Cost-Effectiveness and Synergies for Emissions Mitigation Projects in Developing Countries

Matt Juden and Ian Mitchell

Abstract

This paper assesses the available evidence evaluating the effectiveness of concessional spending on climate mitigation in developing countries. Impact evaluation evidence on climate mitigation in developing countries is very limited. However, the Green Climate Fund and the Clean Technology Fund lead their peers by making available project-level data on the expected mitigation and cost of funded projects. We analyse this data and find that expected cost-effectiveness for real-world mitigation projects in developing countries appears to vary by orders of magnitude both within and between sectors, often exceeding $100 per tonne of carbon removed. In assessing the pursuit of synergies between mitigation and other development objectives, we distinguish between strong and weak synergies, illustrating with examples. We argue firstly for a greater focus on impact evaluation and for much higher reporting standards, including for "transformational" potential, for organisations spending concessional finance on mitigation projects. Secondly, we urge donors to pay closer attention to cost-effectiveness for such projects. In particular, we argue that donors should be cognisant of the balance between mitigation and other outcomes, and should not overcommit mitigation financing to projects with minor secondary mitigation outcomes.

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Contents

1. Summary

This paper assesses the available evidence evaluating the effectiveness of concessional spending on climate mitigation in developing countries. It is written for the benefit of policymakers at concessional financing institutions. It aims to outline what we know (and do not know) about the cost-effectiveness of the mitigation strategies donor institutions support, and what this means for the pursuit of synergies in a time of 'climate mainstreaming.'

Evaluation evidence on concessional finance for climate mitigation is very limited

We conduct a review of the available evidence on the real-world cost-effectiveness of mitigation projects in developing countries and find that evidence sparse. In over 3,700 impact evaluations relating to development; just eight were tagged with climate mitigation. A 2018 systemic review of economic analyses of climate mitigation found just two that report real-world effectiveness and costs for low- or middle-income countries (Gillingham & Stock, 2018). This lack of impact evaluations of mitigation interventions in developing countries associated with costs data is in contrast to other areas of development programming such as public health or education. The evidence base for mitigation interventions is dominated by modelling estimates, which do not model key elements of the real-world operation of projects such as implementation difficulties and behavioural responses. Retrospective impact evaluation is a very powerful tool that provides the best way of learning about the cost-effectiveness of different interventions. It is concerning that this evidence is so lacking for mitigation interventions in developing countries. This motivates our first recommendation: **Development agencies and funds should urgently prioritise independent impact evaluation of mitigation interventions and ensure that these evaluations include costs data.**

Despite the lack of independent evaluation evidence, we find that the modelling evidence for the cost-effectiveness of many interventions is compelling. That is, it seems likely that projects can achieve reductions in developing country emissions at a reasonable cost. Two areas where this is particularly clear is for removing fossil fuel subsidies and implementing carbon pricing, two macro-level interventions available to states. However, the actions available to donors to influence such macro-level interventions are few and very likely to be frustrated by political factors. This motivates our second recommendation: **Where development agencies can support carbon pricing, removing fossil fuel subsidies and other macro-level mitigation policies at home or through multilateral advocacy and technical assistance vehicles, this is likely to offer strong value. The value of bilateral action to support macro-level policies in recipient countries is highly uncertain and can only be assessed on a case-by-case basis considering donor and recipient political circumstances.**

Given the lack of impact evaluations to date, and the long lifecycle of many mitigation projects, prospective estimates of cost-effectiveness from development agencies and funds are the most promising source of data for learning about these sorts of interventions. We investigate for each major fund or development agency whether this data is available at the project level. We find that where this data is reported, it is generally reported annually at the aggregate level. Funding mechanisms like the UK's International Finance Mechanism do not

make public in one dataset the project-level data of this type that we are told is being used for internal purposes. Only two financing organisations, the Clean Technology Fund as part of the Climate Investment Funds, and the Green Climate Fund, were identified that systematically report this information. This leads to the third recommendation of this paper: **Development agencies and funds should systematically report data on emissions mitigated for all emissions mitigation projects, along with costs data for those projects. This should happen ex-ante through reporting funding decisions, during implementation through reporting of interim management information, and ex-post through impact evaluation. As we outline below, this should also incorporate quantified estimates of transformational potential and related uncertainty.**

Fortunately, two large funds provide project-by-project prospective data on the expected costs and expected mitigation of their funded mitigation interventions. These data, from the Green Climate Fund and the CIF Clean Technology Fund represent rare good practice in an otherwise insufficiently transparent sector.[1] Other large funds and commissioning bodies such as the UN's Global Environment Facility and the EU's Global Climate Change Alliance should follow the GCF and CTF's example and provide comparable data. So should bilateral development agencies, who sometimes gather such data internally but only make available headline data aggregated over all projects.

Expected cost-effectiveness for real-world mitigation projects appears to vary by orders of magnitude

We undertake an analysis of the prospective data for 80 projects approved and funded by the Clean Technology Fund and 47 projects approved and funded by the Green Climate Fund to examine levels of expected cost-effectiveness for real-world projects. We construct a naïve, first-cut measure of cost-effectiveness for all 127 projects based on their total costs and total expected mitigation. Analysing this measure allows for an examination of levels of expected cost-effectiveness for real-world projects.

This analysis reveals much greater divergence on cost-effectiveness than is predicted by the modelling evidence. We find that cost-effectiveness within as well as between sectors can differ by more than two orders of magnitude – that is, mitigating a tonne of carbon dioxide (or equivalent) costs under $10 in some cases, tens of dollars in most; but in one sixth of cases costs over $100, and in two cases thousands of dollars per tonne. Similar levels of difference in cost-effectiveness exist whether they are compared over total funding including co-financing, or just over financing provided by the fund itself. Some of this difference in cost-effectiveness is due to the approximate nature of our estimation of project cost-effectiveness. We discuss ways in which such estimates need to be nuanced by considering the need to act across sectors and the 'transformational' temporal effects of innovation and adaptation costs. However, these considerations are not sufficient to explain order-of-magnitude differences in cost-effectiveness.

In all three of the major sectors addressed by both funds – transport, energy efficiency, and energy generation, – cost-effective interventions have been identified and funded by the CTF or the GCF. Costs for forestry and other land use interventions, which the CTF does not fund but the GCF does, are consistently very low in the GCF data. And even in the

[1] The GCF and CTF are very large funds. Between them, they hold 48% of the funds deposited to multilateral mitigation or mixed (mitigation and adaptation) funds tracked by Climate Funds Update.

most expensive sector, transport, a project with a relatively low total cost of $31.16 per tCO_2e of expected mitigation has been identified and funded. The observation of this level of expected performance for real-world projects confirms that apparently cost-effective mitigation options in all sectors exist in developing countries and that these can form an important part of the effort to halt and reverse climate change.

The existence of such large differences in cost-effectiveness between projects, and the existence of cost-effective projects in every sector, suggests that a tighter focus on cost-effectiveness could yield substantial benefits. For example, going forward based on past performance, for a portfolio of renewable energy investments similar to the GCF and CTF projects in the renewable energy sector, focussing on cost effectiveness could mitigate extra emissions equal to 178% of the UK's emissions in 2018.

These considerations should not be interpreted as a criticism of either fund. Both funds have served as a learning lab, experimenting with different approaches to what works in emissions mitigation and adaptation in low- and middle-income countries. They deserve credit for making these estimates and their decision-making available for feedback; and, as noted above, other climate mitigation funders should urgently follow suit. As a recent review of the CTF's operations noted, the CTF and concessional finance for climate change in general is entering a new phase, where many of the approaches to mitigation are no longer novel (BloombergNEF, 2019). In this new phase, across the international financial institutions and development agencies, a higher priority should be placed on cost-effectiveness. This motivates the fourth recommendation of this paper: **In the next phase of mitigation investment a renewed focus on cost-effectiveness is necessary. Funds and development agencies should focus on cost-effectiveness in their use of climate finance to yield substantially more mitigation from the same investment, compared to business as usual.**

We focus in this paper on static cost-effectiveness estimates because these are the estimates reported in the data available. Nevertheless, we agree that 'transformational' changes can occur for example through the promotion of rule changes, development and implementation of new technologies, demonstration of potential at scale etc. While a quantified estimate of transformational changes is sometimes given in project documents, these estimates are not associated with a probability of success and are not reported alongside results or expected results data in a way that allows for an aggregated independent assessment. The likely magnitude of such changes is also not sufficient to explain the order-of-magnitude differences in cost-effectiveness observed for mitigation projects to date. This leads to a fifth recommendation: **Transformational potential should be quantified and reported alongside directly attributable mitigation, along with some measure of that transformational outcome's uncertainty. As with static cost-effectiveness estimates, transformational changes should be estimated ex-ante, monitored during implementation, and assessed ex-post as part of impact evaluation, so that projects can be systematically compared.**

While the pursuit of strong synergies should guide funding decisions, pursuing weak synergies is high-risk

Many climate mitigation projects also address other objectives; and we consider where there are synergies from doing so. We distinguish weak synergies from strong synergies between mitigation and other development objectives. Weak synergies are where two or more objectives are pursued but with a significant reduction in cost-effectiveness relative to only pursuing the primary outcome of interest. For example, mitigation investments tend to be weakly synergistic with economic development. For this reason, prioritising mitigation investments that are synergistic with economic development can lead to much lower cost-effectiveness for mitigation than a pure focus on that primary outcome. By contrast, strong synergies with a secondary outcome are those that imply very little reduction in cost-effectiveness when pursuing both objectives compared to focussing exclusively on the primary outcome. We discuss air pollution, public health, and biodiversity outcomes as examples of outcomes that are strongly synergistic with emissions mitigation for some interventions.

We demonstrate using the example of GCF project FP138 that targeting weakly synergistic co-benefits may explain the very large differences in cost-effectiveness observed in the data. Given these large cost-effectiveness differences between real world mitigation interventions in low- and middle-income countries, it is especially important to distinguish between strong synergies, weak synergies, and trade-offs between mitigation and other development objectives. This motivates the final recommendation of the paper: **When pursuing multiple objectives, donors should ensure they understand and report the balance of objectives being pursued. Where the mitigation benefits of a development project are only weakly synergistic with the main development aims, extra care should be taken to ensure that climate finance investments are a correspondingly small proportion of total financing..**

Section 2 discusses the purpose and scope of this paper. Section 3 assesses the state of the cost-effectiveness estimates and reports what systematic data is available. Section 4 discusses ways in which static estimates of cost-effectiveness based on total project cost can be improved upon. Section 5 presents a conceptual framework for assessing synergies between objectives and provides some examples. Section 6 makes recommendations and concludes.

2. Purpose and scope

This paper assesses the available evidence evaluating the effectiveness of concessional spending on climate mitigation in developing countries. It is written for the benefit of policymakers at concessional finance donor institutions. It aims to outline what we know (and do not know) about the cost-effectiveness of the mitigation strategies donor institutions support, and what this means for the pursuit of synergies in a time of 'climate mainstreaming'.

This paper focusses on spending on mitigation; spending to prevent climate change. We do not consider spending on adaptation; spending to build resilience to the negative effects of climate change. Adaptation spending is an even more complex area, where the distinctions between adaptation and other development objectives are even less clear. It is also therefore worthy of serious cost-effectiveness analysis, but that is not our purpose in this paper.

Consequences of the donor perspective

Our paper is written for policymakers in development agencies of donor countries and the multilateral institutions they fund. That restricts the scope of the paper in two major ways. Firstly, it means that the emissions mitigation activities that should be taking place within high-income countries are out of scope. Secondly, it means that the costs and benefits of opportunities to mitigate emissions are not being assessed from a development finance recipient country point of view, but rather from the point of view of international donors. Because some of the highest-impact ways of mitigating emissions are policy changes at the national level, the costs and benefits of these changes themselves are only briefly considered. They are considered at all only because donors have an opportunity to advocate for and assist with them. The main concern of this paper is therefore the total costs and benefits of emissions reduction attempts at a programmatic level, which donors can directly fund.

Cost-effectiveness and growing the resources available

A large amount of money is being spent on climate mitigation in developing countries. The OECD Climate Finance Dataset records that $26.34 billion was spent by developed countries on projects with a 'significant' or 'principal' mitigation objective in developing countries in 2018, the latest year available.[2] In addition, rich countries contributed $6.59 billion to the climate efforts of multilateral agencies where the balance between adaptation and mitigation spending is not recorded in the data.[3] Despite controversies over the way in which these financing data are defined and generated, it is near-universally acknowledged that a huge financing gap remains if investment sufficient to limit temperature rises to 1.5 degrees Celsius is to be realised (Buchner *et al.*, 2019; Weikmans & Roberts, 2019). Two objectives are therefore necessary: 1) It is crucial to grow the available financing for mitigation, including for developing countries.[4] 2) The available financing must be used as effectively as possible. In this paper we concentrate on 2), but we do not mean to undermine the importance of 1). Of course, 2) may reinforce 1); it may be easier to mobilize more funding when it can be demonstrated that existing funding is being used maximally effectively. It is therefore urgently necessary to assess how effectively mitigation financing is being spent, and especially in developing countries where the opportunity costs of the spend are particularly high.

It is worth noting that assessing the cost-effectiveness on mitigation of climate finance spending by donors is separate from assessing whether such spending should count as ODA. Kenny (2020) is persuasive that it should not. We take no stance on the question here.

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[2] Authors' own calculations based on the OECD Climate Finance Dataset available at http://www.oecd.org/dac/financing-sustainable-development/development-finance-topics/climate-change.htm.

[3] CGD colleagues have analysed the OECD data in much more detail, identifying various shortcomings in the way that climate finance is currently defined and reported (Calleja 2021). In particular, the definition of spending with a 'significant' climate objective is too vague, and it is not clear how much climate finance is indeed 'additional' to other ODA spending.

[4] Although OECD countries are responsible for the overwhelming majority of historical emissions, non-OECD countries were responsible for 62% of global CO_2 emissions in 2018, and this share is rising (Ritchie & Roser, 2017).

The pursuit of synergies

Climate mitigation is often pursued alongside development objectives; and there are claims that doing so produces a 'synergy' – that is, by pursuing objectives together more is achieved for the same cost. The eleventh report of the UK's House of Commons International Development Committee session 2017-19 *UK Aid for Combatting Climate Change* (2019) calls on the UK Government to 'make sure that all climate finance is being spent in the most effective way, to have the greatest impact' (p.17). On the same page, that report calls for climate change to be 'comprehensively integrated across all development assistance strategies,' the report having earlier criticised in particular DFID's Economic Development Strategy for not having integrated thinking about climate change. The OECD (2019:pp.4, 8) makes the strong claim that the 'only way forward' is that all development activities 'should not only "do no harm" [in terms of climate] but contribute positively to the systemic transformation towards low-emissions, climate-resilient societies.' It further asserts that 'ambitious climate action reinforces developing countries' economic growth and development,' implying that all climate mitigation is positive for countries' economic growth.

It is a laudable goal to never lose sight of the effects on climate change of programming in other areas. Certainly, at the level of strategy, it makes sense to integrate management of risks including climate risk; and any climate spillovers from funded activity. However, at the project level, there is a risk to cost-effectiveness associated with targeting multiple objectives, whether the primary objective is mitigation and the secondary objective is another development goal, or vice versa. In the best-case scenario there may exist some strong synergy between the primary objective of a project, e.g. reduced cost of off-grid energy, and the secondary objective of climate change mitigation. In that case, thinking about climate change may allow the identification of additional benefits at no additional cost.[5] However, if the primary objective of the project, e.g. poverty reduction, is unrelated to the secondary objective, or is in a trade-off or anti-synergy with it, then project components intended to address climate concerns may represent poor value for money compared to the most cost-effective mitigation projects.[6] Likewise, mitigation projects targeting secondary objectives that are not strongly synergistic with the primary objective may represent poor value for money compared to the most cost-effective mitigation opportunities. Thinking rigorously about cost-effectiveness is crucial for ensuring that concessional climate financing is well-targeted. It is also of relevance to development agency policy more broadly, where the pressure to identify 'synergies' or 'win-wins' between multiple competing objectives could mistakenly lead to the pursuit of anti-synergies that must be identified. It is tempting to think that killing two birds with one stone is always best, but of course this is not the case if the stone required costs more than twice as much as a regular one-bird stone.

[5] Casillas and Kammen (2010) describe one such situation in a programme in a rural Nicaraguan community that introduced efficiency programmes and new generation capacity to both reduce energy costs and the carbon-intensity of generation at a cost that was substantially less than the savings generated. https://science.sciencemag.org/content/330/6008/1181/

[6] Schreckenberg, Mace and Poudyal (2018) describe a series of trade-offs between poverty alleviation strategies and ecosystem services. https://www.taylorfrancis.com/books/e/9780429507090

Research questions

These considerations motivate two research questions:

1. What do we know about how cost-effective different sorts of climate mitigation projects in developing countries are?
2. What does the cost-effectiveness evidence tell us about when to pursue synergies with other development objectives? When should secondary development outcomes be targeted along with mitigation, and when should mitigation be a secondary objective of projects primarily targeting other development outcomes?

We address these questions in order in the following sections, drawing out lessons of relevance primarily to policymakers in development agencies.

3. Cost-effectiveness: The state of the evidence

Before assessing the different sorts of evidence available for the cost-effectiveness of mitigation interventions in low- and middle-income countries, we must distinguish between two different sorts of interventions. These are interventions at the macro level and interventions at the micro or at meso levels. Macro-level interventions are those which pertain to an entire sector or economy, whereas micro-level interventions pertain to individual persons or firms. Interventions may also make most sense at a 'meso' level of analysis that is somewhere between the macro and the micro, such as interventions pertaining to a region.

Box 1. Dimensions of evidence quality

In assessing the usefulness for our purposes of the evidence available we refer to the following dimensions of evidence quality. The reasons we think each of these dimensions are important are discussed here.

Concrete, project-specific / Abstract, project-independent

Abstract thinking about approaches to a problem will often assume 'best-case' conditions of implementation. Evidence from specific projects has been confronted by realities on the ground, with positive or negative consequences for effectiveness that were difficult to predict in the abstract.

Independent / Self-reported

The best evidence is generated by disinterested observers who have as few relevant explicit or implicit biases as possible. Generating evidence in this way implies additional costs, of course, so much of the available evidence has generally been generated within the organisations implementing or funding the project concerned.

Retrospective / Prospective

Implementing projects is messy, and things happen that are not expected. In addition, there are often incentives to inflate the expected value of a project and to deflate the expected costs, meaning reality can sometimes be disappointing. For these reasons, we consider retrospective evaluations to be more useful when asking which approaches are most cost-effective when implemented.

The extent of theoretical assumptions required to construct the counterfactual

In order to establish a causal connection between changes predicted or observed and the intervention designed to bring them about, we must ask not just what change is predicted or observed, but also what would happen/ would have happened otherwise – we must identify the counterfactual. For prospective studies, we must model both possible futures, and both models will be underpinned by similarly demanding theoretical assumptions. However, for retrospective studies, we do not have to rely on so much theory to observe what happened to people and institutions affected by the intervention. This is the great advantage of retrospective evaluation that the previous bullet point referred to – observation can surprise us with things our theory cannot predict.

Things get trickier when we move from observing what happened to trying to observe the counterfactual. This is because we can never observe what would have happened in the absence of an intervention that was in fact implemented. However, there are many approaches that allow us to construct a counterfactual. Famously, randomised controlled trials minimise the theoretical assumptions required to observe the counterfactual because, in expectation, the control group is not dissimilar from the treated group in any causally relevant way.

So-called 'natural experiments' introduce some more theoretical assumptions in order to identify a counterfactual even when a randomised controlled trial has not been conducted. However, these rely on there being some characteristic of project implementation that can be exploited to identify untreated observations who can be modelled as relevantly similar to treated observations. Where neither natural nor unnatural experiments are possible, we must conduct an 'observational' study and use much more theory about the way causation of the outcome works to try to identify untreated observations that can serve as a comparison to our treated observations.

The more theory is required in order to generate a counterfactual, the closer a retrospective evaluation becomes to a modelling exercise. Some of the advantages of retrospective evaluation are therefore lost the more theory is necessary in generating the counterfactual.[7]

Macro-level interventions

Many macro-level emissions mitigation interventions appear to offer the most cost-effective ways of reducing emissions in developing countries (as elsewhere). However, the cost-effectiveness of donor actions to encourage the adoption of these policies is extremely hard to estimate for two reasons: it is difficult to estimate the costs and effectiveness of macro-level interventions for each new territory; and cost-effectiveness of donor actions differs from moment to moment and from donor to donor on the basis of political considerations.

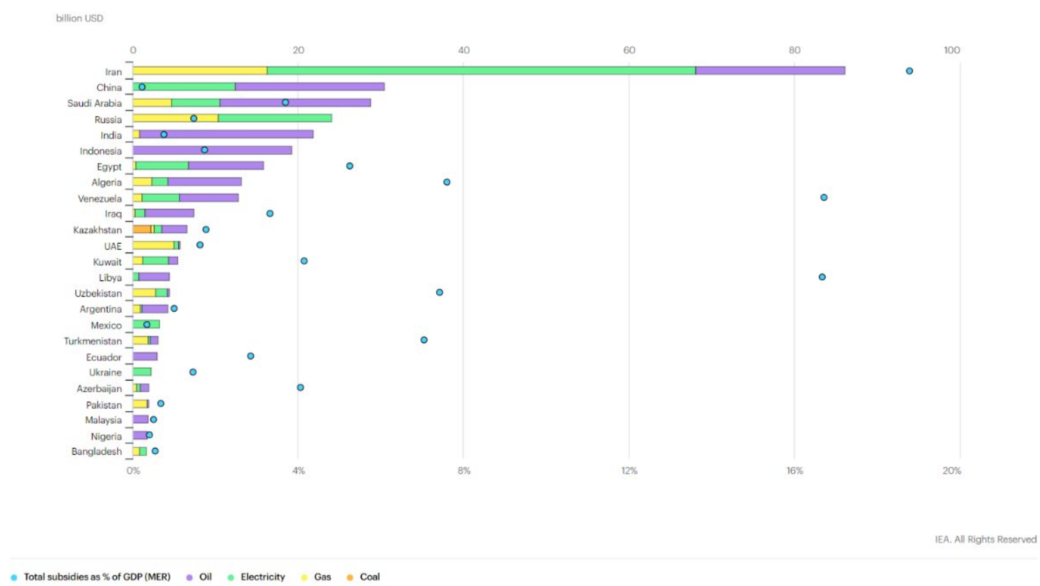
[7] This is not to suggest that randomised controlled trials are categorically 'better' than observational retrospective studies. Observational studies may be possible in more varied locations, give access to greater sample sizes and otherwise compensate for their higher dependence on theory. See Deacon and Cartwright (2018) and the rest of that special issue for a very detailed discussion.

Therefore, the majority of this paper focusses on micro-level interventions, though we briefly consider macro-level interventions in this section.

Fossil fuel subsidy reform and carbon pricing

Fossil fuel subsidy reform is one policy change with large climate benefits and negative costs (financial benefits) for the enacting authority. This is the case for some low- and middle-income countries as it is for some high-income ones. China and India continue to subsidise fossil fuels by large dollar amounts, though these subsidies are small as a percentage of GDP. Algeria, Uzbekistan, Turkmenistan, and to a lesser extent Azerbaijan and Ecuador subsidise fossil fuels to amounts that are still significant but smaller in absolute terms and which are very much larger in terms of GDP. Figure 1 summarises the absolute and relative values of subsidies for the top 25 fossil fuel subsidising countries in 2019.

Figure 1. Value of fossil-fuel subsidies by fuel in the top 25 countries, 2019



(Gould et al., 2020)

The prima-facie case for the cost-effectiveness of reducing or removing fossil fuel subsidies as a measure to reduce emissions is reinforced by modelling, most notably from the IMF (Coady *et al.*, 2019).[8] From the point of view of the state, removing subsidies frees large amounts of resources for other use. The political economy of subsidies and equity

[8] It is challenging to construct a compelling counterfactual to evaluate the effectiveness of macro-level interventions retrospectively. The sorts of retrospective evidence that can be generated, such as case study analysis or the use of the synthetic control method, will be highly dependent on a theory of how the intervention was supposed to work and their findings will be sensitive to flaws in that theory. Likewise, attempts to transfer ex-post cost-effectiveness lessons from one macro-level context to another will be highly dependent on modelling assumptions about the characteristics of the context that are relevant to the action of the intervention and the extent to which these characteristics are relevantly similar between studied context and target context. For these reasons, the distinction between retrospective, observed cost-effectiveness evidence and modelling evidence of what is likely to work breaks down more readily than for interventions at the micro level or meso levels. Therefore, we are more accepting of modelling evidence supported by case studies as the best available in this section than is necessary for micro-level interventions.

considerations may mean that it is necessary to allocate most or all of those resources to transfers to groups who have suffered due to the removal of subsidies (Lockwood, 2015). This reallocation will incur administrative costs. Nevertheless, in this situation the financial cost to the state of removing subsidies remains negative, or positive but very close to zero. This represents an extremely cost-effective climate emissions mitigation option for countries that have not yet undertaken reforms.

The consistent barrier to such reforms has been the political difficulty of enacting them. This is lessened in many countries in the wake of the global COVID-19 pandemic in 2020. The fall in aggregate demand resulting from the pandemic has driven down fossil fuel consumption, providing what Gould et al. at the International Energy Agency (2020) call 'a historic opportunity to phase out fossil fuel consumption subsidies.' For this reason, modelling evidence alone is enough to suggest that fossil fuel subsidy reform is the most cost-effective mitigation action that many countries could take.[9] This does not mean that donor action to promote fossil fuel subsidy reform will be cost-effective. History is littered with 'historic opportunities' that have not been taken, and specifically with failed fossil fuel subsidy reforms (IMF, 2013).

Introducing carbon pricing is an even more powerful policy with high mitigation potential and negative costs for the state. It is widely agreed, on the basis of modelling evidence, that carbon pricing is a necessary (but not sufficient) part of the policy mix to achieve the emissions reductions required to limit global temperature rises below 2°C (Mehling & Tvinnereim, 2018; Stern & Stern, 2007; Stiglitz *et al.*, 2017). Similarly, modelling suggests that other policies will be more effective in the presence of a sufficient carbon price (Edmonds *et al.*, 2019). As with eliminating fossil fuel subsidies, there is widespread theoretical agreement of the desirability of pricing carbon, but many countries face severe technical and political challenges to implementation.

Many other macro-level interventions which appear to be cost-effective are available such as regulation to subsidise mitigation technologies or to disincentivise high-emissions activity such as natural gas flaring. As for carbon pricing and eliminating fossil fuel subsidies, the question for donors is: are there cost-effective donor actions that can increase developing country take-up of these policies?

Are donor actions to encourage macro-level interventions cost-effective?

Development agencies cannot directly implement national policy in recipient countries; that is the purview of the sovereign governments of recipient countries. Therefore, the cost-effectiveness of such policies is only relevant to development agencies in donor countries insofar as it provides and argument for the cost-effectiveness of actions the agency *can* take. In most cases, the relevant actions will be advocacy, convening and technical assistance activities designed to overcome political or capacity barriers to implementation.

Multilateral programmes like the World Bank's Partnership for Market Readiness provide a means for development agencies to contribute to capacity building in carbon pricing while leveraging economies of scale and without duplication of effort (HMG, 2019; PMR

[9] It is worth noting that removing fossil fuel subsidies is one of the domestic actions rich countries can take, which are outside of the scope of this paper. CGD research for the 2020 Commitment to Development Index clarifies that rich countries also continue to subsidise fossil fuels. Australia, Belgium, Finland and Greece all subsidise fossil fuels substantially (CGD, 2020).

Secretariat, 2018). Though the expected cost-effectiveness of such investments is highly uncertain, the investments involved are so modest that an argument for low cost-effectiveness in expectation would have to make implausible assumptions. The business case for the UK Government's contribution to the Partnership for Market Readiness describes a total funding requirement of $100 million US, which is a small price to pay for an intervention that has a credible chance even of very slightly hastening the arrival of a global carbon market that could reduce total global emissions reductions costs by as much as 70% (Lazarowicz, 2009).

Though acting to support multi-lateral efforts such as the World Bank's Partnership for Market Readiness is likely to be cost-effective, donors may also consider acting bilaterally. The likely effectiveness of such actions is extremely difficult to generalise as it will depend on the political situation in the recipient country and the ability of the donor to influence it. This situation is unique to each combination of policy option, donor and recipient, and so we cannot assess the likely cost-effectiveness of such actions here.

Micro- and meso-level interventions

In this section, we first consider the availability and quality of *retrospective impact evaluation evidence* of the cost-effectiveness of micro- and meso-level emissions mitigation projects in developing countries. We then move on to assess the *prospective modelling evidence* that has dominated discussions of emissions mitigation options since the early days of climate change research. The final subsection demonstrates that though there is a dearth of high-quality retrospective evidence in this area, it is nevertheless possible to conclude that projects have radically different levels of cost-effectiveness.

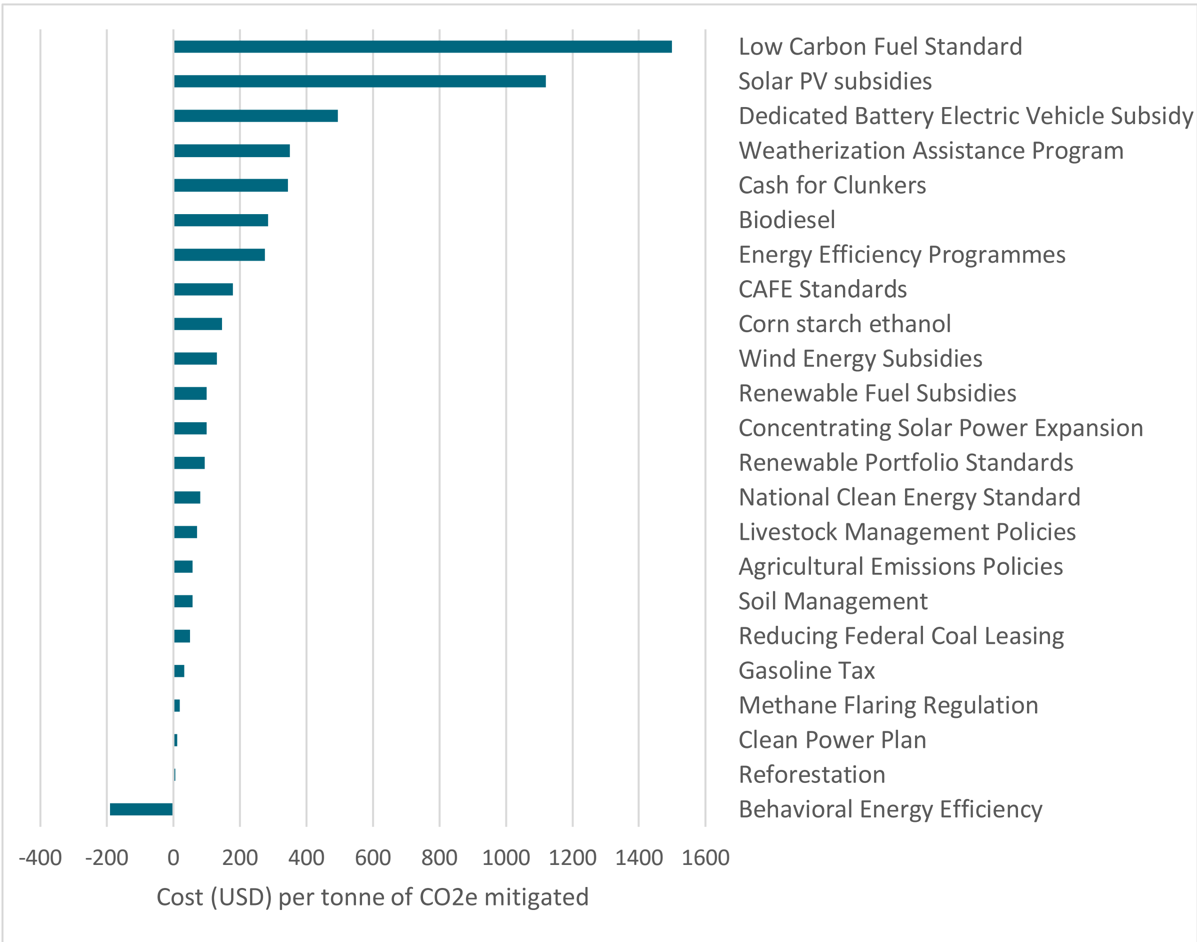
Retrospective impact evaluation evidence

The evidence least reliant on assumptions for estimating the real-world cost-effectiveness of different mitigation options comes from independent impact evaluations of real projects associated with costs data. In areas of development policy like education and public health, the last fifteen years have seen a huge growth in the number of evaluations that meet this standard (Sabet & Brown, 2018). The International Initiative for Impact Evaluation (3ie) maintains a repository of development-relevant evaluations, which aims to be exhaustive. At the time of writing the database contains 3,757 impact evaluations, of which 3,421 have been published since 2005.

Unfortunately, such evidence is very thin in the area of emissions mitigation interventions in low- and middle-income countries. This is clear from the 3ie repository, which tags impact evaluations according to the World Bank's Theme Taxonomy and Definitions (World Bank, 2016). The repository contains 795 evaluations tagged with 'child health', 347 evaluations tagged with 'access to education', 394 evaluations tagged with 'social safety nets', and 38 evaluations tagged with 'water pollution' for example. However, it contains just eight evaluations tagged with 'climate change mitigation', and just two systematic reviews. Manual analysis of results of searches of the 3ie repository using very broad keywords such as 'climate' or 'emissions' only uncovered three evaluations that included a finding for cost per unit of mitigation. More costs data could probably be found through contacting authors and a handful of other cost estimates generated. Systematic reviews often attempt to undertake such work. Unfortunately, none of the systematic reviews of evaluations of climate mitigation interventions identified in the 3ie repository were able to assess cost-effectiveness across studies, due to a lack of costs data.[10]

One 2018 systematic review of economic studies of the cost-effectiveness of different emissions mitigation interventions could be located, but it was not specifically focussed on developing countries. That review found only 50 studies that met its inclusion criteria, of which just two reported effectiveness and real-world costs for low- or middle-income countries (Gillingham & Stock, 2018).

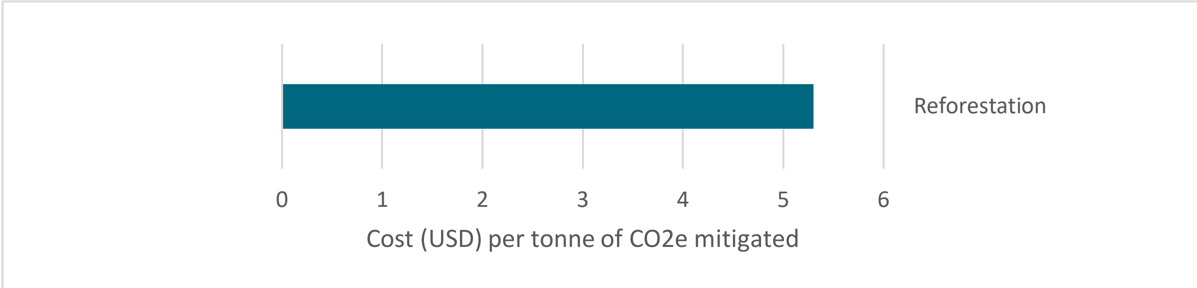
Figure 2. Cost-effectiveness of mitigation options from 50 economic studies (global)



Graphical presentation of Gillingham and Stock's (2018) Table 2, central values

[10] Relatedly, Oswald and Stern find that the top economics journals have largely ignored climate change, with zero articles ever published on climate change in the Quarterly Journal of Economics, just nine in the Economic Journal, three in the Review of Economic Studies and so on.

Figure 3. Cost-effectiveness of mitigation options from economic studies (only low- or middle-income countries)



Graphical presentation of Gillingham and Stock's (2018) Table 2, central values

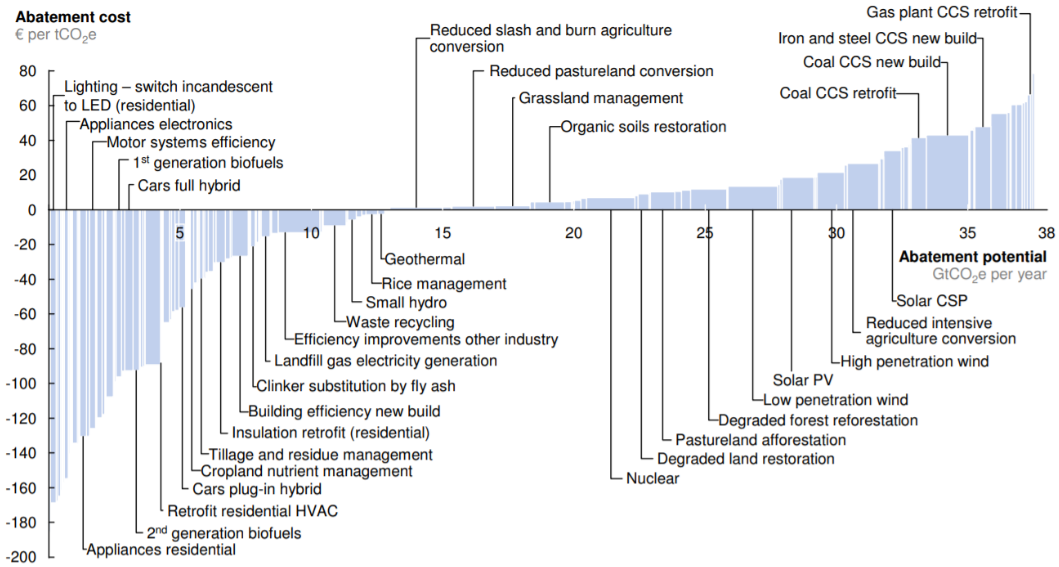
Figure 3 highlights the only studies in Figure 2 that concern only low- and middle-income countries, driving home the point that there is very little available cost-effectiveness evidence based on impact evaluations of mitigation interventions in these countries. This absence has led systematic reviews of emissions mitigation options in the global south to conclude, as Snilsveit et al. do (2019:p.63), that the cost-effectiveness evidence for different mitigation options in recipient countries is 'rather limited' and prevents meta-analyses from deriving estimates of cost-effectiveness. The two evaluations of interventions in developing countries that contribute to the estimate in Figure 3 do report very low cost estimates for anti-deforestation and reforestation interventions in Uganda and Malawi (Jack, 2011; Jayachandran *et al.*, 2017). This is good news certainly, but not sufficient evidence on which to judge the relative cost-effectiveness of the very many different mitigation options available to low- and middle-income countries.

It is possible that the findings of retrospective impact evaluations from projects in rich counties might be useful for developing country contexts. However, such transferring of results is not automatic, as findings in social science are notoriously heterogeneous across contexts, so much so that naïve observational or modelling estimates from the same setting may often be better than the most rigorous evaluations from a different setting (Pritchett & Sandefur, 2015; Vivalt, 2019). Therefore, transferring results of evaluation from rich countries would require careful attention to the differences in context between study area and target area. To our knowledge, this work has not been done.

Prospective modelling evidence

Despite the lack of retrospective impact evaluations, at first sight, it appears that we know plenty about the cost-effectiveness of different mitigation interventions in low- and middle-income countries. The most comprehensive and high-profile attempts to compare the cost-effectiveness of different mitigation activities involve the construction of marginal abatement cost curves (MACCs). The figure below is the most famous MACC, last updated by McKinsey in 2010. It is an engineering estimate of the cost per tonne of emissions reductions for various available technologies based on the difference in cost per unit of installed capacity between a reference technology and a greener alternative, as well as the potential total abatement that could be achieved by employing each technology. The curve pictured is global but is a weighted average of more sectorally and geographically specific cost curves.

Figure 4. Global GHG abatement cost curve beyond business-as-usual – 2030



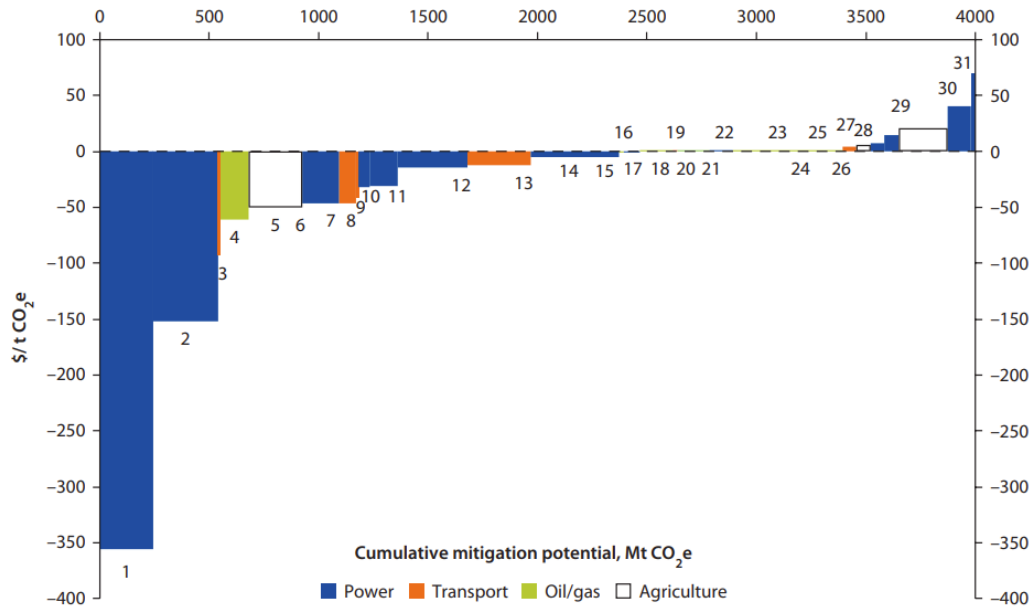
Note: The curve presents an estimate of the maximum potential of all technical GHG abatement measures below €80 per tCO_2e if each lever was pursued aggressively. It is not a forecast of what role different abatement measures and technologies will play.

(McKinsey, 2010, p.8)

Figure 4 Presents McKinsey's 2010 assessment of the magnitude of mitigation (abatement) possible, and the total cost of that mitigation, in the year 2030, if the implementation of each of the named technologies were 'pursued aggressively' between 2010 and 2030. The mitigation potential in their model is represented by the width of each bar, with the cost represented by the height. This is the most famous MACC but is now quite a dated model.

Similar models can be adapted to national contexts to explore the mitigation options available for a country. For instance, consider the MACC developed by the World Bank to assist in Nigerian policymaking in 2013, Figure 5. This MACC predicts huge cost-savings as well as large mitigation potential for technologies 1 and 2, energy efficient lighting off- and on-grid. It also predicts low costs of $1 per tCO_2e (tonne CO_2 equivalent) mitigated for technologies like concentrated solar power (technology 21).

Figure 5. MACC for Nigeria (selected low-carbon interventions)



(Cervigni et al., 2012)

Models like McKinsey's provide a useful starting point for estimation of the cost-effectiveness of different mitigation options. More sectorally and geographically specific modelling like the example drawn from the World Bank assessment of mitigation options for Nigeria can provide some guide to the costs a given country might expect when pursuing different mitigation options. However, such models are blind to many non-engineering determinants of real-world cost-effectiveness, like behavioural response. Most importantly, they may be based on unrealistic assumptions. The so-called 'efficiency-gap' puzzle – why investment in energy efficiency is so much lower than the rational level according to such models – is increasingly being resolved with the realisation that real-world returns to efficiency investments are much, much lower than the models predict. Fowlie, Greenstone and Wolfram (2015) demonstrate that model-predicted savings from energy efficiency investments in 30,000 US homes are, on average, 2.5 times higher than observed savings. This means that up-front investment costs were roughly double the energy savings over the period considered rather than being slightly less as modelling had suggested.

Other well-known models include the integrated models that underpin the findings of the IPCC fifth and most recent assessment report from 2014, or the Project Drawdown integrated model. These models capture the costs and high-level outcomes of global policy scenarios based on a set of assumptions about the policies adopted by governments and the development and adoption of mitigation technologies. The purpose of these models is to contextualise and inform high-level policy choices. The models do contain costs data and do attempt to estimate the total cost of the required mitigation under different scenarios. For example the IPCC estimate the global cost of achieving 'stringent' mitigation targets of 430-530 ppm C02e in 2100 at between 0.8 and 1.3 % of global GDP between 2010 and 2050 for 624 scenarios (IPCC, 2014:p.474). However, these models are not intended to provide a guide for action at the project level; they are so enormous in scope that they are necessarily reductive, omitting many variables of importance to the assessment of the best solution for a given context at a given time. In addition, they suffer the same drawbacks as MACCs in their inability to incorporate non-engineering and non-economic features such as behavioural response, as well as their reliance on perhaps overly optimistic predictions of the real-world performance of technologies. The ultimate test of these sets of assumptions is necessarily by comparison to real-world implementations of the mitigation solutions assessed.

Prospective, project-specific evidence

If modelling estimates like MACCs are not good estimates of real-world costs and impacts, and retrospective impact evaluations are not numerous enough to tell us how cost-effective different mitigation options might be in the real world, we are forced to ask what lower-quality evidence we have. We might hope that governments and other implementers in the global south would be producing high-quality data about the costs and impacts of mitigation projects. However, this data either is not being produced, or is not being made available for aggregation. The CDP, formerly Carbon Disclosure Project, hosts the most high-profile attempt to aggregate data from regions and cities including those in the global south. However, of 3937 projects in their regions and cities mitigation actions database, only 13 have estimated emissions reduction data. None of these entries have costs data.

The richest potential source of data in this middle ground of reliability is self-reported cost-effectiveness data from development agencies and international finance institutions. On reviewing the available data from the major bilateral development agencies and multilateral funds, we find that most of this data is reported as headline figures across multiple projects, meaning it is generally difficult to disentangle the costs and emissions reductions attributable to particular projects. It is this project-level data that are necessary for the purposes of this policy paper. Below we report on the three sources which offer the most potential.

UK International Climate Finance

The UK's International Climate Finance mechanism is one potentially promising source of data where costs and impacts are recorded. Costs, mitigation expected, and mitigation achieved, are all being recorded at the project level and then aggregated for purposes like the ICF annual report's summary figures. However, project level data is not brought together in one public dataset, meaning the data cannot be used for independent research projects like this one. In this subsection, we briefly describe how this is so.

One of the key performance indicators for projects funded using UK International Climate Finance is emissions mitigation. This is recorded for individual projects, both as expected mitigation over the lifetime of the project and as mitigation to date. Both statistics are recorded as a total figure and as a proportion attributable to ICF funding. Rigorous methodology guidelines ensure that these statistics are comparable and are based on a reasonable counterfactual for what would have happened in the absence of the project (Climate Change Compass, 2018).

Cost data for all ICF projects are publicly reported, though they are not systematically published as one dataset. However, mitigation figures, although reported internally, are not systematically publicly reported at all for some ICF-funded projects. Unfortunately, although the UK government reports top-level annual results including tonnes of CO2 equivalent emissions mitigated to date and in expectation for ICF projects, disaggregated, project-level data are not systematically reported (DFID, 2020).[11] It is possible to delve into the UK Foreign, Commonwealth and Development Office online development project database, Devtracker, to locate the annual reports for individual projects. However, mitigation data is not reported in every project's annual report, and there is no database of all ICF-funded projects that collects project-level data together in one place. In 2017 Carbon Brief used a Freedom of Information request to create a dataset of all ICF-funded projects with links to project entries in Devtracker, but even a limited dataset of links such as that dataset is not routinely produced.

It is not just headline results for the annual report that are being aggregated behind closed doors for ICF projects. The annual review of a Colombian sustainable cattle ranching project talks about "ICF portfolio spend weighted average [expected cost-effectiveness] of £8/tCO_2e" (DFID, 2019). This calculation and the underlying data used to make it are not public either. By drilling down to the project level in Devtracker, sometimes this data can be accessed, but not for every project.

The UK has pushed hard for cost-effectiveness to be prioritised by the multilateral funds to which it contributes, and for more emphasis to be placed on independent evaluation at those funds. This is valuable work, but the UK could also do much more at home. The UK government would be doing a service to the entire emissions mitigation sector if it made ICF KPI reporting data openly available in one place associated with program costs. Compass, a four-year programme to help the UK government monitor, evaluate and learn from ICF spending ended in 2020 after providing methodological guidance for all KPIs and publishing reviews of KPI 4 (improved resilience) and KPI 15 (transformational change). Perhaps now is an opportune time for the UK to commission a new learning programme concentrating on KPI 6 (Net Change in Greenhouse Gas Emissions).

The state of the ICF KPI data is a picture mirrored at other development agencies and at IFIs, where annual reports often claim levels of emissions mitigation and cost data can be found, but disaggregated emissions mitigated per project are not made available.[12] This is a missed opportunity that must be rectified in order for the development community to learn collectively, as quickly as possible, what is working well and what is not.

The Green Climate Fund

Two multilateral funds stand out for their transparency in this area and provide some data we can use to estimate cost-effectiveness of emissions mitigation projects in recipient countries. The first of these is the Green Climate Fund (GCF), and the second is the Clean Technology Fund (CTF), which is part of the Climate Investment Funds, a Financial Intermediary Fund held in trust by the World Bank.[13] The GCF publishes approved funding

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[11] Mitigation to date attributed to ICF funding 31,000,000 tCO2e across 39 programmes between 2011 and 2020. Expected total lifetime mitigation is currently estimated at 750,000,000 tCO2e across 55 programmes.
[12] See (Calleja , 2021), Annex 5, for a list of DFI climate-related results claims. A public dataset of project-level data on costs and mitigation expected or achieved could not be located for any of these institutions.
[13] Both are large funds, important in the space. The GCF is the second-biggest multilateral after the International Development Association of the World Bank by recent disbursements per year, with $1.7bn disbursed per year on average 2016-2018 (Calleja, 2021). The CTF is smaller on this measure with $300m disbursed per year on average over this same period (CTF, 2020). However, the CTF is an older fund, focussed purely on mitigation, unlike the GCF which also funds adaptation, and the CTF has approved and funded more than twice as many mitigation projects. Total mitigation resources pledged to the CTF stand at $5.4 billion compared to $10.3 billion

proposals for projects on its website, as well as headline figures on costs, funding modality and expected effectiveness in tonnes CO2 equivalent mitigated. It is possible to aggregate this data and derive cost-effectiveness information for GCD projects. Colleagues Ian Mitchell and Arthur Baker's blog (2019) used an earlier version of the same data to examine the anticipated cost-effectiveness of GCF projects. For this work, we have updated and extended their dataset.

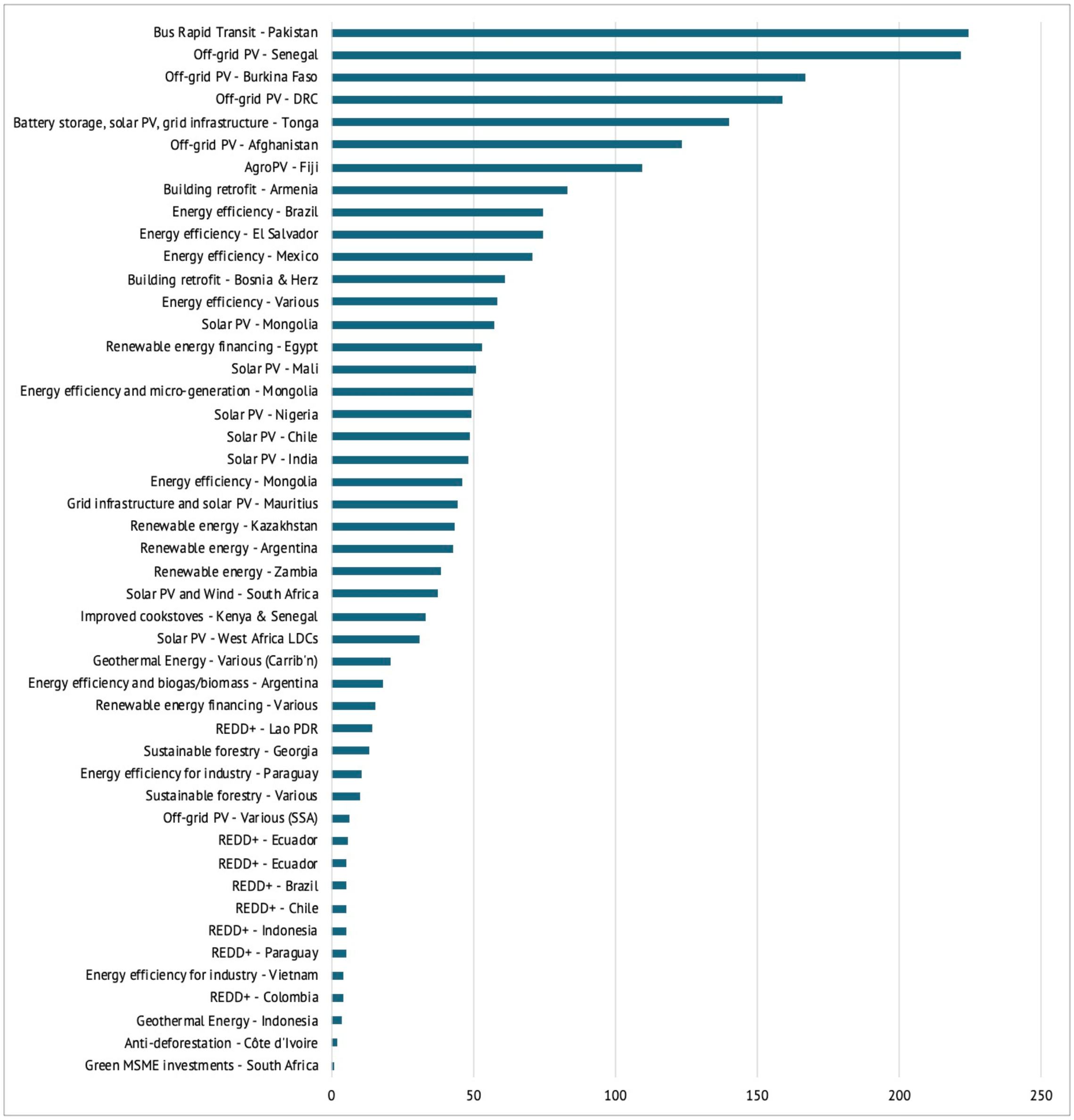
It is worth stressing that the GCF and CTF are islands of excellent transparency. They are also important funds. Between them, they hold 48% of the funds deposited to multilateral mitigation or mixed (mitigation and adaptation) funds tracked by Climate Funds Update (2020). Other large mitigation funds such as the UN's Global Environment Facility do not publish project-level data including expected costs and expected emissions, nor do commissioning bodies such as the EU's Global Climate Change Alliance, nor the big bilateral climate finance providers, as noted above.

The latest data from the GCF includes 47 dedicated mitigation projects with total costs ranging from $10m to $1.3b, and expected emissions mitigated ranging from 91k to 120m tCO_2e. These projects are characterised by the GCF as mitigation projects with no adaptation component, though they may have non-adaptation co-benefits such as for economic growth, air pollution, biodiversity or energy security. It is crude to ignore these co-benefits for now, but the data do not allow us to attribute some component of cost to the mitigation component of outcomes. For now, we consider the cost-effectiveness of projects purely on their principal mitigation aim and discuss co-benefits in Section 5. To this end, by dividing total cost by expected emissions mitigated we can calculate cost per tCO_2e for each project and generate a first-cut or naïve cost-effectiveness estimate. Sections 4 and 5 introduce a variety of ways in which this estimate of cost-effectiveness should be considered naïve and build on the findings of this section by qualifying them. The calculation of a naïve estimate of cost-effectiveness for GCF projects gives a wide range of cost-effectiveness estimates from $1.03 to $224.42 per tonne mitigated with a mean of $50.94 and median of $42.68. Figure 6 shows expected cost-effectiveness for all approved GCF mitigation projects as reported by approved funding proposals and headline summary data on the GCF website.[14]

for the initial resource mobilisation period of the GCF. The first replenishment round for the GCF has so far seen a further $9.8 billion pledged.

[14] Approved funding proposals are not yet available on the GCF website for projects approved after August 2020, though headline data is being reported. In some cases that headline data is slightly different from the pre-approval funding proposals that are available on the GCF site but there are no large discrepancies, suggesting that pre-approval funding proposals give a similarly accurate picture to approved funding proposals for projects that have been approved.

Figure 6. Cost-effectiveness of GCF mitigation projects



Authors' calculations using GCF results data.

Figure 6 shows that GCF projects continue to show the wide range of expected naïve cost-effectiveness reported by Mitchell and Baker (2019). Indeed, two of the projects approved for funding in GCF's most recent round are expected to be the second-least and sixth-least cost-effective projects GCF has approved to date, and one of them is expected to be the second-most cost-effective, on this naïve measure of cost-effectiveness.

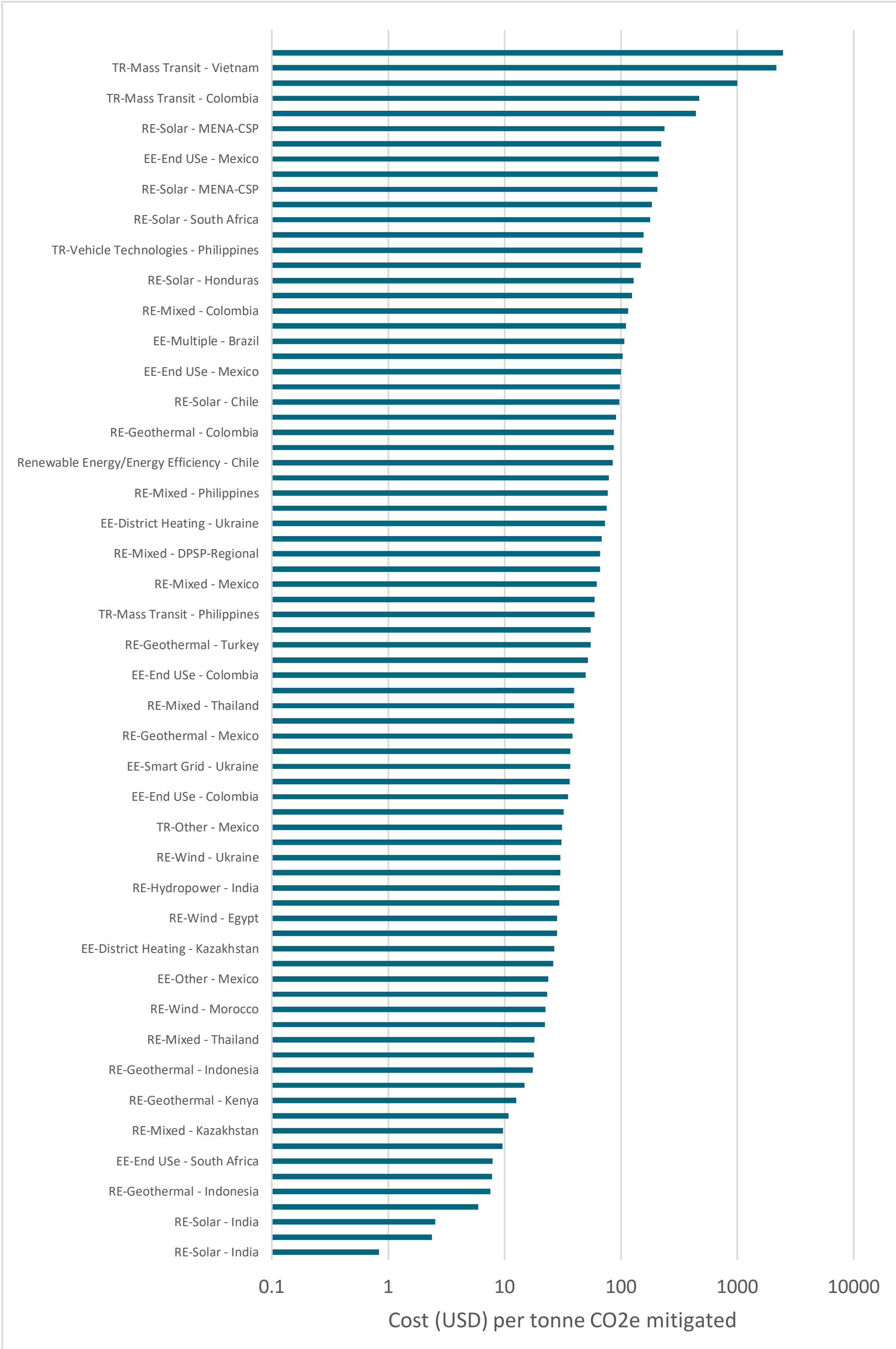
The systematic reporting of ex-ante estimates of effectiveness and costs is an excellent practice, and the Green Climate Fund should be praised for this transparency. However, self-reported prospective estimates of effectiveness are not a substitute for independent retrospective impact evaluation, which was not conducted for GCF projects. The GCF has constituted an Independent Evaluation Unit, but unfortunately their first report was damning on the ability of GCF-funded projects to assess their effectiveness. The report stated that “the current investment portfolio of the GCF does not have sufficient ability to report credibly on its impact and effectiveness” as “half of the investments do not include plans for baseline data collection, two thirds do not have theories of change, and a majority of the investments (more than 90 per cent) will overstate their results because they do not have realistic assumptions or the ability to measure their results credibly” (GCF, 2019:p.xxxvi). The recommendations of that report are being implemented and if that goes well, some good independent evaluation data may come out of GCF in future. However, it will be too late for many projects to collect baseline data, begin with a solid theory of change, or otherwise facilitate measuring impact effectively.

The Clean Technology Fund

Similarly to the GCF, the Climate Investment Funds’ (CIF) Clean Technology Fund (CTF) reports anticipated cost effectiveness for its projects. These data are a rich source of evidence on the real-world expected performance of different emissions mitigation options in low- and middle-income countries, with project-level data reported for 80 mitigation projects across 15 different groups of technologies.[15] This dataset reports total cost for each project, a breakdown of sources of funding, and total expected mitigation across the lifetime of the project. The calculation of a naïve estimate of cost-effectiveness for CTF projects shown in Figure 7 gives an extremely wide range of cost-effectiveness estimates from $0.83 to $2,456 per tCO_2e mitigated with a mean of $144.19 and median of $53.45.

[15] The data is publicly downloadable from the World Bank’s website at https://finances.worldbank.org/Projects/2019-Climate-Investment-Funds-Clean-Technology-Fun/kjmm-jfbk. The total of 80 is after two projects have been removed as accounting outliers. See Section 8, Annex.

Figure 7. Expected cost-effectiveness of CTF projects (log scale)



Authors' calculations using CTF results data.

What is striking from looking at this data is that, even more than the GCF data, the expected cost-effectiveness estimates of projects are different by several orders of magnitude. The table above uses a log scale to be legible, but that should not detract from the impact of the data being reported. Of the 80 projects, 9 report a cost of under $10 per tonne, for 21 it is over $100, and in three of those it exceeds $1000. It is striking that even in anticipation some groups of projects are expected to be tens or hundreds of times more cost-effective from a pure, directly attributed mitigation point of view than others. Section 4 will demonstrate that some of this difference can be explained by the targeting of development outcomes beyond emissions mitigation and by other factors. However, it will also demonstrate that much of it cannot. It will be argued that a much tighter focus on cost-effectiveness and on learning is essential to getting the best value from emissions mitigation spending by development agencies and multilaterals.

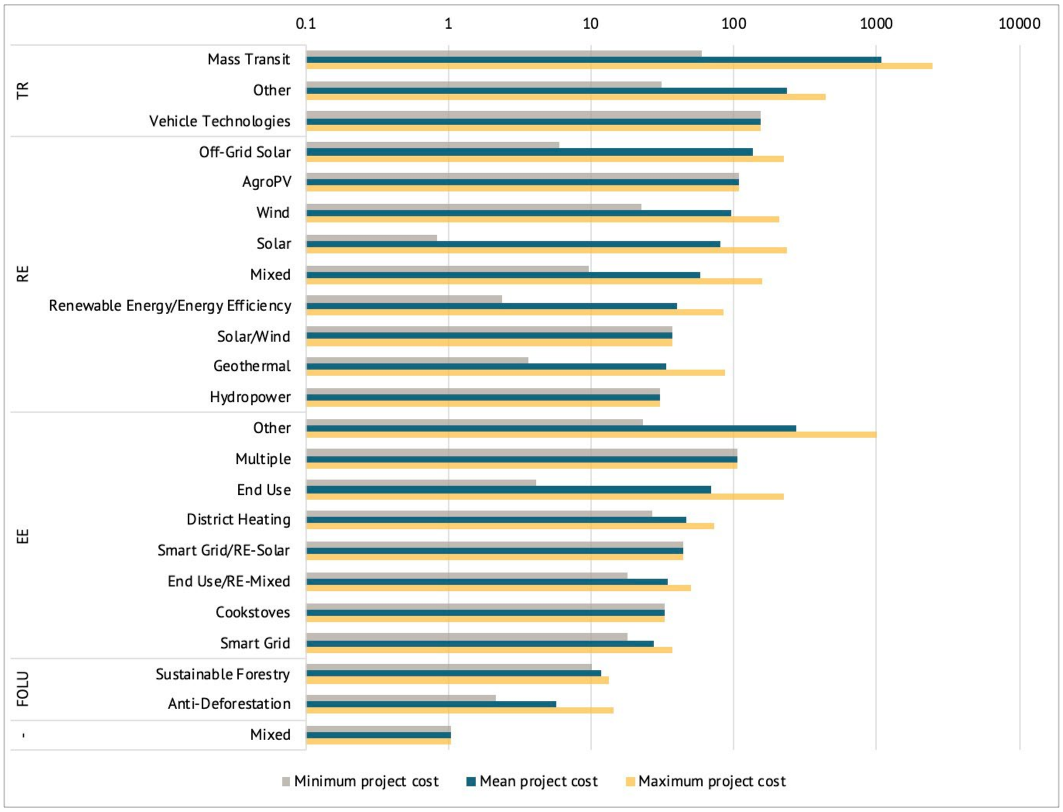
In addition to expected results, the CTF reports emissions mitigation progress to date for projects in implementation. In the future this data will be an informative source for investigations of the relationship between expected cost-effectiveness and final cost-effectiveness. However, as projects have a typical lifetime as defined in the dataset of at least 10 years, and often more than 20, there are as yet very few completed projects in the CTF portfolio. This makes regular updates to expected mitigation figures very important, as well as impact evaluations that report interim as well as final results.

Prospective project-specific evidence aggregated

The data from the GCF and CTF may not be representative of all development spending on emissions mitigation. Smaller funds and direct spending by development agencies could be expected to be systematically different from GCF and CTF spending. However, the projects to which those two funds have contributed represent a large amount of spending on mitigation. The funding requirements for the approved GCF projects detailed above total $11.5 billion. The total cost of CTF projects in the public results dataset is over $48 billion including co-financing. This is a very significant amount of finance, which compares for example to an annual total of just under $40 billion for concessional climate finance in 2018 (Calleja, 2021). The two funds' projects also cover a wide range of approaches to mitigation from forestry and other land use (FOLU) to energy efficiency (EE) to renewable energy generation (RE), to transport (TR).[16] Figure 8 attempts to summarise the range of effectiveness within different types of approach. It shows the maximum, minimum, and mean naïve cost-effectiveness for projects from the two portfolios, with GCF projects manually coded to cohere with the approach groups used in the CTF data.

[16] Of the two funds, only the GCF finances FOLU projects; the other sectors are covered by both funds.

Figure 8. Expected cost-effectiveness of GCF and CTF projects by approach (log scale)



Authors' calculations using CTF and GCF results data

This chart uses a log scale in order to render the findings intelligible, but, again, this log scale risks distracting from the impact of the numbers being presented. Within and between specific approaches to mitigation, there are order of magnitude differences in expected cost-effectiveness on this naïve measure. Some of the approach categories defined by the CTF are too vague to permit much analysis of relative cost-effectiveness because projects are likely to be extremely different from each other, for example those categorised as 'Renewable Energy/Energy Efficiency'. However, other categories are specific enough to ground this sort of analysis. For example, the sustainable forestry projects identified cost between \$10 and \$13 dollars per tCO_2e mitigated. This is a low and consistent cost. By contrast, the most cost-effective on-grid solar project had a total project cost of \$0.83 per tCO_2e mitigated, whereas the least cost-effective cost \$238 per tCO_2e. Similarly the mean cost per tCO_2e mitigated for an anti-deforestation project was \$5.73, whereas the mean cost for a mass transit project was \$1,076.

At the same time, there is much good news in Figure 8. In all four of the major sectors addressed by the funds: transport, energy efficiency, energy generation, and forestry and other land-use; cost-effective interventions have been identified and funded by the CTF or the GCF. Costs for forestry and other land use interventions are consistently very low. And even in the most expensive sector, transport, a project with a total cost of \$31.16 per tCO_2e of expected mitigation has been identified and funded. The observation of this level of expected performance for real-world projects confirms that cost-effective mitigation options exist in developing countries and that these can form an important part of the effort to halt and reverse climate change. These projects are cost-effective not just relative to other projects in our dataset, but also to even conservative estimates of the social cost of carbon.[17]

4. Beyond naïve cost-effectiveness

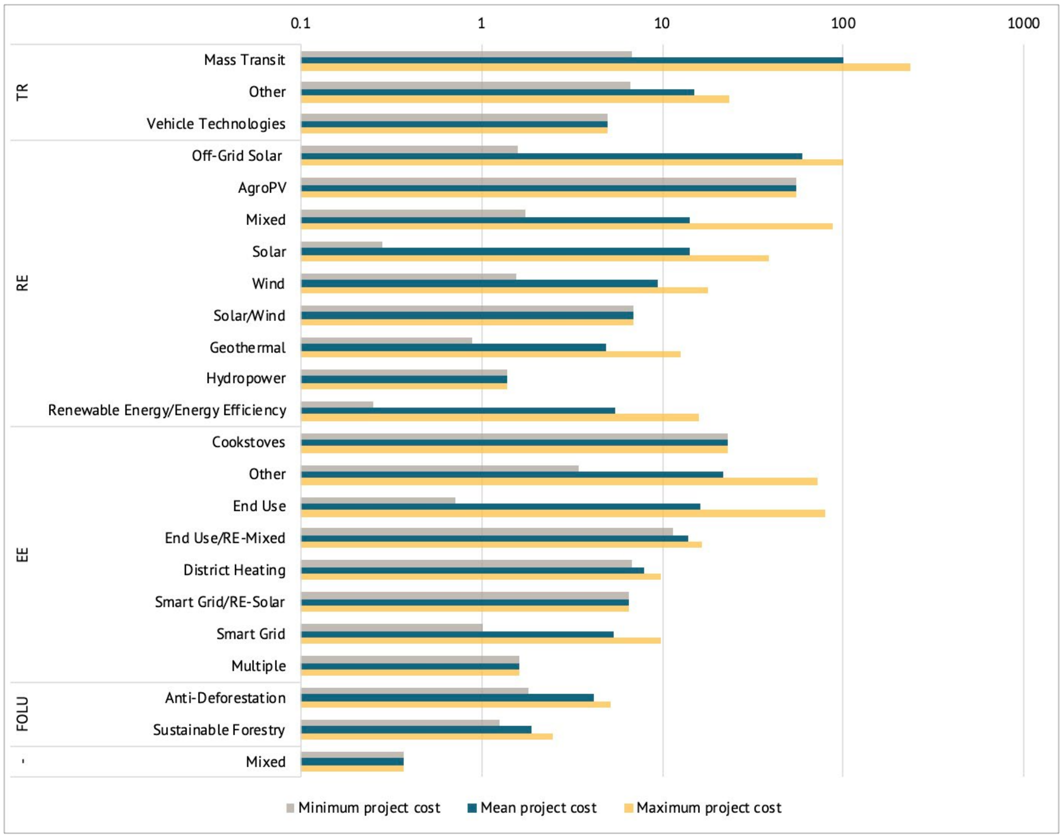
This section moves beyond the naïve estimates of cost-effectiveness to consider some of the ways in which apparently differently cost-effective projects may be more similar than these estimates suggest or that cost-effectiveness differences like those seen above may be a necessary feature of a systemic approach to emissions mitigation.

Leveraging other sources of finance

One of the ways in which the measure of cost-effectiveness employed so far is naïve, is that it ignores the achievements of the funds analysed in leveraging other sources of finance to render projects more cost-effective from the funds' own points of view. It might be the case that programs are more similarly cost-effective from the funds' own points of view, before co-financing, than they are when assessing total cost including co-financing. We can assess this possibility in the combined CTF and GCF data by constructing a measure of cost-effectiveness based on total expected mitigation divided only by CTF or GCF funds contributed. Consulting CTF and GCF project documents, the funds also use a measure similar to this to assess cost-effectiveness, as well as looking at cost-effectiveness including co-financing. In fact, the preferred measures of cost-effectiveness used in fund project documents are slightly more nuanced, bearing in mind the terms of financing and differently weighting different forms of loan or grant instruments. Unfortunately, these more nuanced measures are not systematically reported in the CTF dataset or in the headline data on the GCF website, and it was outside the scope of this paper to extract and standardise such measures from project documents. The cruder measure calculated by dividing total expected emissions mitigation by CTF or GCF funding is nevertheless adequate to ground our sole conclusion, that cost-effectiveness differs by orders of magnitude within and between mitigation sectors. This measure of cost-effectiveness from the funds' own points of view is presented in Figure 9, below.

17 For example, the U.S. EPA's preferred 'central' measure, based on a 3% discount rate, suggests that the social cost of carbon in 2020 is $42 in 2007 US Dollars (The Interagency Working Group on the Social Cost of Greenhouse Gases, 2016:p.4).

Figure 9. Expected cost-effectiveness of GCF and CTF projects by approach, only considering fund's own costs; excluding co-financing (log scale)



Authors' calculations using CTF and GCF results data

Again, Figure 9 must employ a log scale for legibility. Comparing Figure 9 with Figure 8 in the previous section confirms that whether it is from the funds' own points of view, or from a point of view including co-financing to compare total costs, cost-effectiveness differs by orders of magnitude within and between sectors. Costs are much lower from the funds' own perspectives, with mitigation for the most cost-efficient specific subsector, hydropower, projected to cost the GCF only \$1.38 per tCO_2e. However, mean cost-effectiveness in the most expensive sector, mass transit, was \$100, an almost 100x difference. Differences within sectors are also marked, just as they are on the total cost measure in Figure 8. For on-grid solar projects, the most cost-effective project costs just \$0.28 of the fund's own money per tCO_2e. The most expensive project costs \$38.67 per tCO_2e, a more than 100x difference.

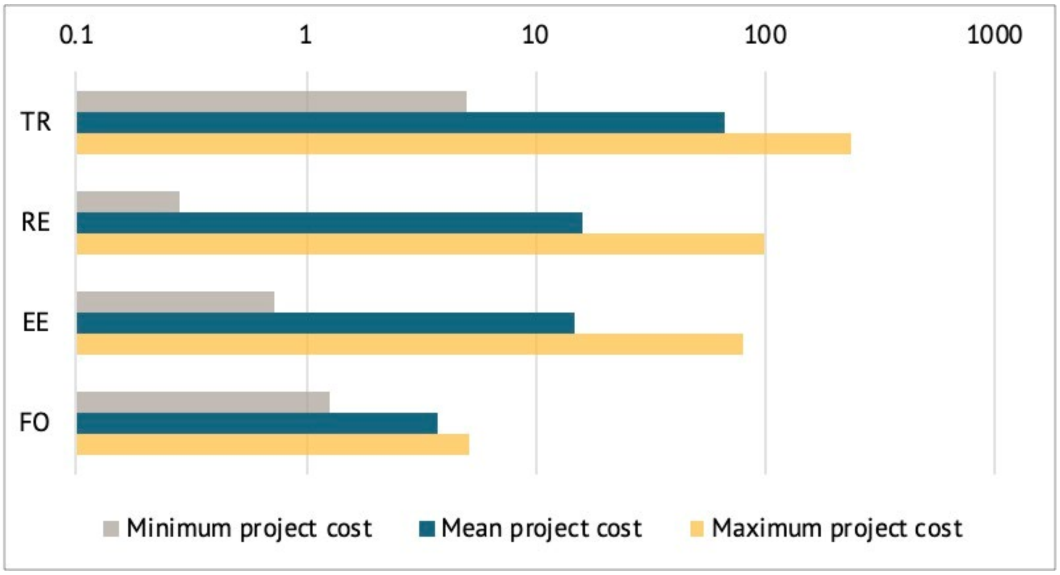
The 'fund's own costs' measure above is very informative not just because it bears in mind the fund's success in co-financing, but also because it is useful for assessing the value of a climate finance contribution to a project that is principally aiming at a different objective, and whose total costs will therefore be inflated from a mitigation point of view. This is discussed more in Section 5. We nevertheless believe that it is important to consider the total cost-effectiveness of projects, and to aim for ever more cost-effective projects on this total measure, as well as to consider cost-effectiveness as limited to a funder's individual investment. This is a belief shared by the CTF, who assess investment opportunities on this total measure as well as on the cost-effectiveness of only CTF funding. The CTF Investment Criteria for Public Sector Operations (2009:p.9) state that "CTF co-financing will ordinarily not be available for investments in which the marginal cost of reducing a ton of CO2-equivalent exceeds US$200." This is an excellent aspiration and Figure 8 confirms that a large majority of CTF projects meet this condition. However, Figure 8 also shows that ten projects do exceed this cost-ineffectiveness limit, at least on our naïve measure. The cost per tCO_2e of the mean mass transit project is six times this limit, which is also exceeded by the most expensive project in seven other sectors.

Acting across all sectors

One justification for differences in cost-effectiveness between mitigation projects is that they are being undertaken in different sectors, and action in all sectors is required. Working Group III's contribution to the fifth IPCC report summarises scientific consensus when it states: 'Stabilizing atmospheric CO^2eq concentrations at any level will ultimately require deep reductions in emissions and fundamental changes to both the end-use and supply-side of the energy system as well as changes in land-use practices and industrial processes' (IPCC, 2014:p.65). Given the need to work across sectors, differences in cost-effectiveness are to be expected across a portfolio of mitigation projects. After all, there is not enough emissions mitigation potential in forestry and other land use for the world to buy all the emissions mitigation required and to otherwise continue business as usual.[18] The indicative evidence from our limited data is that acting across sectors does in fact imply accepting differences in cost-effectiveness. Figure 10 shows that, for GCF and CTF projects in our dataset considering only the funds' own costs, mean project cost was in $67 for transport projects, around $15 and $16 for energy efficiency and renewable energy projects respectively, and around $3.75 per tCO^2e for FOLU projects. While maximum project costs followed a similar pattern, the most cost-effective projects in renewable energy and energy efficiency both had a cost to the fund of under $1 per tCO^2e whereas the most cost-effective FOLU project was just over $1, and transport was nearly $5.

[18] Griscom et al. (2017) find that 'natural climate solutions,' 20 conservation, restoration, and improved land management actions that increase carbon storage and/or avoid greenhouse gas emissions, have a maximum mitigation potential of 74% of the mitigation needed between 2017 and 2030, of which only half meets their definition of cost-effective.

Figure 10. Expected cost-effectiveness of GCF and CTF projects by sector, only considering fund's own costs; excluding co-financing (log scale)



Authors' calculations using CTF and GCF results data

However, as Figures 8 and 9 reveal, the differences in cost-effectiveness for projects in our dataset are even more stark within sectors than between them. There are order-of-magnitude differences between projects operating in the same well-developed subsector, with some on-grid solar projects being delivered at 100x the cost-effectiveness of others from a pure mitigation point of view on fund's own costs (200x on total costs). These differences are even more marked within larger sectors such as energy efficiency or transport. Though action in the transport sector is required to avoid potentially catastrophic climate change, this does not on its own justify investing in a project that mitigates emissions at a cost of $236 per t$CO_2$e on fund's costs only ($17,894 on total costs) when other transport sector projects can achieve costs as low as $6.73 per t$CO_2$e ($31 on total costs). A similar level of difference in cost-effectiveness is present for energy efficiency projects, with the least cost-effective project costing the funds $71 per t$CO_2$e ($1,000 on total costs) and the most cost-effective costing $0.72 ($70 on total costs).

Innovation, transformation, and dynamic costs

The cost-effectiveness estimates used up to this point are 'static' estimates for single projects: they account for the costs and benefits of the project over a fixed period of operation, including emissions mitigated over the expected life of the project. However, they do not account for any possible effects of investments in the studied project on the cost-effectiveness of future projects using the same technology. These potential spillover effects are important because in seeking to avoid potentially catastrophic climate change what matters is the total stock of emissions in the atmosphere built up over time. Therefore, the cost-effectiveness figure of interest for investments in emissions mitigation should include spillover effects on the cost-effectiveness of future projects.

Gillingham and Stock (2018:pp.13–14) present a useful summary of potential temporal spillover effects for emissions mitigation investments and their impact in terms of reducing future costs of particular technologies. They distinguish between four main sources of spillovers:

1. Gains in production efficiency: Economies of scale and learning-by-doing are significant in reducing the cost of nascent technologies. If mitigation investments employ nascent technologies, these gains should be expected to be non-zero and may be large.

2. Non-excludable knowledge: Not all of the gains from research and development on new technologies are excludable. That is to say, some of the knowledge generated can't be captured by the entity doing the research and development, and they become available to other users of the technology. To the extent that investments in mitigation-related technologies lead to more research and development, this should lead to gains in the effectiveness of the technology and reductions in costs.

3. Network effects: investments in new technologies may create incentives for infrastructure provision in a way that changes the options of future decision-makers. The example Gillingham and Stock give is the way in which buying an electric car stimulates the supply of charging infrastructure, which lowers the effective cost of future electric car purchases by creating a more useful, convenient network.[19] This is a classic network effect in that the more people are using the product, the higher its value to users.

4. State dependence: Investments in energy, in particular, tend to be long-lived, with lifetimes of 20 or 30 years or more on some power plants. For this reason, it might be correct to prioritise currently more expensive mitigation investments if they will crowd out long-lived investments in a technology incompatible with sufficient mitigation over its lifetime. Vogt-Schilb *et al.* (2018) show this to be the case in some situations through their modelling.

There is a further principle which combines with state dependence to underpin the results of Vogt-Schilb *et al.'s* modelling (2018) and which we can therefore add to this list:

5. Adjustment costs: It is much more expensive to try to retrofit all the buildings in a country in three months than it is to spread that effort over three or 30 years. This is because there are increasing opportunity costs to using scarce resources such as workers to perform a particular abatement task. Retrofitting all the buildings in a country in three months or even three years would require an enormous investment in retraining workers from other sectors to perform the work, rather than using the existing workforce or enlarging it only slightly. Economists capture this intuition using the concept of 'adjustment costs.' If an intervention has high adjustment costs, then the cost of the marginal project increases quickly the more projects are attempted in a given timeframe. With zero adjustment costs, all else being equal, the cost of the marginal project will not increase when attempting to complete multiple projects in a given timeframe.

[19] This is a classic network effect in the early stages of EV adoption, where charging infrastructure is not widespread enough to cover all parts of a territory and becomes more widespread with increased EV adoption. It is much less clear that this network effect holds later on, as once coverage is complete the quality of the charging experience depends on how many charging points there are at each station. At this point on the adoption curve, more users might mean a *worse* experience if charging network operators fail to scale the number of charging *points* in the same way they expanded the number of *stations*.

> Consider potential mitigation investments in two sectors, A and B. The best individual project investments in mitigation in sector A cost \$25 per tCO_2e at the current margin but have high adjustment costs. Similar investments could eventually be applied to a large proportion of the sector's emissions which must be mitigated in any reasonable pathway to stable concentrations of CO2e in the atmosphere. An alternative investment in sector B is similarly indispensable in the long run but more affordable in the present at \$15 per tCO_2e, with lower adjustment costs. Vogt-Schilb *et al.* (2018) compellingly demonstrate through modelling that it is rational to invest in the marginal project in sector A first even if the present day cost of mitigation per marginal project in that sector is moderately higher.

These dynamic cost considerations mean that the naïve estimates in the previous section may underestimate the true cost-effectiveness of projects that have desirable effects on future emissions mitigation prices. For example, the mean solar project, costing \$80 per tCO_2e mitigated may be closer in value to the mean hydropower project, costing \$30 per tCO_2e mitigated. This is because solar generation is a much newer technology than hydropower. Indeed, the cost of solar PV generation has decreased enormously over the period covered by these investments thanks to spillovers from earlier investments to later ones (Gillingham & Stock, 2018). Even investments in the same sector with much higher costs per tCO_2e mitigated than others may be cost-effective in light of these considerations given that they are the first of their kind in a country or region. Through network effects, the first wind installation in Thailand or the first geothermal plant in Chile (both CTF projects) may be more cost-effective than they appear in the summary data. This is because the first investment in a technology in a region can contribute to a network of private and public-sector institutions who have made human and physical capital investments in the technology, lowering their costs when considering future similar projects (Bird, Cao & Quevedo, 2019).

In considering business cases for investments, development agencies and multilateral agencies should be explicitly considering these potential future benefits. Whilst any such estimates will be speculative, if they form part of the rationale it would be more useful to articulate that potential than to leave it unquantified. For example, these arguments are stronger for newer technologies, and in areas where they are first adopted – and making these assumptions explicit would enable better resource-allocation. Where the benefits are only 'potential', then it would be prudent to attach a probability to such benefits, as would be the case in business cases dealing with uncertain future events in other fields (like disease outbreaks, or extreme weather events).

Box 2. Quantifying transformational change

The naïve estimates of expected cost-effectiveness we have calculated for CTF and GCF projects do not include these projects' potential transformational effects. This is a limitation of the underlying data, which does not include estimates of those effects. However, if we delve into the documentation for individual projects, potential transformational effects are sometimes quantified.

An example of CTF estimating and quantifying 'potential at scale'

In some cases, the CTF considers the future transformational potential of its projects and this is recorded in CTF project documents. CTF projects are approved on the basis of six criteria including 'Demonstration potential at scale'. For example, in the case of the Chile Geothermal Risk Mitigation Program mentioned above, the project document suggests that although the CTF investment only supports 100MW of geothermal generation in the short term, this investment could demonstrate the potential of geothermal energy and make installation of a further 800MW of geothermal power more likely in the medium term (CTF, 2014:p.14). Assuming similar emissions factors to those that currently apply to Chilean electricity, this would result in 70-145 $MtCO_2e$ mitigated. The project document estimate of 'cost-effectiveness including scale' attributes all of this hypothetical further mitigation to the CTF investment with a probability of 1, rather than adjusting by some probability of success and/or considering what proportion of this capacity might be installed absent the CTF's investment. This seems insufficiently conservative. However, the thinking is quantified in the project document in a way that makes the CTF's process clear. Given this good practice, it should be relatively easy for the CTF to focus only on the most cost-effective investments in future, if that is something that the CTF decides to do.

How should potential for transformational change be reported?

The GCF and CTF currently report headline information for the direct expected mitigation for projects but not the expectations of transformational change that are projected to arise from the project. These potential transformational outcomes are used in decision-making, however, and are sometimes quantified in project-level documentation as seen above. *Such estimates of transformational change could be reported alongside direct mitigation results in the summary data in order to provide a more complete picture of the value of projects funded*. In order to be valuable, these estimates would have to include some reflection of the level of uncertainty surrounding them. This could be reported as a point estimate with a single probability, or as a range of outcomes associated with a range of probabilities. So, for example, for the Chilean investment above the CTF estimates that the project may demonstrate the potential of geothermal energy in Chile in a way that unlocks 70-145 $MtCO_2e$ of mitigation. The CTF don't attach probabilities to these outcomes in the project documentation, but we can invent some for the sake of producing an example. For example, say the probability of this demonstration effect were judged to be 0.5, and the probability of the range of mitigation resultant was estimated at 0.9 at the low end, and 0.1 at the top end. This could be reported as a transformational potential of 70-145 $MtCO_2e$ of mitigation with a probability of 0.45-0.05. Although such estimates are uncomfortably uncertain, and seem falsely precise, if these sorts of thoughts about transformational potential are already being used in decision making, then it is beneficial to the quality of decision making and better for transparency to render them explicit and report them.

The *raison d'être* of the CTF has been to make first-mover investments in young technologies, breaking new ground and changing policies and regulation in developing countries, so some of the difference in cost-effectiveness for CTF projects is certainly attributable to the pursuit of these transformative effects. The same may be true for some GCF projects. *How much* of the difference is difficult for outsiders to interpret without standardising the calculation and presentation of these transformative effects and making them a part of public results datasets.

The arguments presented so far in this subsection give compelling reasons to not take naïve estimates of cost-effectiveness to be reliable guides to the true cost-effectiveness for emissions mitigation projects. However, all of these arguments assume similar orders of magnitude for the costs of mitigation options. Vogt-Shilb et al. (2018) demonstrate that it can be rational to invest $25 per tCO_2e mitigated rather than $15. Gillingham and Stock's (2018) main examples of powerful dynamic cost considerations at work show prices of solar PV falling eightfold in 29 years and the price of batteries declining fourfold in six years. Expectations of transformative change in this sort of range cannot explain the much larger 100x differences in cost-effectiveness between GCF and CTF projects. This is especially true if all the investments in a sector are expected to have similarly transformative impacts. The order-of-magnitude differences in naïve estimates of cost-effectiveness reflected in Figures 8, 9 and 10 are therefore sufficient to ground a conclusion that cost-effectiveness has so far differed enormously between mitigation projects in low- and middle-income countries, even in the same sector.

5. Strong and weak synergies between climate and other development objectives

As well as cost-effectiveness, potential for transformative change, ability to leverage other financing, and other criteria, mitigation-focussed funds and development agencies often target other development objectives as co-benefits and secondary outcomes of their investments. For example, these are the six criteria that guide CTF investments, emphasis added:

a) *Potential for GHG emissions savings*

b) *Cost-effectiveness*

c) *Demonstration potential at scale*

d) ***Development impact***

e) *Implementation potential*

f) *Additional costs and risk premium*

(Climate Investment Funds, 2009:p.3)

Similarly, the Green Climate Fund's third criterion for investment decisions is 'Sustainable development potential' (GCF, 2020b). Examining the least cost-effective mitigation investments of both funds, these appear to have large development impact potential in other areas that may explain their lower cost-effectiveness on pure mitigation.

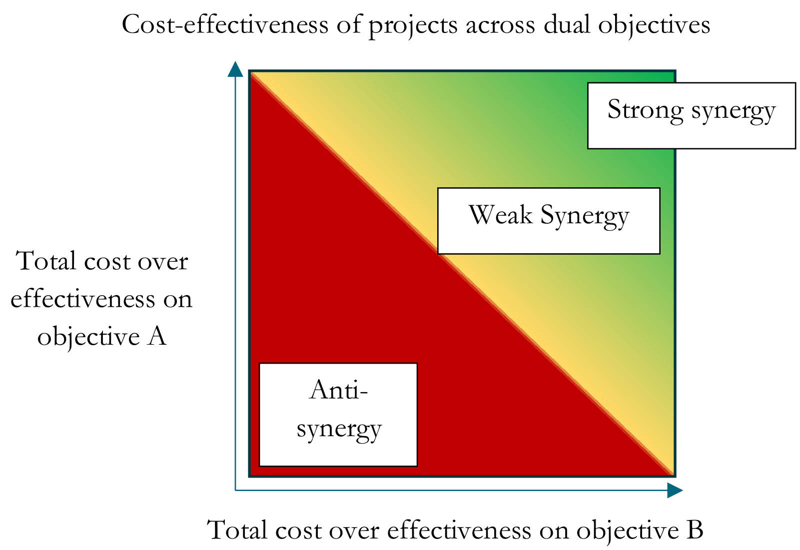
In the subsequent subsections we consider examples from the available evidence on the strength of synergies between objectives.

Box 3. Strong and weak synergies

Synergies between outcomes occur when two or more outcomes can be achieved for less cost together than if they were pursued separately. That is, the cost of achieving A+B is less than that of achieving A plus that of separately achieving B. In a space of possible intervention options, there will be more and less cost-effective ways of achieving A and of achieving B. The strongest possible synergy is when the most cost-effective way of achieving A also happens to be the most cost-effective way of achieving B. For any other case, some reduction in cost-effectiveness on A or B will be required in order to achieve value on the other objective.

In this section we define weak synergies as those which imply a large reduction in cost-effectiveness on one outcome to achieve results on the other outcome. By contrast strong synergies are those which imply little or no reduction in cost-effectiveness on one outcome in order to achieve results on the second outcome. This is a matter of degree, of course. Figure 11 attempts to capture our use of the term.

Figure 11. Strong and weak synergies depicted



Consider a hypothetical forest preservation project. The project is expected to provide mitigation benefits at a highly competitive cost. However, we could imagine a similar project that takes on additional costs in order to have additional benefits for biodiversity. If these outcomes could be delivered for little or no extra cost, then this would put the project in the top-right area of Figure 11. This would represent a strong synergy, where benefits across multiple outcomes can be achieved for little extra cost. However, as the extra cost reached parity with investing in a separate pure biodiversity project, this synergy would become weak and then disappear, pushing the project towards the centre of Figure 11. If making this investment reduced the amount of mitigation the project would achieve by more than it increased the biodiversity gained in cost-equivalent terms, then this would push the project towards the bottom-left area of Figure 11. We would characterise such a project as an anti-synergy or lose-lose.

If both outcomes are equally important to the decision-maker, then the most cost-effective intervention is simply the one that maximises A+B over cost. If one outcome is more important than another to the decision-maker, then they must weight this primary outcome more heavily than the secondary outcome when deciding which intervention to pursue. Symmetrically, if an intervention being pursued is much more cost-effective on one outcome than the other, this implies that the primary outcome is the outcome on which the intervention is more cost-effective, or that factors other than cost-effectiveness have influenced the decision.

Pursuing weak synergies might be an excellent use of resources if projects are very similarly cost-effective on the primary measure of interest, such that reductions in relative cost-effectiveness on that measure are not very consequential. However, if projects are highly varied in cost-effectiveness, then pursuing weak synergies will imply large reductions in cost-effectiveness on the primary measure. This appears to be the case for mitigation interventions in low- and middle-income countries.

Weak synergies and mitigation as a secondary outcome.

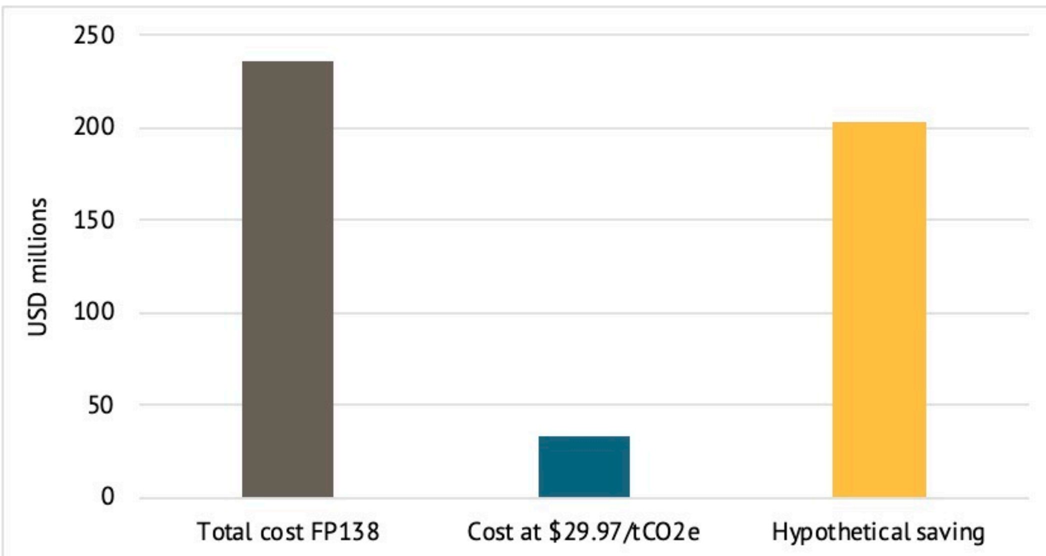
As Box 3 has outlined, weak synergies are synergies which imply a large reduction in cost-effectiveness on one outcome in order to achieve results on the second outcome, or a moderate reduction on both. Lose-lose projects are those for whom pursuing both objectives separately would be cheaper than pursuing them together. When a project is cost-effective on one outcome, but only weakly synergistic with the other outcome, this implies that the outcome on which it is cost-effective is the primary outcome of interest.

The ASER Solar Rural Electrification Project

Consider the ASER Solar Rural Electrification Project, Green Climate Fund project FP138. This $244 million project involves the procurement and installation of solar-powered mini-grids in 1,000 remote Senegalese villages, funds technical assistance for local solar electrification stakeholders, and subsidises energy use through vouchers for the lifetime of the project (GCF, 2020a:pp.64–65). The cost to the GCF per tCO_2e mitigated calculated from GCF reported data is $84.09 ($221.64 on total costs). This makes it the third-least cost-effective GCF project on our naïve measure of cost-effectiveness considering the fund's own costs, or the least effective on total costs. The GCF secretariat's assessment of the project comments that the cost per tCO_2e "could be seen as on the high side compared with some benchmarks" (ibid, p.66). However, it appears from the secretariat's comments that this lower cost-effectiveness was judged to be offset by "significant economic and social co-benefits" (ibid, p.62). These co-benefits stem from the electrification of 1,000 hard-to-reach Senegalese villages including 39,000 households (ibid, p.32).

In order to assess how high a value is implicitly being placed on these development co-benefits by the GCF, we can compare the cost-effectiveness of this project with the most cost-effective projects funded by the GCF or the CTF in the renewable energy generation sector. Looking first at total costs, to permit this comparison, we calculated the 25th percentile of cost-effectiveness on total funding weighted by the total budget of each project. This gives a figure of $29.97 per tCO_2e. We use this figure to generate a realistic best-case estimate for the total cost of mitigation in the sector. We weight this percentile by total project budget in order not to give undue importance to highly cost-effective but small, niche projects. Figure 12 shows the total cost of FP138, the total cost of the same amount of mitigation at the 25th percentile of cost-effectiveness of renewable energy generation projects, and the hypothetical total saving if the same amount of mitigation had been funded at that level of cost-effectiveness.

Figure 12. Hypothetical savings of investing in cost-effective energy generation mitigation versus FP138



Authors' own calculations from GCF data

This hypothetical saving of approximately $200m represents $200,000 per village or $5,205 per affected household. Put another way, investing the same amount of total project financing into averagely cost-effective renewable energy sector mitigation projects would have resulted in almost 7 million (6,774,541) additional tCO_2e mitigated for the same cost; more than six times more total mitigation. It seems difficult to imagine that any effects on the costs of future projects would be sufficient to dramatically change this picture. This is not to say that FP138 is a cost-ineffective solar mini-grid project. At 32MW installed capacity across 1000 mini-grids for $233 million, FP138 costs around $7.37 per watt. This is around average for off-grid PV systems with storage in Africa, but it is a very large capacity at 820 watts per household.[20] The lack of cost-effectiveness on mitigation grounds stems partly

[20] An International Renewable Energy Agency report on solar projects in Africa details cost per watt of installed capacity for implemented projects across the continent between 2011 and 2015 and finds eight off-grid mini-grids with battery storage (Taylor & So, 2016:p.58). These costs range from 2.5 to 13 dollars per watt. Uncharitably, one might expect that economies of scale from developing 1000 systems as well as improvements in technology

from the fact that consumption of energy is very low in these villages; one of FP138's aims is to massively increase that energy consumption through economic development, the "significant economic and social co-benefits" mentioned in project documents. It is possible that the total costs of the system could have been reduced at the expense of more emissions by including diesel and/or biogas generators in a hybrid system (Kumari *et al.*, 2017; Madziga, Rahil & Mansoor, 2018; Oladigbolu, Ramli & Al-Turki, 2019; Yimen *et al.*, 2020, 2018). The project funding proposal does not make clear whether this alternative was considered and whether it would indeed have been more cost-effective on pure electrification grounds or not.

In summary, this project appears broadly in line with the costs of off-grid energy access though perhaps could have done better with or without some increased emissions. On pure mitigation grounds it is highly cost-ineffective. Therefore, the synergy between development and mitigation outcomes is a weak one. The fact that it is a much more cost-effective intervention on the electrification objective than the mitigation objective suggests that the primary objective of this investment is electrification and not mitigation.

The synergy between mitigation and development for FP138 is weak and the primary aim of the project is increasing energy access rather than mitigation. However, these facts do not mean that FP138 is a bad project, nor do they mean that the GCF should not have invested in it. FP138 is a good electrification project with a small but positive secondary mitigation benefit. From a development point of view, then, it is well worth funding. It is possible that many of the projects in the data with a low cost-effectiveness on the total costs measure are in this situation: although they are not cost-effective mitigation projects when considering total costs, they may be cost-effective on some development outcome. For projects like these, where the principle aim of the project is not mitigation, the total costs measure is a bad one because it over-states the cost of the mitigation component of the project. Instead, we should be looking at the fund's own costs measure in this situation, to see whether the mitigation component has been cost-effectively financed. It is possible that a relatively small amount of climate funding was able to unlock the synergy, rendering that investment cost-effective despite the weakness of the synergy.

Unfortunately, in the case of FP138, the amount of financing required from the GCF to unlock the mitigation synergy was disproportionate to the mitigation gained. The median cost to funds of mitigation for renewable energy projects in our data, as weighted by project cost to funds, was \$8.52 per tCO_2e. The 25th percentile on this measure was \$3.01 per tCO_2e. The cost to the GCF for FP138 of \$84.09 per tCO_2e on our fund's costs measure compares very unfavourably.

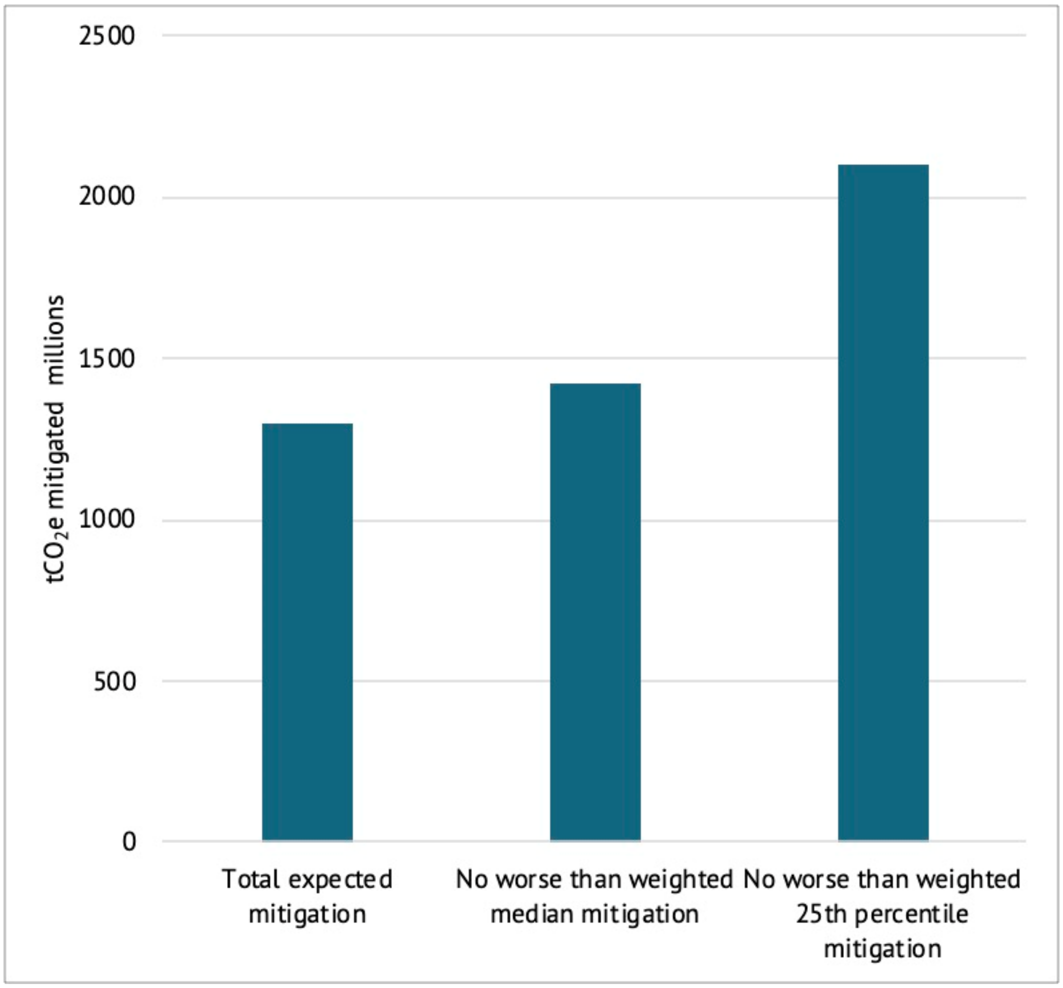
Climate impacts of prioritising cost-effective approaches

Allowing weak synergies such as the synergy with economic development to influence the prioritisation of climate finance-funded projects may have very large climate costs. Consider all GCF or CTF-funded projects in the energy generation sector. We have already seen that the 25th percentile naïve cost-effectiveness estimate for projects on our fund's own costs measure, weighted by total cost, is \$3.01 per tCO_2e mitigated. The median weighted cost-effectiveness is \$8.52. We can consider the hypothetical situation in which all GCF and CTF

since 2013 would mean that FP138 could be expected to beat these figures. However, the project also contains many non-installation components and is working in extremely hard-to-reach villages where costs will be high.

projects to date were delivered at no worse than this average cost-effectiveness. In this first hypothetical scenario, total emissions mitigated would increase by 10 percent, to 1.42 billion tCO_2e, as Figure 13 shows. If all projects were delivered at no worse than the 25th percentile of projects, as weighted by project cost, then total mitigation would rise by 62% to 2.10 billion tCO_2e. Diseconomies of scale might reduce this figure if the funds are proposal constrained. It is not clear whether this is the case or not, though given the order of magnitude differences between the most and least cost-effective projects, these diseconomies of scale should not much reduce the value of improving on the least cost-effective projects.

Figure 13. Hypothetical total mitigation at increased cost-effectiveness for GCF- and CTF-funded renewable energy projects



Authors' calculations using CTF and GCF results data

The amounts in Figure 13 can be helpfully compared to the total greenhouse gas emissions of a medium-sized emitter like the United Kingdom, which emitted 451 million tCO_2e in 2018 (Waite, 2019). An increased focus on cost-effectiveness in an equivalent portfolio going forward, based on the above scenarios, could then deliver mitigation equivalent to between 28% and 178% of the UK's total emissions in 2018. This is just for these two funds, and just in the renewable energy sector. The potential gains in mitigation are proportionally larger across all mitigation funds and across all sectors.

This should not necessarily be interpreted as a criticism of either fund. As we state above, they started from a position of almost no evidence on climate mitigation effectiveness; and both funds have served as a learning lab, experimenting with different approaches to what works in emissions mitigation and adaptation in low- and middle-income countries. They deserve credit for making these estimates and their decision-making available for feedback; and, given the learning potential, other climate mitigation funders should follow suit. Cost-effectiveness has not been the CTF's main goal to date. However, as previously noted, cost-effectiveness is one of the six core principles that govern the CTF's investment decisions. As a recent review of the CTF's operations noted, the CTF and concessional finance for climate change in general is entering a new phase, where many of the approaches to mitigation are no longer novel (BloombergNEF, 2019). In this new phase, across the international financial institutions and development agencies, a higher priority should be placed on cost-effectiveness (quantitatively incorporating the possibility of transformational effects) at the design stage and in the learning outcomes targeted by evaluation.

The hypothetical scenarios in Figure 13 are not intended as a reasonable counterfactual for what emissions mitigation could have been achieved by the two funds in the past. Rather, they are intended to demonstrate the potential benefit of an increased focus on cost-effectiveness in the future, as an experimental stage gives way to a more developed and focussed period of investing ruthlessly where the most difference can be made.

Strong synergies

By contrast with weak synergies, we believe it's helpful to think of 'strong' synergies as synergies the pursuit of which does not imply a large reduction in cost-effectiveness on the primary measure, or indeed increases that cost-effectiveness. For example, according to modelling evidence, some of the most cost-effective mitigation investments in the energy sector involve hastening the decommissioning of coal powerplants or averting their construction through small subsidies to almost cost-equivalent renewable generation projects (BloombergNEF, 2019). These investments have large benefits for air quality and therefore public health over large geographical areas (Strasert, Teh & Cohan, 2019). In this way, there exists a strong synergy between emissions mitigation, air pollution and public health outcomes. This is potentially true not just in the power generation sector but also for many interventions that involve reducing the combustion of fossil or biomass fuels across sectors including domestic burning, industry and transportation. It is a reflection of this strong synergy that IPCC modelling suggests that all cost-effective stringent climate policy scenarios imply large improvements in measures of air quality, as Figure 14 shows.

Figure 14. Working Group III Contribution to the Fifth Assessment Report of the IPCC Figure SPM.6

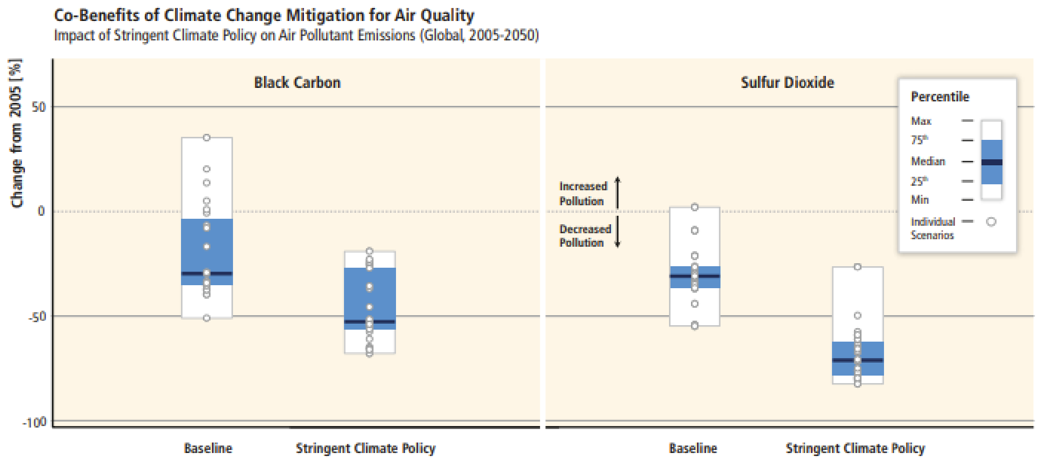


Figure SPM.6 | Air pollutant emission levels for black carbon (BC) and sulfur dioxide (SO_2) in 2050 relative to 2005 (0=2005 levels). Baseline scenarios without additional efforts to reduce GHG emissions beyond those in place today are compared to scenarios with stringent mitigation policies, which are consistent with reaching about 450 to about 500 (430–530) ppm CO_2eq concentrations by 2100. [Figure 6.33]

(IPCC, 2014, p.16)

Epidemiological studies and natural experiments find that reductions in air pollution are associated with very large health benefits. In the US, Pope et al. (2009) find that small decreases in air pollution (10 micrograms per cubic meter of fine particulate matter) were associated with an increase in mean life expectancy of 0.61 years. Chen et al. (2013) find that exposure to high levels of air pollution as a result of burning coal for heating reduced life expectancy for 500 million residents of northern China by an astounding five years.

Considering this strong synergy can reveal a higher social value to many emissions mitigation investments. This could lead organisations to invest more in such projects than they would be able to on mitigation grounds alone, growing the available pool of funds for mitigation interventions. Symmetrically, a consideration of the mitigation benefits of effective air quality and public health interventions like the removal of coal power plants potentially unlocks more funding of use for high-impact air quality and public health interventions. Indeed, West et al. (2013) find that the average modelled co-benefits of avoided mortality from necessary global emissions mitigation are worth \$50-380 per tCO_2e mitigated. These benefits exceed modelled marginal abatement costs in many areas and time periods. They are somewhat concentrated in particular sectors and geographical areas suitable for particular mitigation investments, especially in East Asia. As a result, West et al.'s modelling suggests East Asian co-benefits to mitigation investments are on average 10-70 times the marginal cost of mitigation in 2030. The magnitude of these modelled benefits suggests that, even if the assumptions underpinning the model are faulty, they are unlikely to be so faulty as to undermine the strong synergy between many mitigation investments and public health outcomes.

Similarly, a growing awareness of the importance of biodiversity preservation renders investments in anti-deforestation projects and some other land-use interventions even more attractive than they are on pure mitigation grounds (Dasgupta, 2020). The relationship between emissions mitigation and biodiversity is more complicated than that for air pollution, with some mitigation interventions having negative effects on biodiversity where others have strongly positive effects.[21] However, preventing deforestation and degradation of forest environments, as well as preventing degradation of peat landscapes, are strongly synergistic with biodiversity promotion, implying no extra cost for large biodiversity benefits (Secretariat of the Convention on Biological Diversity, 2009). Other interventions, such as establishing sustainable forestry, have higher economic development and mitigation benefits at the expense of less biodiversity benefits (ibid).

Consideration of strong synergies, then, can achieve extra value from a total societal point of view and grow the pool of available financing for each social objective. For this reason, it should be used to prioritise amongst cost-effective mitigation options. However, as Sections Three and Four have demonstrated, there are very large differences in cost-effectiveness between real-world mitigation projects in recipient countries. In this context, pursuing weak synergies with other development outcomes risks the promotion of projects that are only 1/10 or 1/100 times as cost-effective as the best alternatives. This in turn risks a failure to achieve sufficient mitigation with the limited resources available. Likewise, pursuing development interventions that are weakly synergistic with mitigation may be a poor use of funds compared to concentrating on the most cost-effective intervention options for a given development objective.

If there were a comprehensive literature of impact evaluations of mitigation projects as well as development projects linked to cost data, this would allow us to quantify real-world trade-offs and synergies for development projects across multiple outcomes. It would enormously increase the ability of development agencies and funds to plan to optimise the value of their investments over multiple outcomes in a way that is not currently possible. Unfortunately, as this paper has shown, the cost-effectiveness literature in climate mitigation is much too limited to facilitate this kind of analysis for projects targeting mitigation. With tens of billions of mitigation finance being used, this suggests a more rigorous focus on monitoring and evaluation would have significant benefits for climate mitigation and development alike.

[21] For example, Danielsen et al. (2009), demonstrate the negative biodiversity effects of culturing biofuels and the positive biodiversity effects of preserving extant forests.

6. Conclusion and recommendations

This paper began with a review of the available cost-effectiveness evidence for mitigation interventions available for funding by concessional finance donor institutions. In over 3,700 evaluations relating to development; just eight were tagged with climate mitigation. A 2018 systemic review of economic analyses of climate mitigation found just two that report real-world effectiveness and costs for low- or middle-income countries (Gillingham & Stock, 2018). This lack of impact evaluations of mitigation interventions in developing countries associated with costs data contrasts with other areas of development programming such as public health or education. The evidence base for mitigation interventions is dominated by modelling estimates, which do not model key elements of the real-world operation of projects such as implementation difficulties and behavioural responses. Retrospective impact evaluation is a very powerful tool that provides the best way of learning about the cost-effectiveness of different interventions. It is concerning that this evidence is so lacking for mitigation interventions in developing countries. With tens of billions of dollars of public money being spent on climate mitigation, and in the context of the urgent need to reduce global emissions more quickly than current progress, the first recommendation of this paper follows: **Development agencies and funds should urgently prioritise independent impact evaluation of mitigation interventions and ensure that these evaluations include retrospective costs data.**

Despite the lack of independent evaluation evidence, we find that the modelling evidence for the cost-effectiveness of many interventions is compelling. That is, it seems likely that projects can achieve reductions in developing country emissions at a reasonable cost. Two areas where this is particularly clear is for removing fossil fuel subsidies and implementing carbon pricing, two macro-level interventions available to states. However, the actions available to donors to influence such macro-level interventions are few and very likely to be frustrated by political factors. This motivates our second recommendation: **Where development agencies can support carbon pricing, removing fossil fuel subsidies and other macro-level mitigation policies at home or through multilateral advocacy and technical assistance vehicles, this is likely to offer strong value. The value of bilateral action to support macro-level policies in recipient countries is highly uncertain and can only be assessed on a case-by-case basis considering donor and recipient political circumstances.**

Given the lack of impact evaluations to date, and the long lifecycle of many mitigation projects, prospective estimates of cost-effectiveness from development agencies and funds will often be the most promising source of data for learning about these sorts of interventions. However, funding mechanisms like the UK's International Finance Mechanism do not make public in one dataset the project-level data of this type that is being used for internal purposes. Only two funds were identified that systematically report this information. This leads to the third recommendation of this paper: **Development agencies and funds should systematically report data on emissions mitigated for all emissions mitigation projects, along with costs data for those projects. This should happen ex-ante through reporting funding decisions, during implementation through reporting of interim management information, and ex-post through impact evaluation. As we outline below, this should also incorporate quantified estimates of transformational potential and related uncertainty.**

Fortunately, two large funds do provide project-by-project prospective data on the expected costs and expected mitigation of their funded mitigation interventions. This data, from the Green Climate Fund and the Clean Technology Fund is an island of good practice in an otherwise insufficiently transparent sector. As noted above, other large funds, such as the the EU's Global Climate Change Alliance, and the UN's Global Environment Facility should follow the GCF and CTF's example and provide comparable data. So should bilateral development agencies, who gather such data internally but only make available headline data aggregated over all projects, if that.

Analysing the GCF and CTF data reveals much greater divergence on cost-effectiveness than is predicted by the modelling evidence. Cost-effectiveness within as well as between sectors can differ by one or two orders of magnitude – that is, mitigating a tonne of carbon dioxide (or equivalent) costs under $10 in some cases, tens of dollars in most; but in one sixth of cases costs over $100, and in two cases thousands of dollars per tonne. Similar levels of difference in cost-effectiveness exist whether they are compared over total funding including co-financing, or just over financing provided by the fund itself. Some of this difference in cost-effectiveness may be due to the need to act across sectors and the 'transformational' temporal effects of innovation and adaptation costs. However, these considerations are not sufficient to explain order-of-magnitude differences in cost-effectiveness. The existence of such large differences in cost-effectiveness between projects suggests that a tighter focus on cost-effectiveness could yield substantial benefits. For example, going forward based on past performance, for a portfolio of renewable energy investments similar to the GCF and CTF projects in the renewable energy sector, focussing on cost effectiveness could mitigate extra emissions equal to 178% of the UK's emissions in 2018. This motivates the fourth recommendation of this paper: **In the next phase of mitigation investment, as many of the technologies concerned reach maturity, a renewed focus on cost-effectiveness is necessary. Funds and development agencies should focus on cost-effectiveness to yield substantially more mitigation from the same investment, compared to business as usual.**

We focus in this paper on static cost-effectiveness estimates because these are the estimates reported in the datasets available. Nevertheless, we agree that 'transformational' changes can occur for example through the promotion of rule changes, development and implementation of new technologies, demonstration of potential at scale etc. While a quantified estimate of transformational changes is sometimes given in project documents, these estimates are not associated with a probability of success and are not reported alongside results or expected results data in a way that allows for an aggregated independent assessment. The likely magnitude of such changes is also not sufficient to explain the order-of-magnitude differences in cost-effectiveness observed for mitigation projects to date. This leads to a fifth recommendation: **Transformational potential should be quantified and reported alongside directly attributable mitigation, along with some measure of that transformational outcome's uncertainty. As with static cost-effectiveness estimates, transformational changes should be estimated ex-ante, monitored during implementation, and assessed ex-post as part of impact evaluation, so that projects can be systematically compared.**

We distinguished weak synergies from strong synergies between mitigation and other development objectives. Weak synergies are synergies that imply a large reduction in cost-effectiveness on one outcome in order to achieve results on the second outcome, or a moderate reduction on both. For example, mitigation investments are sometimes only weakly synergistic with economic development, when they are not in outright anti-synergy or trade-off with it. For this reason, focussing on mitigation projects that are synergistic with economic development may lead to much lower cost-effectiveness than a pure focus on mitigation. By contrast, strong synergies are synergies the pursuit of which implies very little reduction in cost-effectiveness on either objective by pursuing the other outcome simultaneously. Such synergies appear to exist between mitigation and public health via increased air quality, as well as between mitigation and biodiversity for some interventions. Given the large cost-effectiveness differences between real world mitigation interventions in low- and middle-income countries, it is especially important to distinguish between strong synergies, weak synergies, and trade-offs between mitigation and other development objectives. This motivates the final recommendation of the paper: **When pursuing multiple objectives, donors should ensure they understand and report the balance of objectives being pursued. Where the mitigation benefits of a development project are only weakly synergistic with the main development aims, extra care should be taken to ensure that climate finance investments are a correspondingly small proportion of total financing.**[22]

[22] In this paper we are exploring mitigation financing by funds whose spend is exclusively focussed on climate outcomes. However, an increasing share of climate finance is being channelled through projects of development agencies that are marked as having a merely 'significant' climate component, rather than projects that are 'principally' climate related. This *may* pose a threat to cost-effectiveness on climate outcomes, at least for mitigation programmes. Not all projects with a 'significant' climate component will represent the pursuit of weak synergies with other development objectives, but it seems likely that many more of them do than for those projects that are 'principally' climate related. More transparency on the balance of objectives pursued would help to clarify whether this is indeed the case or not, as well as being desirable for other reasons. CGD colleagues Calleja (2021) document the increasing share of climate spending made up of projects with a 'significant' climate objective, as well as the weakness of the definitions of 'significant' in use by various climate finance institutions.

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Annex 1. Handling of CTF data outliers

Three projects in the CTF results data had 0 projected lifetime GHG reductions and were excluded as outliers.

Some of the programs with apparently the lowest cost-effectiveness on our naïve measure are outliers as a result of accounting decisions. For example, The Efficient Energy Demand Management in Non-Interconnected Zones-San Andrés, Providencia and Santa Catalina Archipelago Pilot Programme is assessed in the project document as having a cost-effectiveness on the $10 million CIF investment of $71 per tCO_2e mitigated. The total cost of the project is reported in the results dataset as $103.58 million, giving a naïve cost-effectiveness estimate of $735 per tCO_2e mitigated. However, this 'total cost' is a result of counting co-financing that the project documents do not suggest will be used for any of the project activities. Rather, this 'co-financing' has been accounted for because 'Given that the two programs (SAPSC and Pacific coastline) were planned together, we are including here the co-financing figures of the Pacific coastline project. (The indicators and targets correspond only to the SAPSC Program) (CIF, 2015:p.4). Including this 'co-financing' that is not related to project activities artificially increases the total cost, and so this project has been excluded from our results.

A similar accounting decision explains another outlier in the data which has therefore been excluded from the analysis. The CTF-funded Vietnam Distribution Efficiency Project looks cost-ineffective in the raw data with a total cost of $800.4 million and expected lifetime greenhouse gas reductions of 2,691,480 tCO_2e, meaning a total cost of $297 per tCO_2e mitigated. However, the decision has been made to report as 'co-financing' large spends on project components that are not expected to contribute to emissions reductions. The total spend on the project component to which the CTF is contributing, and which is expected to drive all of the emissions reductions attributed is $102.2 million after interest and contingencies, meaning a total cost of $38 per tCO_2e mitigated (World Bank, 2012:p.9). This practice of including finance that is unrelated to the project activities generating mitigation as 'co-financing' is confusing and renders the aggregated CTF data less useful for anyone seeking to learn from it.

Our treatment of two other outliers of a sort should also be clarified. Two CTF projects have anomalous values for 'Expected GHG reductions (lifetime, tCO2)' in the CTF results data available for download from their website. The projects are the Sustainable Urban Transport for Ho Chi Minh City Mass Rapid Transit Line 2 Project and the Ha Noi Sustainable Urban Transport Program. In both cases, the value for 'Expected GHG reductions (lifetime, tCO2)' in the dataset is much lower than the projections in the project documents also available for download from the CTF. In correspondence, the CTF clarified that this was due to an unusual method of calculating the value reported in the dataset, rather than a change in the expected value of reductions subsequent to the project documents being published. Specifically, for these two projects this variable has been populated in the CTF dataset by multiplying the next year's annual target from the most recent reporting period by the lifetime of the project. As both projects are very early in development and annual targets are expected to ramp up steeply each year, this results in a large under-statement in the dataset of the expected GHG reductions resultant from the project. We have been told that these are the only two projects in the dataset for which this unusual method of calculation has been used. For consistency with other entries in the dataset we have calculated expected cost-effectiveness for these projects based on the expected GHG reductions reported in the project document rather than in the multi-project results dataset. This avoids under-stating the expected cost-effectiveness of these projects.

In comments on this paper the CTF have informed us that the Ho Chi Minh City Mass Rapid Transit Line 2 Project has been cancelled and that the Ha Noi Sustainable Urban Transport Program may also be cancelled. We have nevertheless included both projects as the relevant data for our purposes is the ex-ante assessment of project costs and effectiveness at the point of the funding decision. It remains the case that both projects were funded on the basis of the projections for cost and effectiveness included in the data.

Annex 2. Handling of GCF data outliers

Original data collection for GCF projects was carried out by Barker and Mitchell in August 2019. This process was repeated by Juden and Mitchell in August 2020. Subsequent to the first publishing of this report, we were alerted to the fact that some GCF projects publicly available on the website were missing from our data. We updated our analysis in March 2021 to correct this, adding seven missing projects and updating finance and emissions data for older projects that the GCF had published updated data for. We believe the missed projects were not included in earlier rounds of data collection as they did not appear in the results furnished by asking GCF's project page to filter by 'Mitigation' projects. However, we cannot be certain of this.

Four projects were identified in earlier rounds of data collection but were marked by the GCF as 'lapsed' in March 2021. One project was identified in earlier rounds of data collection but its project page was inaccessible altogether in March 2021, giving error code 'Access denied.' These projects were included in the final dataset and in this analysis on the same basis as the included but cancelled CTF projects: this ex ante data about funding decisions is valid for cancelled projects just as it is for completed projects.