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Brian O'Callaghan

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A COP29 CLIMATE FINANCE TARGET THAT MAKES ECONOMIC SENSE

Brian O'Callaghan[1,2]
1. Smith School of Enterprise and the Environment, University of Oxford, Oxford, UK
2. Institute for New Economic Thinking, Oxford Martin School, University of Oxford, Oxford, UK

EXECUTIVE SUMMARY

Developed countries committed to financially support developing countries under the 1992 United Nations Framework Convention on Climate Change and in 2009 pledged $100 billion per year by 2020. A New Collective Quantified Goal (NCQG) for finance must be agreed by 2025. The question is: how much finance should be provided?

In this study, negotiation transcripts and all submissions to the negotiation process are analysed with deep learning to uncover financial concepts overlooked in discussions, including discounting to recognize the time value of money and a clawback mechanism to recover undelivered finance. A formula for the new commitment is derived and applied to 11,875 NCQG scenarios, covering different durations, ramping, total need estimates, and more. These suggest a justifiable goal of $0.3-9.5Tn per year ($1.7Tn median) across scenarios ($0.4-3.9Tn, $1.4Tn median, if funding ramps to 2030 and ends in 2040). The findings offer a data-driven foundation to guide negotiations, grounding them in economic realities and enabling climate and development progress.

KEY FINDINGS

1. **The climate finance goal can be mathematically set.** The appropriate quantum can be considered as a mathematical question with seven key variables (developing country needs, developed country shares, start year, end year, financial discount rate, clawback and ramp).
2. **There have been gaps in the negotiations.** Two essential variables have been entirely neglected in the NCQG negotiations to date:
    a. **Discount rate:** the time value of money means $1 today is worth more than $1 tomorrow—a fundamental financial principle. For developing countries, borrowing $1 today can cost over 10% annually, making immediate funds significantly more valuable.
    b. **Clawback mechanism:** there is a need to consider how missed finance goals of the past can be "made right" through larger contributions in the future.
3. **Median target: $1.7 Tn.** This analysis finds the range of economically-justifiable targets for the new climate finance goal is $0.3-$9.5 Tn per year, with a median of $1.7 Tn per year. This is based on 12,000 scenarios, with variables informed by the negotiations.
4. **No fair argument that "we can't afford it".** Fossil fuel subsidies totalled $7 Tn in 2022, net fossil fuel income $4 Tn in 2022, and total COVID-19 response allocations approached $17.5 Tn.
5. **Public vs private finance.** A public finance backstop would allow that if private finance falls short of a target, public funds cover the gap, incentivizing policies to derisk private investment.
6. **Periodic reassessment.** Uncertainty to the pace of technological change and the impacts of climate change suggest a need for mechanisms to periodically reassess and adjust the goal.
7. **Prioritising *quality*.** Not every dollar is created equal – focus should be on maximizing positive impact (including economic impact) and governance. Details are left to other works.
8. **New calculator tool.** A free-to-access calculator is available, allowing negotiators and stakeholders to evaluate if proposals align with economic realities.

This paper introduces innovative methods to apply machine learning to international negotiations, merging outputs with economic theory for quantitative insights. There is significant scope to apply these methods to broader topics within and outside of the UNFCCC.

INTRODUCTION

The purpose of this paper is to establish a plausible range for a new climate finance target that is economically and scientifically defensible, providing a corridor for political deliberations.

Many of the nations most vulnerable to climate change have contributed the least to its causes, yet bear the heaviest burden of its consequences.[1–3] A 2-degree Celsius rise in global warming could bring a 3.6-degree increase in some regions of Africa, and a higher then 2-degree increase in most of Asia and Latin America.[4] The impacts of warming are also exponentially greater in these regions, with vulnerable populations more dependent on climate-exposed primary industries like agriculture and more exposed to disaster risk.[5,6] These same groups have a lower ability to respond to climate threats than others, driven by constrained finance and capacity.[7,8]

Meanwhile, up to 70% of the cheapest emissions reduction solutions are in developing countries.[9] Equalising abatement costs globally rather than nationally could eliminate inefficiencies of US$2.6Tn.[10] Additionally, green investment often provides greater economic benefits in developing nations, as each dollar invested in renewable energy generation can bring a 40% larger economic boost and transform lives through increased electricity access.[11,12]

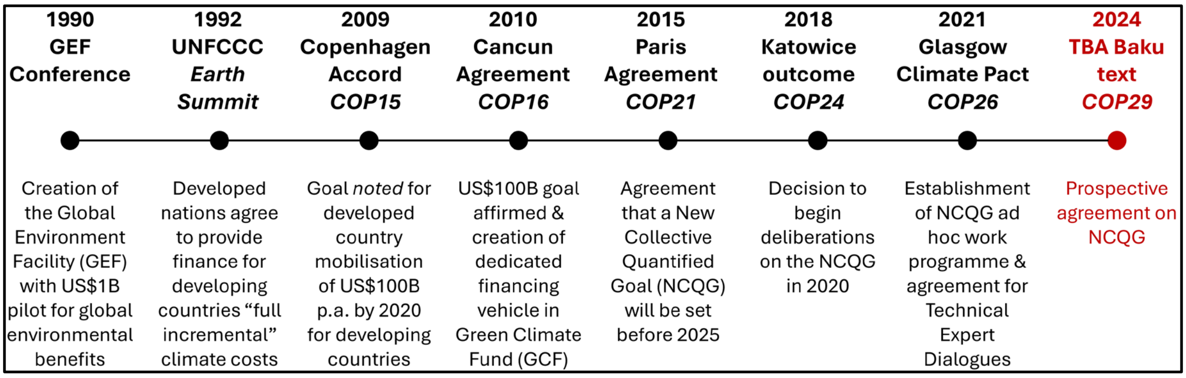
However, despite the threats and scope for outsized impact, proportionally little mitigation and adaptation finance has flowed to developing countries, with the cost of finance being a key constraint.[7,13] Inadequate climate finance is a concern across the public, private, and third sectors, requiring rapid scaling for developing countries in domestic and international markets.[13] Increasing developing country indebtedness,[14,15] an unfavourable global financial architecture,[16] and worsening climate change mean even higher costs.[14,17]

The United Nations Framework Convention on Climate Change (UNFCCC), to which 197 countries are Parties, set a legally-binding commitment for Annex II countries ("developed countries") to provide financial resources to "meet the agreed full incremental costs of [developing countries] implementing measures" to address climate adaptation and mitigation, as well as related efforts (Fig. 1).[18] The commitment recognizes the extreme needs of non-Annex I countries ("developing countries"), the costs of climate investments, and potential impacts on development. At COP15, in 2009, Parties noted the Copenhagen Accord, which set a financing goal for developed countries of USD100bn per year in "new and additional" resources by 2020, mobilised from a wide variety of sources, including public, private, bilateral, multilateral, and other.[19] This was affirmed in the COP16 Cancun Agreements.[20] At the time of writing, the USD100bn commitment may or may not have been met, depending on which accounting standards are used, acknowledging significant disparities between approaches.[21–23]

Through the 2015 Paris Agreement, Parties agreed that further mobilisation of climate finance was necessary.[24] They determined that a "new collective quantified goal" (NCQG), from a floor of USD100bn, would be set by 2025, "taking into account the needs and priorities of developing countries".[25] At COP26 in Glasgow, an "ad hoc work programme" was created to explore the issue through 2022-2023 and set the NCQG in 2024.[26] Progress since then has been slow,[27] stalled in part by a significant gap in expectations of developing and developed countries. The 2023 COP28 decision text noted that "the structure (of the Goal) will influence the scale"—this paper demonstrates exactly how important structural factors are to setting an appropriate goal on quantum.[28]

It is in this context that we ask: what is a justifiable quantity range for the NCQG? How could leading science, economics, and legal interpretations set a viable corridor for political negotiations? To date, there have been several attempts to quantify developing countries' needs. For instance Songwe *et al.* (2022) use Bhattacharya *et al.*'s (2022) analytical method to suggest that $1 trillion in external finance per year is required by 2030 for emerging markets and developing economies (EMDEs), excluding China, to constrain warming to 1.5 degrees Celsius. However, these needs have not been translated into a NCQG.[13,29] Indeed, Songwe *et al.* clarify, *"the $1 trillion figure is not the new $100 billion goal".*[13] Prior works do not consider practical matters like timelines for disbursement of capital (including appropriate discount rates), nor ramp rates for reaching new targets, what portion should be provided by developed countries, mechanisms to adapt targets based on future updated information, and other factors. Moreover, they do not account for how changes to these factors influence outcomes, thereby limiting negotiators' ability to respond effectively to proposals.

Fig 1. Historical context for international climate finance commitments and the NCQG.



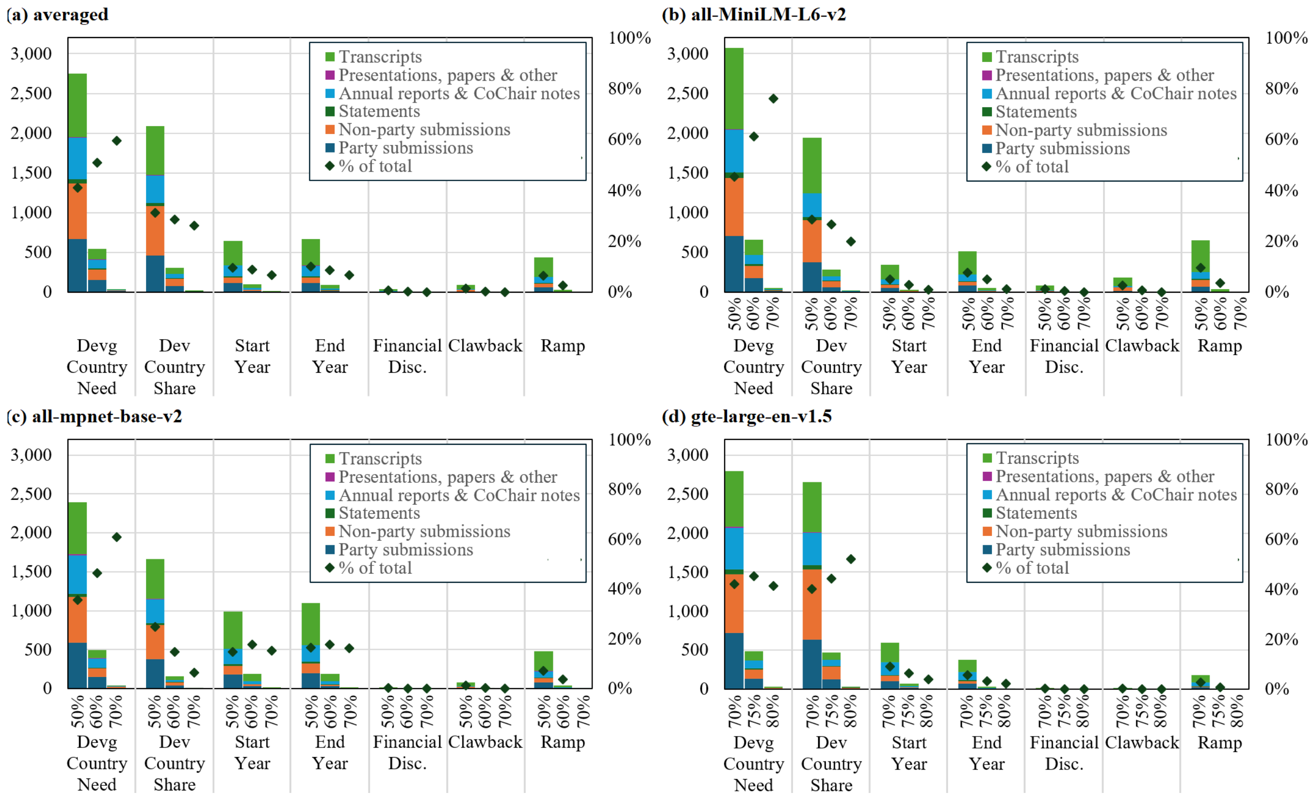
RESULTS

Analysis of negotiation materials suggest seven key financial variables

We collected and analysed all 184 submissions and statements to the ad hoc work programme of the NCQG by Party and non-Party stakeholders, 33 notes, annual reports, and presentations, as well as 24 transcripts, built from all recorded Technical Expert Dialogues (TEDs) and meetings of the ad hoc work programme (MAHWPs). These 241 documents (the "Materials"), equivalent to over 2,000 single-spaced pages and containing a million words were analysed using deep learning (DL) techniques in natural language processing (NLP). This involved five state-of-the-art sentence embedding models applied for semantic similarity analysis, aiming to uncover the range of perspectives that exist amongst negotiators on the role of developed countries in climate finance and variables relevant to establishing climate finance targets. The NLP analysis was in part conducted as a second-choice research method, but the results are arguably more powerful than what might have emerged from the original approach, a structured factual elicitation survey of negotiators. The survey was carefully developed in line with established principles for high-quality survey design and shared with all stakeholders in attendance at the Seventh NCQG TED (30th September to 2nd October 2023).[30,31] It was also provided to the UNFCC Secretariat for additional sharing. Several informal off-the-record responses were conveyed (the "Informal Discussions") but no formal responses were submitted, reflecting a strong hesitance of Parties to speak outside of the formal negotiations and further justifying the NLP analysis.

The NLP analysis built on manual review of the Materials and the Informal Discussions to quantify the *frequency* of discussion of certain financial and other variables (Fig. 2). Seven major financial variables were identified and tested, with five forthcoming from the Materials and Informal Discussions (total need *[S]*, developed country share of finance provision *[D]*, start year for the goal *[y]*, end year for the goal *[n]*, and the years required to "ramp" to reach the goal *[g]*) and two identified as basic variables standard in financial valuations processes but almost entirely absent from the Materials (discounting of future cash flows *[r]* and a clawback mechanism *[Cl]*). The Informal Discussions confirmed that the two additional "basic" variables have also not been discussed outside of formal negotiations and therefore have not flowed into quantitative estimates for appropriate finance quantity goals.

Fig. 2: Frequency of discussion of seven key variables in NCQG negotiations.



a-d. number of sentences in the NCQG Materials (y-axis) pertaining to each financial variable (x-axis), segmented by document type and by sentence transformer sensitivity level. The data is normalized by the total number of recognized sentences for all variables to enhance comparability across models (all-mnpet-base-v2 used as base model for normalization). All-mnpet-base-v2 used as base model. Corpus includes all publicly-available NCQG materials on UNFCCC website (see Methods for descriptive statistics). Average across three primary models shown **(a)** as well as individual model performances: all-MiniLM-1.6-v2 **(b)**, all-mnpet-base-v2 **(c)**, and gte-large-en-v1.5 **(d)**. Model characteristics are described in Methods.

An equation for annual climate finance disbursement

Equation (1) computes a steady-state annual climate finance target that is constant in absolute terms (*i.e.*, a single target goal) and incorporates all these variables. It accounts for the time value of money through a discounting term and considers all plausible disbursement timelines. The equation is useful to negotiators in understanding how changes to input variables impact the required quantum, relevant both in setting a 2025 goal and future goals.

Variables in Equation (1) include (i) foundational variables, like the *additional* annual finance needed to meet climate goals (S) and the portion of that need to be covered by external sources (D), (ii) additional variables identified through the Materials and Informal Discussions, including ramp rates for reaching the target (g) and the start year for increasing towards the new goal (y), and (iii) variables not identified by Parties but standard to financial valuations, like a discount rate to account for the time value of money (r) and a clawback mechanism to make whole missed finance goals in prior years (Cl). Table 1 lists all variables and Fig. 3 illustrates the four time periods in the model and the impact of discounting on the real value of annual contributions. Loss and damage allowances can be optionally added to the term for total annual financial need (S) once such values are determined.

Table 1 Variables in climate finance equation and their ranges.

Term	Variable identity (unit)	Range	Discretised values
A	Annual sum required from developed countries in steady state (*i.e.*, the NCQG) (US$B)	*dependent variable*	
S	Total annual financial need of developing countries to address climate change over the relevant period in real terms (US$B)	800-1600	800, 1,000, 1,200, 1,400, 1,600
D	Percentage of total need to be met by developed countries (%)	33-100	33%, 50%, 67%, 83%, 100%
z	Year in which estimate is conducted (suggest 2025 to eliminate differential discounting concerns; year)	2025	2025
y	Start year for new goal (year)	2025	2025
j	Start year for increasing disbursements above the 2025 goal (year)	2025	2025
g	Time to ramp spending from pre-NCQG level (*c*) to ultimate NCQG annual target (years)	1-5	1, 5, 10, 15, 20
n	End year for goal (year)	2030-2050	2030, 2035, 2040, 2045, 2050
p	Annual funding from developed countries from year that analysis begins (*z*) to 2025 (*y*) (US$B)	100	100
c	Annual funding from developed countries from start year for new goal (*y*) to start year of ramp (*j*) ($B)	100	100
Cl	Undelivered finance (*uf*) from 2020 to y to be clawed back ($B), $Cl = \sum_{year=2020}^{y-1} uf_{year} \cdot (1+r)^{y-year}$	40-454 (see supp. information)	40, 143, 247, 350, 454
r	Discount rate (%)	4-9%	3%, 4.5%, 6%, 7.5%, 9%
δ	Discount term, $\delta = \frac{1}{1+r}$	0.92-0.97	0.92, 0.93, 0.94, 0.96, 0.97

Note: Variable ranges are discussed in the Methods, being based on the Party perspectives in the NCQG Materials and existing literature. Estimates for *A* and *Cl* are particularly dependent on global progress mitigating and adapting to climate change and could be updated through an adjustment mechanism, applied at defined intervals.

Integrating these variables for a target steady-state goal in Equation 1, four geometric sequences were used, applying the discounting term (r) to each period (1-4 in Fig. 2). Period (3) includes a linear growth rate for contributions, requiring an arithmetic geometric sequence. While progress to the 2020 goal suggests perfectly linear growth in annual finance contributions is unlikely, it seems a reasonable approximation. See Methods for derivation and example in Box 1.

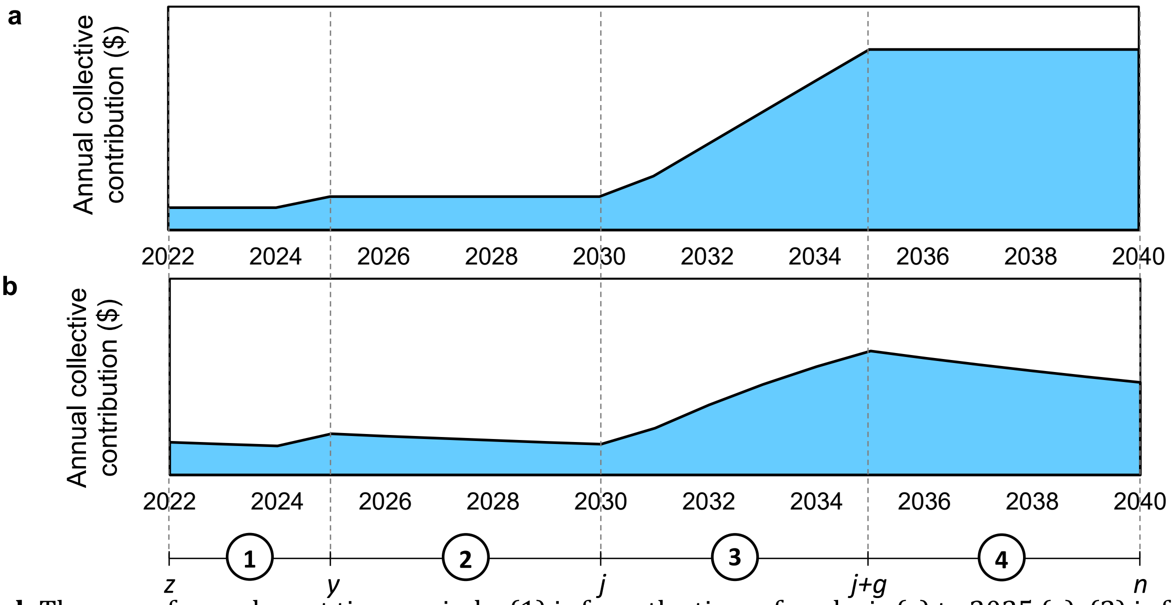
$$A = \frac{\frac{c\cdot(\delta^{g}\cdot[1+r]+r\cdot[g-1]-1)\cdot(1+r)^{z-j}}{g\cdot r^2} + \frac{c\cdot\delta^{-y}\cdot(\delta^{y}-\delta^{j})\cdot(1+r)^{z-y}}{r} + \frac{p\cdot(1-\delta^{y-z})}{r} - S\cdot D\cdot(n-y+1) - Cl}{\frac{(\delta^{g}\cdot[g\cdot r+r+1]-r-1)\cdot(r+1)^{z-j}}{g\cdot r^2} - \frac{\delta^{-g-j}\cdot(1+r)^{-g-j+z-1}\cdot(\delta^{g+j}\cdot[1+r]-\delta^{n})}{r}} \quad | \quad j+g \leq n \quad . \; . \; (1)$$

BOX 1. NCQG CALCULATOR APPLIED TO TYPICAL PROPOSAL

Based on an archetypal proposal, the NCQG could be US$2.6 Tn. This considers: (i) the annual need of developing countries to deal mitigate and adapt to climate change is US$1,200 and developed countries will fund 75% of that (S = $1,200, D = 75%), (ii) it is required that support for developing countries linearly ramp their support from 2025 to 2035 and then the goal continues until 2040 (y = z = j = 2025, g = 10, n = 2040), (iii) there will be no clawback of finance that developed countries failed to provide under their 2020 goal commitments, and (iv) the discount rate is 8%.

1. **Observation 1: failing to consider the time-value of money undermines the goal.** Using a discount rate of 0% (economically and financially indefensible position) more than halves the NCQG to $1.2 Tn, a discount rate of 2.9% (average inflation over 2012-2022) implies $1.6 Tn, a discount rate of 12.2% (African sovereign bond returns) implies $3.7 Tn.
2. **Observation 2: reaching the goal earlier reduces the required annual contributions**. Meeting the goal in 2025 (instead of a 10-year ramp) reduces the NCQG by 37% to $1.6 Tn.
3. **Observation 3:** the most controversial variable is likely to be the *share* of developing country needs to be met by developed countries (see online methods). A strong form legal interpretation of the 1992 Convention suggests that all developing country needs should be covered by developed countries (implies $3.5 trillion NCQG). Straying from the Convention, authors like Bhattacharya *et al.* (2022, p. 9) suggest closer to 50% share, implying a $1.7 Tn goal.

Fig. 3: Illustration of a hypothetical timeline for annual climate finance disbursement.

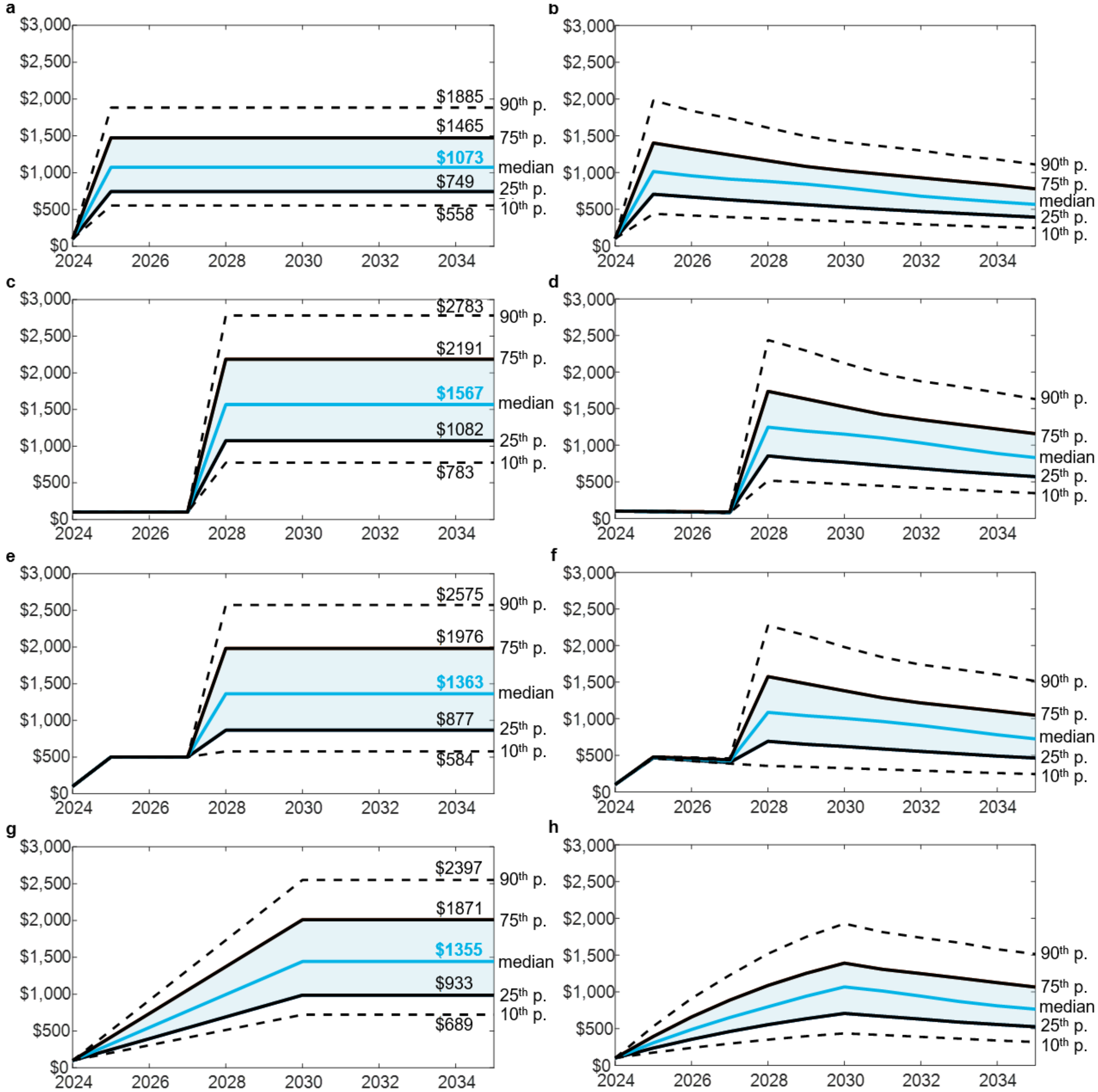


a,b There are four relevant time periods: (1) is from the time of analysis (*z*) to 2025 (*y*), (2) is from 2025 (*y*) to the year that the annual goal begins to increase (ramp) in absolute terms (*j, j-y>=0*), (3) is the period over which annual support ramps up (*g*), and (4) is the period that the full new goal is provided (*n*). These are illustrated in absolute terms (**a**) and real terms (**b**), where the area under the curve equals the cumulative total of contributions to be provided by developed countries over the period *(z)* to *(n)*.

12,000 scenarios for climate finance targets

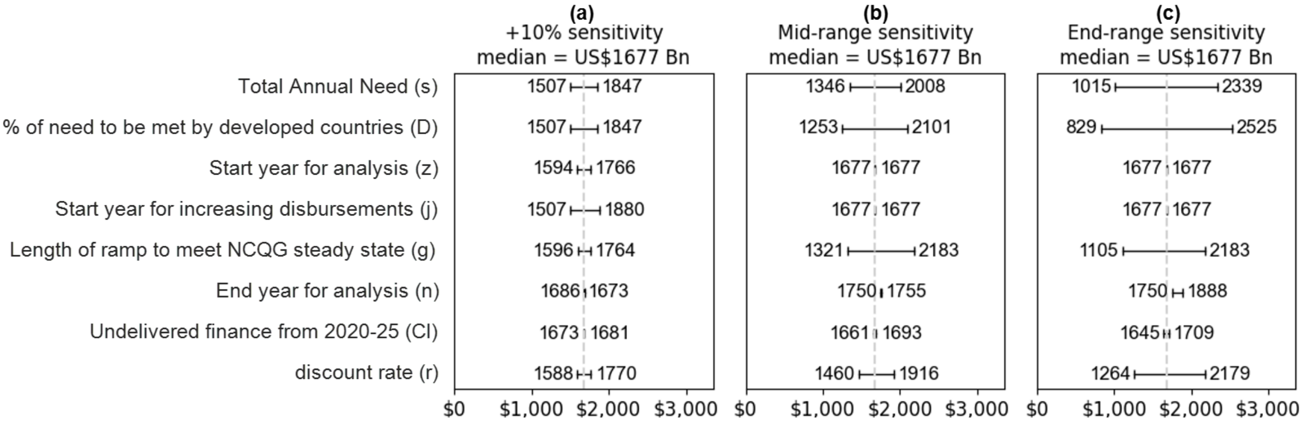
Table 1 provides a range of plausible values for each variable in Equation (1) based on existing literature and analysis of the Materials (see Methods). These were discretised into 5 values per variable, creating 11,875 scenarios (examples in Fig. 4). Across scenarios, NCQG requirements range from US$303B to US$9,548B (10th percentile: US$763B; 90th percentile: US$3,589B), with a median of US$1,677B, on a 2025 Net Present Value (NPV) basis. For context to the size of this sum, developed countries allocated US$17.5 trillion to COVID-19 responses (O'Callaghan, forthcoming) and fossil fuel subsidies totaled US$7 trillion in 2022, with net income from fossil fuel sales at US$4 trillion in 2022.[32,33] The most sensitive factors in the calculations are the total need of developing countries, the proportion to be provided by developed countries, the start year for increasing disbursements, and the discount rate (Fig. 5, focus on panel **c** for most extreme cases).

Fig. 4: Projected climate finance needs for selection of 2035 scenarios with range intervals.



a-h. distribution of finance needs over time under four disbursement timing scenarios, where n=2035 (end year for analysis) and default variables are the mid-case for estimates (see table 1). Shaded intervals show interquartile ranges between the 25th and 75th percentiles. Disbursements are shown in absolute terms (**a,c,e,g**) and real terms (**b,d,f,h**). When g=1 (*i.e.,* one year to ramp from US$100 billion to new goal) and j=2025 (*i.e.,* ramping begins in 2025), steady-state NCQG of US$1,073 billion must be reached by 2025 in the median case (**a,b**). When g=1 but j=2028, steady-state NCQG of US$1,567 billion must be reached by 2028 in the median case (**c,d**). When g=1, j=2028, and c=US$500 billion (*i.e.,* a step-up in finance to $500 billion per year over the period 2025 to 2027), steady-state NCQG of US$1,363 billion must be reached by 2028 in the median case (**e,f**). When g=5 and j=2025, steady-state NCQG of US$1,355 billion must be reached by 2030 in the median case (**g,h**).

Fig. 5: Sensitivity of NCQG target to variable perturbations: ± 10%, mid-, and end-range scenarios.



a,**b**,**c**. Comparisons relative to median base case across 11,875 scenarios. Considering: ±10% perturbation for quantity variables and ± 1 year for time variables in (**a**), interquartile mid-range estimates (*i.e.,* 2nd and 4th discrete values for each variable in table 1) in (**b**), and maximum *justifiable range* estimates (*i.e.,* 1st and 5th discrete values for each variable in table 1) in (**c**). Values for g and n limited in **b** and **c** by constraint $j + g \leq n$.

DISCUSSION

This study offers a first-of-its-kind framework for setting quantitative global climate finance goals, offering a robust and defensible target range for international climate negotiations. By integrating critical financial principles—such as **discounting and clawbacks**—mostly overlooked in UNFCCC negotiations to date, this model provides a more accurate reflection of the economic realities that must be addressed to achieve meaningful global climate action.

The results of this study refine and expand on quantitative targets proposed during negotiations (e.g., $1.1-1.3Tn in Clause 201, $1.1 Tn in Clause 306, >$1Tn in Clause 307, and >$1.3Tn in Clause 308 of the May 2024 MAHWP Co-Chairs Input Paper).[34] Such proposals have often been provided without a mathematical basis or contributing variables. By accounting for factors like the time value of money (therein, the economic impact of delayed finance), the model offers precision and scope for user-adjustment, both crucial for negotiators seeking economically- grounded targets.

The absence of basic financial metrics like discounting in negotiations is alarming. This could stem from a lack of financial expertise among negotiators—based on the Informal Discussions, very few negotiators have prior experience in financial markets. It may also stem from the minimal input of private sector stakeholders to the negotiations—only two private sector actors made submissions in 30 months of consultations. Alternatively, it might stem from a resignation to the notion that forthcoming decisions are likely to be politically driven and not economically grounded. This issue warrants further investigation, as it may reveal systemic failings across UNFCCC negotiations with significant consequences for climate action.

By considering the impact of discounting, we see significant benefit in meeting climate finance goals earlier. Future cash flows are lower in nominal terms when discounted, meaning that providing finance earlier reduces the gross financial requirement. This is important as the cost of capital is typically far greater in developing countries than developed ones, meaning that a developing country gains more value from a dollar than a developed country loses. In some cases, providing finance more quickly, for example by immediately meeting the goal, can reduce the size of the goal by two thirds or more. Beyond the economic imperative, assuming appropriate governance, early delivery of climate finance also minimizes the devastating impacts of climate change on the world's most vulnerable populations, accelerating mitigation efforts and enabling faster adaptation.[35,36] Further, earlier investment in the energy transition minimizes total system costs on a global basis through technological learning.[37] The

findings make it clear: slow finance mobilization will lead to higher costs, greater damages, and a narrower window for effective action.
The uncertainty surrounding the future impacts of climate change and potential technological advancements means flexibility in climate finance goals is essential. The severity of the impacts of climate change become clearer with time and hence adaptability is likely to enhance the relevance and effectiveness of a finance goal. A dynamic approach to climate finance, incorporating **mechanisms that allow for periodic reassessment and adjustment of finance commitments** could be useful, perhaps facilitated by the Equation proposed in this study.

The need for adaptability is also reflected in divergent views in the Materials on the role of private funds in achieving finance commitments. Meeting climate needs requires contributions from both public and private sectors, but developing nations are often concerned that governments cannot ensure private sector accountability, given private sector hesitance to absorb the financial risks of developing country investments.[38,39] One practical solution is for developed countries to commit to a total finance target, covering both private and public finance, with a **public funding backstop** to make up any shortfall that the private sector is unable to meet. This approach would lock-in necessary resources while incentivizing foreign government policies that promote and de-risk private investments in developing economies. Additional governance protocols would be required to ensure private investments are not predatory.

The quantity of climate finance commitments is the central focus of this study, yet the Materials show that nearly all parties also consider finance *quality* crucial. Indeed, higher quality finance that crowds in domestic resources and is directed to the most impactful measures could reduce the total need of developing countries. This supports the ultimate intent of climate finance targets to improve climate action—$1 well spent may be more desirable than $2 without impact. Consensus on what constitutes "high quality" is lacking in the Materials, with cited including, increasing the proportion of grants over debt, more effective governance, and more strategic allocations.[34] Such allocations could prioritize, for example, initiatives with higher positive economic impacts (e.g., a higher long-run economic multiplier, stronger job creation) or those that maximally boost adaptation and resilience.[40,41] Prioritizing finance mechanisms that attract private sector investment, especially in regions with lower economic resilience, can significantly enhance the impact of climate finance.[38,42] The specifics of such mechanisms, as well as consideration of subgoals, accounting protocols, transparency arrangements, and many qualitative factors, are left to future works.

While this study demonstrates the criticality of integrating financial rigor into climate finance negotiations, political realities can often conflict with empirical models and data. The $100 billion target, for example, was largely a political compromise and negotiators in the Materials frequently voice concerns that needs will not be at the centre of future climate finance discussions.[40] How might this study's findings address the pressure for a politically-driven agreement? One approach is to apply the calculator to analyse and position each proposal within the negotiations – specifically, do the variable assumptions match to an aligned target? Practically, there are natural incentives for this approach, including: (i) opposing Parties holding proponents of a certain position accountable, (ii) the need of the negotiation Co-Chairs for a clear and consistent verification method to guide discussions, and (iii) the interests of non-Party stakeholders to maintain a transparent process and often, a more ambitious goal. In each scenario, a practical tool (the calculator) could help align negotiations with economic and environmental realities, supporting three decades of Party commitments and reaffirming the relevance of the UNFCCC process. The first step on this path would be for a major negotiating bloc to introduce the calculator into the discussions—a move they are free to make at any time.

In the context of the UNFCCC's goal to address and mitigate the impact of climate change, this paper provides a clear call to action: the harms of the climate crisis demand that the NCQG be guided by the best available science and economics, not short-term politics. There is no exaggeration in suggesting that this decision will influence the lives of millions—both for its climate impact and its essential role in supporting development.

METHODS

NCQG text corpus ("the Materials")

A NCQG dataset was assembled, intending to capture all publicly available content on the UNFCCC website relating to the NCQG negotiations. This consisted of 184 submissions and statements from Party and non-Party stakeholders, along with 33 notes, annual reports, and presentations from Co-Chairs, video and audio recordings of nine out of the ten TEDs as well as the High-Level Ministerial Dialogues (HLMDs) and meetings of the ad hoc working programme (MAHWP). Recordings from the first day of the third TED and the entirety of the fourth TED were unavailable on the UNFCCC website. The recordings tended to cover all "main" sessions and sometimes online breakout group discussions, but not in-person breakout discussions.

Transcriptions were extracted from the recordings using OpenAI's Whisper, an automatic speech recognition (ASR) system known for its high relative precision, reported to broadly match the robustness and accuracy of human transcribers.[43] Whisper was selected for its strong performance in transcribing spoken language across various domains, making it a suitable choice for processing the diverse and complex discussions within the TEDs, often involving many speakers. However, ASR systems, including Whisper, can experience a dip in performance when processing accented speech, which is common in international dialogues such as these.[44] To address this limitation, an additional layer of postprocessing was applied with OpenAI's "GPT-4o (omni)" and "GPT-4o mini" language models.[45] These models were used to enhance transcription accuracy by refining language, separating long flow-on text into sentences, correcting misrecognized words and phrases based on surrounding context, and improving overall coherence. Manual corrections were subsequently performed. In some cases, poor audio quality led to indecipherable language. In cases where core content could not be inferred, the related language excerpts were excluded.

Table 2. Descriptive statistics of NCQG corpus.

		Documents	Sentences	Avg characters per sentence
Submissions (including to MAHWPs)				
Parties				
	2022	24	2,287	166
	2023	37	1,768	177
	2024	33	1,564	164
	Subtotal	*94*	*5,619*	*169*
non-party stakeholders				
	2022	22	2,593	143
	2023	23	1,692	152
	2024	32	2,019	176
	Subtotal	*77*	*6,304*	*156*
Total submissions		171	11,923	*162*
Transcriptions				
TED transcriptions		16	13,172	106
HLMD transcriptions		8	4,194	107
Total transcriptions		24	17,366	106
Statements		13	370	148
Notes from CoChairs		20	4,092	180
Annual Reports		5	846	219
Presentations & publications		8	257	150
Grand total		**241**	**34,854**	**137**

Notes: Documents reflect all publicly available NCQG materials on the UNFCCC website as of August 1st, 2024. "Presentations & publications include reports and non-official technical papers. TED: Technical Expert Dialogue. HLMD: High-level Ministerial Dialogue. MAHWPs: Meetings of the ad hoc Working Programme.

Deep learning analysis

Once transcribed and processed, the documents were analysed using several natural language processing (NLP) techniques to understand the key topics discussed and their relative frequency of discussion. This analysis included term frequency analysis, supervised and guided topic modelling with visualization, and semantic similarity analyses. Topic modelling with Latent Dirichlet Allocation (LDA) was employed to explore the thematic structure of the NCQG discussions, utilizing an iterative refinement process to optimize the number of topics and identify the most relevant ones. The process involved calculating topic similarities and refining the model based on similarity thresholds. After identifying key topics and incorporating manual review of the Materials to set priority financial variables, the Materials were analysed with semantic similarity analyses, measuring the closeness in meaning between elements. This did not rely on particular words or terms, instead focusing on underlying ideas and concepts, useful for understanding the nuanced relationships between specific topics in the context of NCQG negotiations.[46,47]

To perform the semantic similarity analyses, three primary and two secondary sentence transformer models were employed, ensuring results would not be biased by the limitations of a single model:

- Primary: 'all-MiniLM-L6-v2' (22.7 million parameters) was selected for its efficiency in clustering and semantic search tasks.[48] It uses a 384-dimensional vector space and was fine-tuned on a large dataset of 1 billion sentence pairs using contrastive learning, making it suitable for identifying thematic similarities within the NCQG texts.
- Primary: 'all-mpnet-base-v2' (109 million parameters) offers a deeper architecture with a 768-dimensional vector space, enabling it to capture more complex semantic relationships.[48] This model was also fine-tuned using the same large dataset, with a particular focus on deeper contextual understanding.
- Primary: 'Alibaba-NLP/gte-large-en-v1.5' (434 million parameters) is a recent, state-of-the-art model with very high performance against the Massive Text Embedding Benchmark (MTEB) in multiple categories.[49,50] Its large parameter count and advanced architecture, built upon the transformer++ encoder, make it effective for analysing extensive and complex transcripts. It is a large model, but not quite as enormous as the secondary models, which are highly resource-intensive to run.
- Secondary: To ensure robustness and further validate the findings, two additional larger models were employed for sub-corpus analysis ('BAAI/bge-en-icl', and 'Lajavaness/bilingual-embedding-large')[51,52], with the results compared to the performance of the initial three models across the same sub-corpus. All models were aligned in their findings for the relative frequency of topic occurrence across the corpus. The two models were selected based on their top performance on the MTEB benchmarks and their in-context learning capabilities, which enhance their ability to handle nuanced tasks. At the time of writing, both are considered state of the art. Their large parameter training sizes (from 560 million to 7 billion parameters) brought an additional layer of certainty for cross-verification of the results.

The consideration of the seven key financial variables involved predefining comparator sentences that described each variable and then calculating the number of sentences with high similarity to these sentences. Multiple comparator sentences were used for each financial variable to capture the full range of relevant discussions, and the results were averaged to account for variability in sentence formulation. For each of the sentence transformer models, similarity scores between the corpus and predefined topic descriptions were calculated using cosine similarity, a standard metric in NLP for measuring the alignment between vectorized representations of text.[47] The analysis trialled 10 similarity thresholds per model (representing the degree of similarity between two sentences), ultimately focusing on the 0.5, 0.6, and 0.7 levels for the mpnet base model, balancing precision and recall, and calibrating sensitivity levels for the other models to the mpnet base. This calibration was necessary as the semantic meaning of similarity scores differ based on how models understand and encode language—models are trained on different datasets and might be better at capturing short- vs long-term dependencies, or vice versa. In other words, a similarity score of 0.7 might indicate a strong match in one model but a relatively weak match in another.

Limitations of using similarity scores
While similarity scores are effective for identifying relevant content in large datasets, they have inherent limitations that can impact accuracy. One issue is sensitivity to text length; longer texts often produce higher similarity scores due to increased term frequency, potentially skewing results. To mitigate this, multiple sentence lengths were tested for each variable. Another limitation is that similarity scores may

not fully capture the semantic meaning or context of the text. To address this, multiple models were used, each contributing different strengths in semantic analysis, thereby capturing a broader range of nuances. The complexity of natural language, particularly nuanced expressions, also poses challenges, as a single similarity score may not adequately reflect subtle differences in meaning or tone. To counter this, multiple comparator sentences were used for each financial variable, with averaged results providing a more accurate reflection of the discussions.

Finally, scalability and computational efficiency are concerns when applying similarity metrics to large datasets. This was managed by analysing the full corpus with three large yet computationally efficient models, and a sub-corpus with two enormous, more resource-intensive models. This approach balanced comprehensive analysis with practical resource management, enhancing the reliability and scalability of the findings.

Structured factual elicitation survey

Originally, this study intended to address its research questions through a structured survey of climate negotiators, however, insufficient (zero) responses necessitated the shift to an NLP-led analysis. The intent of the survey was to gain insights into how climate finance negotiators conceptualize the purpose and key variables of the NCQG. Elicitation methods remain underutilized in the context of climate change research,[53] however have been effectively employed in previous studies on climate finance economics to gather expert opinions.[54–56]

The survey design process aimed to minimize the likelihood of biased results at all stages, including through question design and survey framing, as guided by principles outlined by Morgan (2014) and Fowler (2014).[30,31] Consideration was given to the wording of questions to avoid leading responses or introducing biases. For example, questions were framed neutrally without implying any preferred outcome, Likert scale options were balanced to avoid favouring positive or negative responses, and requests for subjective probability estimates avoided. Additionally, questions were ordered to prevent earlier questions from unduly influencing responses to later ones. To aid clarity and consistency in interpretation, definitions of key terms were provided, and the survey was iterated over several months, incorporating feedback from colleagues with expertise in climate economics, finance, and negotiations.

A combination of open-ended and Likert-scale questions was employed, alongside a guided response section with multiple input boxes. The survey was intentionally concise, comprising four demographic questions, six content-related questions (one with three sub-parts), and one question eliciting personal opinions. Question types included multiple choice, short open response, long open response, and a complex multi-part tabulated question. The target population for the survey was climate finance negotiators and their advisors, identified through their participation in the Seventh NCQG Technical Expert Dialogue (TED7) and subsequent outreach by the UNFCCC Secretariat. Several informal off-the-record discussions provided additional context—some of the survey questions were used as framing for these discussions.

Deriving a climate finance equation

The equation was developed for computing the climate finance goal based on the variables identified through the NLP analysis and discussions (see Table 1). The annual sum required from developed countries in the steady state (i.e., the NCQG), A, is a function of these variables, over the period from when the goal is calculated (i.e., today), z, to the final year of the goal (i.e., prior to a new goal), n. There are four key segments of the period $z \rightarrow n$:

i. between the year in which the goal is calculated, z, and the year at which the new goal will come into force, y (i.e., 2025),

ii. between the year in which the new goal will come into force, y, and the year that the annual amount begins to ratchet up from the $100B annual baseline, j,

iii. between the year in which contributions begin to ramp up, j, and the year in which the new target for steady state finance is met, $y+g$, and

iv. between the year that the new steady state goal is first met, *y+g*, and the end year for the goal, *n*.

The discounted value of necessary finance over each term is treated as a geometric sequence, with term 3 an arithmetic geometric sequence (assuming its growth rate increases linearly). In sigma notation, using *k*, *l*, *m*, and *o* as the index of summation for the terms 1 through 4 respectively, this is:

$$S \cdot D \cdot (n-y+1) + Cl = \sum_{k=1}^{y-z} P\left(\frac{1}{1+r}\right)^{k} + \frac{1}{(1+r)^{y-z}} \cdot \sum_{l=1}^{j-y} c\left(\frac{1}{1+r}\right)^{l} + \frac{1}{(1+r)^{j-z}} \cdot \sum_{m=1}^{g}\left(c + \frac{m\cdot(A-c)}{g}\right)\cdot\left(\frac{1}{1+r}\right)^{m} + \frac{1}{(1+r)^{j-z+g}} \cdot \sum_{o=1}^{n-j+g} A\left(\frac{1}{1+r}\right)^{o} \quad ..\,(2)$$

Or in closed form:

$$S \cdot D \cdot (n-y+1) + Cl = \frac{p\left(\frac{1}{1+r}\right)^{-z}\cdot\left(\left(\frac{1}{1+r}\right)^{z}-\left(\frac{1}{1+r}\right)^{y}\right)}{r} + \frac{c\left(\frac{1}{1+r}\right)^{-y}\cdot\left(\left(\frac{1}{1+r}\right)^{y}-\left(\frac{1}{1+r}\right)^{j}\right)\cdot(1+r)^{z-y}}{r} + \frac{(1+r)^{z-j}\cdot\left(A\cdot r+A+c\cdot\left(\frac{1}{1+r}\right)^{g}+c\cdot r\cdot\left(\frac{1}{1+r}\right)^{g}+c\cdot g\cdot r-c\cdot r-c-A\cdot\left(\frac{1}{1+r}\right)^{g}-A\cdot r\cdot\left(\frac{1}{1+r}\right)^{g}-A\cdot r\cdot g\cdot\left(\frac{1}{1+r}\right)^{g}\right)}{g\cdot r^{2}} + \frac{A\cdot\left(\frac{1}{1+r}\right)^{-j-g}\cdot\left(r\cdot\left(\frac{1}{1+r}\right)^{g+j}+\left(\frac{1}{1+r}\right)^{g+j}-\left(\frac{1}{1+r}\right)^{n}\right)\cdot(1+r)^{-g-j+z-1}}{r} \quad .....\,(3)$$

Which can be simplified to:

$$S \cdot D \cdot (n-y+1) + Cl = \frac{p\cdot\delta^{-z}\cdot(\delta^{z}-\delta^{y})}{r} + \frac{c\cdot\delta^{-y}\cdot(\delta^{y}-\delta^{j})\cdot(1+r)^{z-y}}{r} + \frac{(1+r)^{z-j}\cdot(A\cdot r+A+c\cdot\delta^{g}+c\cdot r\cdot\delta^{g}+c\cdot g\cdot r-c\cdot r-c-A\cdot\delta^{g}-A\cdot r\cdot\delta^{g}-A\cdot r\cdot g\cdot\delta^{g})}{g\cdot r^{2}} + \frac{A\cdot\delta^{-j-g}\cdot(r\cdot\delta^{g+j}+\delta^{g+j}-\delta^{n})\cdot(1+r)^{-g-j+z-1}}{r} \quad .....\,(4)$$

Solving for A, we get equation (1):

$$A = \frac{\frac{c\cdot(\delta^{g}\cdot[1+r]+r\cdot[g-1]-1)\cdot(1+r)^{z-j}}{g\cdot r^{2}} + \frac{c\cdot\delta^{-y}\cdot(\delta^{y}-\delta^{j})\cdot(1+r)^{z-y}}{r} + \frac{p\cdot(1-\delta^{y-z})}{r} - S\cdot D\cdot(n-y+1)-Cl}{\frac{(\delta^{g}\cdot[g\cdot r+r+1]-r-1)\cdot(r+1)^{z-j}}{g\cdot r^{2}} - \frac{\delta^{-g-j}\cdot(1+r)^{-g-j+z-1}\cdot(\delta^{g+j}\cdot[1+r]-\delta^{n})}{r}} \quad \Big| \quad j+g \leq n \quad ..\,(1)$$

Here, the clawback term, *Cl*, is applied assuming that its value is to be equally spread over future years, with each year's contribution slightly higher than the last in nominal terms. The same mechanism could be used in future reviews of progress to the goal quantum, where unmet commitments must be "made up" in future years. This is equivalent to a self-liquidating preferred equity contribution, where the outstanding equity increases annually in line with the cost of capital. The value of *Cl* in real terms, as show in Equation (5), represents the total accumulated undelivered finance for each year, *uf*, compounded at the discount rate, *r*, up to the start year of the new goal.

$$Cl = \sum_{year=2020}^{y-1} uf_{year} \cdot (1+r)^{y-year} \quad ....\,(5)$$

Range estimates for key financial variables

The variable ranges used for computing the climate finance scenarios and provided in Table 1 emerged from a review of existing literature and analysis of the negotiations Materials. There is a reasonable volume of existing literature for the finance needs of developing countries and the responsibilities of developed countries to share the burden in meeting those needs, as well as some literature available to be interpreted for relevant discount rates.

Estimating the total climate finance needs of developing countries is challenging due to data gaps and uncertainties in climate impacts and development pathways. The UN's High-level Expert Group estimates that Emerging Markets and Developing Economies (EMDEs) require $1.8-2.4 trillion annually by 2030, with $0.9-1.2 trillion as additional to core development needs.[13,29] The IEA suggests $0.7 trillion per year for energy mitigation alone,[57] while Vivid Economics considers an additional $1.4 trillion by 2030 compared to 2020.[58] Nationally Determined Contributions (NDCs) suggest $0.8-1.1 trillion annually, though these figures likely understate actual needs due to data gaps.[59] Estimates, including those aforementioned, often omit many needs from their calculations and are not up to date in understanding the full extent of the impacts of climate change. For example, they may not consider the impacts on changing crop yields and nutrition,[60] "lethal humidity",[61,62] or modern human slavery.[63] They also do not include overhead costs like transaction and administration fees, which can exceed 10% (international implementing agencies like UNDP charge ~9% for their services).[64] Using only available studies, and therefore excluding all these missing factors, the additional climate finance needed by 2030 is plausibly in the range of $0.8-1.6 trillion per year.

Questioning what portion of additional finance needs should be met by external sources includes moral, legal, and economic perspectives. Morally, corrective justice suggests that developed countries should bear a significant share of costs due to their historical excess usage of the global "carbon budget" and the resultant harms.[2,65] On the other hand, distributive justice holds that countries should contribute based on their capacity to pay, founded on the principle of equal moral worth.[65,66] Considering these varied philosophical approaches as inputs to the *Climate Equity Calculator* and accounting for varying perspectives on base years (with a maximum of 1990), development thresholds, and more,[67,68] developed countries are responsible for 33%-77% of the need to deal with climate change to 2030 (notably this is total costs, not developing country costs). Legally, interpretations vary: a literal reading of the 1992 UNFCCC suggests developed countries should cover up to 100% of additional costs, while some consider the 2009 Copenhagen Accord implies a more constrained contribution, focusing on "meaningful" actions (UNFCCC, 2009, Paragraph 8). Another view, though lacking a clear legal basis, suggests that developing countries should contribute what they can afford, with developed nations filling the gap—this perspective still leads to an overwhelming role for developed countries, given the financial limitations in many developing nations. Although Bhattacharya *et al.* (2022, p. 9) suggest, *"about half the financing needed could come from domestic resource mobilisation"*, implying a capacity to provide around US$1T per year.[29] This is wholly unrealistic in the short to medium term, especially with over half of low-income countries in or at high risk of debt distress.[69] Lower still, the Informal Discussions suggested that some developed countries consider a benchmark of 33% to align with Economically, as up to 70% of the cheapest mitigation options are located in developing regions, there is an efficiency argument for needs to be met by external sources if they cannot be met internally.[9,70] Integrating these perspectives, this study considers a range for the portion of finance to come from external sources of 33-100%.

Differing views on the appropriate discount rate for future financial contributions significantly impact results, both by reducing the real value of future cash flows and amplifying the impacts of the timing-based variables (i.e., start year, time to ramp, end year). Note that the valuation of present versus future investment dollars is distinct from ethical considerations on discounting climate harms, which require a different discount rate.[71] The investment discount rate, r, should reflect the marginal cost of capital or otherwise an indifference point between receiving $1 of capital today or $\$1 * (1 + r\%)$ tomorrow. While there has been practically no discussion on this in negotiations (Fig. 2), presumably opinions would vary on whether to use sovereign rates, private rates, or a composite figure, e.g., a composite/weighted average cost of capital. World Bank data shows that from 1980-2021, interest payments on external debt in EMDEs excluding China averaged 4.4% for the public sector and 6.1% for the private sector (nonguaranteed), both excluding concessional lending.[72] Analysis suggests that for these nations sovereign bonds provided an average 12.4% in total returns.[73] Clearly, appropriate discount rates will vary meaningfully between developing countries, for example, dollar-denominated African bond yields in Q4 2022 exceeded 15% and averaged 9% for 2019-2022.[74] The most conservative view might align the discount rate with long-term inflation, which averaged 5.4% from 1981-2022, or 2.9% from 2012-2022.[75] A discount range of 3-9% is used in the analysis.

LIST OF SUPPLEMANTARY INFORMATION

1. Supplementary Note (.docx)
2. Code for Semantic Similarity Analysis (.py)
3. Equation Calculator (.py)
4. Equation Calculator (.xlsx)

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ETHICS DECLARATION

Alongside other roles, I currently serve as a consultant to the United Nations Economic Commission for Africa, advising on topics of climate finance. I have not formally advised on the negotiations of the NCQG but have shared informal comments in response to requests of several Parties (developed and developing) through the NCQG technical expert dialogues and negotiations. Many of those comments have been expanded upon in this paper.