Modeling paths and strategies to net-zero emissions by 2050:

How should donors support lower-income countries?

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December 2025

Key words: Climate mitigation; climate finance; carbon pricing; financial market constraints.

JEL codes: F35, H23, O19, Q54, Q57, Q58.

Abstract

This paper discusses how donors can fruitfully assist low- and middle-income "host" countries (LICs and MICs) to enhance their climate mitigation policies, on two fronts: provide climate finance (CF) to increase the volume of zero-carbon ("green") energy investments; and provide support to implementing carbon taxation. I find that providing CF for green investments is highly advantageous when host countries are constrained in credit and capital markets and face severe fiscal constraints limiting their own investments. For a host to accept carbon taxation two types of costs must be compensated: the host's deadweight loss of implementing the tax; and its political tax implementation cost. I study two cases for carbon tax implementation support: the host's tax implementation costs are public information; and this information is known by the host's government only. Under public information the donor will support a higher carbon tax when the tax implementation cost is lower. Under private information, the donor supports a given carbon tax, which is accepted by hosts with low implementation cost, and rejected by others. This is less efficient as carbon taxes cannot be implemented by all hosts. Green investments and carbon taxation are mutually reenforcing: a higher carbon tax leads to more green investments; and more green investments implemented lead to a higher carbon tax supported by the donor.

1. Introduction

This paper seeks to provide a consistent analytical model structure for efficient greenhouse gas (GHG) mitigation policies required to reach a net-zero equilibrium (NZE) for the global economy by around 2050, with focus on middle-income and low-income countries (MICs and LICs; also hosts). Our focus is on GHG mitigation in MICs and LICs, which are assumed to need high degrees of assistance to their mitigation activity from high-income countries (HICs; also donors) and multilateral financial institutions (MFIs), for this activity to reach a sufficient volume; that donors and MFIs have access to adequate volumes of finance, and are willing to provide this finance to the respective MICs and LICs. Van der Ploeg and Venables 2022 stress that three sets of policies are essential for reaching an NZE by mid-century:[1]

1) Comprehensive, robust and predictable carbon taxation or pricing.
2) A high level of international climate finance (CF) support to the implementation of zero-carbon ("green") investments, to ensure that the path for such energy investments, required for reaching an NZE by around mid-century, is implemented.
3) A high level of public R&D support to develop and implement new and improved zero-carbon technologies.

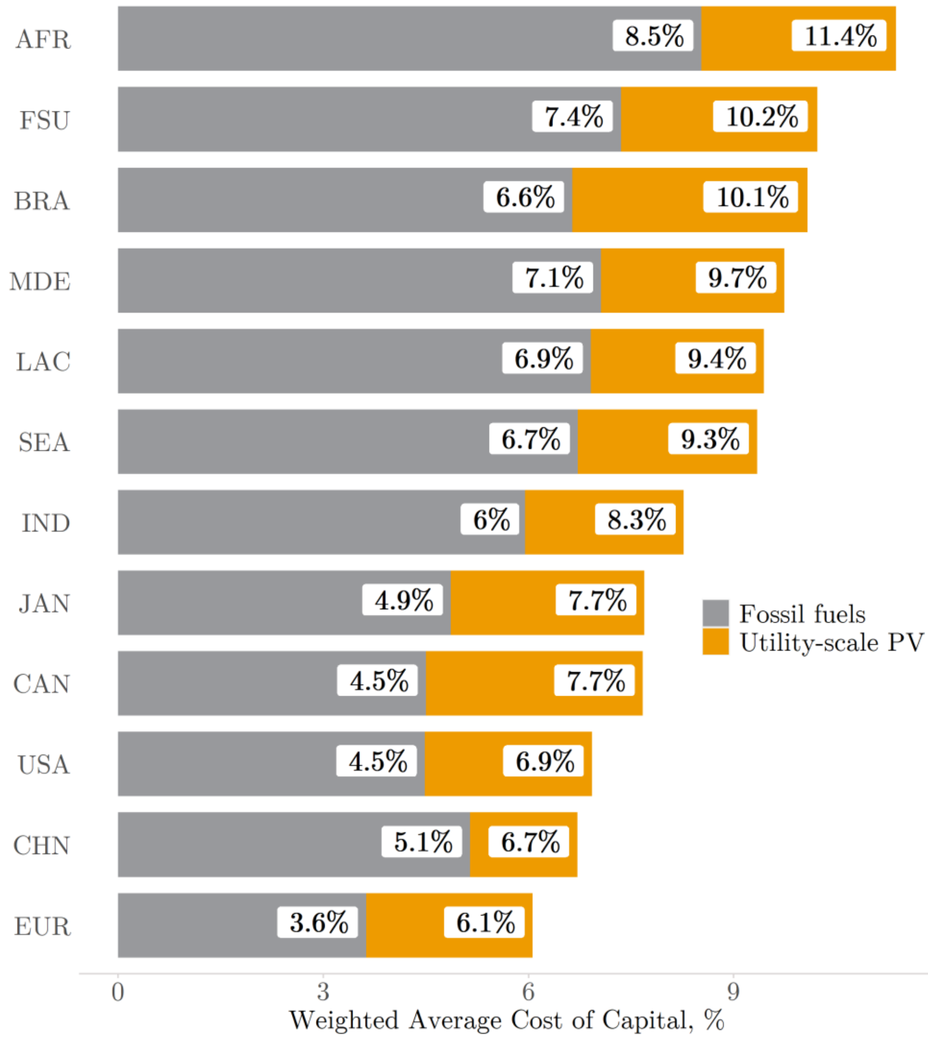
Our focus is on policies 1 and 2, which we view as crucial policy categories today for MICs and LICs, and on the relationship between the two policies. The importance of robust carbon pricing, preferably carbon taxation, is clear and should not need an extensive discussion here; it has the endorsement of virtually all economists and is considered as an essential aspect of an efficient climate policy agenda.[2] Carbon pricing creates a price wedge between zero-carbon and carbon-based energy making the former sufficiently attractive for investments by the private sector. Empirical evidence on the efficacy of carbon pricing for GHG emissions reduction is still limited but accumulating.[3] Sen et. al. 2024 demonstrate that carbon pricing leads to a reduction in a country's GHG emissions by 8-12% in the short run, and 19-23% after 10 years.[4] Best et al. 2020 find that adding one euro per ton of CO_2 to the carbon price reduces the annual emissions growth rate by 0.3 percentage points. Green 2021 draws similar conclusions, and also finds that, among alternative carbon pricing policies, carbon taxation reduces GHG emissions by more than cap-and-trade mechanisms for given carbon price. A study of the EU ETS, the largest and most comprehensive carbon

[1] See also Forni and Tavoni 2023, and Kotchen 2024 for a wider survey of climate policy options.
[2] See e. g. Golosov et. al. 2014, Gillingham and Stock 2018, Metcalf 2019, 2023.
[3] Such a wedge can also be created by carbon markets for trading of carbon credits such as those set up via Article 6 of the Paris Agreement; see e.g. Strand 2024. Carbon prices are here however highly uncertain and volatile; then can always only be an addition and cannot replace carbon taxes as the most reliable instrument.
[4] The reason for the additional reduction in the longer run is that substitution out of fossil fuels and into zero-carbon fuels takes time; such substitution seems to be their most likely main path to lower GHG emissions, while improved efficiency of energy use has a lower impact.

pricing scheme ever implemented, by Colmer et. al. 2024 shows that this scheme reduced GHG emissions from European businesses by 14-16%, with no detectable negative impact of business profitability or viability.

The importance of policy 2 has the background in two important interrelated problems. First, hosts (including their governments and private sectors) in most LICs and MICs are fiscally and financially constrained in their ability to make the required, heavy and up-front, energy investments.[5] Secondly, these countries also face high borrowing costs or rationing in credit markets, and often no access to bond and equity markets for project financing.[6] Having access to affordable credit will for many of these countries be necessary for making their required volumes of green investments. The problem is most crucial for LICs (where bond and equity markets are often nonexistent).[7] There is also the possibility of multiple equilibria and the need for a "big-push" global effort to shift the world or main regions from an adverse to a much more benign climate outcome.[8] Increased green investment volumes can also reduce costs of future similar investments.[9] This could have transformative impacts by helping to push (national, regional or global) economies toward a zero-carbon state which otherwise could not be reached.

[5] For discussion of the heavy up-front costs related to zero-carbon investments in the electricity sector, see Borenstein 2012.
[6] This is reflected in recent reports on what is required to reach an NZE by around 2050, and mechanisms for accomplishing this; see Buchner et al. 2019, IEA 2021, 2023, IEA and IFC 2023, IMF 2023, World Bank 2023; and how MICs and LICs can best contribute to achieving such a goal. World Bank 2023 stresses that main problems for MICs and LICs are underdeveloped domestic financial markets; inadequate alignment with the standards of international financial markets; underdeveloped policy and regulatory frameworks; and institutions that lack adequate capacity. The average cost for HICs is substantially lower than that of for MICs, and capital costs for MICs are substantially lower than that for LICs. Briera and Lefèvre 2024, and Haas et al. 2025, show that credit constraints and weak management seriously hold back corporate investment in green technologies for both MICs and LICs.
[7] Bolton and Freixas 2008 discuss alternative financing mode choices (between credit, bonds and equity), and argue that credit is overwhelmingly important for LIC firms. Wei and Wu 2023 show that both credit and bond markets are important for the renewable energy industry in China, while equity markets, and foreign direct investments (FDI), are consequential only in the most developed parts of China. This supports our view that credit markets are always important, while bond financing is consequential only in financially more developed countries (largely MICs).
[8] See e. g. Acemoglu et al. 2012, 2016 and Aghion et al. 2016 for such views.
[9] Consumer choice externalities can also be important, but will not be formally modelled here. Such externalities can be given alternative interpretations. One is that higher consumer uptake of "green" products increases the social acceptability of the products, which can lead to further increase in their uptake; see e. g. Dechezleprêtre et. al. 2025, Gillingham and Bollinger 2021. Another is that consumer preferences regarding "green" products and lifestyles are endogenous and affected by social acceptability; see Besley and Persson 2019, 2023, and "domain one" in Grubb, Hourcade and Neuhoff 2014.



The figure above (from Briera and Lefèvre 2024) shows average real returns required by investors for providing capital for fossil fuel energy capacity (grey bars), and solar energy capacity (additional orange bars, not counting battery or network investments), in 2019.[10] For all regions, costs are much higher for PV investments than for fossil-fuel investments; costs in Africa are close to double those in Europe.[11]

Sections 2 and 3 in this paper analyze the importance and impact of support by donors and MFIs to hosts' green investments. In section 2 se assume that hosts are not financially constrained and donors subsidize hosts' green investments. Section 3 instead assumes that hosts need financial help from donors or MFIs to implement their green investments. We find that when LICs and MICs are unable (or unwilling) to raise the

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[10] The regions represented are: Europe (EUR), China (CHN), USA (USA), Canada (CAN), OECD Pacific (JAN), India (IND), South East Asia (SEA), Latin America and the Caribbean except Brazil (LAC), Middle East (MDE), Brazil (BRA), Former Soviet Union (FSU), and Africa (AFR).

[11] This figure however does not tell the entire story. Much of the investments in the AFR, LAC and SEA regions are already substantially "de-risked" by donors and MFIs; otherwise much would not be implementable.

necessary capital for such investments, it is efficient for donors and MFIs to financially support the LICs/MICs' required additional green investments. Such support is then needed for LICs/MICs to make their required mitigation contributions for reaching a global NZE by around mid-century.

Section 4 expands on this analysis, in novel ways. We there combine donors' CF support to hosts' green investments, with their support to implementing carbon taxation in the same host countries. In their financial support to carbon taxation, donors are assumed to use "results-based climate finance" (RBCF), donors' and MFIs' maximally efficient financing modality: each host is then promised a compensation from the donor, exactly sufficient for the host to accept the proposed comprehensive domestic carbon tax, with the compensation paid after the carbon tax has been implemented. We assume that hosts are unwilling to implement carbon taxation on their own, and need compensation from donors for doing so. The payment from donors must compensate hosts for two categories of costs. One category is the deadweight production loss (DWL) incurred when adopting the carbon tax. The other is the political cost to the host government when implementing this tax, arising among other things from popular protests against the tax. We study interactions between support to green investments and carbon taxation, and find that the two policies are closely related, in a two-way relationship: a carbon tax provides incentives to increase the green investment level; and a higher volume of green capital held by the host facilitates carbon taxation, and allows for a higher carbon tax. We show that donors (and MFIs) have incentives to provide these types of support.

We study two cases related to donors' information about hosts' political implementation costs. In the first case we assume public information about all categories of hosts' costs related to implementing carbon taxation. In the second case, the host's tax implementation cost is assumed to be known only to the host itself, but not to the donor. This leads to a case of asymmetric information between host and donor. We derive conditions under which it is advantageous for donors to provide financial support to carbon tax implementation in MICs and LICs; and what levels of carbon taxation in host countries are optimal to support from the point of view of donors. In both cases, the maximal carbon tax in host countries supported by donors is found to be lower than the optimal carbon tax in the donor countries themselves. The public information case leads to the more efficient outcome. In that case, positive carbon taxes are implemented by all hosts, at different rates depending on the host's level of tax implementation costs. In the second case, donors instead support the same carbon tax for all hosts. Some hosts will then accept the offered tax, while others will not. The outcome is then that carbon taxation will be implemented by hosts with relatively low political tax implementation costs, but not in the countries where these costs are the highest.

2. Financial support by donors to hosts' green investments

This section considers donor CF subsidies to hosts' zero-carbon investments given that hosts are not constrained in financial markets. The welfare function of the host government is assumed to take the following simple linear-quadratic form:[12]

$$(1) \quad V_G = E - \frac{1}{2}\gamma E^2 - pE_F - r[E_R - E_{R0} + \frac{1}{2}\sigma(E_R - E_{R0})^2] + q(E_{F0} - E_F) + (s+h)(E_R - E_{R0}) - C(t) + F$$

(1) represents periodic utility for the host government, ignoring intertemporal aspects. The utility value of the host's energy consumption (the two first terms on the right-hand side), and its costs of green investments (in the square bracket), both take simple quadratic forms. The donor provides a subsidy at rate s to all the host's new green investments.[13] Increases in the green capital stock has additional benefits to both the government and the private sector, represented by $h > 0$.[14] q represents the offset price when selling carbon offsets (ITMOs) in the Article 6 market.[15] This term depends on the degree to which the host's NDC constraint is over-fulfilled ($E_{F0} > E_F$; the host is a net supplier of internationally transferred mitigation outcomes, ITMOs), or under-fulfilled ($E_{F0} < E_F$: the host is a net ITMO buyer). We consider hosts with net ITMO sales. $C(t)$ represents the host's political costs of implementing a carbon tax t. The last term represents the RBCF transfer, F, from donors to the host country, in response (and as a reward) to the host setting a carbon tax t. We come back to the specific content of the last two terms in section 4 below.[16]

The corresponding objective function of the private sector in the host country is:

$$(2) \quad V_P = E - \frac{1}{2}\gamma E^2 - pE_F - r[E_R - E_{R0} + \frac{1}{2}\sigma(E_R - E_{R0})^2] + (s+h)(E_R - E_{R0}) + q(E_{F0} - E_F) - tE_F$$

The differences between (1) and (2) are that in (1) the (net) political cost of implementing a carbon tax for the host government, $C(t)$, and F, the payment from the donor to the host for implementing carbon taxation, are added. In (2), the private carbon tax expenditure, tE_F, is included.[17] The term including q in (2)

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[12] See Strand 2023 for further discussion of the current model set-up. Our analysis ignores benefits to the host from more green investments at home, such as reduced maintenance costs, higher energy security, and co-benefits from reduced air pollution when fossil fuel consumption is reduced.

[13] See Tarr et al. 2023 for a related application of subsidies to green investments as mitigation policy.

[14] This could represent several possible effects, including improved energy security, and reduced environmental impacts and provision costs.

[15] We do not distinguish between Articles 6.2 and 6.4 as the market basis, simply assuming that host participants face a given and exogenous ITMO price q.

[16] The direct allocation loss (deadweight loss, or DWL) is represented by the so-called Harberger triangle; see Harberger 1974; which equals $t(E_{F0}-E_F)/2$. See also Hines 1999, and Strand 2020, for more recent applications.

[17] tE_F is not included in the host government's objective function as the host fully internalizes this private-sector outlay. This item, and also all or part of the finance transfer F from donors to the government, can in principle be transferred back to the private sector in lump-sum fashion, without altering the analysis in the following.

represents private revenues from net ITMO sales, not eliminated even when it is eliminated in (1) (when the host government needs to purchase back ITMOs sold by the private sector).[18] The host's private sector is subject to two compounding carbon prices, q and t, making the effective carbon price $q + t$.

The host is here not financially constrained, and faces the same interest rate r in the credit market as the donor. Private actors select optimal E_F and E_R for given parameters (p, q, t, s, h and r). The first-order conditions for E_F and E_R for the private sector are (assuming equalities):

(3) $$\frac{\partial V_P}{\partial E_F} = 1 - \gamma E - p - q - t = 0$$

(4) $$\frac{\partial V_G}{\partial E_F} = 1 - \gamma E - p - q = 0$$

(5) – (6) $$\frac{\partial V_P}{\partial E_R} = \frac{\partial V_G}{\partial E_R} = 1 - \gamma E - r[1 + \sigma(E_R - E_{R0})] + s + h = 0 .$$

From (3) and (5),

(7) $$E_{RP} = E_{R0} + \frac{p + q + t + s + h - r}{r\sigma}$$

(8) $$E_{F1} = \frac{1 - p - q - t - s}{\gamma} - E_{R0} - \frac{p + q + t + s + h - r}{r\sigma} ,$$

Assuming $p + q + h + t > r$, from (7), green investments by the host are positive even with no subsidy.

The private-sector optimality conditions differ from that for the host government which has no carbon tax:

(9) $$E_{RG} = E_{R0} + \frac{p + q + s + h - r}{r\sigma} .$$

E_{RP} is green investment for a financially unconstrained host facing a carbon tax t and investment subsidy s. This implies:

(10) $$\frac{dE_{RP}}{dt} = \frac{dE_{RP}}{ds} = \frac{1}{r\sigma} .$$

[18] It is the responsibility of the host government, not its private sector, to ensure that the private sector can trade freely in the ITMO market at price q, even when the host government needs to purchase nationally determined contributions (NDCs) back to ensure that either its NDC target will be fulfilled, or potentially upscaled.

A carbon tax and a renewable investment subsidy have the same positive impact on green investments.

From (3), the effect of carbon taxation on energy use, E, is

(11) $$\frac{dE}{dt} = -\frac{1}{\gamma}.$$

The impact of carbon taxation on the host's fossil-fuel use (and carbon emissions) is:

(12) $$\frac{dE_F}{dt} = \frac{d(E - E_R)}{dt} = -\frac{1}{\gamma} - \frac{1}{r\sigma} < 0.$$

The impact of renewable subsidies on fossil-fuel use (and carbon emissions) is:

(13) $$\frac{dE_F}{ds} = -\frac{1}{r\sigma}.$$

Comparing (12) and (13), renewable energy subsidies are found to be less efficient than carbon taxation at reducing carbon emissions, as only the latter, and not the former, reduces the host's total energy use.

We next derive the donor's optimal subsidy rate, s, to the host's green investments. Define donor welfare in the following simple way:

(14) $$D_s = v(E_{F0} - E_F) - s(E_R - E_{R0}).$$

The donor has a negative utility from the host's GHG emissions, in amount E_F, v being the donor's SCC; and a negative utility from its own investment subsidy cost, the last term in (14). Taking the derivative with respect to s in (14), we find the following optimality condition for the donor:

(15) $$\frac{dD_s}{ds} = -v\frac{dE_F}{ds} - (E_R - E_{R0}) - s\frac{dE_R}{ds} = 0.$$

Inserting from (10) and (13) yields

(16) $$s = \frac{1}{2}(v + r - p - q - h - t).$$

For the donor to be willing to subsidize the host's green investments, (16) must yield $s > 0$. The donor's SCC, v, then needs to exceed $p + q + h + t - r$. Since $p + q + t > r$, donors with positive but "sufficiently low" SCC values will not provide investment subsidies to hosts.

The impact on the host's carbon emissions, and the optimized welfare impact for the donor of the subsidy rate given from (16), are:

(17) $$-\Delta E_F = \frac{1}{2r\sigma}(v+r-p-q-h-t)$$

(18) $$D_s(s) = (v-s)s\frac{1}{r\sigma} = \frac{1}{2r\sigma}[v^2-(p+q+h+t-r)^2].$$

A high carbon tax stimulates green investments in the host economy; the government investment subsidy can be considered as a substitute for absent carbon taxes, seen from (7) – (8).

Our conclusion is that the donor support policy, subsidizing all the host's new zero-carbon investments at a given and constant rate, is not a particularly efficient policy for the donor, and neither very efficient for the donor and host taken together.[19] When hosts face no significant restrictions in credit and capital markets, and have sufficient fiscal and other financial resources to carry out the required green investments, there is no major distortion affecting the market for green energy investments. As long as carbon taxation is optimal, there is then no need for a second corrective instrument to deal with the investment issue.[20]

3. Donor support to climate finance access when hosts are financially constrained

3.1 The donor fully finances the host's additional renewable energy investments

In section 2 we assumed that hosts receiving donor support for new green energy investments are unconstrained in credit and other financial markets, and do not face severe fiscal or affordability constraints to financing their required green energy investments. This does not represent the current reality for most MICs and LICs, which typically face serious imperfections in credit markets, and lack the ability to mobilize the required CF. In such situations, a major role of donors or MFIs can be to provide the required climate finance access to MICs and LICs. This can often be accomplished without donors directly subsidizing such access. Instead, the donor can serve as a combined creditor and guarantor, putting up the required finance up-front; requiring it to be paid back (in alternative ways) from hosts over an extended future payback time; and covering potential losses for those green investment projects that turn out as failures.

[19] Several recent reports dealing with possible implementation of the net-zero transition, including the World Bank 2023, stress that the amount of donor funding available for such purposes is limited and must be deployed with a very disciplined approach.
[20] Casey and Gao 2024 find a larger positive empirical effect of energy subsidies than found from theoretical considerations alone; their empirical results then tend to support the subsidy policy discussed in this section. Some of this positive effect may however be due to energy subsidies at least in part relieving fiscal constraints and credit market bottlenecks, ignored in this section, but addressed in section 3.

In this section we take such a perspective, assuming that the host in question has insufficient funds available for its required zero-carbon energy investments; cannot attract sufficient private funding (as such investments are viewed as too risky to investors and banks); and may have limited technical capacity to itself implement these investments. Lending constraints, undeveloped financial markets, and a high interest rate all facing hosts, can contribute to such outcomes.[21]

We assume that the donor covers all of the host's investment costs beyond E_{R0}. Assume (here and in later sections) that green energy investments lead to phase-out of fossil fuels, keeping the host's total energy use unaltered. The host obtains co-benefits from green investments, and incurs no additional costs. This also means that the host always prefers, and accepts, the amount of green investments offered by the donor.

The welfare impact for the donor from providing green investments to the host is simply the donor's value of lower carbon emissions, minus the green investment costs incurred by the donor:

(19) $$D_I = v(E_{F0} - E_F) - r[E_{RD} - E_{R0} + \frac{1}{2}\sigma(E_{RD} - E_{R0})^2],$$

given that the donor supports an investment volume E_{RD} - E_{R0} for the host, and faces the cost function for green investments from (1).

The optimal investment volume $E_{RD} - E_{R0}$ selected by the donor is found by maximizing (19) with respect to E_{RD}, found from (20):

(20) $$\frac{dD_I}{dE_{RD}} = v - r[1 + \sigma(E_{RD} - E_{R0})] = 0 \Leftrightarrow E_{RD} = E_{R0} + \frac{v - r}{r\sigma}.$$

We can interpret r as the cost of reducing carbon emissions by one unit replacing fossil fuels with zero-carbon (green) energy investments. When $v > r$, the donor's SCC exceeds the cost of removing one unit of CO_2; there then always exists a positive green investment level $E_{RD} - E_{R0} > 0$ that the donor is willing to pay for. When $v < r$, the first equation in (20) holds with inequality, and no green investments are beneficial for the donor; thus $E_{RD} - E_{R0} = 0$.

The optimized welfare level for the donor, and the reduction in carbon emissions, are in this case:

[21] A large literature explains credit rationing, and higher-than-normal interest rates, on the basis of informational problems such as moral hazard and adverse selection. See early contributions by Jaffee and Russell 1976 and Stiglitz and Weiss 1981; and further by Jaffee and Stiglitz 1990, Dabla-Norris et al. 2015, Mertzanis 2019, Kampouris et al. 2022, and chapters 4-5 of Freixas and Rochet 2008. Such problems tend to be most serious for private and government actors in LICs with poor macroeconomic management and poorly developed financial markets; and small firms with no foreign ownership shares.

(21) $$D_I = \frac{1}{2}\frac{(v-r)^2}{r\sigma}$$

(22) $$-\Delta E_F = \frac{v-r}{r\sigma}.$$

Donor welfare from this policy could be greater than from subsidizing investments in section 2; and the reduction in emissions could easily be larger (comparing these conditions to (17) - (18)). This stems from the less efficient current "starting point" as the host needs donor funds to overcome credit rationing.

To further interpret (20), note that the optimal solution for a financially unconstrained host, setting the derivative with respect to E_R in (1) equal to zero, is:

(23) $$E_{R1} = E_{R0} + \frac{p+q+h-r}{r\sigma},$$

where E_{R1} is the optimal green investment choice for a financially unconstrained host, from (5). Setting $E_{RD} = E_{R1}$ (the donor implements the host's optimal investment), the donor would support (at least) this investment level given that[22]

(24) $$v \geq p+q+h.$$

(24) is the condition for the donor to be willing to finance (at least) the investment volume desired by the host. Expressed differently, when (24) does not hold, the maximum amount of the host's green investments that the donor is willing to finance is smaller than the host's preferred green investment volume.

3.2 The donor pays the host's investment costs and reaps all gains

A perhaps more attractive alternative for donor support is to pay for all the host's green investments, and require the host to later pay back these costs, plus (a fraction of) other gains. The (periodic) net cost difference for the host, between relying on zero-carbon energy instead of fossils, is $p + q + h$ per energy unit per time period, minus the interest cost on the invested renewable capital. The donor may then offer to supply the required green investments keeping the host to its reservation utility. This is equivalent to optimizing the joint utility of the donor and host. Assuming that $p + q + h - r = z > 0$, the host then needs to be charged z per period per unit of investment by the donor.[23] Such a support policy, if clear from the

[22] This corresponds to the optimal investment volume for the host only when the host pays fully for this investment. Clearly, when as here the donor bears this investment cost, the preferred investment level for the host is higher.
[23] Alternatively, if $z < 0$, the donor will need to provide equivalent positive payments to the host. Optimality of donor support would still require that $v + z > 0$.

donor and not subject to future alterations, would not be subject to strategic manipulation by hosts as long as hosts maintain trustworthy and credible long-run policies.

We define the donor and host's combined periodic objective function as follows (where all potential net gains of the host are paid back to the donor):[24]

(25) $$D_G = v(E_{F0} - E_F) + p(E_{F0} - E_F) - r[E_R - E_{R0} + \frac{1}{2}\sigma(E_R - E_{R0})^2] + (q+h)(E_{F0} - E_F),$$

where we still assume $dE_F = -dE_R$. We then have the following value of the marginal benefit of donor support to the host's zero-carbon investments:

(26) $$\frac{dD_G}{dE_R} = v - r[1 + \sigma(E_R - E_{R0})] + p + q + h.$$

The optimal green investment, considered jointly by donor and host, E_{R2}, is found setting (26) equal to zero:

(27) $$E_{R2} = E_{R0} + \frac{v + p + q + h - r}{r\sigma}.$$

(27) differs from the condition for an unconstrained host, (23), as v (= the donor's SCC) is now added to the last term on the right-hand side.

An alternative for hosts is to fund the same amount of green investment in the credit market, given that the host is not subject to credit rationing nor higher risk-adjusted interest rates or other lending costs.[25] The green investment level would then be given by (8).

The solution derived in this section has potential pitfalls. In particular, we ignore potential problems of host moral hazard. Paying back the future fossil-fuel cost savings and carbon market benefits is difficult or impossible to enforce, as the pay-back period, corresponding to the period of operation of the supported green energy infrastructure, could extend over decades. This problem could be exacerbated by political regime shifts in host countries.

Another problem is that the host cannot be required to carry out much mitigation itself. Hosts may lack the ability to implement the necessary green investments, due to a combination of CF shortage, missing financial market access, and lack of technical expertise. It would have been better for the donor if the host

[24] This formulation does not involve carbon taxation, which is not optimal from the point of view of the host government without specific support for its implementation from the donor. We come back to the carbon tax issue in section 4.
[25] To have maximal effect, such solutions can be accompanied by donor insurance provision against default and other market risk facing the commercial credit market for borrowers in MICs or LICs.

were required to put up its own mitigation effort before CF support, providing for a more efficient financing structure based on RBCF.

4. Combined donor support to carbon taxation and zero-carbon investments

4.1 Deterministic host tax implementation cost

We will now extend the analysis in section 3, by considering donor support to hosts' zero-carbon investments, in a similar way as in section 3, but where the donor at the same time supports, and incentivizes, carbon tax implementation by the host. This is of interest for various reasons. Carbon taxation remains an essential policy tool for an effective and efficient NZE transition, for all countries including all MICs and LICs. Incentivizing these countries to adopt robust carbon taxation is thus also essential, and how to achieve it is essential to know. Another set of reasons in our specific modeling context is the two relations identified between green energy investments and carbon taxation. First, as should be already well known, carbon taxation incentivizes green investments by making them more profitable to investors.[26] Secondly, and less obvious, more green investments in the host economy can facilitate carbon tax implementation by reducing the host's political costs of such new taxes, by less resistance against carbon taxes among the host country's citizens and firms. In our model below we assume that the donor, in its support to implementing new green investments for the host (including new green investments incentivized by the donor-sponsored carbon tax), keeps the host's utility at the same level as with no such investments.

Sections 4.1 – 4.2 study two alternative cases. In this section, the host's cost of implementing the carbon tax is publicly known. In section 4.2, the host's carbon tax implementation cost is known only to the host. This leads to an information asymmetry where the host has an incentive to hide information about this cost. This implies a less efficient solution than when the host's tax implementation costs are public.

Defining the host's fossil fuel consumption and green energy capital by E_{F3} and E_{R3}), the donor's objective function can be written as follows:

$$
\begin{aligned}
(28)\qquad D_{T3} &= v(E_{F0}-E_{F3}) + p(E_{F0}-E_{F3}) - r[E_{R3}-E_{R0}+\frac{1}{2}\sigma(E_{R3}-E_{R0})^2] \\
&+(q+h)(E_{F0}-E_{F3}) + vAt_3 - \frac{At_3^2}{2} - \alpha t_3 E_{F3}
\end{aligned}
.
$$

(28) can be considered a joint objective function for the donor and host, where the donor (as in section 3.2) incentivizes the host's green investments and reaps all net benefits. The first 4 terms in (28) constitute the right-hand side of equation (25). The last three terms in (28) summarize the added impacts of carbon

[26] See e. g. Pienknagura 2024.

taxation, relative to section 3.2. $A = -(dE_F/dt)$ from (12), is the (constant) marginal reduction in the host's fossil-fuel use due to a higher carbon tax in the host economy. E_{F3} includes the carbon emission reduction induced by donor support to zero-carbon investments. We assume that green energy investments lead to equivalent reductions in the host's fossil-fuel use. This implies $d(E_{F0} - E_{F3}) = d(E_{R3} - E_{R0})$, where $d(E_{F0} - E_{F3})$ is the reduction in the host's fossil fuel consumption as a result of the donor' support to the host's green investments. The donor also gains v per unit of additional reduction in E_F due to the carbon tax t.

The donor's cost of implementing this policy has two elements. The first is the host's DWL or allocation loss when implementing the carbon tax, which needs to be compensated by the donor. This is well-known and can be represented by $At^2/2$.[27] We assume that the donor provides this financial support to the host upon observing that the desired carbon tax is implemented.

The donor's second cost element captures the resistance against carbon taxation within the host economy, which also requires financial support by the donor.[28] A higher political or implementation cost when the carbon tax is higher appears plausible.[29] We assume as a special case that this cost is *proportional to t, and to the host's remaining fossil-fuel consumption*. The resistance against carbon taxation, by both the public and the economy's energy sector, is likely to be greater when the amount of fossil-fuel consumption is greater, due to both greater economic impacts of such taxation on the public and on establishments in the sector, which makes their resistance against such taxes greater. The parameter α scales this cost. When α is (close to) zero, such costs are unimportant; while when α is large, such costs are important for the host's decision to adopt a carbon tax. When α is sufficiently large, no carbon tax is implemented. We assume that α lies between zero and a maximum value α^*.

Maximizing (28) with respect to E_{R3} yields:

(29) $$\frac{dD_{T3}}{dE_{R3}} = -r[1+\sigma(E_{R3}-E_{R0})] + v + p + q + h + \alpha t_3 = 0,$$

which implies

(30) $$E_{R3} = E_{R0} + \frac{v + p + q + h + \alpha t_3 - r}{r\sigma}.$$

[27] Subtracting exactly the DWL implies that compensation to the host is done based on the principle of RBCF, the smallest and most efficient compensation that can be provided. See discussion in Strand 2020.

[28] Surveys have shown that such resistance appears to be moderate in most MICs (and less than in HICs), in particular when carbon taxes are accompanied by offsetting transfers to the taxed groups; see Carattini et al. 2018, Harring et al. 2023, and Dechezleprêtre et al. 2025.

[29] See also Carattini 2022 for discussion of such costs, how they can be an obstacle to carbon tax implementation, and mechanisms by which to overcome this obstacle.

From (30), t_3 incentivizes additional green investments (and resulting GHG mitigation) in the amount $\alpha t_3/r\sigma$ in addition to the level given in (27). Thus, the larger is the host's cost of implementing its carbon tax, and the higher is the host's carbon tax, the larger is its optimal level of zero-carbon investment. This follows as the carbon tax implementation cost is reduced by more for higher α and t_3, when the host's green investments increase.

The donor's optimal carbon tax implemented in the host economy is found from (28):

(31) $$\frac{dD_{T3}}{dt_3} = vA - At_3 - \alpha E_{F3} = 0 \Leftrightarrow t_3 = v - \frac{\alpha E_{F3}}{A}.$$

When $\alpha > 0$, the carbon tax implemented in the host economy, optimally supported by the donor, is below v. As long as α is "not too large" (takes values such that $\alpha E_{F1}/A \leq v$), t_3 remains non-negative but is reduced below v by $\alpha E_{F3}/A$ which represents the host's unit cost of implementing carbon taxation (indicating the host's resistance against carbon taxation). In (31) t_3 drops linearly in $\alpha E_{F3}/A$, from v (for hosts with $\alpha = 0$) to zero (for hosts with $\alpha E_{F3}/A \geq v$). The host's optimal carbon tax, from the donor's perspective, is lower when the host's tax implementation cost is higher.

Given $\alpha E_{F3}/A < v$, as the host economy is decarbonized with further support to green investments (reducing E_{F3}), the host's tax implementation cost is reduced, and the optimal carbon tax increases by $\alpha(E_{F0} - E_{F3})/A$. From (30) and (31), the solutions for E_{F3} and t_3 vary across hosts as both depend on α, which generally varies by hosts.

When $\alpha E_{F3}/A > v$, no carbon tax is implemented for this host. The donor's cost of implementing any positive carbon tax is then greater than the benefit to the donor.

(30) and (31) imply *a double-sided positive "feedback" effect*: From (30), a higher carbon tax incentivizes a higher green investment level, and a lower carbon emission level. From (31), a lower carbon emission level, E_{F3}, leads to a higher carbon tax in the host economy, supported by the donor and accepted by the host. While the former of these effects is standard and well-known, the latter effect is less standard. Intuitively, a lower fossil fuel consumption in the host economy reduces the host's resistance to fossil-fuel taxation. At least two mechanisms are relevant: the lobby of the fossil fuel industry becomes weaker and that of the renewables industry stronger; and public resistance against carbon taxation is reduced when less fossil fuels and more green energies are consumed.

4.2 The host's tax implementation cost is unknown to the donor

We now alter the analysis in section 4.1 by assuming that the host's cost of implementing carbon taxation is known only to the host itself. The donor is assumed to not know the actual level of the host's carbon tax implementation cost, only the statistical distribution of this cost. This leads to a problem of asymmetric information. Hosts are then given incentives to not report truthfully to the donor about the value of this cost, but instead claim that the host's value of α is higher than its true level.[30]

The main modeling change relative to the public information case is that *the scaling parameter α in the implementation cost function now is stochastic for the donor,* with distribution function $F(\alpha)$ and positive density $f(\alpha)$ over its entire support $[0, \alpha^*]$.

The donor in this case selects t, E_F and α, t_4, E_{F4} and α_4, where the latter value indicates the highest tax implementation cost for the host that the donor is willing to compensate, and where E_{F4} is the fossil fuel consumption level chosen optimally by a host with $\alpha = \alpha_4$. The compensation by the donor to cover the host's carbon tax implementation costs will then equal $\alpha_4 t_4 E_{F4}$ for all potential hosts. Hosts with a higher cost parameter than α_4 will not implement the carbon tax supported by the donor.[31]

Assuming $\alpha_4 \leq \alpha^*$ implies that the solution for α_4 implies $F(\alpha_4) \leq 1$. Given $F(\alpha_4) < 1$, only a fraction $F(\alpha_4)$ of all potential hosts will accept the donor's offer and implement the proposed carbon tax. Given that the donor has rational expectations with respect to hosts' tax implementation costs (and the donor's Bayesian assessment regarding the distribution function F is correct), the donor's chosen carbon tax will then be incentivized, and implemented, in a fraction $F(\alpha_4)$ of all potential hosts. We still assume that green energy investments lead to equivalent reductions in the host's fossil-fuel use.

Assuming $F(\alpha_4) < 1$, the objective function of the donor can be written as follows:

(32)
$$\begin{aligned} D_{T4} = F(\alpha_4) & \begin{pmatrix} v(E_{F0} - E_{F4}) + p(E_{F0} - E_{F4}) - r[E_{R4} - E_{R0} + \frac{1}{2}\sigma(E_{R4} - E_{R0})^2] \\ +(q+h)(E_{F0} - E_{F4}) + vAt_4 - \frac{At_4^2}{2} - \alpha_4 t_4 E_{F4} \end{pmatrix}, \\ +[1 - F(\alpha_4)] & \begin{pmatrix} v(E_{F0} - E_{F5}) + p(E_{F0} - E_{F5}) - r[E_{R5} - E_{R0} + \frac{1}{2}\sigma(E_{R5} - E_{R0})^2] \\ +(q+h)(E_{F0} - E_{F5}) \end{pmatrix} \end{aligned}$$

E_{F4} and E_{R4} are the fossil fuel consumption and green capital volume for a host with $\alpha \leq \alpha_4$, which accepts and implements the donor's proposal of a supported carbon tax t_4. This carbon tax is accepted by hosts with probability $F(\alpha_4)$, as viewed by the donor. The donor's net benefit from supporting a carbon tax in the host economy is vAt_4, which represents the reduction in carbon emissions in the host economy resulting from

[30] This problem is similar to that studied by Stern 2022.

[31] Without going into analytical detail, the contracting relationship between the donor and host can be played out in two steps: In the first step, the donor sets E_{R4}, and in the second step, t_4 and α_4. The donor then cannot differentiate the E_{R4} supported by whether or not the carbon tax is implemented in the host economy.

the carbon tax. E_{F5} and E_{R5} are the fossil fuel consumption and green capital volume for a host with $\alpha > \alpha_4$, that does not accept the carbon tax t_4.

First-order conditions for the donor are now found with respect to t_4 and α_4 in (32):

(33) $$\frac{dD_{T4}}{dt_4} = F(\alpha_4)[(v - t_4)A - \alpha_4 E_{F4}] = 0$$

(34) $$\frac{dD_{T4}}{d\alpha_4} = f(\alpha_4)\left(vAt - \frac{At_4^{\ 2}}{2} - \alpha_4 t_4 E_{F4} + \Delta D_{T4,5} \right) - F(\alpha_4) t_4 E_{F4} \geq 0$$

(35) $$\frac{dD_{T4}}{dE_{R4}} = F(\alpha_4)\{-r[1 + \sigma(E_{R4} - E_{R0})] + v + p + q + h + \alpha_4 t_4\} = 0,$$

The term $\Delta D_{T4,5}$ in (34) represents the difference between the two large parentheses in (32) when the terms containing t_4 are taken out. This term is negligible when t_4 is small (as it turns out here) and will be dropped.

When the solution for α_4 is internal on [0, α*], corresponding to $F(\alpha_4) < 1$, (34) is fulfilled with equality. Focusing on a uniform distribution of α, $F(\alpha_4)/f(\alpha_4) = \alpha_4$, and (34) can be written as

(36) $$\frac{dD_{T4}}{d\alpha_4} = f(\alpha_4)\left(vAt_4 - \frac{At_4^{\ 2}}{2} - 2\alpha_4 t_4 E_{F4} \right) = 0.$$

From (33) and (36), $t_4 = 2v/3$ in the uniform distribution case. The donor's optimal carbon tax can be either lower or higher, and the support to zero-carbon investments in the host economy lower or higher, compared to the case of deterministic implementation costs, given internal solutions for α_4. In all cases the carbon tax will be set lower than with no tax implementation cost, so that always $t_4 < v$.

Assume first that (34) holds with inequality. We then have a border solution with $F(\alpha_4) = 1$ (all hosts accept the proposed carbon tax), and $\alpha = \alpha_4$. This occurs when tax implementation costs are always "low".

Hosts with $\alpha < \alpha_4$ enjoy a welfare gain as their tax implementation costs are lower than required to implement the carbon tax. Low-cost hosts earn informational rents as the donor does not know their exact implementation costs.

(33) can be expressed in the following way given a uniform distribution for α:

(37) $$t_4 = v - \frac{\alpha_4 E_{F4}}{A} = \frac{2}{3} v \Leftrightarrow \frac{\alpha_4 E_{F4}}{A} = \frac{v}{3}.$$

From (33) and (36),

(38) $$\alpha_4 t_4 E_{F4} = (v - t_4)t_4 A = \frac{2A}{9} = \frac{At_4^{\ 2}}{2} = DWL .$$

These results imply that the amount received by the host from the donor, to compensate the host's tax implementation cost, equals the compensation the host receives to compensate its production DWL for implementing the same required carbon tax t_4. Thus, *the total compensation the host receives from the donor*, related to implementing the tax t_4, is exactly 2 DWL. This compensation is received by the fraction $F(\alpha_4)$ of potential hosts that choose to implement the carbon tax t_4. The fraction $1 - F(\alpha_4)$ of potential hosts which do not implement any carbon tax get no compensation from the donor.

For hosts that implement the proposed carbon tax t_4, the donor's optimal CF support to the host's green investment is found from (35):

(39) $$E_{R4} = E_{R0} + \frac{p + v + q + h + \alpha_4 t_4 - r}{r\sigma} .$$

Also here, carbon taxation by the host leads to greater support to the host's renewable investments. This increase in CF support is now the same for all hosts that implement a positive carbon tax, while in section 4.1 this increase differed by the host's implementation cost. For hosts that do not implement any carbon tax, their CF support is given by (38) setting $t_4 = 0$.

The corresponding solution for hosts which do not adopt carbon taxation (given that $F(\alpha_4) < 1$) is the same as E_{R2} from (27).

We find that the expected value of green investments, called $E(E_R)$, over the entire distribution of possible host types is given by:

(40) $$E(E_R) = E_{R0} + \frac{p + v + q + h + F(\alpha_4)\alpha_4 t_4 - r}{r\sigma} .$$

The current solution, with asymmetric information about hosts' carbon tax implementation costs, differs from and is less efficient than the solution with fully observable costs, in several respects:

A. The carbon tax supported by the donor is here the same for all hosts. In section 4.1, where the hosts' tax implementation costs were publicly observable, the carbon tax is fine-tuned to each host, with lower carbon taxes for hosts with higher implementation cost.

B. While in section 4.1 the carbon tax is set at the highest level for given host implementation cost, we here have a "pooling" solution with a given carbon tax for all hosts. This leads to two inefficiencies. First, the carbon tax is inefficiently low for hosts whose α values are below α_4. Secondly, hosts with

implementation cost parameters greater than α_4 will not accept the offered t_4, and implement no carbon tax. In section 4.1, by contrast, all countries with tax implementation cost less than v implement a carbon tax.
C. In section 4.1 all hosts are kept at their reservation utilities. In the present case, hosts with $\alpha < \alpha_4$ enjoy an informational rent, being paid more than required to accept the carbon tax t_4. While this is an advantage for the countries which enjoy the informational rent, the current solution is inefficient for the donor, who would prefer to increase the carbon tax for hosts with cost parameters lower than α_4.
Given an internal solution for α_4, from (36), when E_{F4} falls, α_4 increases proportionately. This increases the probability $F(\alpha_4)$ that a host will accept the equilibrium compensation from the donor (represented by the two last terms in (32)), and the proposed carbon tax.

D. When the host's carbon tax implementation cost is stochastic and uniformly distributed, the donor-supported carbon tax equals $t_4 = 2v/3$. Hosts with implementation costs greater than $v/3$ will then refuse the policy-compensation package offered by the donor, and will not implement any carbon tax.[32]

CF support to green investments by the host can in these two models be tied to an RBCF incentive structure, because *the compensation from the donor to the host for implementing carbon taxation (the two last terms in each of (28) and (32)) can be tied to the donor's provision of finance to the host's green investments*. At least part of this CF financing, built into the solution for E_R, can be tied to the host's adoption of the required carbon tax. Here, we have simply postulated such a connection by assuming that the donor keeps the host at its initial utility level when supporting both green investments and carbon taxation in the host economy.[33]

5. Conclusions and final comments

This paper has studied policy support from donors and MFIs to increased GHG mitigation activity in MICs and LICs, required for these countries, and the world, to stay on an efficient path to reach an NZE by around mid-century of somewhat later. Two policies are essential, namely direct support to these countries' zero-carbon ("green") energy investments; and support to the countries' carbon tax implementation.

Sections 2 and 3 study impacts of direct support to these countries' green investments. In section 2 we assume that receiving countries are unconstrained in credit and other financial markets, while in section 3

[32] A question not answered is what will happen to hosts that do not accept the donor's proposed carbon tax t_4. More complex games can be designed where donors optimally exploit information from hosts' decisions to accept or refuse a particular carbon tax. Some of these countries may have $\alpha EF/A < v$ and thus implement a positive carbon tax when information is symmetric (from (31)). We could elaborate further on this problem by imposing more complex and elaborate contractual structures. E.g., donors can further differentiate their green investment support by whether or not the host has a carbon tax. We refer to Ausubel and Deneckere 1992, Cramton 1984, Gul, Sonnenschein and Wilson 1986, and Milgrom 2004 for related analytical modeling. See Fudenberg and Tirole 1991 and Laffont and Tirole 1993 for background analysis; and Stern 2022 for the alternative model most closely related to ours.
[33] As already mentioned, under asymmetric information only the hosts with $\alpha = \alpha_4$ are kept exactly to their reservation utilities when adopting a carbon tax; those with lower α values earn an informational rent.

we assume, more realistically, that these countries ("hosts") are severely constrained. When hosts are unconstrained in financial markets and not subject to serious budgetary limits, unit subsidies to hosts' green investments are found to be a useful but not particularly efficient support policy. When hosts are subject to severe financial constraints, and cannot on their own implement their required levels of green investments, CF assistance to hosts is crucial. Donors and MFIs can then serve as CF providers requiring hosts to pay back the entire or part of the provided CF amount over time given that investment projects are successful; and as guarantors in events of project failure. This could lead to a relatively small present discounted cost for the donor or MFI when project failure rates are low. When hosts are trustworthy and willing and able to pay back their debts to donors over a long future period; and donors are not subject to limitations on lending to MICs and LICs, the optimal CF, from the point of view of both donor and host, can be implemented this way. A dramatic scale up of such finance arrangements may be crucial for green investments to be on track to NZE by mid-century.

Section 4 extends the analysis in sections 2-3 by combining donors' CF provision with direct support to hosts' implementation of comprehensive carbon taxation, the second crucial mitigation policy element for hosts. Suich support compensates hosts for two classes of costs: production losses in the form of DWL; and political tax implementation costs. Support to cover these costs is made conditional on the carbon tax, required by the donor, being implemented by the host. The solution leads to a two-way, and mutually reinforcing, relationship between support to green investments and carbon taxation in MICs and LICs: a higher carbon tax leads to more green investments being supported by the donor; and more green investments in the host economy increases the carbon tax that the donor prefers to support. It is already well known that a higher carbon tax incentivizes more green investments. The relationship between green investment support and carbon taxation also goes the other way: A greater degree of decarbonization of host economies facilitates the implementation of carbon pricing, leading them to adopt higher carbon prices than what otherwise would be possible. Decarbonization of the economy is likely to reduce the host government's political cost associated with its population's resistance against carbon taxation. We also find that the preferred solution for the donor depends on whether or not the donor is able to precisely identify the country's political carbon tax implementation cost. When this political cost is publicly observable, the host's carbon tax, chosen by the donor, is lower when the tax implementation cost is higher. This is efficient as this carbon tax is maximal for a given implementation cost, and equals the donor's social cost of carbon (SCC) when the implementation cost is zero; then the country is only compensated for its deadweight loss (DWL) of implementing the carbon tax. In section 4.2 we assume that the political cost is observable only to the host country. This leads to asymmetric information where the donor only knows the (Bayesian prior) statistical distribution of hosts' possible political implementation costs. The donor will then offer to support a given level of the carbon tax to all potential receiving countries, and only a fraction of all potential receiving countries will accept this carbon tax. The countries with the highest tax implementation costs will reject the donor's offer, and implement no carbon tax; while countries with low implementation costs will implement the offered tax. Hosts will earn an informational rent as they are offered a higher than necessary compensation by the donor. This solution is less efficient, for these and other reasons.

The level of host carbon taxation that a donor is willing to support and incentivize is found to be no higher than the donor's SCC, and typically lower. In a special case with a uniform distribution of host types the carbon tax supported by the donor under asymmetric information equals 2/3 of the donor's SCC. No carbon tax is implemented by the hosts when the host's political implementation costs are very high.

Our analysis stresses the importance of donors and MFIs as catalysts for comprehensive climate mitigation action in MICs and LICs, on a large and unprecedented scale. This result is not simply hypothetical and idealistic: such comprehensive support to MIC and LIC mitigation is generally efficient and optimal for individual and groups of HICs with high SCC values, which care deeply about global mitigation. It is founded on the fact that GHG mitigation is dramatically less costly to implement in MICs and LICs than in the donor countries themselves, making donor support to both substantial mitigation, and setting low-income countries on the path to NZE by mid-century, a highly advantageous undertaking for the donor group.[34] Indeed, costs to donors can be small, much smaller than benefits, in particular when it concerns helping LICs and MICs to mobilize CF for mitigation purposes which these countries are unable to do themselves; and mobilizing goodwill for introduction of carbon taxation that in the end can be favorable to the host countries themselves. Organizing and mobilizing the funds is an obstacle that needs to be overcome. Lower-income countries are today found lacking in two important aspects regarding climate mitigation: a) in the economic resources including sufficient access to credit, to implement a sufficient volume of green investments; and b) in the willingness, ambition and ability to implement a comprehensive domestic carbon pricing regime. They need a high degree of external support in these two key areas. Such support they will be provided given that donors, jointly with MFIs, collectively get their acts together.

[34] See Edmonds et al. 2021 for further documentation of the huge differences in GHG abatement costs, in particular when comparing LICs and important donors.

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List of acronyms used in the paper

AFR = Africa Region

BRA = Brazil

CAN = Canada

CF = climate finance

CHN = China

CO_2 = carbon dioxide

DWL = deadweight loss

EU ETS = European Union Emission Trading System

FDI = foreign direct investment

FSU = Former Soviet Union

GHG = greenhouse gas

HIC = high-income country

IEA = International Energy Agency

IFC = International Finance Corporation

IMF = International Monetary Fund

IND = India

ITMO = Internationally traded mitigation outcome

JAN = OECD Pacific Region

LAC = Latin America and Caribbean Region

LIC = low-income country

MDE = Middle East

MFI = multilateral finance institution

MDE = middle-income country

NDC = nationally determined contribution (to the Paris Agreement)

NZE = net-zero equilibrium

PA = Paris Agreement

RBCF = results-based climate finance

R&D = research and development

SCC = social cost of carbon

SEA = South-East Asia