalry' (SSP3-7.0) pathway exposes the greatest proportion of the population due to climate and demographic change combined, and the greatest absolute numbers across all three measures of exposure (Fig. 2 and Extended Data Fig. 6).

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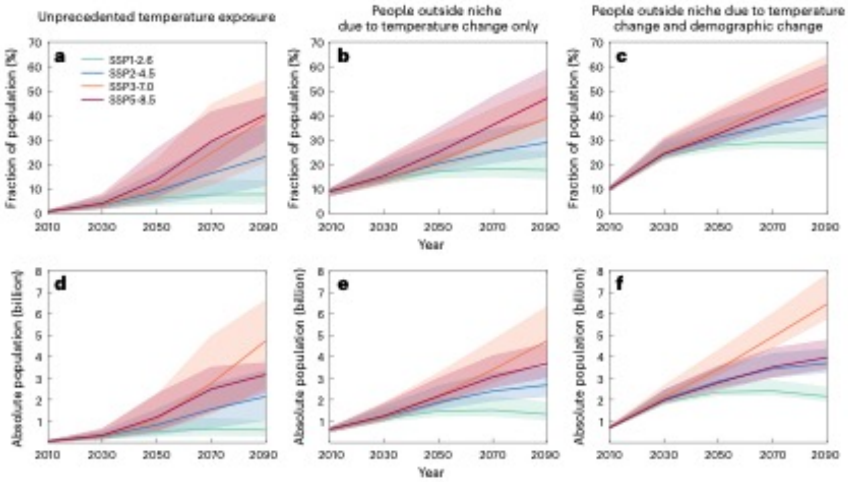

Fig. 2 | Population exposed outside of the temperature niche, following different SSPs. **a–f**, Fraction of population (%; **a–c**) and absolute population (billion people; **d–f**) exposed to unprecedented temperatures (MAT ≥29 °C; **a**,**d**), left outside the niche due to temperature change only (**b**,**e**,) and left outside the niche due to temperature change and demographic change (**c**,**f**) for different SSPs. Calculations are based on MAT averaged over the 20-year intervals and population density distribution at the centre year of the corresponding intervals. Data are presented as mean values with the shaded regions corresponding to the 5th–95th percentiles.

Controlling for demography

Larger global populations following the SSPs place a greater proportion of people in hotter places, tending to leave more outside the niche (irrespective of global warming). To isolate the effects of climate policy and associated climate change on exposure, we fix the population and its distribution, exploring three different options: (1) 6.9 billion (as in 2010); (2) 9.5 billion (as in SSP2 in 2070); and (3) 11.1 billion (as in SSP3 in 2070). Having controlled for demography, global warming shifts the whole distribution of population density to higher temperatures (Fig. 1c and Extended Data Fig. 7). This results in linear relationships (Fig. 3) between global warming and the percentage of the population exposed to unprecedented heat or left outside the niche from temperature change only, or temperature change plus demographic change. Hot exposure (Fig. 3a) starts to become significant above the present level of ~1.2 °C global warming and increases steeply at 11.9 % °C^{-1} (6.9 billion) to 17.5 % °C^{-1} (11.1 billion). Exposure due to temperature change alone increases 11.8 % °C^{-1} above the baseline defined at 0.3 °C global warming (1960–1990; Fig. 3b). Factoring in demography, for a greater fixed population, the percent exposed is always greater, but the dependence on climate weakens somewhat towards 9.1 % °C^{-1} (for 11.1 billion). The relationships between global warming and exposure are all steeper for the temperature–precipitation niche (Extended Data Fig. 8a). The mean temperature experienced by an average person increases with global warming in a manner invariant to demography at ~1.5 °C °C^{-1} (Extended Data Fig. 8b), consistent with observations and models that the land warms ~1.5 times faster than the global average[51].

Worst-case scenarios

We now focus on a future world of 9.5 billion. When assessing risk it is important to consider worst-case scenarios[52]. If the transient climate response to cumulative emissions is high, current policies could, in the worst case, lead to ~3.6 °C end-of-century global warming[1] (as projected under SSP3-7.0; Extended Data Table 1). This results in 34 ± 10% (3.3 ± 0.9 billion) hot exposed, 39 ± 7% (3.7 ± 0.7 billion) left outside the niche from temperature change only and 48 ± 7% (4.5 ± 0.6 billion) when including demographic change (Fig. 3). There also remains the possibility that climate policies are not enacted, and the world reverts to fossil-fuelled development (SSP5-8.5), leading to ~4.4 °C end-of-century global warming. This gives 45 ± 7% (4.2 ± 0.7 billion) hot exposed, 47 ± 8% (4.5 ± 0.7 billion) left outside the niche from temperature change only and 55 ± 7% (5.3 ± 0.6 billion) when including demographic change (Fig. 3).

Gains from strengthening climate policy

Having controlled for demography, strengthening climate policy reduces exposure (Figs. 1c and 3), including to unprecedented heat (Fig. 4), through reducing geographical movement of the temperature and temperature–precipitation niches (Extended Data Fig. 9). Following Climate Action Tracker's November 2021 projections[1], different levels of policy ambition result in ~0.3 °C changes in end-of-century global warming as follows: current policies lead to ~2.7 (2.0–3.6) °C; meeting current 2030 nationally determined contributions (without long-term pledges) leads to ~2.4 (1.9–3.0) °C; additional full implementation of submitted and binding long-term targets leads to ~2.1 (1.7–2.6) °C; and fully implementing all announced targets leads to ~1.8 (1.5–2.4) °C. Overall, going from ~2.7 °C global warming under current policies to meeting the Paris Agreement 1.5 °C target reduces hot exposure from 22 to 5% (2.1 to 0.4 billion; Fig. 3a). It reduces population left outside the niche due to temperature change only from 29 to 14% (2.8 to 1.3 billion) and it reduces population left outside the niche by temperature plus demographic changes from 39 to 28% (3.7 to 2.7 billion; Fig. 3b). Thus, each 0.3 °C decline in end-of-century warming reduces hot exposure by 4.3% or 410 million people, it reduces population left outside the niche due to temperature change only by 3.7% or 350 million people, and population left outside the niche due to temperature and demographic changes by 2.8% or 270 million people.

Country-level exposure

We focus on hot exposure as the simplest and most conservative metric. The population exposed to unprecedented heat (MAT ≥29 °C)

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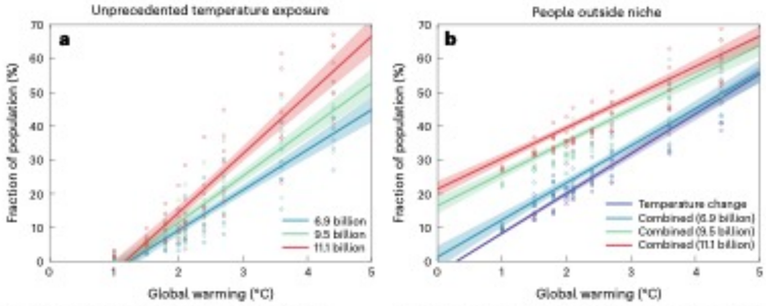

Fig. 3 | Relationships between global warming and population exposed outside the temperature niche for different fixed population distributions. **a**, Population (%) exposed to unprecedented heat (MAT ≥29 °C) for the different population distributions: 6.9 billion (blue; $n = 65$, coefficient = 11.9 % °C^{-1}, $r^2 = 0.83$); 9.5 billion (green; $n = 65$, coefficient = 13.8 % °C^{-1}, $r^2 = 0.83$); and 11.1 billion (red; $n = 65$, coefficient = 17.5 % °C^{-1}, $r^2 = 0.83$). **b**, Population (%) exposed outside the temperature niche due to temperature change only (purple; $n = 65$, coefficient = 11.8 % °C^{-1}, forcing intercept at 1960–1990 global warming of 0.3 °C), and due to the combined effects of temperature change and demographic change, for different fixed population distributions: 6.9 billion in 2010 (blue; $n = 65$, coefficient = 11.0 % °C^{-1}, $r^2 = 0.83$); 9.5 billion following SSP2 in 2070 (green; $n = 65$, coefficient = 9.5 % °C^{-1}, $r^2 = 0.84$); and 11.1 billion following SSP3 in 2070 (red; $n = 65$, coefficient = 9.1 % °C^{-1}, $r^2 = 0.84$). The shaded regions correspond to 95% two-sided confidence intervals of the estimated regression coefficients.

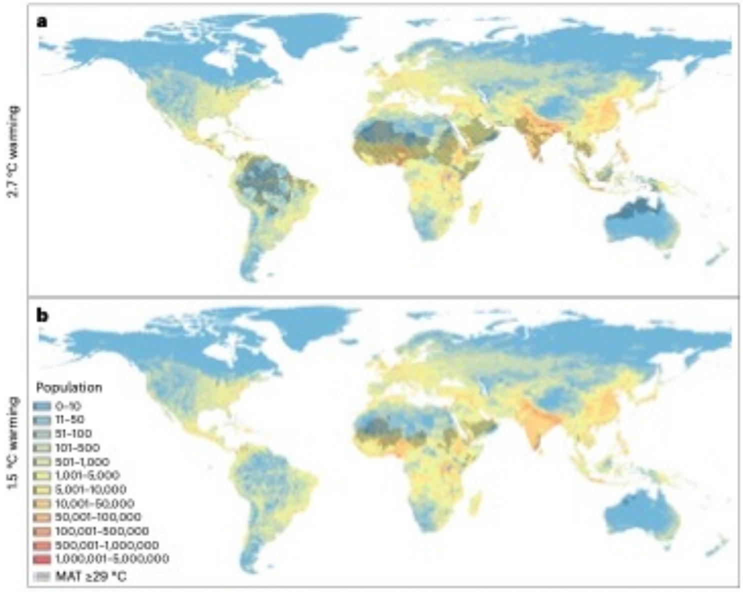

Fig. 4 | Regions and population densities exposed to unprecedented heat at different levels of global warming. a,b, Regions exposed to unprecedented heat (MAT ≥29 °C) overlaid on population density (number in a ~100 km² grid cell) for a world of 9.5 billion (SSP2, 2070) under 2.7 °C global warming (**a**) and 1.5 °C global warming (**b**).

worldwide declines ~5-fold if global warming is reduced from ~2.7 °C under current policies to meeting the 1.5 °C target (Fig. 5a and Supplementary Data). Assuming a future world of 9.5 billion, India has the greatest population exposed under 2.7 °C global warming, >600 million, but this reduces >6-fold to ~90 million at 1.5 °C global warming. Nigeria has the second largest population exposed, >300 million under 2.7 °C global warming, but this reduces >7-fold to <40 million at 1.5 °C global warming. For third-ranked Indonesia, hot exposure reduces >20-fold, from ~100 million under 2.7 °C global warming to <5 million at 1.5 °C global warming. For fourth- and fifth-ranked Philippines and Pakistan with >80 million exposed under 2.7 °C global warming, there are even larger proportional reductions at 1.5 °C global warming. Sahelian–Saharan countries including Sudan (sixth ranked) and Niger (seventh) have a ~2-fold reduction in exposure, because they still have a large fraction of land area hot exposed at 1.5 °C global warming (Fig. 5b). The fraction of land area exposed approaches 100% for several countries under 2.7 °C global warming (Fig. 5b). Brazil has the greatest absolute land area exposed under 2.7 °C global warming,

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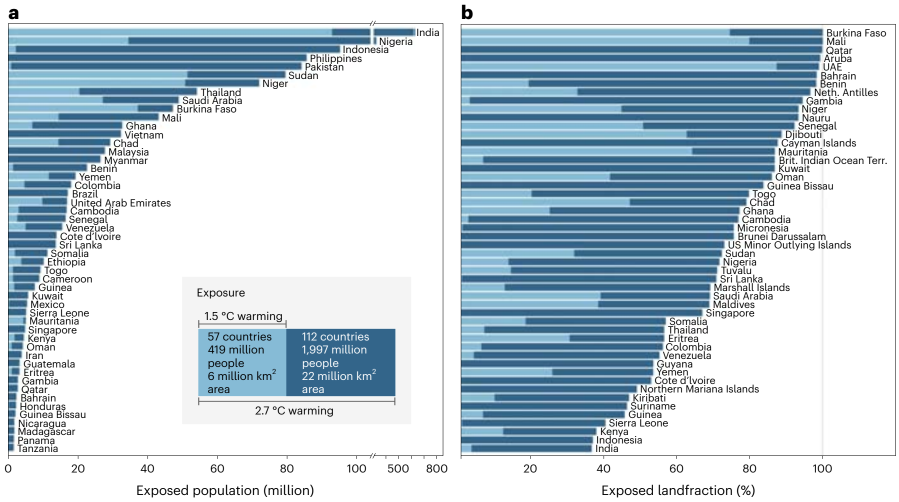

Fig. 5 | Country-level exposure to unprecedented heat (MAT ≥29 °C) at 2.7 °C and 1.5 °C global warming in a world of 9.5 billion people (around 2070 under SSP2). **a**, Population exposed for the top 50 countries ranked under 2.7 °C global warming (dark blue) with exposure at 1.5 °C global warming overlaid (pale blue). Note the break in the *x* axis for the top two countries. **b**, Fraction of land area exposed for the top 50 countries (again ranked under 2.7 °C global warming with results for 1.5 °C global warming overlaid). The inset in **a** summarizes the total global exposure of countries, population and land area at the two levels of global warming, with results for all countries provided in Supplementary Data. UAE, United Arab Emirates; Neth. Antilles, Netherlands Antilles; Brit. Indian Ocean Terr., British Indian Ocean Territory.

despite almost no area being exposed at 1.5 °C, and Australia and India also experience massive increases in absolute area exposed (Fig. 4). (If the future population reaches 11.1 billion, the ranking of countries by population exposed remains similar, although the numbers exposed increase.) Those most exposed under 2.7 °C global warming come from nations that today are above the median poverty rate and below the median per capita emissions (Fig. 6).

Relating present emissions to future exposure

Above the present level of 1.2 °C global warming, the increase in hot exposure of 13.8% $°C^{-1}$ for a future world of ~9.5 billion people (cap.; Fig. 3a), corresponds to 1.31×10^9 cap. $°C^{-1}$. The established relationship[53] of cumulative emissions (EgC) to transient global warming is ~1.65 (1.0–2.3) °C EgC^{-1}. Therefore one person will be exposed to unprecedented heat (MAT ≥29 °C) for every ~460 (330–760) tC emitted. Present (2018 data) global mean per capita CO_2-equivalent (C_{eq}) emissions[54] (production-based) are 1.8 tC_{eq} $cap.^{-1}$ yr^{-1}. Thus, during their lifetimes (72.6 years) ~3.5 global average citizens today (less than the average household of 4.9 people) emit enough carbon to expose one future person to unprecedented heat. Citizens in richer countries generally have higher emissions[54], for example, the European Union (2.4 tC_{eq} $cap.^{-1}$ yr^{-1}), the USA (5.3 tC_{eq} $cap.^{-1}$ yr^{-1}) and Qatar (18 tC_{eq} $cap.^{-1}$ yr^{-1}; Fig. 6), and consumption-based emissions are even higher. Thus, ~2.7 average European Union citizens or ~1.2 average US citizens emit enough carbon in their lifetimes to expose one future person to unprecedented heat, and the average citizen of Qatar emits enough carbon in their lifetime to expose ~2.8 future people to unprecedented heat. Those future people tend to be in nations that today have per capita emissions around the 25% quantile (Fig. 6), including the two countries with the greatest population exposed: India (0.73 tC_{eq} $cap.^{-1}$ yr^{-1}) and Nigeria (0.55 tC_{eq} $cap.^{-1}$ yr^{-1}). We estimate that the average future person exposed to unprecedented heat comes from a place where today per capita emissions are approximately half (56%) of the global average (or 52% in a world of 11.1 billion people).

Discussion

Our estimate that global warming since 1960–1990 has put more than 600 million people outside the temperature niche is consistent with attributable impacts of climate change affecting 85% of the world's population[55]. Above the present level of ~1.2 °C global warming, exposure to unprecedented average temperatures (MAT ≥29 °C) is predicted to increase markedly (Fig. 3a), increasing exposure to temperature extremes (Extended Data Fig. 4). This is consistent with extreme humid heat having more than doubled in frequency[42] since 1979, associated with labour loss of 148 million full-time equivalent jobs[19], with exposure in urban areas increasing for 23% of the world's population[56] from 1983 to 2016 (due also to growing urban heat islands) and the total urban population exposed tripling[56] (due also to demographic change). Both India and Nigeria already show 'hotspots' of increased exposure to extreme heat due predominantly to warming[56], consistent with our prediction that they are at greatest future risk (Fig. 5). These and other emerging economies (for example, Indonesia, Pakistan, Thailand) dominate the total population exposed to unprecedented heat in a 2.7 °C warmer world (Fig. 5). Their climate policy commitments also play a significant role in determining end-of-century global warming[5].

The huge numbers of humans exposed outside the climate niche in our future projections warrant critical evaluation. Combined effects of temperature and demographic change are upper estimates. This is because at any given time the method limits absolute population density of the (currently secondary) higher-temperature peak based on absolute population density of the (currently primary) lower-temperature peak. Yet absolute population density is allowed to vary (everywhere) over time. (This is not an issue for the temperature change only or hot exposure estimates.) Nevertheless, a bias of population growth to hot places clearly increases the proportion (as well as the absolute number) of people exposed to harm from high temperatures[57]. Colder places are projected to become more habitable (Extended Data Fig. 9) but are not where population growth is concentrated.

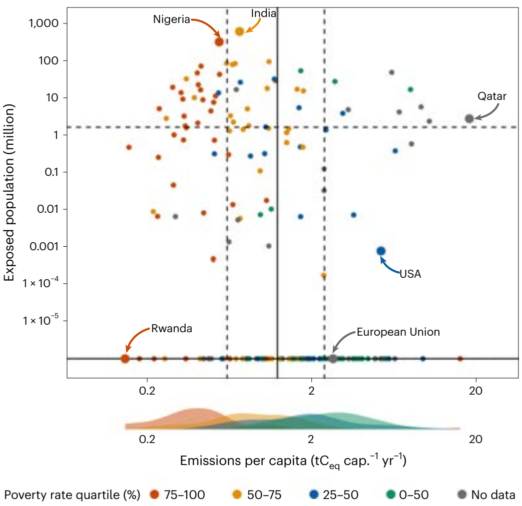

Fig. 6 | Country-level per capita greenhouse gas emissions[54] related to population exposed to unprecedented heat (MAT ≥29 °C) at 2.7 °C global warming (Fig. 5a) and poverty rate[80]. Solid lines show the median (50% quantile) and dashed lines show the 25% and 75% quantiles for emissions and heat exposure. Points are coloured by quartile of the poverty rate distribution, where poverty rate is defined as the percentage of national population below the US$1.90 poverty line. The density plots at the bottom show the distribution of emissions per capita for each poverty rate quartile.

Nor do we consider exposure to other sources of climate harm there (or elsewhere), including sea-level rise[30,31], increasing climate extremes[58] and permafrost thaw[59].

Overall, our results illustrate the huge potential human cost and the great inequity of climate change, informing discussions of loss and damage[60,61]. The worst-case scenarios of ~3.6 °C or even ~4.4 °C global warming could put half of the world population outside the historical climate niche, posing an existential risk. The ~2.7 °C global warming expected under current policies puts around a third of the world population outside the niche. It exposes almost the entire area of some countries (for example, Burkina Faso, Mali) to unprecedented heat, including some Small Island Developing States (for example, Aruba, Netherlands Antilles; Fig. 5b)—a group with members already facing an existential risk from sea-level rise. The gains from fully implementing all announced policy targets and limiting global warming to ~1.8 °C are considerable, but would still leave nearly 10% of people exposed to unprecedented heat. Meeting the goal of the Paris Agreement to limit global warming to 1.5 °C halves exposure outside the temperature niche relative to current policies and limits those exposed to unprecedented heat to 5% of people. This still leaves several least-developed countries (for example, Sudan, Niger, Burkina Faso, Mali) with large populations exposed (Fig. 5a), adding adaptation challenges to an existing climate investment trap[62]. Nevertheless, our results show the huge potential for more decisive climate policy to limit the human costs and inequities of climate change.

Methods

Reassessing the climate niche

We plot the running mean of population density against MAT, with a step of 1 °C and a bin size of 2 °C, and then apply double-Gaussian fitting to the resulting curve[14]. Our previous work[14] assessed the human temperature niche by quantifying the 2015 population distribution in relation to the 1960–1990 MAT (Extended Data Fig. 1; 'old reference'). Here, we re-assessed the temperature niche, changing the data to the 1980 population distribution (total 4.4 billion) under the 1960–1990 MAT, for greater internal consistency (Fig. 1a and Extended Data Fig. 1; '1980'). This is important because there has been significant population growth between 1980 and 2015 with a distinct bias to hotter places. The 1980 population distribution data were obtained from the History Database of the Global Environment (HYDE) 3.2 database[63]. The ensemble mean 1960–1990 climate and associated uncertainty (5th/95th percentiles) were calculated from three sources: (1) WorldClim v.1.4 data[64]; (2) Climate Research Unit Time Series (CRU TS) v.4.05 monthly data[65,66]; and (3) National Aeronautics and Space Administration Global Land Data Assimilation System (NASA GLDAS-2.1) 3-hourly data[67]. The revised temperature niche was compared with existing results for different historical intervals and datasets from ref. 14 (Extended Data Fig. 1). A revised temperature–precipitation niche was also calculated from both MAT and MAP, following the methods in ref. 14, but using the 1980 population distribution with the 1960–1990 mean climate.

Projecting the niche

Hot exposure is calculated (as previously[14]) for a given climate and population distribution as the percentage of people exposed to MAT ≥29 °C, from a direct spatial comparison of MAT and population distributions (without any smoothing). The MAT ≥29 °C threshold was chosen as only 0.3% of the 1980 population (12 million) experienced such conditions in the 1960–1990 climate. To separate the effects of climate and demographic changes on geographic displacement of the temperature niche (or the temperature–precipitation niche), we consider the following (Extended Data Fig. 3): (1) the geographic distribution of the reference niche ('reference distribution'); (2) projecting the reference niche function to the geographic distribution of present/future climate ('ideal distribution'); and (3) the geographically projected 'assumed distribution' of present/future population with respect to present/future climate conditions. Here, (2) minus (1) gives the effect of climate change only (as previously[14]), and (3) minus (2) gives the combined effect of climate and demographic change.

Linking average temperature to other thermal metrics

We assessed the relationships between MAT and other thermal metrics proposed to better capture thermal tolerance of humans, focusing on the recent interval 2000–2020. The correlations between MAT and annual MMT or mean annual WBT were assessed using linear regression with the ordinary least square method. MMT was calculated from the fifth generation European Centre for Medium-Range Weather Forecasts (ECMWF) reanalysis (ERA5) daily data at ~10 km spatial resolution and CRU TS v.4.06 monthly data at 0.5° spatial resolution. Mean annual WBT was calculated from ERA5 using the 'one-third rule' approximation based on a weighted average of dry-bulb and dewpoint temperatures[68] (this is reasonable for the annual average but overestimates daily maximum WBT). We used bias-corrected WBT[69] calculated from temperature and relative humidity data following the method of ref. 70 for six Coupled Model Intercomparison Project Phase 6 (CMIP6) models (limited to CNRM-CM6-1, CNRM-ESM2-1, CanESM5, GFDL-ESM4, MIROC-ES2L and MRI-ESM2-0 due to data availability) to derive daily maximum WBT and mean annual WBT. A model ensemble was created by resampling all model outputs to the coarsest model spatial resolution (2.8°; that of CanESM5 and GFDL-ESM4) using a bilinear interpolation method—each pixel in the resampled raster is the result of a weighted average of the nearest pixels in the original raster (this avoids biassing the ensemble towards higher resolution models). To assess the relationships between MAT and heat extremes, we considered the number of days with maximum temperature >40 °C or with WBT >28 °C. We used the ERA5 hourly data to calculate by grid point the average number of days in a year (between 2000 and 2020) with maximum dry-bulb temperature >40 °C. We used the CMIP6 model ensemble daily maximum WBT to calculate by grid point the average number of days per year (between 2000 and 2020) with maximum WBT >28 °C. Running means were calculated with a bin width of 2 °C, a step of 0.5 °C and a minimum bin size of 20 data points.

Changes up to present

To calculate changes up to (near) present, we construct an ensemble mean 2000–2020 climate and associated uncertainty (5th/95th percentiles) from five sources: (1) CRU TS v.4.05 monthly data[65,66]; (2) NASA GLDAS-2.1 3-hourly data[67]; (3) ECMWF ERA5-Land monthly averaged climate reanalysis data[71]; (4) NASA Famine Early Warning Systems Network Land Data Assimilation System (FLDAS) monthly data[72,73]; and (5) the United States National Centers for Environmental Prediction Climate Forecast System Version 2 (NCEP CFSv2) 6-hourly data[74]. Each climate dataset is aggregated to calculate MAT and precipitation. The 2000–2020 climate represents 1.0 °C global warming relative to the pre-industrial level. The 2010 population distribution data was obtained from the HYDE 3.2 database[63]. We followed the methods described above to calculate exposure.

Future projections

We used projected climate and population distribution under four different SSPs, which combine different demographic[75] and emissions projections under consistent storylines: SSP1-2.6 (sustainability), SSP2-4.5 (middle of the road), SSP3-7.0 (regional rivalry) and SSP5-8.5 (fossil-fuelled development). We focused on 20-year mean climate states for 2020–2040, 2040–2060, 2060–2080 and 2080–2100, and the projected population distribution data of 2030, 2050, 2070 and 2090, to represent average demographic conditions of corresponding time periods (Extended Data Table 1). We obtained downscaled CMIP6 climate data available from WorldClim v.2.0 at 0.0833° (~10 km) resolution, which restricts us to up to eight CMIP6 models: BCC-CSM2-MR, CNRM-CM6-1, CNRM-ESM2-1, CanESM5, GFDL-ESM4, IPSL-CM6A-LR, MIROC-ES2L and MRI-ESM2-0 (Supplementary Table 1). We obtained SSP population projection data at 1 km resolution from the spatial population scenarios dataset[76,77]. The SSP population projections were derived at national level using methods of multi-dimensional mathematical demography[75]. Alternative assumptions on future fertility, mortality, migration and educational transitions align to the SSP storylines on future development[78] (and exclude climate-induced migration). Spatially explicit data in line with those country-level projections were derived at 1/8° resolution using a parameterized gravity-based downscaling model[76], and further downscaled to 1 km resolution[77]. We aggregated this population data to a consistent resolution of 0.0833° (~10 km) to match the climate data and our previous analyses. We combine results across climate models to create a multi-model ensemble mean, and a 5–95% confidence interval, recognizing that the number of models available varies somewhat between SSPs and time-slices (Supplementary Table 1). To this end, we apply the MAT data of each climate model to plot population density against MAT and then combine the resulting curves to calculate the mean, and 5th and 95th percentiles.

Controlling for demography

To control for demography and thus isolate the effects of climate policy and associated climate change on exposure, we consider three different fixed populations and their spatial distributions: (1) 6.9 billion as in 2010; (2) 9.5 billion following SSP2 in 2070[75–77]; and (3) 11.1 billion following SSP3 in 2070[75–77]. These are combined with the observed (2000–2020) 1.0 °C global warming and with different future levels of global warming (1.5, 1.8, 2.0, 2.1, 2.4, 2.7, 3.6 and 4.4 °C) corresponding to different 20-year climate averages from different SSPs (Figs. 1c and 3, and Extended Data Fig. 7). Global warming of 1.5 °C and 2.0 °C are considered because of their relevance to the Paris Agreement. Values of 1.8, 2.1, 2.4 and 2.7 °C are chosen as best estimates of end-of-century global warming corresponding to different policy assumptions, taken from the Climate Action Tracker[1], which uses an ensemble of runs of the MAGICC6 model that, in turn, emulates different general circulation models from CMIP6. Global warming values of 3.6 and 4.4 °C are chosen as worst-case scenarios that also enable examining the shape of relationships between global warming and population exposure. Twenty-year SSP intervals corresponding to these different levels of global warming are chosen based on mean global warming levels from the CMIP6 model ensemble given in Table SPM.1 of the Sixth Assessment Report (AR6) of the Intergovernmental Panel on Climate Change[79] (IPCC). We try to match to warming in 2081–2100, but where earlier time intervals must be used this should have little effect on the results because the spatial pattern of temperature change is highly conserved on the century timescale. The different combinations are: 1.5 °C = SSP1-2.6 in 2021–2040; 1.8 °C = SSP1-2.6 in 2081–2100; 2.0 °C = SSP2-4.5 in 2041–2060; 2.1 °C = SSP3-7.0 in 2041–2060; 2.4 °C = SSP5-8.5 in 2041–2060; 2.7 °C = SSP2-4.5 in 2081–2100; 3.6 °C = SSP3-7.0 in 2081–2100; and 4.4 °C = SSP5-8.5 in 2081–2100. For the same time interval and SSP, different CMIP6 models can give different levels of global warming due to differing climate sensitivity. This is apparent in the spread of population exposure results for individual models (open circles in Fig. 3; Extended Data Fig. 8). However, we checked that global warming in the multi-model ensemble mean of the CMIP6 models we consider (Supplementary Table 1) matches that of the larger CMIP6 ensemble (Table SPM.1 of IPCC AR6).

Country-level estimates

Results for hot exposure for 2.7 °C and 1.5 °C global warming and populations of 9.5 or 11.1 billion were aggregated from the 0.0833° (~10 km) scale of the population and climate data to country scale. This summed the population in all grid cells within a country boundary where MAT ≥29 °C, using geographic information system data for country boundaries from the World Borders Dataset. For the grid cells that are intersected by a country boundary, they were associated with a country if over half the grid cell area fell within the country territory. Results for all countries are given in Supplementary Data.

Emissions and poverty rate of those exposed

Using the country-level breakdown of exposure to unprecedented heat in a 2.7 °C warmer world with 9.5 billion people (Fig. 5a and Supplementary Data), we calculated a weighted average for number of people exposed multiplied by percentage of global average emissions per capita today. This uses production-based, country-level C_{eq} greenhouse gas emissions from the emissions database for global atmospheric research[54], for which 2018 is the latest year. The calculation was also done for country-level exposure in a 2.7 °C warmer world of 11.1 billion. Consumption-based emissions (accounting for trade) tend to be lower than production-based emissions in poorer countries and higher in richer countries. This would increase the inequity already apparent in the results. We also examined poverty rate defined as the percentage of population per country below the US$1.90 poverty line, using the interpolated data for 2019 from the World Bank's Poverty and Inequality Platform[80]. The resulting distribution is heavily skewed with 25% quantile = 0.26%, 50% quantile = 1.79% and 75% quantile = 20%.

Reporting summary

Further information on research design is available in the Nature Portfolio Reporting Summary linked to this article.

Data availability

The historical and current population distribution data are available from the HYDE 3.2 database at https://landuse.sites.uu.nl/datasets/. The WorldClim v.1.4 data are available at https://doi.org/10.5061/dryad.fj6q573q7. The CRU TS v.4.05 and v.4.06 monthly data are available at https://crudata.uea.ac.uk/cru/data/hrg/. The NASA GLDAS-2.1 3-hourly data are available at https://developers.google.

com/earth-engine/datasets/catalog/NASA_GLDAS_V021_NOAH_G025_T3H. The ECMWF ERA5 daily data are available at https://developers.google.com/earth-engine/datasets/catalog/ECMWF_ERA5_DAILY. The bias-corrected WBT data are available at https://cds.climate.copernicus.eu/cdsapp#!/dataset/sis-extreme-indices-cmip6. The ECMWF ERA5-Land monthly data are available at https://developers.google.com/earth-engine/datasets/catalog/ECMWF_ERA5_LAND_MONTHLY. The NASA FLDAS monthly data are available at https://developers.google.com/earth-engine/datasets/catalog/NASA_FLDAS_NOAH01_C_GL_M_V001. The NCEP CFSv2 6-hourly data are available at https://developers.google.com/earth-engine/datasets/catalog/NOAA_CFSV2_FOR6H. The downscaled CMIP6 climate data are available from WorldClim v.2.0 at https://worldclim.org. The SSP population projection data are available at https://www.cgd.ucar.edu/iam/modeling/spatial-population-scenarios.html. The geographic information system data for country boundaries from the World Borders Dataset are available at https://thematicmapping.org/downloads/world_borders.php. The poverty data for 2019 from the World Bank's Poverty and Inequality Platform are available at https://pip.worldbank.org/home. All data generated during this study are available from https://doi.org/10.6084/m9.figshare.22650361.v1.

Code availability

Code used for the analysis is available from https://doi.org/10.6084/m9.figshare.22650760.v1.

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Author contributions
T.M.L., C.X. and M.S. designed the study. C.X. performed the climate niche analyses with input from T.M.L. T.M.L. and J.F.A. related present emissions to future exposure. C.X., J.F.A. and S.L. produced the figures with input from T.M.L., B.S. and C.Z. T.M.L. wrote the paper with input from C.X., J.F.A., A.G., S.L., B.S., C.Z., K.L.E., R.R.D., J.-C.S. and M.S.

Competing interests
The authors declare no competing interests.

Additional information
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Supplementary information The online version contains supplementary material available at https://doi.org/10.1038/s41893-023-01132-6.

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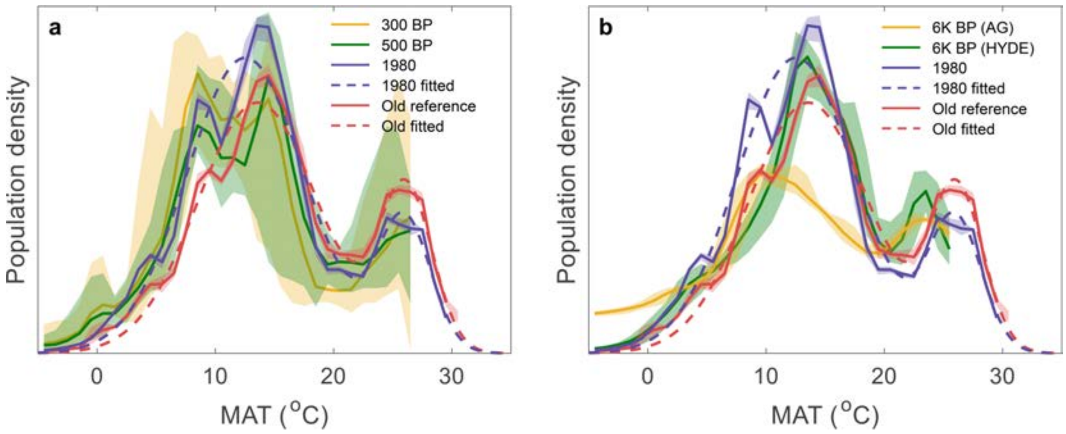

Extended Data Fig. 1 | Relative human population density with respect to Mean Annual Temperature (MAT). Reconstructions from ref. 14. for **a**. 300 BP, 500 BP (population data from HYDE database), and **b**. 6000 BP with population data from ArchaeoGlobe (AG) or HYDE, compared to the 1960-1990 climate (~0.3 °C above pre-industrial) with 2015 population distribution ('Old reference', from ref. 14) or 1980 population distribution ('1980', used here; as in Fig. 1a), and the smooth fitted functions for the temperature niche used previously[14] ('Old fitted') and here ('1980 fitted'; as in Fig. 1a) for future projections. Data presented as mean values with the shaded regions corresponding to 5-95th percentiles. Truncation of the historical reconstructions at higher temperatures is due to excluding bins of data with too few points in them to avoid outlier effects (see ref. 14).

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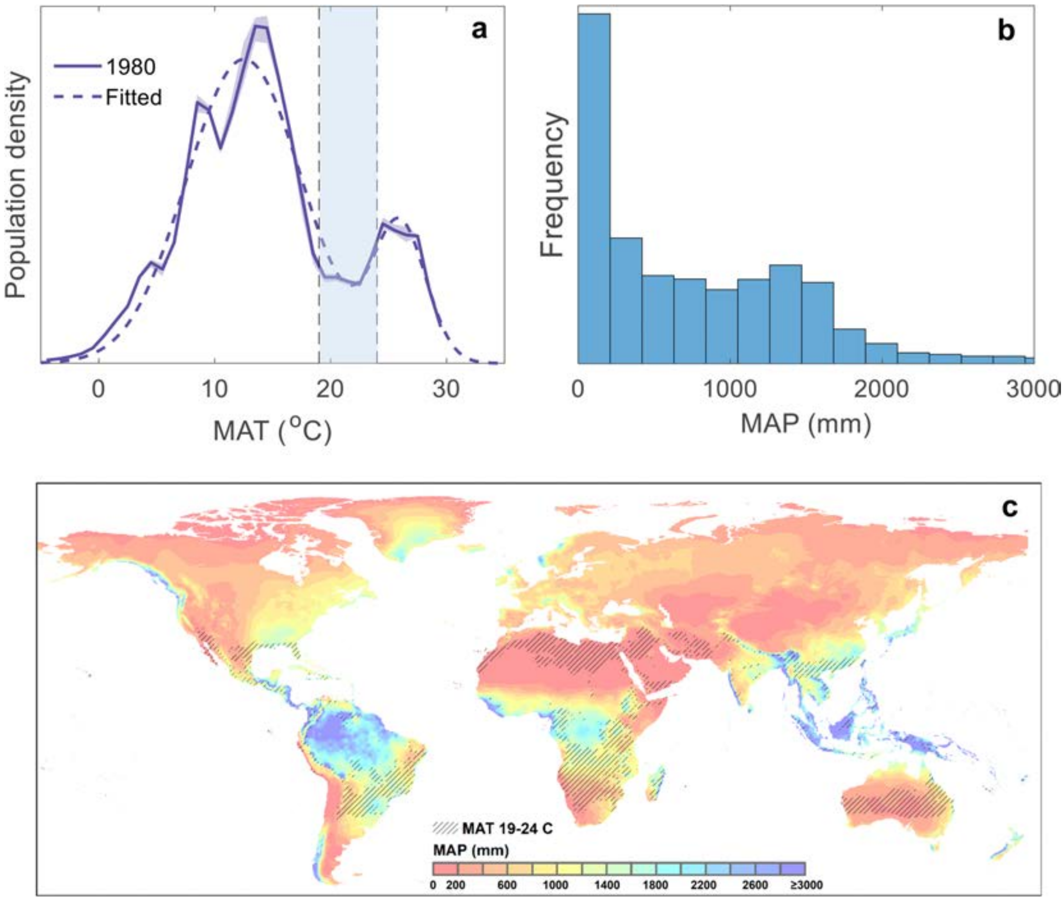

Extended Data Fig. 2 | Association of the temperature niche minimum with drier climates. a. The temperature niche has relatively low population density between 19 °C and 24 °C (blue vertical band). Data for 1980 presented as mean values with the shaded regions corresponding to 5-95th percentiles. **b**. Frequency distribution of mean annual precipitation (MAP) in the 19-24 °C MAT regions. **c**. Map of mean annual precipitation with the 19-24 °C MAT regions overlaid (cross hatching) showing they include large areas of deserts.

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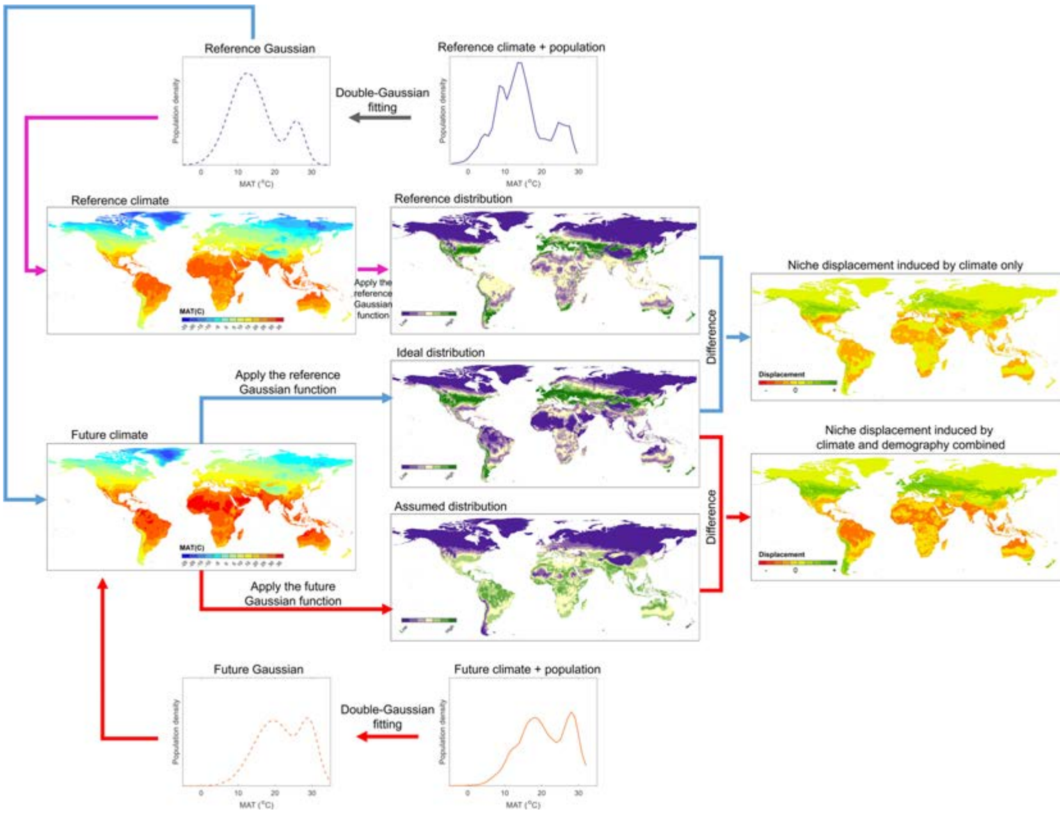

Extended Data Fig. 3 | Workflow for quantifying displacement of the human climate niche due to climate change only or climate and demographic change. Workflow shown for the temperature niche (but the same approach is used for the temperature-precipitation niche).

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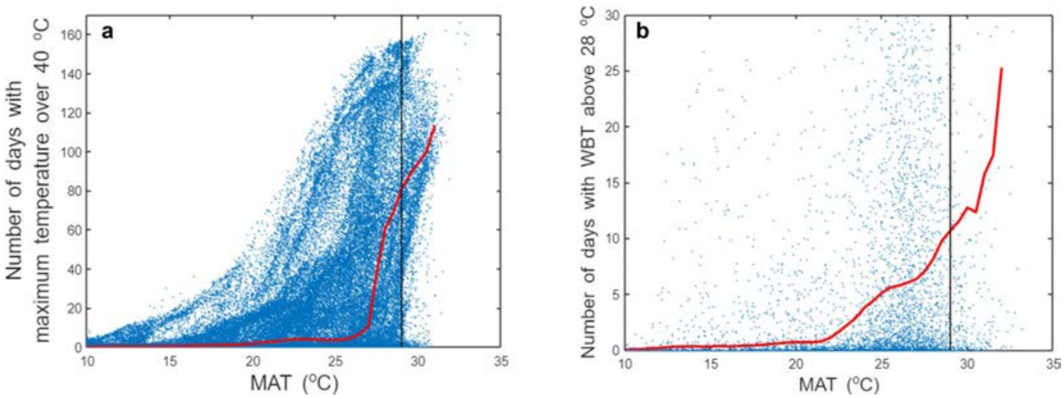

Extended Data Fig. 4 | Relationships between mean annual temperature (MAT) and accumulated intolerable heat extremes (for 2000-2020). **a**. Number of days with maximum temperature above 40 °C calculated using ERA5 data (10 km spatial resolution, n = 2287025). **b**. Number of days with maximum wet bulb temperature (WBT) above 28 °C calculated using bias corrected data from an ensemble of six CMIP6 models (2.8° spatial resolution, n = 49152). Red curves represent running means (with a bin width of 2 °C and step of 0.5 °C); black vertical lines mark 29 °C MAT. See Methods for further details of models and calculations.

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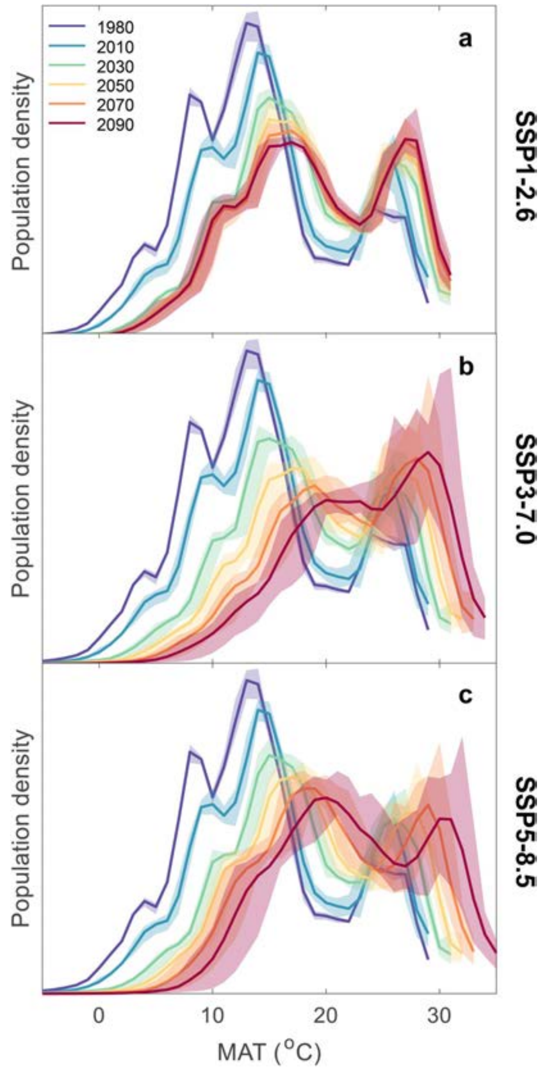

Extended Data Fig. 5 | Observed and projected future changes in human population density with respect to Mean Annual Temperature (MAT), following different Shared Socio-economic Pathways (SSPs). a. SSP1-2.6 leading to ~1.8 °C global warming with a peak of 8.5 billion people. **b**. SSP3-7.0 scenario leading to ~3.6 °C global warming and 12.1 billion people. **c**. SSP5-8.5 scenario leading to ~4.4 °C global warming and a peak of 8.6 billion people. (The SSP2-4.5 scenario is shown in Fig. 1b.) For each SSP and 20-year averaged climate interval, global warming and corresponding population levels (for the central year) are summarized in Extended Data Table 1. Data presented as mean values with the shaded regions corresponding to 5-95th percentiles.

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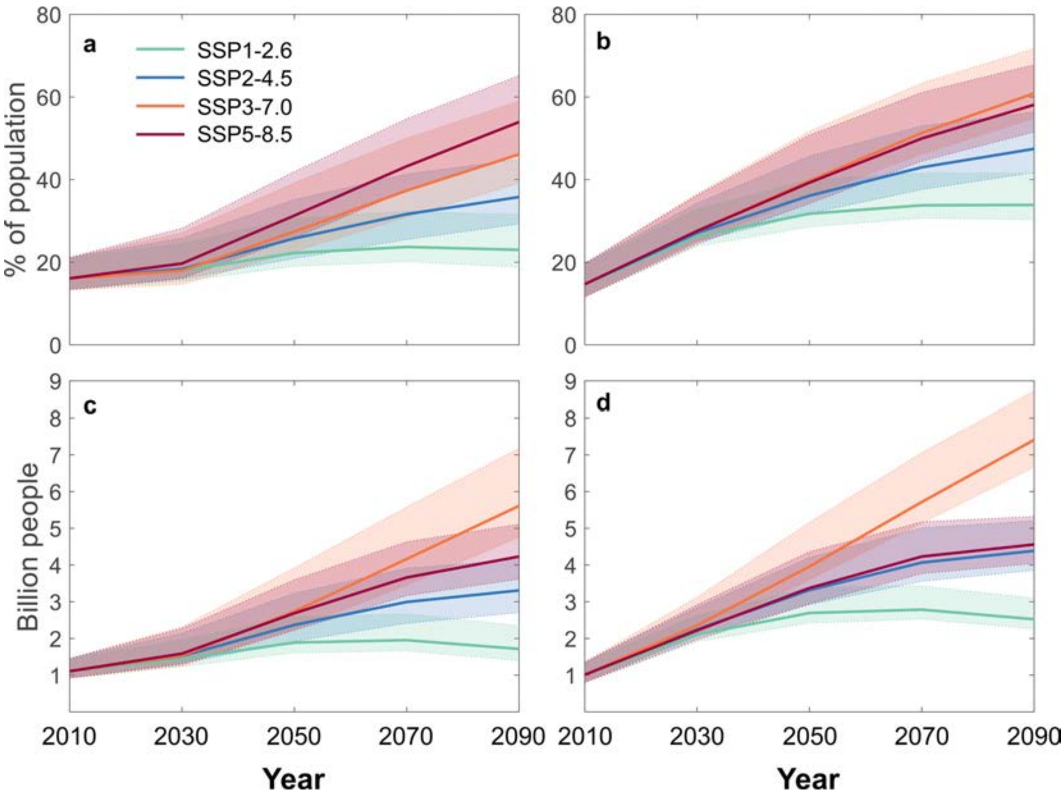
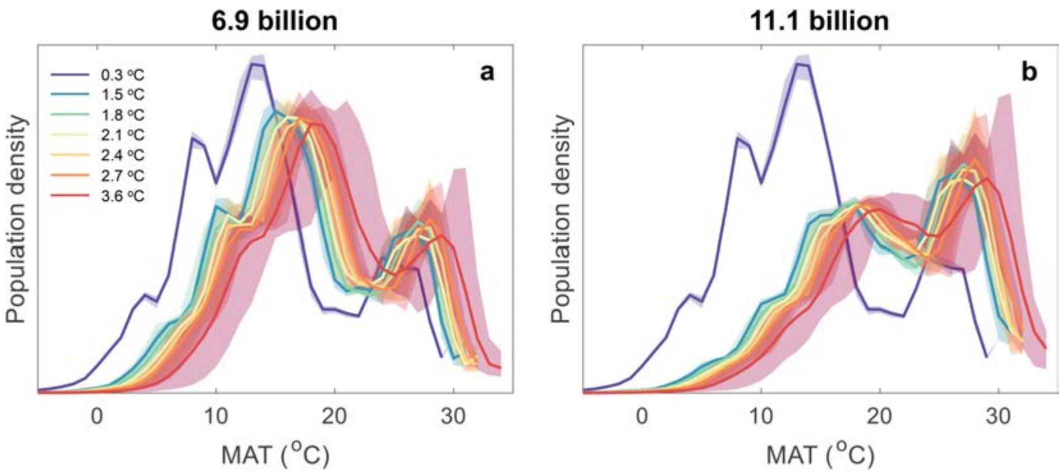
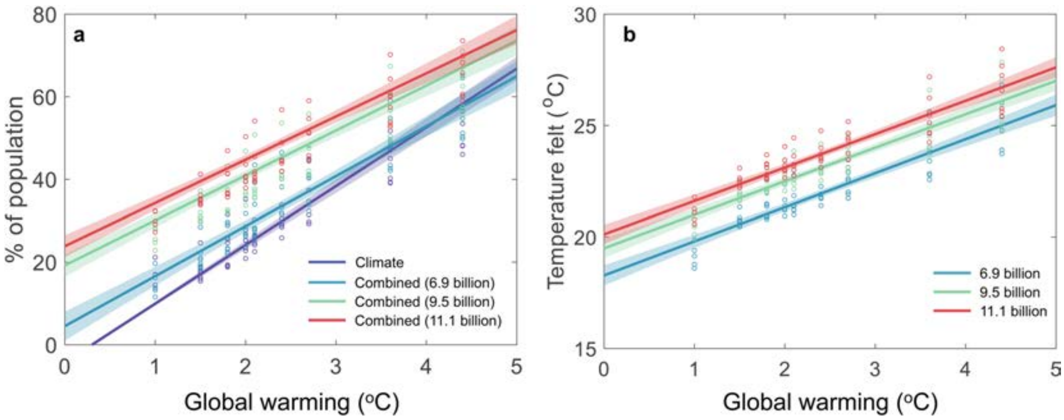


Extended Data Fig. 6 | Population exposed outside of the temperature-precipitation niche, following different Shared Socio-economic Pathways (SSPs). a, b. Fraction of population (%) left outside of the niche due to: **a**. climate change only. **b**. climate and demographic change. **c, d**. Absolute number left outside of the niche due to: **c**. climate change only. **d**. climate and demographic change. Calculations based on mean annual temperature (MAT) and precipitation (MAP) averaged over the 20-year intervals and population density distribution at the centre year of the corresponding intervals. Data presented as mean values with the shaded regions corresponding to 5-95th percentiles. (Note that the population exposed to unprecedented hot MAT ≥ 29 °C is unaltered by considering precipitation changes).



Extended Data Fig. 7 | Changes in human population density with respect to Mean Annual Temperature (MAT) for different fixed population distributions and levels of global warming. The population distributions are: **a**. 6.9 billion in 2010, **b**. 11.1 billion under SSP3 in 2070 (9.5 billion under SSP2 in 2070 is shown in Fig. 1c). See Methods for the combinations of SSP and 20-year time interval representing different global warming levels. Data presented as mean values with the shaded regions corresponding to 5-95th percentiles.



Extended Data Fig. 8 | Relationships between global warming and temperature-precipitation niche displacement and between global warming and average temperature experienced. a. Near linear relationship between global warming and temperature-precipitation niche displacement (%) due to temperature and precipitation change only ('Climate') and due to climate plus demographic change ('Combined'). Linear regression results: Climate (n = 65, coefficient=14.2 % °C^{-1}; forcing intercept at 1960-1990 global warming of 0.3 °C); Combined 6.9 billion (n = 65, coefficient=12.0 % °C^{-1}, r^2 = 0.84); Combined 9.5 billion (n = 65, coefficient=10.9 % °C^{-1}, r^2 = 0.84); Combined 11.1 billion (n = 65, coefficient=10.5 % °C^{-1}, r^2 = 0.84). **b**. Mean annual temperature felt by an average person for different levels of global warming for fixed population distributions. Linear regression results: 6.9 billion (n = 65, coefficient=1.53 °C °C^{-1}, r^2 = 0.83); 9.5 billion (n = 65, coefficient=1.50 °C °C^{-1}, r^2 = 0.84); 11.1 billion (n = 65, coefficient=1.50 °C °C^{-1}, r^2 = 0.84). The shaded regions correspond to 95% two-sided confidence intervals of the estimated regression coefficients.

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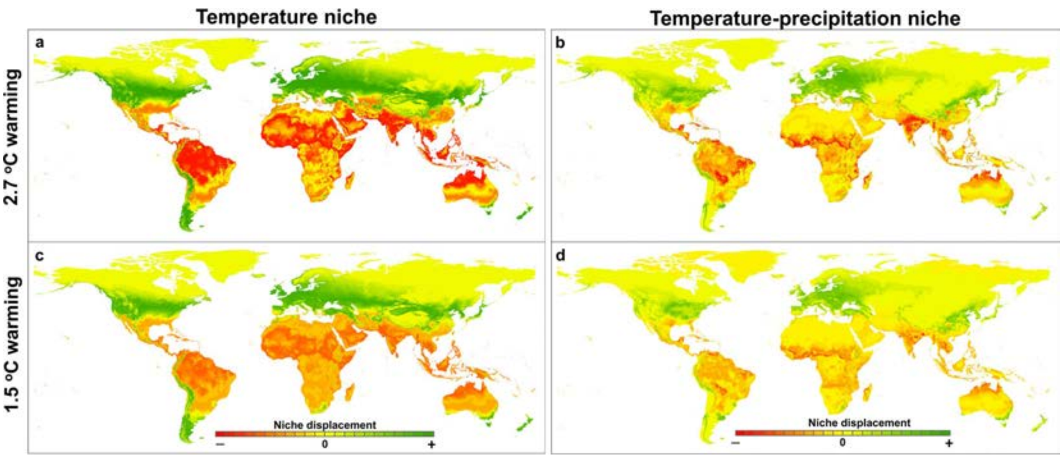

Extended Data Fig. 9 | Displacement of the temperature and temperature-precipitation niches under different levels of global warming. a, b. 2.7 °C global warming due to current policies, **c, d**. 1.5 °C global warming meeting the Paris Agreement. Red indicates a decrease in suitability, green an increase. Note that the less extensive changes in the temperature-precipitation niche are because it already constrains population density more in the driest and wettest regions.

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Extended Data Table 1 | Global warming and world population levels for each Shared Socioeconomic Pathway (SSP)

	Scenario	**2020-2040**	**2040-2060**		**2080-2100**
Warming (°C)	SSP1-2.6	1.5 (1.2-1.8)	1.7 (1.3-2.2)		1.8 (1.3-2.4)
	SSP2-4.5	1.5 (1.2-1.8)	2.0 (1.6-2.5)		2.7 (2.1-3.5)
	SSP3-7.0	1.5 (1.2-1.8)	2.1 (1.7-2.6)		3.6 (2.8-4.6)
	SSP5-8.5	1.6 (1.3-1.9)	2.4 (1.9-3.0)		4.4 (3.3-5.7)
	Scenario	**2030**	**2050**	**2070**	**2090**
World total Population (billion)	SSP1	8.0	8.5	8.2	7.4
	SSP2	8.3	9.2	9.5	9.2
	SSP3	8.5	9.9	11.1	12.1
	SSP5	8.0	8.6	8.4	7.8

Global warming levels are the 20-year averages from the full CMIP6 ensemble (Table SPM.1 of IPCC AR6 WG1). World population levels are given for the central year of each 20-year interval.