https://doi.org/10.1038/s44168-025-00220-x

Filling the climate finance gap: holistic approaches to mobilise private finance in developing economies

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Transitioning to a low-carbon economy requires over $8.4 trillion annually for the rest of this decade, but current efforts are insufficient, especially in emerging markets and developing economies (EMDEs). Using a theoretical model of the climate finance gap, we identify key factors needed to close this gap and examine how adjustments in carbon pricing could effectively mobilise the required investment. Our findings highlight the importance of strengthening two core elements: (1) Reframing 'international carbon markets' to focus on supporting comprehensive, equitable transitions in EMDEs and fostering large-scale systemic cooperation, and delivering real mitigation impacts. (2) Implementing holistic transition plans and cohesive packages of public, private, and market support to create economic, social, and political environments that enable credible and effective policy implementation, while providing the critical technology and skilled labour needed to make private financial flows more responsive to carbon price signals.

Climate change mitigation is a global challenge that necessitates a collective, humane, and imaginative response. Increasing 'climate finance'—the varied flows of funding to finance a myriad of efforts to reduce greenhouse gas emissions and increase resilience to climate change impacts—is crucial. The United Nation's COP29 climate summit in 2024 led to a new international climate finance goal. This goal includes providing more concessional finance, especially for the poorest countries, and unlocking new sources of international climate finance but still falls well short of what is needed.

Climate finance flows reached an annual average of USD 1.3 trillion in 2021/2022[1], according to Climate Policy Initiative estimates, almost doubling 2019/2020 level[2]. However, the finance gap remains huge: global investments needed to mitigate climate change exceeds USD 8.4 trillion per year by 2030 according to one credible estimate[1]. It is imperative that we accelerate innovative strategies through global efforts to fill this gap.

To fill the climate finance gap, there are two main challenges. First is the uneven distribution of climate investments worldwide (shown in Fig. 1). Only one-third of the total energy investments and 20% of global investments in clean energy technologies are directed toward EMDEs outside China, even though these regions account for two-thirds of the world's population[3]. Rapid economic growth in EMDEs would, without systemic change in energy systems, be driven by massive reliance on fossil fuel-based energy systems. This means that by 2030 if the world is on track to meet global climate goals, as much as 40% of emission reduction opportunities would be in EMDEs other than China. In contrast, one-third of mitigation opportunities would be in China and one-quarter from advanced economies[3].

Climate mitigation efforts in EMDEs are often restricted by limited financial resources, as well as regulatory and implementation capacities. The International Energy Agency (IEA)[4] identifies the high cost of capital, reflecting higher risks at country, sectoral and project levels, as a major obstacle hindering capital flows into clean energy projects in EMDEs. The cost of capital for utility-scale solar photovoltaic projects in EMDEs is more than twice that in advanced economies. This could result in a climate investment trap by limiting low-carbon investments and delaying the energy transition. Consequently, climate change risks may lead to economic losses or political instability, further heightening perceived investment risks[5].

Meanwhile, advanced economies express high levels of concern for climate issues and have substantial wealth to fund mitigation. They face relatively high abatement costs within their borders[6] yet have political concerns about spending resources abroad, even it is more cost-effective for global emission reduction[7]. At COP15 in 2009, developed countries pledged to mobilise USD 100 billion annually by 2020 for climate action in developing countries. The goal was first met in 2022, with USD 115.9 billion mobilised[8]. However, this amount is far from sufficient to meet overall climate finance needs, it is largely at market rates and fails to address the critical issue of uneven distribution[9]: there is not enough clean energy investment where it is most needed. The new goal of USD 300 billion per

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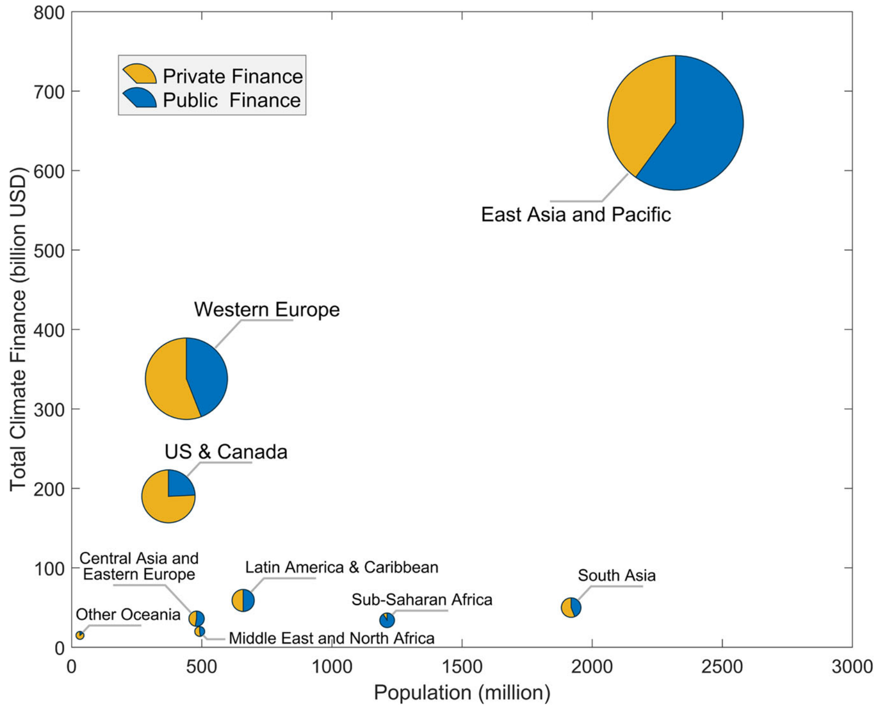

Fig. 1 | Distribution of global climate finance by regions and sources in 2023. Figure 1 illustrates the distribution of global climate finance in 2023 across regions, disaggregated by funding source, based on data (Supplementary Table 1) from CPI and the World Bank. The size of each bubble represents the total climate finance volume (in billion USD), while the *x*-axis shows the population size of each region (in millions). The pie charts within the bubbles depict the proportional contributions of private finance (yellow) and public finance (blue) to the total. East Asia and the Pacific have the largest climate finance volume, with a significant share from public finance. In contrast, Western Europe and the US & Canada demonstrate substantial finance levels, where private finance is the predominant contributor. Regions such as Sub-Saharan Africa and South Asia display lower total climate finance despite their large populations. This visualisation highlights both the magnitude and composition of climate finance across regions, revealing disparities in funding levels and sources.

year set at COP29 in 2024 is still weak. Not only is the amount insufficient, but it is also not clear how much of the finance will be concessional and the definition of what investments count as 'climate' investments is still ambiguous. Even if countries are able to attract these funds, they may not be effectively applied to meet mitigation needs. Much of this funding is expected to come from the private sector.

This leads to the second challenge: how to leverage more private finance, especially in EMDEs[10]. EMDEs will not be able to finance the scale of climate investments to meet their climate goals without huge additional efforts from the private sector[11]. In 2022, public funds accounted for about half of clean energy spending in EMDEs compared to less than 20% in advanced economies. IEA[12] estimated that about 60% of clean energy investment in EMDEs (excluding China) must come from the private sector, reaching USD 0.9-1.1 trillion annually by the early 2030s—markedly higher than the USD 135 billion in 2022. Estimates of the need for private finance reflect inherent limitations in public sector financing, exacerbated recently by COVID-19 which has increased fiscal stress and, in some countries, led to a crisis of unsustainable debt[13]. However, climate investment risks are typically higher in developing countries[14]. The capacity to mobilise more private investment is closely tied to the enabling environment of host countries[15]. This requires policymakers and regulators to create a more attractive business environment through systemic actions, such as creating a shared national vision for clean energy transition, implementing well-designed regulations and workforce planning, increasing the reliability of revenues from heavily regulated sectors such as electricity, and enabling access to critical infrastructure and land[16].

Carbon pricing policies are widely considered a key instrument for mobilizing resources from the private sector to accelerate mitigation. As of 2024, there are 75 carbon taxes and emissions trading systems implemented globally, concentrated in developed economies[17]. A limited number of EMDEs, such as Mexico and Indonesia, have introduced domestic carbon pricing instruments, but these often feature relatively low price levels and incomplete market designs[18]. The extent to which carbon markets can catalyze climate finance varies considerably in response to regulatory frameworks, environmental conditions, and market structures[19]. However, empirical analyses and integrated models that evaluate the effect of carbon markets on crowding in private finance remain scarce.

International carbon markets are similarly posited as mechanisms to facilitate resource transfers aimed at bridging climate finance gaps in EMDEs. However, most of them are voluntary offsetting mechanisms and project-based activities that have often resulted in isolated interventions characterized by short duration and limited scalability. These approaches have raised doubts about their effectiveness in achieving net global emission reductions, as well as concerns regarding additionality, carbon leakage, rebound effects, equity, and potential harm to indigenous and local communities[20–23]. The Clean Development Mechanism (CDM) under the Kyoto Protocol, originally designed to reduce mitigation costs in developed countries while providing low-carbon capital and technology diffusion to developing countries, exemplifies these challenges. These debates are paralyzing voluntary carbon markets and posing serious threats to emerging compliance markets such as those under Article 6 of the Paris Agreement and the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA)[24–28]. Historically, participation in CDM has been heavily concentrated in a few countries—China, India, and Brazil accounted for over 70% of CDM projects and Certified Emission Reductions (CERs). As a result, many other EMDEs remain insufficiently equipped to engage with the evolved rules of implementation under Article 6, and lack the institutional capacity and holistic frameworks necessary for large-scale international cooperation agreements[29].

Based on the above considerations, this research aims to address three core questions: (1) How can the various sources of climate finance be categorized, and what will their respective shares be like by 2030? (2) How can carbon markets effectively leverage climate finance? (3) What strategies can enhance the role of carbon markets in mobilizing investment for climate action?

First, drawing on existing research data and a simplified modeling framework, we identify the relative global magnitude of potential impacts arising from different efforts and provide scenarios that illustrate the influence of expanded domestic and international carbon markets. Rather than estimating the level of carbon price required for efficient achievement of global goals – which many other studies do with detailed integrated assessment models[30,31], we identify the distinct roles of three factors that enhance the effectiveness of carbon markets in unlocking climate finance—carbon price levels, carbon price coverage, and leverage ratios. By examining

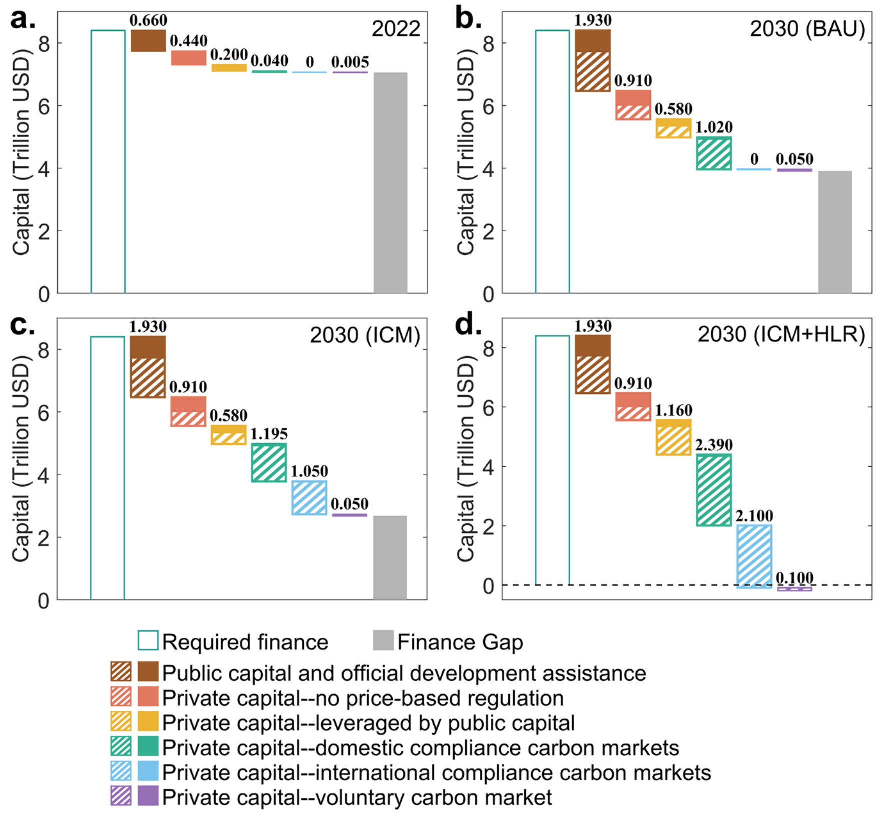

Fig. 2 | Current and three scenarios of future global climate finance drivers. Figure 2 shows the total climate finance needs and the capital mobilized from various channels under different scenarios (data in Supplementary Table 3). It distinguishes between full shades, which represent existing contributions as of 2022, and partial shades, which depict additional contributions mobilized after 2022. **a** Provides the 2022 baseline breakdown. **b** Illustrates the projected 2030 Business As Usual (BAU) scenario, with steady growth across all sources. **c** Introduces the International Carbon Market (ICM) scenario, where international and domestic compliance markets play a significant role in narrowing the gap. **d** Represents the International Carbon Market with High Leverage Ratio (ICM + HLR) scenario, which further boosts private capital through enhanced leverage of public investments and carbon credit mechanisms, thereby effectively closing the finance gap.

different scenarios, this work also provides insights that can inform future research and policy development.

Second, we propose a theoretical model that suggests how reframed carbon markets could support integrated packages of systemic support and price incentives. These packages could enable higher carbon prices and greater coverage by supporting activities such as energy and climate policy development, critical electricity infrastructure and workforce planning, as well as enabling innovative risk management approaches, could help create a more favourable environment for climate investments in EMDEs. This would increase the capital leverage ratio of carbon pricing policies and public finance by increasing rewards and reducing risks at the project level. A well-designed institutional framework and favourable investment environment would not only mobilise greater private sector investment but also increase greater willingness by the governments of advanced economies to transfer resources (e.g., capital, technology, capacity) to EMDEs and facilitate the development of more ambitious emission reduction initiatives in these countries. Ultimately, these strategies could help bridge the investment gap for achieving global climate stabilisation goals.

Results

Bridging the global climate finance gap: drivers and scenarios for 2030

All estimates suggest that trillions of investment capital are needed annually by 2030 to meet Paris Agreement goals but there is no clarity on how to achieve this[12]. There is a scarcity of modeling analyses on the amount and aggregation of each financing source needed to bridge the gap, as well as a lack of empirical evidence to reflect differential financing conditions. Based on data and estimates from diverse sources (Method section and Supplementary Table 2), we divide the drivers of finance into public funding, private funding not driven by price-based regulation or public finance, private capital mobilised by public funding, and private capital mobilised by domestic carbon pricing and international compliance markets (Article 6 and CORSIA) and the voluntary carbon market (VCM). We show a projection of each source's contribution (Fig. 2 and data in Supplementary Table 3).

We present three scenarios for 2030 that illustrate how market-based approaches could help fill the global climate finance gap. We first introduce how we estimate current climate finance leveraged from each source in 2022(Fig. 2a) and 2030 under stated policies and trends (BAU scenario, Fig. 2b). Next, we propose two promising scenarios that integrate new approaches, one is international carbon market (ICM scenario, Fig. 2c) and the other one is a scenario with holistic strategies designed to achieve a high leverage ratio (HLR scenario, Fig. 2d), which represents a potential pathway to almost bridge the funding gap. These are not intended to be accurate predictions or optimal scenarios, instead, aiming to show the potential scale of the mobilisation of finance by each driver and highlight the need to use all instruments to drive finance, including emerging international carbon market. We make certain simplifications to the model and conduct a series of sensitivity analyses on key parameters and assumptions to explore further possibilities (Discussion section and Supplementary Table 4).

The public finance for mitigation (brown bar) includes contributions from governments, state-owned enterprises, multilateral development banks and official development assistance. Public finance is currently about 51% of total climate finance and accounted for USD 660 billion in climate finance for mitigation in 2022[2,32,33], and is projected to grow to nearly USD 1.9 trillion by 2030 under the BAU scenario.

The private capital mobilised without price-based regulation (pink bar) results from the investments becoming profitable as costs fall; from voluntary efforts driven by environmental, social, and governance (ESG) concerns; or as a result of non-price regulatory factors. For 2022, we derived a net value of USD 438 billion for this portion of private finance by subtracting the estimated amount mobilised through public finance and other carbon pricing policies from the total private finance flows as reported by the CPI (2023)[1]. Our simple projection for 2030 assumes that private finance will continue to grow at the cumulative average rate since 2011 to reach nearly USD 908 billion in 2030.

The orange bar is private finance mobilised by public finance. Public finance could act as a catalyst in mobilizing private finance through an array of finance instruments, such as guarantees or feed-in tariffs for new technologies. We adopt a public finance leverage ratio of 0.3 from empirical evidence from IEA[4] and Organisation for Economic Co-operation and Development (OECD)[34,35]. In 2022, this particular segment was approximately USD 200 billion. By 2030, under both BAU and the ICM scenarios, it is projected to reach USD 579 billion.

The green bar represents capital mobilised by domestic carbon pricing instruments, such as carbon taxes or emissions trading systems. By adopting a series of assumptions—including carbon price level, coverage, emissions reduction effect, and the carbon price leverage ratio for capital both currently and in 2030 (details in the Methods section)—our estimate indicates that in 2022, existing domestic carbon pricing mechanisms could only mobilise USD 41 billion. In the 2030 BAU case, domestic carbon pricing could mobilise over USD 1 trillion annually in private capital.

The blue bar in Scenario ICM 2030 represents potential capital mobilisation through perfectly functioning international carbon markets enabled by Article 6 of the Paris Agreement. The estimates by Piris-Cabezas, Lubowski and Leslie[36] suggest that a perfectly functioning market consistent with meeting a 2 °C target would involve carbon payments between countries of over USD 210 billion annually and therefore might achieve additional annual capital mobilisation of USD 1 trillion by 2030.

The small purple bar is the contribution of the VCM to mobilizing capital. We calculate this by multiplying current payments for VCM credits (around USD 1.3 billion in 2022, according to Trove Research[37]) by the assumption of capital mobilised per dollar of credit payment. For the 2030 BAU case we use the low estimate from Trove Research[38] and World Bank[39] that voluntary carbon markets are expected to grow to a size of $10 – 40 billion by 2030, which suggests this market could leverage USD 50 billion after multiplying by carbon price leverage ratio. Here, we adopted the most conservative estimate for the VCM to avoid any overlap with calculations related to the international carbon market.

In 2022, the finance gap amounted to approximately USD 7.1 trillion[1] (Fig. 2a). In the Business As Usual (BAU) scenario in 2030, we project that public finance and private finance leveraged by public initiatives could triple from 2022 levels under the right conditions. Similarly, private finance driven without support from government might double. Continued strengthening and expansion of emissions coverage by domestic compliance carbon pricing policies (including carbon taxes, emissions trading systems) could leverage growth in private finance from USD 41 billion in 2022 to USD 1022 billion by 2030. Voluntary markets may expand, but their impact remains small. Nevertheless, the finance gap would still remain at USD 3.9 trillion (Fig. 2b).

In the International Carbon Market (ICM) scenario (Fig. 2c), potential capital mobilisation to EMDEs of USD 1 trillion by 2030 could be achieved through highly functioning international carbon markets enabled by Article 6 of the Paris Agreement. This international agreement can directly support investment and may also enable an increase in the ambition of domestic carbon pricing in developing countries or provide institutional support[40]. Higher carbon prices in developing countries could mobilise another US$174 billion. However, the gap would still be USD 2.7 trillion.

Understanding how to provide the right incentives is the first step in driving large-scale resource flows. Relying solely on individual carbon credits projects or donations typically do not catalyze the systemic changes necessary for large-scale, long-term mitigation goals. To bridge this gap, it is essential to increase private sector capital leverage ratios of both public finance and carbon pricing policies. In the International Carbon Market and High Leverage Ratio (ICM + HLR) scenario (Fig. 2d), we assume that when host governments successfully implement holistic plans in conjunction with other climate finance sources, we could double the leverage ratio of public finance from 0.3 –0.6 and the carbon pricing leverage ratio from 5 to 10. With these adjustments, the finance gap could be fully addressed, in theory. In the following sections, we delve deeper into these mechanisms and illustrate how a reframed international carbon market and a holistic national plan can work together to drive systemic changes.

Reframed large scale international carbon market

Compared with the business-as-usual scenario, we believe that international carbon markets can play a pivotal role—provided they address concerns about integrity and effectiveness and operate under a reframed, large-scale international agreement. We argue that a large part of previous problems of international carbon market arise from the specific conception of carbon markets as 'offsets' which focus on supporting project-scale activities. In a broader interpretation, markets could represent a mechanism for transferring resources, e.g., capital, technology, and capacity, toward those who need these resources to accelerate mitigation while compensating with carbon credits to those who possess them, fostering mutual benefit and enhanced climate ambition.

We propose that international carbon markets could be based on a few, large, bespoke agreements among countries in the way that domestic compliance markets are based on government regulations or laws. Bespoke carbon market agreements at a sectoral or national scale can help ensure that the resources contributed by foreign non-state actors (e.g., companies) in exchange for carbon credits are clearly targeted toward the actions most needed to enable effective, additional mitigation in the specific sector and country[41].

Credits are created and transferred only after successful changes and large-scale reductions have been clearly demonstrated. This large scale 'results-based' approach gives hosts and partners a strong incentive to work together to ensure success at the system scale[42]. Under such agreements, buyers or 'partners' will fund in advance only activities consistent with delivering reductions through systemic change. This approach also largely resolves two related concerns of partner countries—effectiveness of their contributions in addressing climate change, which matters to their voters and taxpayers, and credit integrity and hence others' recognition of the credits they claim.

Various initiatives are now exploring and trialing large-scale, or jurisdictional crediting (e.g., the LEAF Coalition, the US Energy Transition Accelerator, Climate Action Teams). Each agreement can involve the creation and sale of large volumes of high integrity credits. For example, the LEAF Coalition addresses these challenges through a coordinated group of buyers joining to generate sufficient scale of demand and a jurisdictional approach, ensuring emissions reductions are accounted for across entire regions to enhance additionality, reduce leakage, and improve transparency[43]. Supported by over $1.5 billion in buyer pledges, LEAF utilizes the ART-TREES framework to uphold stringent monitoring, accounting, and social safeguards. The state of Pará, Brazil, recently signed a $180 million agreement under LEAF[44] to support their ongoing efforts to lower deforestation rates[45]. In addition, Ghana has made notable progress in implementing Article 6 frameworks. Ghana plans to use international cooperation under Article 6.2 to achieve up to 55% of its conditional absolute emission reductions, which will require an estimated investment of USD 4.9 billion[46]. In January 2023, Ghana published its framework for international carbon markets and non-market approaches, outlining strategies to minimize overselling risks against its NDC targets. Ghana has also signed MOUs with Sweden, Singapore, South Korea, and Switzerland. Although no Article 6 units had been transferred as of August 2024, Ghana's institutional readiness and framework design demonstrates a solid foundation for engaging in future large-scale agreements.

Effective governance is vital for achieving systemic mitigation goals. Large-scale electrification initiatives, for instance, call for long-term commitment, clear priorities, strategic planning, and significant upfront funding. Countries such as Vietnam and Indonesia have shown how robust governmental engagement can lead to successful electrification outcomes. In contrast, countries with significant political and administrative challenges may present higher risks for international climate finance, potentially undermining the success of large-scale initiatives.

Innovative supporting finance instruments, as well as reframed contracts, are needed in high-risk investment environments to achieve the potential of international carbon markets. Carbon credit contracts can be structured to make a difference to large-scale capital mobilisation by taking advantage of new risk management possibilities. Risk management in agreements may include provisions for advance payments or commitments (e.g., advance market commitments) or approaches to mitigate and efficiently allocate investment risks from political instability or project delivery uncertainties. Advance payments motivated by anticipated recognition of contributions to global mitigation (such as carbon credits) can be allocated for insurance coverage or as equity stakes, thereby facilitating more conventional private sector investments. Carbon credit contracts can also incorporate pricing mechanisms that share the carbon price risk, mitigating the impact of lower-than-expected prices while still sharing gains in times of high carbon prices.

Holistic strategies and mitigation 'avocados'

Our model results indicate that the leverage ratios plays a critical role in bridging the finance gap. Instead of addressing issues piecemeal, the host EMDEs have to bear the responsibility to undertake the technically, economically, and socially holistic strategies to scale up the effects of private funding from carbon markets and public funding.

To illustrate a holistic approach more concretely, we propose the concept of a "mitigation avocado", an analogy based on the avocado's layered structure (seed, flesh, and skin) to represent a cohesive and mutually supportive package of incentives and resources that spans various levels of the economy—and apply it in the electricity sector (Fig. 3).

The electricity sector alone could provide about half of the required annual global emission reductions by the year 2030, and reliable and affordable low-carbon electricity is key to decarbonising the rest of our economies[47]. These make it a key area for immediate focus. Decarbonizing electricity involves some discrete projects that can be implemented by the private sector. These projects, which we refer to as the "seed" of the mitigation avocado, include building renewable energy and storage facilities, electrifying buildings and industrial processes, improving the efficiency of fossil fuel facilities that must continue to operate during the transition, and accelerating the closure of unnecessary and inefficient plants.

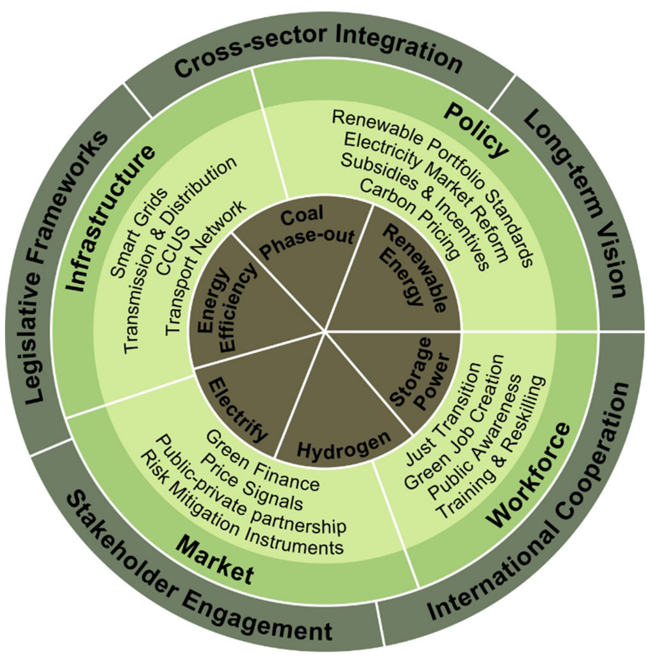

Fig. 3 | An example of an electricity sector "mitigation avocado". Figure 3 uses the "mitigation avocado" framework to illustrate a holistic climate mitigation plan for the electricity sector. In this conceptual model, the "seed" represents foundational mitigation projects like building renewables and phasing out coal. The "flesh" corresponds to the broader economic, political, and social environment, such as regulatory reform and infrastructure management, which underpin successful climate mitigation actions. The "skin" symbolizes overarching visions and coordination. The proportions may vary across countries depending on specific contexts and priorities.

However, to nurture these 'seeds' into sustainable and impactful outcomes, a supportive environment—the 'flesh' of the avocado—is essential. For electricity decarbonisation, this entails regulatory reforms that eliminate barriers to profitable renewable electricity generation, and policies, possibly including local carbon pricing, that induce a high level of renewable energy demand and efficient dispatch. It necessitates infrastructure investments and grid management for a more decentralised, reliable, and renewable-focused energy system. Long-term power purchase agreements to reduce transaction costs, stable pricing mechanisms, green bonds, and risk-sharing instruments can improve revenue certainty and lower the cost of capital. Human capital development to provide the skilled labour needed and support for individuals and communities affected by closure of fossil fuel plants, mines, and wells also may be needed to facilitate a just and hence politically feasible transition.

Beyond the "seed" and "flesh", the "skin" of the mitigation avocado represents the critical institutional framework. Key institutions include climate targets and monitoring, and planning and governance institutions (e.g., Climate Commissions) that coordinate different sources of finance, and technical and capacity support at the national or even global scale, and facilitate social processes to inform and shape the national or sectoral visions for a low emissions future and provide the social licence governments need to act in an ambitious and sustained way. The 'skin' is what can support effective international carbon market agreements.

Many OECD countries (for example the European Union, the United Kingdom, Korea, Chile, New Zealand and U.S. states such as California) have already developed integrated plans and created key institutions and are moving ahead, albeit at varying rates, to implement change. However, most EMDEs still lack such frameworks, resulting in ad hoc and piecemeal approaches to climate mitigation whether funded by domestic or international resources. Previous research indicates that technology transfer under the CDM was frequently driven by cost minimisation rather than alignment with host country priorities[48]. Even if host countries were to establish comprehensive plans, and partner countries were to commit to supporting their implementation, the challenge would still be significant. Host countries have to ensure that mitigation efforts are impactful, credible, and equitable among domestic stakeholders, as well as between host and partner countries. For example, Kenya, which scored above the Sub-Saharan African average in government effectiveness, began receiving support from the African Development Bank in 2015 for the "Last Mile Connectivity Project", aiming to expand electricity access[49]. With local government involvement, Kenya was able to leverage these investments to achieve higher rates of electricity access, showcasing how a holistic national plan can amplify the benefits of climate finance[50].

Holistic approaches with large-scale international agreements mean a strategy to align different stakeholders' actions (Fig. 4). Private investors can focus on profitable opportunities in the energy transition, particularly in underexplored markets, while adopting innovative solutions to financing challenges and improving risk assessments. Insurance companies can complement these efforts by offering tailored financial products to mitigate risks associated with climate transitions. Meanwhile, public funders and multilateral development banks can reduce or offset private financing risks through guarantees or subsidies, thus encouraging broader participation. Additionally, international creditors can support debt relief programs linked to results-based transition agreements, enabling countries to secure new private financing for clean investments.

Discussion

This paper has outlined the challenge of the current climate finance gap, highlighting the mismatch of mitigation opportunities and capital flows and the substantial need for increased private finance across countries. Through

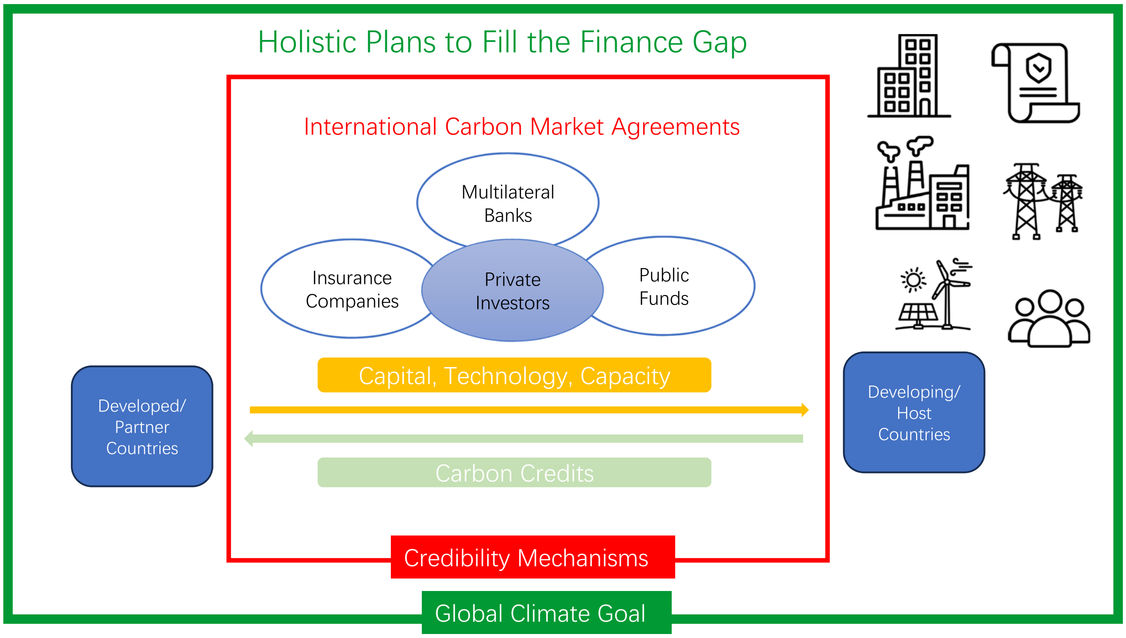

Fig. 4 | Holistic plans to fill the finance gap. Figure 4 illustrates how international carbon markets can support holistic plans to close the climate finance gap. At the core are International Carbon Market Agreements, linking developed (partner) countries with developing (host) countries through carbon credit transfers, supported by capital, technology, and capacity building. Key actors, including private investors, multilateral banks, insurance companies, and public funds, contribute to mobilizing resources. The icons on the right represent key actions in host countries, such as renewable energy infrastructure, energy efficiency retrofits, building energy conservation, grid management, policy reforms, and workforce training. These holistic plans aim to improve the leverage ratios, enabling public investments and carbon markets to attract more private capital. Credibility mechanisms ensure trust and transparency, aligning efforts with global climate goals and fostering sustainable and equitable outcomes.

several scenarios, we demonstrate the necessity of utilizing all funding sources and the potential roles of domestic carbon pricing, international carbon markets, and increased leverage ratios as ways to jointly fill the gap.

To address the climate finance gap in EMDEs, we propose three interconnected strategies. First, developed and developing countries should engage actively in large-scale international carbon market agreements to facilitate the transfer of capital, technology, capacity, and carbon credits, aligned with the framework of global and national climate goals[51,52].

Second, host countries should adopt, and partner countries should support, a holistic approach to enhance the effectiveness of carbon markets by increasing the leverage ratio of public and private capital. This requires strengthening policy formulation and implementation capacities, accelerating renewable energy infrastructure development, electrification, and workforce training. Such systemic improvements are crucial for creating a more conducive investment environment for the energy transition and fostering sustainable capital inflows.

Finally, we advocate for a reframed carbon market framework and holistic plans that enable diverse stakeholders—such as public funders, multilateral development banks, private investors, and insurance companies—to work collaboratively in EMDEs. By aligning their efforts, these actors can amplify their collective impact. By integrating these finance strategies with holistic plans and reframed international carbon markets, we can create a robust climate finance ecosystem that effectively mobilises resources and accelerates sustainable development in EMDEs.

Some limitations of this work are worth further exploration and discussion. First, the methods we used to develop the scenarios for calculating the climate finance gap inevitably rely on numerous assumptions, including carbon prices and coverage in 2030, the size of international and voluntary markets, leverage ratios, and the growth rate of existing private and public finance. These assumptions are primarily based on the limited evidence currently available from large international organisations and non-governmental organisations. The scarcity of robust empirical studies and advanced modeling approaches in the current literature underscores the need for further research, particularly regarding leverage ratios within various carbon markets and projections of the global carbon market landscape under diverse socioeconomic conditions. To examine the implications of these uncertainties, we conducted sensitivity analyses on key parameters (Supplementary Table 4). In the ICM + HLR scenario, halving the carbon price leverage ratio yields the largest finance gap (approximately 25%), while halving carbon prices or coverage leads to gaps of 19% and 12%, respectively. These findings also highlight the critical importance of adopting a holistic strategy to enhance carbon market effectiveness. In addition, we provide an interactive tool (publicly available at https://carbonfinancegap.streamlit.app/) that allows readers to input their own assumptions—potentially informed by future modelling studies—and observe the resulting finance gap. Our goal is to provide a framework for understanding the climate finance gap and to emphasise the role of each parameter in shaping the outcomes.

Second, this analysis can be refined by incorporating country- and sector-level perspectives. Climate finance in EMDEs is multidimensional, influenced by an interplay of policy clarity, macroeconomic stability[53], institutional quality, financial market development[54], external support, climate vulnerability[55], and technological readiness[56]. It is essential to consider how the proposed strategies may be adapted to these diverse circumstances. There is no one-size-fits-all solution, and each country has to identify its own path. Although many studies have examined the heterogeneous effects of existing carbon markets on emission reductions within specific countries or sectors[57,58], no amount of detailed analysis about further assumptions such as capital leverage ratios or the scale of international carbon markets nor be able to resolve the deep uncertainties involved in a global system shift of large magnitude.

Third, the "mitigation avocado" approach introduced in this paper remains primarily a conceptual framework, particularly in terms of the internal allocation of resources. The proportions of funding required for individual programs, environmental improvements, and integration efforts may vary substantially between countries and sectors. At present, comprehensive quantitative estimates of these financial needs are lacking. To address this gap, future research should explore collaborations between energy system modellers and economic modellers, enabling assessments of not only technical and economic feasibility but also social cost-benefit outcomes. Such an approach would provide a more detailed understanding of what constitutes a holistic plan for climate transitions and help policymakers choose cost-effective transition plans based on local conditions. Additionally, there are currently very few examples in practice of large-scale agreements under international carbon markets as outlined in Article 6 and effectively integrated with host countries' holistic plans. Implementing these agreements requires significant research, technical capabilities, institutional development, and substantial financial resources. In some countries with weaker governance, implementing a fully integrated strategy may not be immediately feasible, making incremental or piecemeal efforts the realistic option. However, situating these discrete actions within a broader conceptual framework can help ensure that each initiative contributes to an overarching climate finance pathway rather than functioning in isolation. Understanding both successful and failed cases will be crucial for shaping future global climate finance strategies.

Methods

Calculation of climate finance gap

In the methods section, we describe how we calculate the capital mobilised from various instruments and finance gap under different scenarios. The assumptions of parameters are listed in Supplementary Table 2.

We divide the drivers of finance into public funding, private funding not driven by carbon pricing, capital mobilised by public finance, domestic and international compliance pricing, and the voluntary carbon market. The climate finance gap is defined below:

$$\mathrm{CFG}_t = \mathrm{CF}_t - \left(\mathrm{PUB}_t + \mathrm{PRIV}_t + \mathrm{PRIVpub}_t + \mathrm{PRIVdom}_t + \mathrm{PRIVint}_t + \mathrm{PRIVvol}_t\right) \tag{1}$$

The public finance for mitigation PUB_t is about 51% of total climate finance and accounted for USD 660 billion in climate finance for mitigation in 2022[1]. We calculate the long-term compound annual growth rate r from 2011 to 2022 with data from CPI[2,32,33], which is 14.37%. Assuming that public finance continues to grow at its current rate, we estimate that it will grow to nearly USD 1.9 trillion by 2030 under the BAU scenario. Growth in the last 2 years has been faster so this estimate may be conservative.

$$\mathrm{PUB}_t = \mathrm{PUB}_{2022} \times (1 + r)^{t-2022} \tag{2}$$

To explore the effects of carbon markets on private finance mobilisation, we carefully differentiate between market-driven and non-market-driven private finance flows. First, the private capital mobilised without price-based regulation (PRIV_t) includes funds from non-financial corporations, commercial financial institutions, individual and institutional investors. For 2022, total private finance for mitigation was 683 billion as reported by the CPI (2023)[1]. We derive a net value of USD 438 billion for this portion of private finance by subtracting the estimated amount mobilised through public finance and other carbon pricing policies, as introduced below, from the total private finance flows. Our simple projection for 2030 assumes that private finance will continue to grow at the cumulative average growth rate g since 2011 to reach nearly USD 908 billion in 2030. The CAGR for this part is estimated at 9.54%[2,32,33].

$$\mathrm{PRIV}_t = \mathrm{PRIV}_{2022} \times \left(1 + g\right)^{t-2022} \tag{3}$$

$\mathrm{PRIVpub}_t$ is private finance mobilised by public finance. Public finance could act as a catalyst in mobilizing private finance through an array of finance instruments, such as guarantees or feed-in tariffs for new technologies. According to the IEA[4] and Organisation for Economic Co-operation and Development (OECD)[34,35], concessional funding from the international community is currently observed to leverage private finance by a factor of 0.3. In other words, each dollar of international concessional support mobilises an additional USD 0.3 of private investment. Though international concessional funding represents only a portion of what we define as public finance, we adhere to this assumption and incorporate a public finance leverage ratio of 0.3. In 2022, this particular segment stood at approximately USD 200 billion. By 2030, under both BAU and the ICM scenarios, it is projected to reach USD 579 billion. Determining the public leverage ratio L_{pub} is critical, as it may be influenced by country-specific policies, investment climates, and evolving capabilities over time. At present, we rely on historical global level investment data to estimate the average parameter.

$$\mathrm{PRIVpub}_t = \mathrm{PUB}_t \times L_{\mathrm{pub}} \tag{4}$$

$\mathrm{PRIVdom}_t$ is estimated as capital that was in 2022 and could in future be mobilised by domestic carbon pricing instruments, such as carbon taxes or emissions trading systems (ETS). This estimate relies on several simplifying assumptions: In 2022, carbon price policies cover C_t 23% of global greenhouse gas emissions[59]. Average global carbon prices P_t (including a wider range of pricing instruments such as renewable portfolio standards and fossil fuel subsidies) are estimated at USD 18.5 per ton of CO_2 by Carbon Barometer[60]. We use a long-run semi-elasticity ϵ, with a low estimate of 0.0028, from an OECD report[61], based on the most comprehensive cross-country longitudinal database on direct and indirect carbon pricing, to estimate emission reductions driven by carbon prices. Econometric estimates suggest that a EUR 1 increase in carbon pricing decreases CO2 emissions from fossil fuels by 0.28% in the full sample. Allowing for country- or sector-specific semi-elasticities will be important for future analyses. For example, the study also reports a semi-elasticity of 0.45% in the electricity sector, and another research of 20 OECD countries finds a figure of 0.73%[62]. Total spending on emission reduction credits can be approximated as $\mathrm{E}_t \times \epsilon \times \mathrm{P}_t \times \mathrm{C}_t \times \mathrm{P}_t$. We then mimic a private sector claim that every dollar spent on buying emissions reduction credits mobilises 5 dollar in private capital, which is defined as carbon price leverage ratio L_{cp}. This factor is drawn from Trove Research[63], based on the ratio of capital investment in carbon credit projects to the value of the primary carbon credit market in 2022. The World Bank provides similar evidence from the Clean Development Mechanism, where each USD 1 invested in emissions reductions unlocked USD 4.60 in underlying low-carbon investments[64]. We acknowledge that L_{cp} should ultimately be refined to reflect country- and sector-specific conditions, but such data are currently limited. Using these aggregate, global-level estimates, we find that existing domestic carbon pricing mechanisms in 2022 could only mobilise USD 41 billion. For the 2030 BAU case, we assume that compliance carbon pricing will be set at USD 80.7 per ton for greenhouse gas pricing coverage reaching 30% in countries with existing pricing systems, plus an additional 30% of new coverage in developing countries at a low price of USD 10. The USD 80.7 price is a global price required in 2030 to be on track to limit global warming to 2 °C [36]. We assume that in developing countries, the potentially weaker governance or economic conditions would result in more modest incentives due to lower prices. The coverage is consistent with the Global Carbon Pricing Challenge, which was launched in 2021 at COP26 and sets a collective goal for carbon pricing to cover 60% of global emissions by 2030[65]. Under these assumptions, more than USD 1 trillion in private capital could be mobilised annually. We also recognise that carbon pricing is likely to have a non-linear impact on capital mobilisation, and different effects across sectors, but we are unable to account for that currently.

$$\mathrm{PRIVdom}_t = \mathrm{E}_t \times \epsilon \times \left(\mathrm{P}_t \times \mathrm{C}_t \times \mathrm{P}_t + \mathrm{Plow}_t \times \mathrm{Clow}_t \times \mathrm{Plow}_t\right) \times L_{\mathrm{cp}} \tag{5}$$

$\mathrm{PRIVint}_t$ represents potential capital mobilisation through perfectly functioning international carbon markets enabled by Article 6 of the Paris Agreement. The estimates by Piris-Cabezas, Lubowski and Leslie[36] suggest that a perfectly functioning market consistent with meeting a 2 °C target would involve carbon payments between countries of over USD 210 billion annually. Another rough estimate from the World Bank[39] suggests that markets established under Article 6 of the Paris Agreement could reach around USD 300 billion annually. Similarly, assuming that every dollar spent in these international markets yields a comparable leverage effect on private finance, such spending could mobilise an additional USD 1 trillion per year in private capital by 2030.

$$\mathrm{PRIVint}_t = \mathrm{ICMS}_t \times L_{\mathrm{cp}} \tag{6}$$

$\mathrm{PRIVvol}_t$ is the contribution of the VCM to mobilizing capital. We calculate this by multiplying current payments for VCM credits (around USD 1.3 billion in 2022, according to Trove Research[37]) by the assumption of USD 5 of capital mobilised per dollar of credit payment. For the 2030 BAU case we use the low estimate from Trove Research[38] and the World Bank[39], which suggests this market could grow to USD 10–40 billion in credit payments and mobilise five times the capital. Here, we adopt the most conservative estimate for the VCM to avoid any overlaps with calculations related to the international carbon markets.

$$\mathrm{PRIVvol}_t = \mathrm{VMS}_t \times L_{\mathrm{cp}} \tag{7}$$

Scenarios

In Figure 2, we present four panels: one for climate finance in 2022, and three depicting projected scenarios—Business as Usual (BAU), International Carbon Market (ICM), and High Leverage Ratio (ICM + HLR). The BAU scenario, driven solely by increases in public finance, private finance, and the gradual expansion of domestic carbon pricing, illustrates that relying only on public funding, gradual growth in private investment unrelated to carbon pricing, and voluntary markets falls well short of the required levels of climate finance.

The ICM scenario highlights the potentially significant role of international Article 6 transfers. Furthermore, we assume that this international support would allow for increased ambition in domestic carbon pricing in developing countries[66], raising it from USD 10 (Plow_2030) to USD 35 (Pmid_2030). Under these enhanced conditions, an additional USD 174 billion in capital mobilisation can be attributed to the improved domestic carbon pricing.

$$\mathrm{PRIVdom}_t(ICM) = \mathrm{E}_t \times \epsilon \times \left(\mathrm{P}_t \times \mathrm{C}_t \times \mathrm{P}_t + \mathrm{Pmid}_t \times \mathrm{Clow}_t \times \mathrm{Pmid}_t\right) \times L_{\mathrm{cp}} \tag{8}$$

Finally, the ICM + HLR scenario demonstrates a pathway to closing the finance gap if the leverage ratios of public finance and carbon markets could be doubled through more holistic strategies. As discussed above, in the case of clean power investment, such holistic strategies may encompass well-coordinated finance from different sources, complemented by strong planning, good policy frameworks and regulations, reliable payments, and the provision of grid infrastructure and skilled labour. These measures together can help mitigate risk for private financiers and decrease the cost of capital. In the model, this is represented as an increase in the carbon market to private capital leverage ratio and the inclusion of a public capital to private capital leverage ratio. As estimated by IEA[67], even a marginal reduction of 1 percentage point in the cost of capital could lead to substantial savings of USD 150 billion annually for EMDEs in their energy transition.

To illustrate the potential impact of more effective holistic strategies, in the ICM + HLR scenario, we double the leverage ratio of carbon prices from 5 to 10. This higher leverage factor is derived from a review of multiple sources[68–70]. For example, the UNFCCC[71] reported that under the Kyoto Protocol, the CDM created a market that leveraged USD 10 for every USD 1 in public financing. Early estimates from the World Bank[72] reported an average leverage ratio of 1:9 for carbon finance projects to private investment. While the assumption seems ambitious, our intention is to depict the potential impacts of holistic plans and how they can help fill the gap. In this scenario, the private capital leveraged by domestic compliance carbon markets, voluntary carbon markets, and international carbon markets, would all be significantly amplified, increasing by USD 1.20, USD 0.05, and USD 1.05 trillion, respectively. In addition, we also double the public finance leverage ratio from 0.3 to 0.6. This implies that every dollar of public finance mobilises an additional 0.3 dollars of private finance, resulting in a surge of USD 579 billion in private finance driven by public finance in the HLR scenario. These synergistic effects have the potential to fully bridge the remaining finance gap.

$$\mathrm{PRIVdom}_t(ICM + HLR) = \mathrm{E}_t \times \epsilon \times \left(\mathrm{P}_t \times \mathrm{C}_t \times \mathrm{P}_t + \mathrm{Pmid}_t \times \mathrm{Clow}_t \times \mathrm{Pmid}_t\right) \times L_{\mathrm{highcp}} \tag{9}$$

$$\mathrm{PRIVvol}_t(ICM + HLR) = \mathrm{VMS}_t \times L_{\mathrm{highcp}} \tag{10}$$

$$\mathrm{PRIVvol}_t = \mathrm{VMS}_t \times L_{\mathrm{highcp}} \tag{11}$$

$$\mathrm{PRIVpub}_t(\mathrm{ICM} + \mathrm{HLR}) = \mathrm{PUB}_t \times L_{\mathrm{highpub}} \tag{12}$$

Data availability

Data used in this research is available at:https://github.com/Xian-Hu/ClimateFinance.git.

Code availability

Code used in this research is available at https://github.com/Xian-Hu/ClimateFinance.git.

Received: 24 September 2024; Accepted: 10 January 2025;
Published online: 24 February 2025

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Acknowledgements
We would like to thank Anshuman Tiwari and Aurora Barone for support with data and assumptions, and audiences in South Africa, China, Colombia, Japan and the US for feedback. We are also grateful to G. Leonard Baker, Jr. and Mary Anne Nyburg Baker for their support of our work on the economics of carbon pricing. We thank Michael A. Toman for his helpful comments and review. The authors are responsible for all opinions and any errors and omissions.

Author contributions
All authors: Conceptualisation, Data Analysis, Methods, Writing, Review and Editing.

Competing interests
The authors declare no competing interests.

Additional information
Supplementary information The online version contains supplementary material available at https://doi.org/10.1038/s44168-025-00220-x.

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