

Submission to the Call for Inputs for the Belém Mission to 1.5

Submitted by: Potsdam Institute for Climate Impact Research (PIK)

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This submission responds to the invitation by the COP Presidencies to provide scientific inputs to the Belém Mission to 1.5. Drawing on recent peer-reviewed research from the Potsdam Institute for Climate Impact Research (PIK) and other leading research institutions, it highlights evidence-based solutions with high potential to strengthen the ambition and implementation of Nationally Determined Contributions (NDCs) and National Adaptation Plans (NAPs), while supporting the achievement of the goals of the Paris Agreement.

1. What action areas and solutions have the highest impact potential to support the submission, ambition and implementation of NDCs and NAPs?

- **Green investments in steel**

- **Reference:** Bachorz, C., Dürrwächter, J., Gong, C.C. *et al.* Averting the steel carbon lock-in through strategic green investments. *Nat. Clim. Chang.* 16, 681–689 (2026). <https://doi.org/10.1038/s41558-026-02635-8>
- **Relevant themes:** investments in green steel production, avoiding carbon lock-in in industry.
- **Geographical scopes:** Global, India, China, EU, US
- **Summary:** A new wave of steel capacity additions in emerging economies threatens to lock in coal-based production for decades. By combining detailed steel production modelling with plant-level data in an integrated assessment model, we estimate that existing and planned coal-based steel plants could commit the world to nearly 60 GtCO₂. If current policy and investment trends continue beyond current plans, committed emissions reach 114 GtCO₂, consuming 20% of the remaining carbon budget for limiting peak warming to 1.7 °C. We show that 60% of this lock-in risk can be avoided at moderate average abatement costs of US\$100–150 tCO₂⁻¹. In India alone, 22 GtCO₂ of future emissions could be avoided by leveraging climate finance to redirect US\$50 billion this decade towards hydrogen-ready direct reduction steel plants. Near-term investment decisions on new steelmaking capacity represent a critical opportunity to avert the carbon lock-in and align the sector with climate targets.

- **Renewables-based electrification**

- **Reference:** Luderer, G., Madeddu, S., Merfort, L. *et al.* Impact of declining renewable energy costs on electrification in low-emission scenarios. *Nat Energy* 7, 32–42

(2022). <https://doi.org/10.1038/s41560-021-00937-z>

- **Relevant themes:** Renewable Electricity, electrification of transport, heat and industry sectors
 - **Geographical scope:** Global
 - **Summary:** Cost degression in photovoltaics, wind-power and battery storage has been faster than previously anticipated. In the future, climate policy to limit global warming to 1.5–2 °C will make carbon-based fuels increasingly scarce and expensive. Here we show that further progress in solar- and wind-power technology along with carbon pricing to reach the Paris Climate targets could make electricity cheaper than carbon-based fuels. In combination with demand-side innovation, for instance in e-mobility and heat pumps, this is likely to induce a fundamental transformation of energy systems towards a dominance of electricity-based end uses. In a 1.5 °C scenario with limited availability of bioenergy and carbon dioxide removal, electricity could account for 66% of final energy by mid-century, three times the current levels and substantially higher than in previous climate policy scenarios assessed by the Intergovernmental Panel on Climate Change. The lower production of bioenergy in our high-electrification scenarios markedly reduces energy-related land and water requirements.
- **Barriers to hydrogen upscaling**
 - **Reference:** Odenweller, A., Ueckerdt, F. The green hydrogen ambition and implementation gap. *Nat Energy* 10, 110–123 (2025). <https://doi.org/10.1038/s41560-024-01684-7>
 - **Relevant themes:** Challenges of green hydrogen and derivatives (e-fuels), gaps between ambition and reality
 - **Geographical scope:** Global
 - **Summary:** Green hydrogen is critical for decarbonizing hard-to-electrify sectors, but it faces high costs and investment risks. Here we define and quantify the green hydrogen ambition and implementation gap, showing that meeting hydrogen expectations will remain challenging despite surging announcements of projects and subsidies. Tracking 190 projects over 3 years, we identify a wide 2023 implementation gap with only 7% of global capacity announcements finished on schedule. In contrast, the 2030 ambition gap towards 1.5 °C scenarios has been gradually closing as the announced project pipeline has nearly tripled to 422 GW within 3 years. However, we estimate that, without carbon pricing, realizing all these projects would require global subsidies of US\$1.3 trillion (US\$ 0.8–2.6 trillion range), far exceeding announced subsidies. Given past and future implementation gaps, policymakers must prepare for prolonged green hydrogen scarcity. Policy support needs to secure hydrogen investments, but should focus on applications where hydrogen is indispensable.

- **Credible plans for sustainable use of carbon dioxide removal**

- **References:**

- Lamb, W.F., Reynolds, C. et al. Carbon dioxide removal in the G20 pledges: limited and lacking credibility. A State of Carbon Dioxide Removal Insight Report. <https://www.stateofcdr.org>, doi: <https://doi.org/10.17605/OSF.IO/X8U9M> (2025).
- Prütz, R. et al. Biodiversity implications of land-intensive carbon dioxide removal. *Nat. Clim. Chang.* 16, 155–163 (2026). <https://doi.org/10.1038/s41558-026-02557-5>

- **Relevant themes:** Lacking credibility and sustainability concerns over countries' plans for using carbon dioxide removal
- **Geographical scope:** Global
- **Summary:** In addition to deep and rapid emission reductions, countries also need to plan for and invest in the scale up of carbon dioxide removal (CDR) methods. However, in current NDCs, CDR pledges lack clarity and credibility, risking a delayed and insufficient growth of CDR required to achieve net zero CO₂ and to manage temperature overshoot. Transparency and ambition is particularly lacking concerning the scale up of novel CDR methods such as direct air capture with carbon capture and storage (DACCS). Over-reliance on conventional methods such as forestation and lack of transparency concerning feasibility of implementation pose sustainability risks and may interfere with other policy goals such as biodiversity conservation due to the immense resource consumption (land, water, nutrients). Biomass-based novel CDR methods such as bioenergy with carbon capture and storage (BECCS) face similar challenges. Raising ambition and transparency concerning future CDR use and diversifying CDR method portfolios are important steps to increase credibility of countries' near- and mid-term climate targets.

- **Transitioning away from fossil fuels to meet climate goals**

- **References:**

- Schreyer, F., Ueckerdt, F., Pietzcker, R. et al. From net-zero to zero-fossil in transforming the EU energy system. *Nat Commun* 16, 10700 (2025). <https://doi.org/10.1038/s41467-025-66682-z>
- Mori, S., Joshi, S., Krey, V. et al. Challenges and opportunities of the full phase-out of fossil fuels under the 1.5 °C goal. *Nat Commun* 17, 4379 (2026). <https://doi.org/10.1038/s41467-026-72841-7>

- **Relevant themes:** transitioning away from fossil fuels, energy system transformation, net zero
- **Geographical scope:** Global, European Union

- **Summary:** Achieving climate neutrality and limiting global warming to 1.5°C may require a complete phase-out of fossil fuels, going beyond conventional least-cost net-zero pathways. Modelling studies show that while fossil fuel use can be reduced dramatically through renewable energy deployment, electrification, and low-carbon fuels, eliminating the remaining fossil fuel demand in hard-to-abate sectors such as aviation, shipping, and industry requires additional technological deployment and significantly higher investments. A full phase-out could reduce reliance on carbon dioxide removal and strengthen the likelihood of meeting long-term climate goals, but it would require accelerated expansion of renewable electricity, hydrogen production, and synthetic fuels, alongside stronger policy commitment and societal determination.

- **Investment needs for the energy transition**
 - **Reference:** Guo, C., Bertram, C., Byers, E., Edmonds, J., Fawcett, A., Furhman, J., George, M., Hayez, L., Ju, Y., Kriegler, E., Lécuyer, F., Luderer, G., van Ruijven, B. (2025). Network of Greening the Financial System. <https://www.ngfs.net/en/publications-and-statistics/publications/explanatory-notes-ngfs-long-term-climate-scenarios>
 - **Relevant themes:** climate finance, energy transition
 - **Geographical scope:** global
 - **Summary:** Based on the results of Phase V of NGFS long-term scenarios, which were released in November 2024, the report finds: (1) Current total energy investment levels are insufficient to deliver a Paris-aligned transition. However, the recent, very fast upscaling of clean energy investments means that trends in particular sectors and regions have already achieved the scale of investment required. (2) Further upscaling is particularly needed in lower-income regions and electrified transport solutions. (3) Achieving the NZ scenario will require a major reallocation of capital, particularly into electric vehicles (EVs), grids, and renewables, with a global investment upscaling to USD 5 trillion by 2050 compared to 2025: EVs (USD 3 trillion - 67%), Power grids (USD 1 trillion - 19%), Renewables (USD 0.7 trillion - 14%).

- **Food system transformation as a mitigation and sustainable development pathway**
 - **References:**
 - Beier F, Dietrich J, Heinke J et al. Planetary boundaries under a land-based climate change mitigation scenario with a food demand transformation: a modelling study. *The Lancet Planetary Health*, 2025; 9. [https://doi.org/10.1016/S2542-5196\(25\)00087-7](https://doi.org/10.1016/S2542-5196(25)00087-7)
 - Bodirsky, B.L., Beier, F., Humpenöder, F. *et al.* *Nat Food* 6, 1133–1152 (2025). A food system transformation pathway reconciles 1.5 °C global warming with

improved health, environment and social inclusion.

<https://doi.org/10.1038/s43016-025-01268-y>

- Florian Humpeöder *et al.* Food matters: Dietary shifts increase the feasibility of 1.5°C pathways in line with the Paris Agreement. *Sci. Adv.* 10, eadj3832 (2024). DOI: [10.1126/sciadv.adj3832](https://doi.org/10.1126/sciadv.adj3832)

- **Relevant themes:** food system transformation, healthy diet, public health, social inclusion, land-system and energy-system climate change mitigation
 - **Geographical scope:** global
 - **Summary:** Transforming the global food system is essential for achieving climate, global health, social justice and further sustainability goals. Modelling studies show that combining measures across agricultural management, nature conservation, dietary change, and food waste reduction can generate substantial co-benefits, including lower greenhouse gas emissions, improved public health, reduced pressure on natural resources, and enhanced social outcomes. In particular, shifts towards healthier, more plant-rich diets reduce the short-term forcer methane and ease demands on land and other environmental resources, decreasing overshoot and the risk of transgressing 1.5°C for longer periods. All single levers for transformation come with benefits but also with trade-offs towards other sustainability goals. Only a bundling of multiple measures in a food system transformation can substantially lower global warming while improving also with respect to nature conservation, social justice and global health.
- **Technology availability, sector policies and behavioral change are complementary strategies for achieving net-zero emissions**
 - **Reference:** Strefler, J., Merfort, L., Bauer, N. et al. Technology availability, sector policies and behavioral change are complementary strategies for achieving net-zero emissions. *Nat Commun* 15, 8440 (2024). <https://doi.org/10.1038/s41467-024-52424-0>
 - **Relevant themes:** carbon price and complementary policies.
 - **Geographical scope:** global, European Union
 - **Summary:** In this study, we analyze the effects of technology availability, political coordination, and behavioral change on transformation pathways toward net-zero greenhouse gas emissions in the European Union by 2050. We implemented an iterative stakeholder dialogue to co-design the scenarios that were calculated using a global multi-regional energy-economy-land-climate model. We find that in scenarios without behavioral change and with restriction of technologies, the target of greenhouse gas neutrality in the European Union cannot be reached. Already a target of 200 Mt CO₂eq/yr requires CO₂ prices above 100 €/tCO₂ in 2030 across all sectors in all scenarios. The required CO₂ price can increase to up to 450 €/tCO₂ by 2030 if technologies are constrained, if no complementary regulatory measures are

implemented, and if changes in consumer behavior towards a more sustainable lifestyle do not materialize.

- **Separating CO₂ emission from removal targets comes with limited cost impacts**

- **Reference:** Merfort, A., Strefler, J., Abrahão, G. *et al.* Separating CO₂ emission from removal targets comes with limited cost impacts. *Nat Commun* 16, 5298 (2025). <https://doi.org/10.1038/s41467-025-60606-7>
- **Relevant themes:** separate targets for emissions and removals
- **Geographical scope:** global
- **Summary:** Net-zero commitments have become the focal point for countries to communicate long-term climate targets. However, to this point it is not clear to what extent conventional emissions reductions and carbon dioxide removal (CDR) will contribute to net-zero. An integrated market for emissions and removals with a uniform carbon price delivers the economically efficient contribution of CDR to net-zero. Yet it might not fully internalise sustainability risks of CDR and hence could lead to its overuse. In this study, we explore the implications of separating targets for emissions and for removals delivered by novel CDR in global net-zero emissions pathways with the Integrated Assessment Model REMIND. We find that overall efficiency losses induced by such separation are moderate. Furthermore, limiting the CDR target comes with increasing emission prices but also significant benefits: lower cumulative emissions, a lower financial burden for public finance of CDR and limited reliance on geologic CO₂ storage but fails to lower the biomass demand. Proposed targets should also ensure sufficient CDR deployment to achieve net-negative emissions in the second half of the 21st century.

- **Decent living standards and energy transition pathways**

- **Reference:** Jarmo S Kikstra *et al* 2025 *Environ. Res. Lett.* 20 054038 DOI 10.1088/1748-9326/adc3ad
- **Relevant themes:** equity in global climate action, energy transition, decent living standards (DLS), inequality reduction, sustainable development pathways
- **Geographical scope:** Global
- **Summary:** Social and environmental agendas are intricately connected and shape the international policy discourse. To support these discussions, we present a framework for interpreting global scenario outcomes on energy demand and supply-side transitions through the lens of societal well-being and minimum resource requirements. We develop and apply a new model called Decent living standards and the Environment in Scenarios considering Inequality and Resource Efficiency (DESIRE) to fill a critical gap in modelling inequality-growth-efficiency interactions. Utilising bottom-up literature on energy inequality and minimum energy

requirements, we analyse system-wide changes from integrated assessment models to assess whether levels of energy consumption in pathways can be consistent with providing decent living standards (DLS) for all, covering three sectors in 173 countries. We apply DESIRE to multiple new sustainable development pathways (SDPs). By 2040, the combination of ambitious inequality reductions, service provisioning efficiency, and higher energy services in the SDPs reduces the global residential and commercial energy deprivation—currently over 5 billion people—by at least 90%. Industry energy gaps are closed, but transport gaps remain. In the SDPs, more than half of the global population—including in low-income countries—achieve living standards more than twice as high as the DLS benchmark for the residential and commercial sector. Energy use beyond DLS across all sectors accounts for about two-thirds of total energy use globally. Efficiency improvements reduce global energy requirements 30%–46% by 2040 in the SDPs (across countries from 17–35 GJ cap⁻¹ in 2020 to 9–23 GJ cap⁻¹), while climate policies reduce CO₂ emissions related to energy for DLS to almost zero in 2050, keeping cumulative emissions for DLS for all until 2050 close to the size of the remaining carbon budget to 1.5 °C (at 50% probability). This work illustrates the possibility of pathways that deliver DLS for all while meeting the Paris Agreement.

- **Mitigating distributional impacts of climate policies and ensuring a just transition**

- **References:**

- Emmerling, J., Andreoni, P., Charalampidis, I. et al. A multi-model assessment of inequality and climate change. *Nat. Clim. Chang.* 14, 1254–1260 (2024). <https://doi.org/10.1038/s41558-024-02151-7>
- Johannes Emmerling, Pietro Andreoni, Massimo Tavoni, Global inequality consequences of climate policies when accounting for avoided climate impacts, *Cell Reports Sustainability*, Volume 1, Issue 1, 2024, 100008, ISSN 2949-7906, <https://doi.org/10.1016/j.crsus.2023.100008>.
- Fujimori, S., Hasegawa, T., Oshiro, K. et al. Potential side effects of climate change mitigation on poverty and countermeasures. *Sustain Sci* 18, 2245–2257 (2023). <https://doi.org/10.1007/s11625-023-01369-2>

- **Relevant themes:** just transition, intra-national distributional impacts, particularly on poverty and household incomes, climate policy side effects

- **Geographical scope:** Global

- **Summary:** Climate change and inequality are closely interconnected, as climate impacts are projected to increase domestic inequality by an average of 1.4 points on the Gini index by 2100, while climate policies can either reduce or exacerbate these distributional impacts depending on their design. Limiting warming in line with the goals of the Paris Agreement reduces this long-term increase in inequality by half to two-thirds, while well-designed redistribution schemes can offset short-term

pressures, lowering the Gini index by nearly 2 points and leaving most of the population economically better off today. Targeted transfers to low-income households can eliminate increases in inequality entirely, highlighting the importance of considering both the costs of climate policies and the benefits of avoided climate impacts. At the same time, large-scale mitigation policies risk increasing poverty through changes in prices and incomes; specifically, a global uniform carbon price could increase the global poverty headcount by 69 million people (19%) by 2030, with price changes accounting for 55% and income changes for 40% of this effect. These adverse side effects can be successfully countered through complementary measures, including targeted redistribution of carbon revenues, direct emission regulations, enhanced energy efficiency standards, and greater international attention to economic development in poor countries. Together, these approaches demonstrate that climate policies can stabilize the climate while reducing inequality, limiting poverty, and supporting a just transition.

- **Targeting compensation to the losers of climate policy**

- **References:**

- Missbach, L., & Steckel, J. C. (2026). The heterogeneous effects of climate policy on households: Evidence from 88 countries. *Journal of Environmental Economics and Management*, 103382.
- Missbach, L., Steckel, J. C., & Vogt-Schilb, A. (2024). Cash transfers in the context of carbon pricing reforms in Latin America and the Caribbean. *World Development*, 173, 106406.

- **Relevant themes and scope:** Distributional effects of climate policy; design of compensation schemes; acceptability of climate policy.
- **Geographical scope:** global scope; country specific results
- **Summary:** Carbon pricing and other climate policies impose costs that fall unevenly across households. Managing these distributional effects is not only an equity imperative but a precondition for political acceptability of climate policy. Household income alone is a poor predictor of who bears the heaviest burden. Drawing on novel household-level data from 88 countries (Missbach and Steckel 2026), we show that effective targeting of compensation requires additional information beyond income, and that the distribution of climate policy costs and their predictors varies substantially across country contexts. Critically, the households most affected by climate policy are often not covered by existing social protection systems — meaning that effective compensation requires purpose-designed schemes, not just repurposing of existing transfers. Evidence from Latin America and the Caribbean (Missbach, Steckel & Vogt-Schilb 2024) illustrates both the potential and the design requirements for cash transfers as a compensation instrument.

2. What is required to further strengthen international cooperation to enhance ambition and enable the effective implementation of NDCs and NAPs?

- **Create new performance-based, rules-based climate finance funds at scale**
 - **References:**
 - Edenhofer et al. (2025), How to scale up effective international climate finance by the EU? Tax coalitions and jurisdictional reward funds for the case of fossil fuel, Kieler Arbeitspapiere, 2296 <https://www.kielinstitut.de/de/publikationen/how-to-scale-up-effective-international-climate-finance-by-the-eu-tax-coalitions-and-jurisdictional-reward-funds-for-the-case-of-fossil-fuel-18266/>
 - Edenhofer, O., Leisinger, C., Stern, L., Kalkuhl, M. (2026): Making international carbon markets work for Europe: Jurisdictional Reward Funds and the EU's 2040 climate target, Potsdam : Potsdam Institute for Climate Impact Research, 18 p. <https://doi.org/10.48485/pik.2026.17>
 - Banerjee, Sreoshi and Franks, Max and Kalkuhl, Matthias and Stern, Lennart and Xie, Xuan, Jurisdictional Reward Funds for Tropical Forest Conservation and Restoration (June 10, 2026). Available at SSRN: https://papers.ssrn.com/sol3/papers.cfm?abstract_id=6915562
 - Bolton et al., Why coalitions of wealthy nations should fund others to decarbonize, Nature 639, 574-576 (2025), <https://doi.org/10.1038/d41586-025-00779-9>
 - **Relevant themes:** climate finance, NDCs, international flexibility
 - **Geographical scope:** Global
 - **Summary:** To increase international cooperation in climate policy, new financing institutions, so-called Jurisdictional Reward Funds, are needed. They use universal reference levels to reward countries for specific climate policies, following a performance-based, rules-based approach. The use of universal reference levels creates strong dynamic incentives to increase NDCs; the jurisdictional approach overcomes many problems of project-based climate finance (baseline manipulation, low additionality, high government crowding out); the performance- and rules-based approach creates credibility and trust in a world of increasing geopolitical tensions. Jurisdictional Reward Funds can receive contributions from large economies like the EU or China, that have substantial self-interest in financing emission and fossil-fuel reduction in other countries (to reduce climate damages on their territory, and to reduce import costs of fossil fuels). A role model constitutes the tropical conservation fund, TFFF, launched at COP30. Small improvements in its design can increase efficiency by a factor of 3 (Banerjee et al. 2026).

- **International collaboration on energy intensive materials**

- **Reference:** Verpoort, P.C., Gast, L., Hofmann, A. *et al.* Impact of global heterogeneity of renewable energy supply on heavy industrial production and green value chains. *Nat Energy* 9, 491–503 (2024). <https://doi.org/10.1038/s41560-024-01492-z>
- **Relevant themes:** Green Steel, Green Ammonia, Green Ethylene, benefits of trading renewables-based energy intensive goods and intermediate products
- **Geographical scope:** Global
- **Summary:** On the path to climate neutrality, global production locations and trade patterns of basic materials might change due to the heterogeneous availability of renewable electricity. Here we estimate the ‘renewables pull’, that is, the energy-cost savings, for varying depths of relocation for three key tradable energy-intensive industrial commodities: steel, urea and ethylene. For an electricity-price difference of $\text{€}40 \text{ MWh}^{-1}$, we find respective relocation savings of 18%, 32% and 38%, which might, despite soft factors in the private sector, lead to green relocation. Conserving today’s production patterns by shipping hydrogen is substantially costlier, whereas trading intermediate products could save costs while keeping substantial value creation in renewable-scarce importing regions. In renewable-scarce regions, a societal debate on macroeconomic, industrial and geopolitical implications is needed, potentially resulting in selective policies of green-relocation protection.

- **Phasing out coal demands context-sensitive international support beyond climate finance**

- **References:**
 - Steckel, J. C., & Jakob, M. (2022). To end coal, adapt to regional realities. *Nature*, 607(7917), 29-31.
 - Ohlendorf, N., Jakob, M., & Steckel, J. C. (2022). The political economy of coal phase-out: Exploring the actors, objectives, and contextual factors shaping policies in eight major coal countries. *Energy Research & Social Science*, 90, 102590.
 - Manych, N., Müller-Hansen, F., & Steckel, J. C. (2023). The political economy of coal across 12 countries: Analysing qualitative interviews with topic models. *Energy Research & Social Science*, 101, 103137.
 - Jakob, M., & Steckel, J. C. (2022). *The political economy of coal* (Vol. 10, p. 9781003044543). Routledge.
- **Relevant themes:** Coal phase out; political economy; overcoming barriers.
- **Geographical scope:** global scope, country-specific results
- **Summary:** Ending coal is indispensable for keeping 1.5°C within reach. Effective phase out strategies must reflect that societal and political objectives why coal is still used (and partly continued to be invested in) are heterogeneous. A systematic

political economy analysis across major coal-using countries (see references above) reveals that coal's entrenchment takes fundamentally different forms depending on context. In high-income countries, the main barriers are incumbent interests and transition costs for workers and regions — tractable through compensation schemes and credible domestic policy. In LMICs, coal is often tied to energy security and industrialisation imperatives; hence, external financial support and technology transfer are prerequisites for a phase out, not optional add-ons. Framing coal exit purely as a climate obligation, without addressing legitimate development needs, is both politically untenable and normatively problematic. Development needs must be addressed, by making clean alternatives genuinely competitive taking specific country contexts into account — not just in cost, but in reliability, financing access, and institutional capacity. NDC ambition on coal will only translate into implementation if domestic political coalitions supporting transition are actively built. International climate policy needs to invest in understanding and shaping these coalitions, not just setting targets.

- **Aligning national ambition with fair effort sharing globally**

- **References:**

- Dekker, M.M., Hof, A.F., du Robiou Pont, Y. *et al.* Navigating the black box of fair national emissions targets. *Nat. Clim. Chang.* **15**, 752–759 (2025). <https://doi.org/10.1038/s41558-025-02361-7>
- S. Pelz, G. Ganti, R. Lamboll, L. Grant, C. Smith, S. Pachauri, J. Rogelj, K. Riahi, W. Thiery, & M.J. Gidden, Using net-zero carbon debt to track climate overshoot responsibility, *Proc. Natl. Acad. Sci. U.S.A.* **122** (13) e2409316122, <https://doi.org/10.1073/pnas.2409316122> (2025)

- **Relevant themes:** equity in global climate action, fair emission reduction allowances, fair effort sharing, net-zero carbon debt, international climate finance fluxes, intergenerational equity
- **Geographical scope:** Global
- **Summary:** Current national climate targets remain insufficient to meet the goals of the Paris Agreement, highlighting the urgent need for equitable approaches to distributing mitigation efforts globally. Fair emissions allowances provide a basis for aligning national ambition with global equity by quantifying countries' fair shares under different fairness principles while accounting for physical and social uncertainties, global strategies, and equity. This enables the identification of countries whose current pledges fall short of their fair share and informs the balance between increased domestic mitigation and international climate finance, indicating a required cross-border finance flow of US\$0.5–7.4 trillion in 2030. As current emissions trends are projected to deplete the remaining 1.5°C carbon budget around 2030, the concept of net-zero carbon debt extends effort-sharing beyond budget exhaustion by clarifying responsibilities for carbon budget exceedance, informing



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regional carbon drawdown obligations, and supporting the assessment of responsibilities for increased lifetime exposure to extreme heatwaves across generations. Together, these approaches strengthen the implementation of equitable effort-sharing mechanisms and support the alignment of national climate ambition with the goals of the Paris Agreement.