


A dynamic climate finance allocation mechanism reflecting the Paris Agreement

Journal Article**Author(s):**

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Publication date:

2019-11

Permanent link:

<https://doi.org/10.3929/ethz-b-000384626>

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Originally published in:

Environmental Research Letters 14(11), <https://doi.org/10.1088/1748-9326/ab443b>

LETTER • **OPEN ACCESS**

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To cite this article: Florian Egli and Anna Stünzi 2019 *Environ. Res. Lett.* **14** 114024

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Environmental Research Letters



LETTER

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OPEN ACCESS

RECEIVED
20 May 2019REVISED
8 September 2019ACCEPTED FOR PUBLICATION
13 September 2019PUBLISHED
6 November 2019

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Florian Egli¹ and Anna Stünzi² ¹ Energy Politics Group, ETH Zurich, Haldeneggsteig 4, 8092 Zürich, Switzerland² Chair of Economics/Resource Economics, ETH Zurich, Zürichbergstrasse 18, 8092 Zürich, SwitzerlandE-mail: florian.egli@gess.ethz.ch and stuenzia@ethz.ch**Keywords:** climate finance, climate policy, equity principlesSupplementary material for this article is available [online](#)**Abstract**

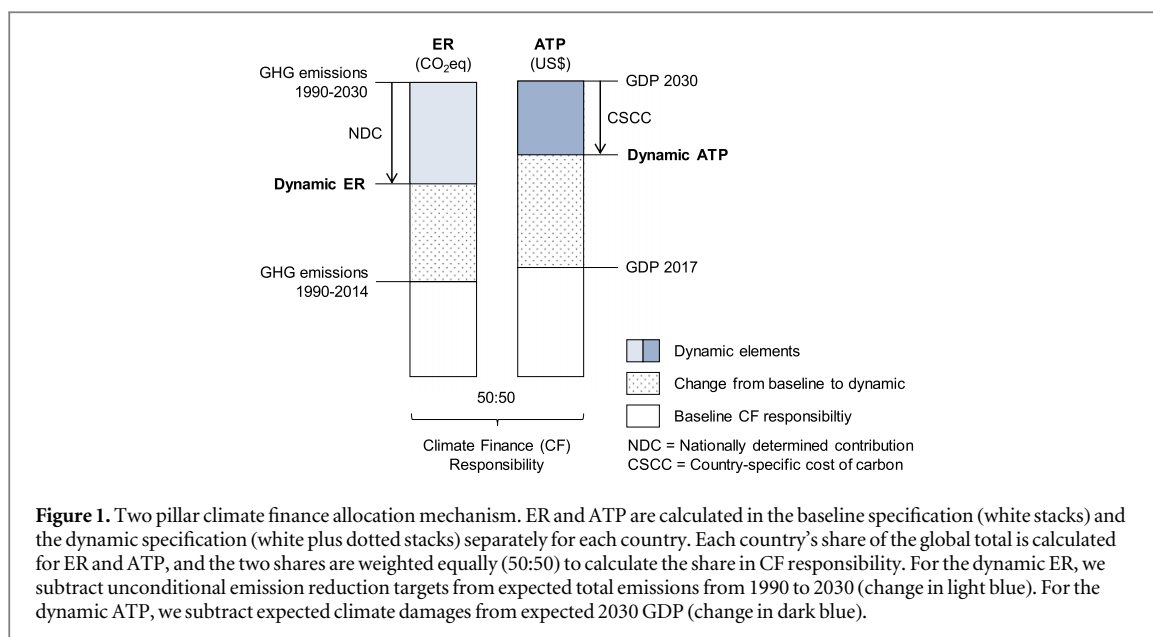
Reaching the goal of the Paris Agreement requires substantial investment. The developed country parties have agreed to provide USD\$100 billion in climate finance annually from 2020 to 2025. Ongoing negotiations on post-2025 commitments are likely to exceed that sum and include a broader scope of parties. However, there is no guidance regarding the allocation of contributions. Here, we develop a dynamic mechanism based on two conventional pillars of a burden sharing mechanism: emission responsibility and ability to pay. The mechanism adds dynamic components that reflect the Paris principle to ‘ratchet-up’ ambition; it rewards countries with ambitious mitigation targets and relieves countries with a high degree of climate vulnerability. Including developed country parties only, we find that ten countries should bear 85% of climate finance contributions (65% if all parties to the Paris Agreement are included). In both scopes, increasing climate ambition is rewarded. If the EU increased its emission reduction target from 40% to 55% by 2030, member states could reduce their climate finance contributions by up to 3.3%. The proposed mechanism allows for an inclusion of sub-, supra- or non-state actors. For example, we find a contribution of USD\$3.3 billion annually for conventionally excluded emissions from international aviation and shipping.

1. Introduction

In contrast to its predecessor, the Kyoto Protocol, the Paris Agreement requires all parties (i.e. countries) to submit nationally determined contributions (NDCs) outlining what each country considers its fair share of emission reduction and adaptation targets [1]. Achieving the NDCs requires substantial climate finance efforts. The associated problem is threefold: first, the contributing parties have no guidance to determine their fair share; thus the civil society has no tools to evaluate contributions. Moreover, current climate finance pledges may be insufficient to reach the target. Public climate finance is projected to reach USD\$67 billion in 2020, with mobilised private climate finance possibly filling the gap [2]. Second, the 2018 United Nations Climate Change Conference (COP24) in Katowice introduced biennial ex-ante communications of climate finance contributions from 2020

onwards [3], reinforcing the need for guidance. Third, the COP24 opened deliberations on a new climate finance target (likely post-2025) [4], reflecting the fact that the USD\$100 billion p.a. are most likely insufficient to reach the goal of the Paris Agreement [5] let alone sustainable development goals [6]. Although a higher target seems possible, it may be conditional on a broader scope of contributing parties (see Art. 9, Paris Agreement).

Various researchers have calculated optimal mitigation contributions based on equity principles [7–9] and argue that transparent and equity-based allocation of mitigation responsibilities may increase ambition [10]. However, there is little research offering guidance on how to allocate climate finance responsibility. Current approaches either cover a small set of countries [11] or are based on existing international donor schemes unspecific to climate change, such as the United Nations (UN) [12]. Here, we propose a



novel climate finance allocation mechanism, which provides a benchmarking tool for national deliberations on climate finance contributions. The mechanism embodies the key principles of the Paris Agreement. First, it reflects the principle of common but differentiated responsibilities in providing flexibility regarding the scope of contributors and in accounting for expected future climate damages. Second, it introduces a dynamic forward-looking component that rewards increasing ambition over time (ratcheting-up), similar to policy sequencing to increase stringency over time [13]. Thus, if a country exceeds the average level of ambition, it can thereby reduce its climate finance contribution.

2. Mechanism

We define a baseline specification, which is calculated from historical data on emission responsibility (ER) and ability to pay (ATP) [14]. We use cumulative greenhouse gas (GHG) emissions from 1990 to 2014 to operationalise ER and the gross domestic product (GDP) in 2017 for ATP. We weigh both indicators equally and define a country's share of the total climate finance contribution as the average between the country's share of global cumulative GHG emissions and its share of global GDP (see figure 1 and Methods).

We further define a dynamic specification, where we introduce forward-looking elements for ER and ATP, as illustrated in figure 1. On the left-hand side, ER is extended to cover future emissions up to 2030. Unconditional emission reduction targets submitted in the first NDC of each country are subtracted from ER to calculate the dynamic ER (see Methods). For countries without an unconditional NDC, the dynamic ER is a business as usual (BAU) projection of 2030 emissions. On the right-hand side, we include future climate damages to calculate a climate-adjusted

ability to pay in 2030 [15, 16]. We operationalise future climate damages using country-level social costs of carbon (CSCC) and combine these numbers with GDP forecasts to calculate the dynamic ATP (see Methods). The aim of the two dynamic elements is to reward ambitious climate action and to account for future climate change impacts as proposed by De Cian *et al* [17]. Because the total sum of climate finance contributions remains fixed, a more ambitious NDC for one country directly translates into higher climate finance responsibility for the rest (see Methods).

The current climate finance regime (developed countries' pledge to contribute USD\$100 billion annually from 2020 onwards) was formalized at the COP16 in Cancun [18]. To reflect this, we define the Cancun scope covering 49 developed countries (see methods and supplementary table 3 is available online at stacks.iop.org/ERL/14/114024/mmedia). To reflect potential future climate finance regimes, we define the Paris scope covering all countries that have signed and/or ratified the Paris Agreement. Finally, we exclude the least-developed countries (LDC) with per capita emissions within a carbon budget consistent with the Paris Agreement (see Methods). The exclusion criteria apply in the Paris scope only and exclude 34 out of 47 LDCs.

3. Methods

This section describes the methodological approach to the mechanism and the data sources. It proceeds in four steps. First, we describe the definition of the scope. Second, we define the baseline mechanism. Third, we describe the dynamic elements. Fourth, we explain the inclusion of bunker fuels.

3.1. Scope

We include all parties that either signed or ratified the Paris Agreement in our analysis ($N = 196$, excluding

the European Union). We define two exclusion criteria based on the two pillars described in figure 1. First, we identify countries with 2014 per capita greenhouse gas (GHG) emissions in line with a carbon budget consistent with the Paris Agreement. Specifically, we use the mean of a 2015–2100 carbon budget in line with a >66% chance of limiting global warming to below 2 °C relative to pre-industrial levels [19]. We allocate this budget linearly over 85 years and convert it into per capita budgets using 2014 population data from the World Bank [20]. Second, we identify countries classified as least-developed countries (LDC) by the UN [21]. To classify as a LDC, a country must meet criteria on three dimensions: poverty (Gross National Income (GNI) per capita below USD\$1025), weak human resources (e.g. education and health) and high economic vulnerability (e.g. instable agricultural production or export) [22]. Countries fulfilling both exclusion criteria are excluded from the sample. This reduces the sample size from 196 to 164 (see supplementary table 3 for a full list of countries).

Based on the sample of 164 countries, we define two scopes, which we use for all calculations. First, the Cancun scope, reflecting the fact that the pledge to raise USD\$100 billion annually from 2020 onwards was formalised at the COP16 in Cancun. The Cancun pledge was made by developed country parties only, which limits the scope to 49 countries. Second, the Paris scope, reflecting the fact that the 2015 Paris Agreement abandoned the bifurcation of the international community in developed and developing countries. Hence, the Paris scope covers all 164 countries. Note, that the scope could also be defined differently and include other actors. For example, emitters of bunker fuels (i.e. the aviation and shipping industry) are currently excluded from emission inventories, but they represented 2.9% of global emissions in 2014 and 3.7% of global GDP in 2017. As an extension we include those two industries as separate actors in the scope and show the distribution of responsibility for all countries and the two industries for the baseline mechanism. Scope adjustments can also be used to include sub-national actors as exemplified in the discussion.

3.2. Baseline calculation

Emission responsibility (ER) is based on the ‘polluter pays principle’ [23]. Countries that are responsible for large amounts of emissions should also be accountable for the damages they produce and thus contribute more to climate finance. The ability to pay (ATP) or capacity principle reflects a long tradition of tax schemes worldwide based on the notion that actors should pay in proportion to their capacities [14]. We conceptualise ER as total emissions in GHG-equivalent, excluding emissions from land use, land-use change and forestry (LULUCF) from 1990 to 2014 [24]. Several scholars and nongovernmental

organisations propose dating emissions further back to 1900 or 1850. We follow the scientific literature in starting to assign responsibility when climate negotiations started, thus 1990 [25]. Where emissions data is unavailable, we search for online sources and complement the data manually for Monaco [26] and San Marino [27].

To represent ATP, we use GDP data for 2017 in constant 2010 USD from the World Bank [28]. Where World Bank data is unavailable (Cook Islands, Cuba, Djibouti, Eritrea, Liechtenstein, Monaco, Democratic People’s Republic of Korea, Somalia, South Sudan, Syrian Arab Republic, Venezuela and Yemen), we use UN data from 2016 [29]. The resulting dataset contains 159 countries and excludes Andorra, Niue, South Sudan, Timor-Leste and West Bank Gaza due to a lack of data.

We calculate the share of climate finance responsibility F for each country i according to equation (1) and impose equal weights for the two pillars.

$$F_i = \left(\frac{ER_i}{\sum_{n=1}^N ER} + \frac{ATP_i}{\sum_{n=1}^N ATP} \right) / 2. \quad (1)$$

For the purpose of this paper, F is multiplied with the annual climate finance commitment from 2020 to 2025, hence USD\$100 billion.

3.3. Dynamic elements

The dynamic elements add a forward-looking component to both pillars. Namely, we add emission commitments for 2030 to the ER pillar and expected climate damages in 2030 to the ATP pillar. For ER, the first pillar, we search for publicly available *unconditional* NDCs—hence, emission reduction commitments for 2030. In the first step, if a country has submitted an NDC, we calculate the total emissions from 2015 to 2030, assuming a linear annual decrease/increase from the 2014 level of emissions (67 countries submitted either an absolute emission target for 2030 or a target relative to historic emissions, and 25 countries submitted an emission target relative to the BAU). If a country has not submitted an NDC, we use a BAU scenario instead ($N = 68$) and follow the same procedure. By considering unconditional emission reduction targets only, we avoid conflicting targets that could arise from using targets conditional on climate finance. Projected emissions by 2030 were directly read from the NDC targets [26] and, if necessary, calculated as shares from BAU scenarios. BAU scenarios were taken from the NDCs if available; otherwise they were taken from estimations by the Climate Equity Reference Project (CERP) [27]. National targets expressed as emission intensities were translated to total emissions based on GDP projections from the ETH Climate Calculator [30].

In the second step, we add future emissions to historic emissions to calculate the new ER from 1990 to 2030 for each country. To do so, we calculate

the average emissions over 16 years (2014–2030) that map the emission path until 2030 as submitted in the country's NDC. Equation (2) describes the new ER for each country i , where NDC is replaced by BAU in case a country has not submitted an unconditional NDC.

$$ER_{new,i} = ER_{old,i} + \left[GHG_{2014,i} + \frac{NDC_{2030,i} - GHG_{2014,i}}{2} \right] \times 16. \quad (2)$$

For ATP, the second pillar, we use GDP forecasts for 2030 [30], country-specific costs of carbon [16] and 2030 emission forecasts using the above result according to equation (3), where again NDC is replaced by BAU if no NDC exists.

$$GHG_{2030,world} = \sum_{n=1}^N NDC_{2030,i}. \quad (3)$$

We calculate the new ATP for each country i according to equation (4) by allocating the marginal costs of each ton of GHG emissions to countries via the country-specific social cost of carbon (SCC) from Ricke *et al* [16] and subtracting expected climate damages from expected GDP in 2030. Note that this is an economic conceptualisation of vulnerability.

$$ATP_{new,i} = GDP_{2030,i} - GHG_{2030,world} \times SCC_{2020,i}. \quad (4)$$

Note that due to data availability, the SCC estimates are for 2020 instead of 2030. Assuming increasing economic damages with increasing global temperatures, this yields a conservative estimate of climate damages in 2030. We use a median SCC estimate of an average scenario assuming a middle of the road socioeconomic pathway (Shared Socio-economic Pathway scenario 2, SSP2) and the closest corresponding climate scenario (Representative Concentration Pathway 6.0, RCP6.0), a pure time preference of 2% and an elasticity of marginal utility of 1.5 [16]. Where Ricke *et al* [16] does not provide a country-specific SCC, we use the median value (28 countries). Because this implies using median values for 19 of the 39 Small Island and Developing States (SIDS), we verify whether the SCC for SIDS differs from the median. The SCC for SIDS is slightly below the median, we hence do not penalise SIDS.

The two forward-looking elements can introduce a trade-off: a more ambitious NDC, reducing future global emissions, reduces future damages and hence increases future ATP. However, applying equations (2) and (4) to the data, it can be shown that the effect of reduced domestic emissions through the ER is stronger than its effect on ATP via reduced global emission, ensuring the dynamic efficiency of the mechanism.

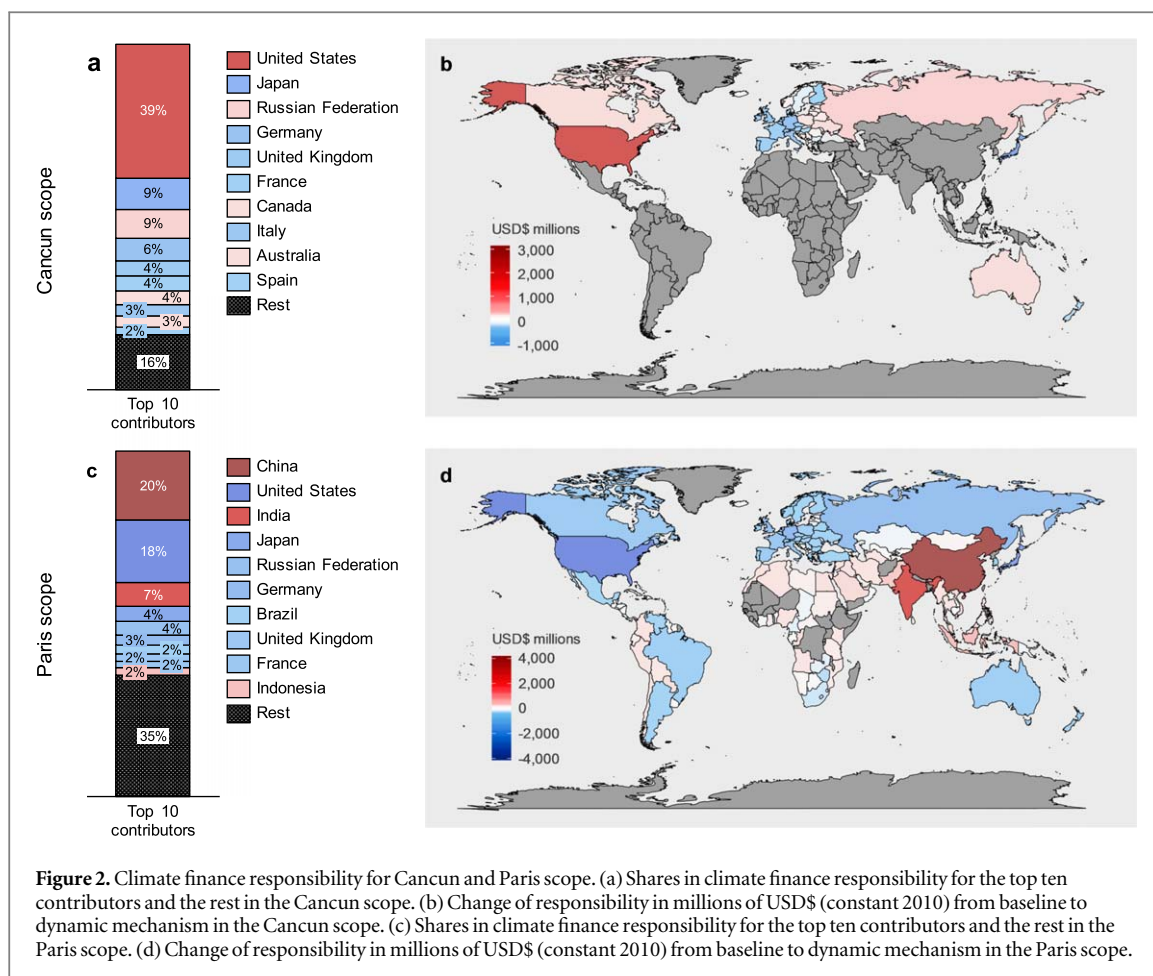
3.4. Bunker fuels

To include bunker fuels, we draw on emissions data for the international aviation and shipping industries. Due to a lack of forward-looking data, we compute only the baseline allocation. For aviation, we estimate the cumulative emissions in 2014 from the IPCC 2014 report [31], assuming linear growth similar to the growth rates from 1990 to 2012. We do not include a radiation factor and hence provide a conservative estimate. For shipping, we estimate cumulative emissions based on the data from the International Maritime Organization [32], with an emission growth rate of 2.4% between 2013 and 2015 [33]. To approximate the ATP, we estimate the aviation share at 3.5% of global GDP 2017 [34]. For shipping, we estimate the share of global GDP 2017 at 0.3% [35]. Although this approach ensures a more complete accounting of global emissions, it comes with the caveat of a small double counting on the ATP, primarily affecting large economies. There is currently no data available to allocate international aviation and shipping industries to domestic GDP in a consistent manner to alleviate this concern.

4. Results

Figures 2(a) and (b) show the top ten contributors in the Cancun and Paris scope, respectively (see supplementary tables 1 and 2 for the contributions of each country in both scopes). In the Cancun scope, ten countries are responsible for 84% of total climate finance and 21 for 95%. The US covers 39%, followed by Japan (9%) and Russia (8.5%), Germany (6.5%), the UK (4.5%) and France (4%). The EU as one entity would be responsible for 32%. In the Paris scope, 10 countries together contribute 65% of the climate finance contributions and 60 countries contribute 95%, with the US and China accounting for 38%. All G20 countries together represent 77% of the contributions, whereas African countries contribute 4.5%. The EU as one entity would be responsible for 15%.

Figures 2(b) and (d) show the change in climate finance contributions when including the dynamic elements for both scopes. Countries coloured in blue benefit from including the dynamic elements, countries in red suffer. In the Cancun scope, 28 countries benefit and 21 suffer from the inclusion of dynamic elements (83 and 76 in the Paris scope, respectively). To analyse the effects more systematically, figure 3 shows the ten most affected countries for both scopes and reveals that the choice of scope is crucial. For Russia and the US, the effect of including dynamic elements reverses depending on the scope. In the Cancun scope, these countries would face a higher contribution in a dynamic setting; in the Paris scope, the opposite is true. There are two reasons for this. First, compared to the average developed country, these countries have unambitious emission reduction



targets. However, when compared to emission-intensive economies on a growth path, such as India for example, their expected emissions are lower. Second, the Paris scope contains emerging economies that typically grow faster than developed economies. Hence, the developed countries' share of world GDP decreases over time in the Paris scope, reducing their future ATP (in relative terms). In addition, some countries, such as Russia, benefit from climate change, which increases their future ATP.

For other countries, such as the EU and Japan, the direction of the effect does not change depending on the scope. For the EU, the responsibility decreases by 5% and 18% for the Cancun and Paris scopes, respectively. For Japan, the decrease amounts to 10% and 23% for the Cancun and Paris scopes, respectively. In the case of the EU, this is the result of ambitious emission reduction targets and high climate vulnerability; in the case of Japan, it is mainly due to its coastal exposure and the high climate vulnerability. On the other hand, China increases its contribution by 24% due to its relatively lower emission reduction ambition, higher economic growth and lower vulnerability.

The substantial changes due to dynamic ER illustrate the rewards for ambitious NDCs. For example, Moldova's contribution is reduced by 17% due to its high-ambition NDC. On the other hand, Paraguay

contributes almost 2.5 times as much (USD\$140 million) compared to the baseline (USD\$59 million) due to the relatively high projected 2030 emissions under a BAU scenario in their NDC. As such, one can calculate the potential for future action: Paraguay could reduce its climate finance contribution by 15% (USD\$20 million) by increasing its emission reduction target from 10% to 30%. More generally, 21 countries in the Paris scope *only* have an NDC *conditional* on international support (e.g. climate finance). If all of them implemented an unconditional NDC of 15% compared to BAU 2030 (average of the rest) instead, they could reduce their climate finance responsibility up to 7% (e.g. Pakistan: 7%, Kenya: 4%). Similarly, if the EU increased its emission reduction target from 40% to 55%, some of the member states' finance responsibilities would decrease by up to 3.3% (e.g. Estonia and Bulgaria).

Finally, the proposed mechanism can be extended to include the international aviation and shipping industries (see Methods). We find that the climate finance responsibilities of international aviation and international shipping amounts to USD\$2.2 billion and USD\$1.1 billion, respectively, placing both among the top 20 contributors (Paris scope, baseline calculations).

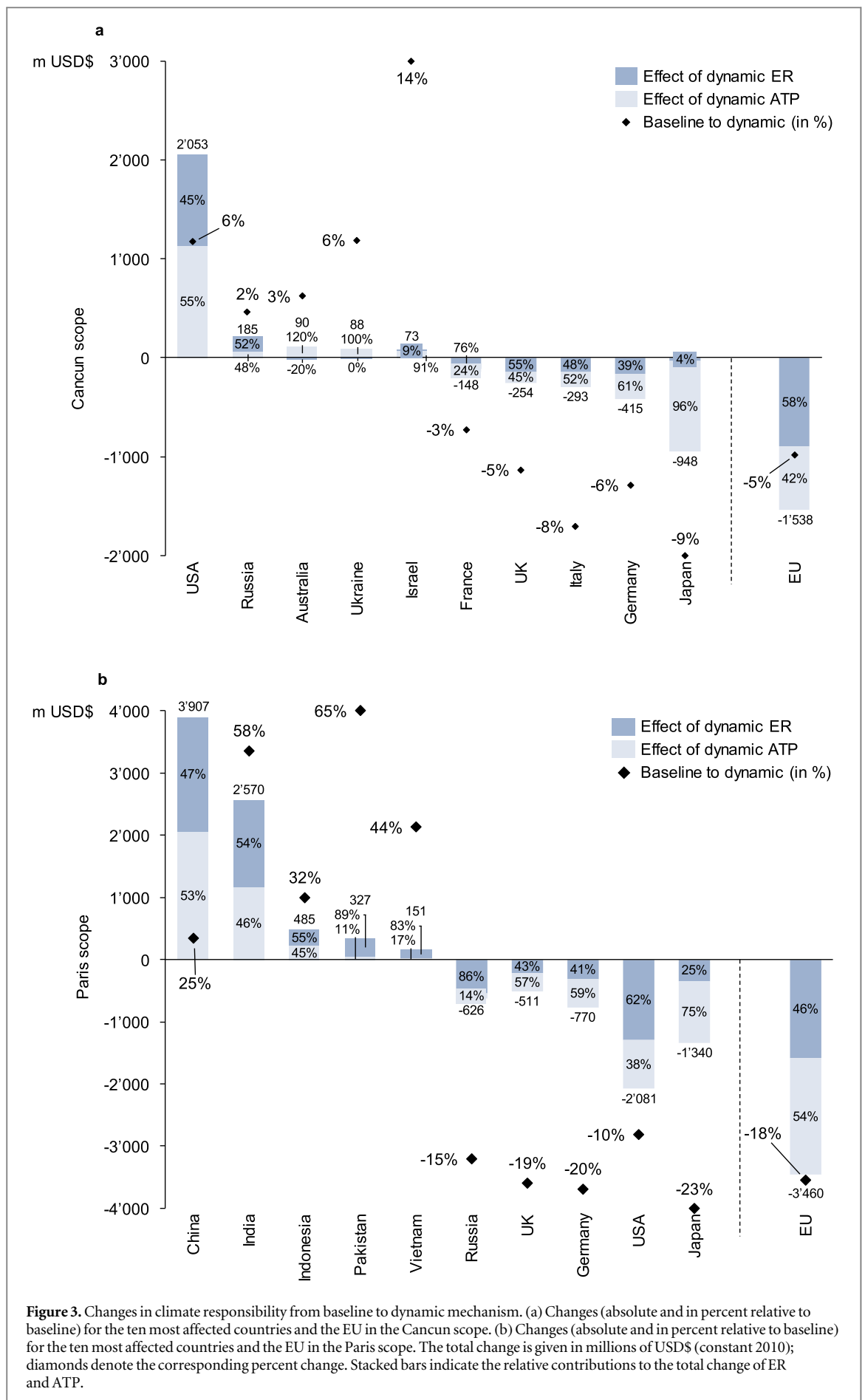


Figure 3. Changes in climate responsibility from baseline to dynamic mechanism. (a) Changes (absolute and in percent relative to baseline) for the ten most affected countries and the EU in the Cancun scope. (b) Changes (absolute and in percent relative to baseline) for the ten most affected countries and the EU in the Paris scope. The total change is given in millions of USD\$ (constant 2010); diamonds denote the corresponding percent change. Stacked bars indicate the relative contributions to the total change of ER and ATP.

5. Discussion

Our findings reveal four insights: First, several European countries have pledged more than the amounts calculated in the Cancun scope (e.g. Germany pledged USD\$10 billion instead of USD\$6.4 billion, France pledged USD\$5 billion instead of USD\$4.2 billion) [36, 37]. However, for other European countries, the pledges are insufficient in the current contribution scheme. Namely, Switzerland would need to increase its contribution by USD\$339 million to reach USD \$789 million (+75%) [38]. Moreover, the US plans to spend about USD\$2 billion in 2019 [39], one ninth of what is required in the Paris scope and one eighteenth of what is required in the Cancun scope. To lay the foundation for a post-2025 framework with a broader scope, developed country parties may need to legitimate this discussion by stepping up current contributions to their fair share for the 2020–2025 period.

Second, our results for the Paris scope show that some countries currently claiming financial support may have to acknowledge that they will need to contribute instead in a post-2025 framework due to their ER and ATP. Pakistan, for example, claims that it would need about USD\$40 billion in assistance to reach its conditional emission reduction target of 20% compared to BAU 2030. However, according to our results, Pakistan would have a climate finance responsibility of around USD\$830 million per year in the Paris scope.

Third, two thirds of all countries use vulnerability to explain their (small) mitigation and adaptation efforts [1]. Accounting for future vulnerability may therefore alleviate some of these concerns and make political consensus easier. However, fewer countries benefit from including vulnerability in the mechanism ($N = 64$) compared to including NDCs ($N = 96$). Hence, according to the proposed mechanism, ambitious NDCs help more countries lower their climate finance responsibility than vulnerability does.

Fourth, the mechanism provides an incentive to peer-review the implementation of NDCs, in line with insights regarding policy surveillance [40]. Countries that implement their NDCs and incur related costs will want to ensure that other countries follow up on their commitments so that they avoid overpaying within the climate finance mechanism. In the absence of an international body with oversight and sanctioning capacity, increasing incentives for peer-reviewing NDCs will be crucial to achieve substantial emission mitigation.

These four insights relate to a broader political science literature. Three refer to the question of fair burden sharing, while one links to effective international governance. Mitigating climate change depicts a public good provision dilemma. Despite altruistic motivation to contribute to the public good [41], there is an incentive to free-ride on other countries' efforts and procrastinate climate action to future governments

[42]. Scholars assign the success of an agreement to strong leadership [43] and intentionally sticky policy design [44]. A commitment to a mechanism instead of an ad hoc climate finance contribution may be more successful in 'tying successors' hands' and therefore lock-in the policy regime [42]. Moreover, a public commitment to the mechanism could create leadership on the issue that may lead to other countries learning from the experience, imitating the leaders or even responding to coercion from leaders; patterns that have been observed in policy adoption among cities [45]. Lastly, the mechanism provides the civil society and countries with a tool to check the adequacy of a governments' climate finance contribution. Such reviewing and subsequent naming and shaming can also be important to ensure more effective international collaboration [46].

The allocation mechanism builds on the most common equity principles, namely the ability to pay (or capacity) principle and the polluter pays principle (including historic responsibility). These two principles are also among the most frequently used when countries explain the fairness of the contribution in their NDC [1]. Moreover, the mechanism relates to other principles, which are debated in the literature, too [14]. For example, the egalitarian principle is applied to define one exclusion criterion (per capita emissions in line with a 2°C carbon budget). The merit principle is reflected in the forward-looking element, rewarding countries that have ambitious emission reduction paths. The right to development principle is also partly reflected. On the one hand, by excluding LDCs with emissions in line with a 2°C carbon budget from the pool of contributors and on the other hand, by accounting for future climate vulnerability. Lastly, the cost sharing principle demands that emissions are reduced where abatement costs are lowest. This principle is not reflected in the mechanism, because the mechanism abstracts from the debate on where to allocate the funds geographically and whether to allocate them to mitigation or adaptation efforts. The proposed mechanism also does not make a claim on the type of finance that should be used [47]. Overall, the mechanism focuses on the allocation of climate finance responsibility based on the two most common equity principles.

Future research could propose additional criteria—such as green finance or green research and development—to be included as dynamic elements and analyse conditions for political feasibility. Additionally, future research could address the issue that some national governments have threatened or decided to withdraw from the Paris Agreement, but several sub-national actors have committed to remaining in the Agreement. For example, the United States have submitted their withdrawal to the Paris Agreement, which will take effect in late 2020. In response, a coalition of US States has formed the US Climate Alliance to maintain their commitment irrespective of the federal

decision. Conditional on data availability, our mechanism would be flexible to including sub-national actors, which play an increasingly important role in pursuing ambitious climate policies [48, 49]. Moreover, future research could investigate how to deal with domestic emission reduction targets versus international compensation schemes, how to account for differences in consumption-based GHG accounting compared to the commonly used production-based approach [50] or how to better reflect the need for short-term mitigation targets by accounting for differences in warming potentials [51].

6. Conclusion

A common understanding of climate finance responsibility will be vital to the successful mitigation of and adaptation to climate change. In this paper, we propose a mechanism for evaluating the adequacy of current climate finance pledges. Furthermore, the mechanism creates co-benefits beyond secured and stable finance, particularly in the form of incentives for ambitious emission reduction targets and peer-reviewing their implementation. The mechanism is designed to fit the Paris architecture. First, the mechanism is based on established principles to allocate responsibility, increasing the likelihood of acceptance. Second, its design is Paris-compatible in that it uses forward-looking elements to reflect the ‘ratcheting-up’ of ambition over time. Third, it offers a transparent and tractable method to calculate climate finance contributions. Fourth, these contributions can be calculated in regular time intervals, reflecting the five-year stocktake envisaged in the Paris Agreement or the planned biennial climate finance communication. Fifth, the mechanism is open to extensions in scope, such as bunker fuels or other sub-, supra- or non-state actors.

To policymakers, this paper provides a tool to commit to a rules-based climate finance contribution, making the commitment more robust and potentially more sustainable. In committing to the mechanism, policymakers should be aware of the importance of accurate and timely data. For example, emissions data should be readily available (incl. LULUCF) and targets (e.g. NDCs) should be comparable. More work is needed on the international level to attain these goals. Most importantly, a consensus on the definition and the accounting of climate finance will be required in order to have a meaningful comparison of climate finance contributions across countries. Lastly, this paper stresses the importance of conventionally excluded sectors, such as international aviation and shipping, which are responsible for large shares of global emissions. It is questionable whether the current separate negotiation track through the ICAO and the IMO will deliver commitments that honour adequate climate finance contributions of these sectors.

Acknowledgments

The authors thank seminar participants at the University of Graz, participants of the envecon 2019 in London, two anonymous reviewers in the Swiss Federal Office for the Environment and the State Secretariat for Economic Affairs, members of the Chair of Economics and Resource Economics and members of the Energy Politics Group at ETH Zurich for helpful comments on earlier drafts of the paper.

Author contributions


Both authors contributed equally.

Data availability

The data used in this paper are available from the authors upon reasonable request.

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