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Managing climate change: Challenges related to uncertainty, distributional impacts, technology transfer and transnational governance

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Managing climate change

Challenges related to uncertainty, distributional impacts, technology transfer and transnational governance

PhD Thesis

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«Senyor, – digué l'hoste, – no podria hom estimar lo damnatge que se segueix per malvat princep. L'una raó es per lo mal que fa; l'altra, es pel bé que fer podria, lo qual no fa. I, en així, per mal princep se segueix damnatge en dues maneres, segons que haveu oit.»

R. Llull (1232-1316)

«Je n'ay fait celle-cy plus longue que parce que je n'ay pas eu le loisir de la faire plus courte.»

B. Pascal (1623-1662)

Preface

On the 4th of March of 2016, two dozen PhD students gathered at the Faculty of Science of the University of Copenhagen, for the first session of a PhD course named “the art of scientific writing”. The lecturer, a widely published economist, opened the course with the statement «scientific writing is about storytelling».

Although not a PhD student at the time, I was one of the attendants of the course. I could not help but sympathise with the comment made by a fellow participant, who pointed to the seeming contradiction between “scientific” and “storytelling”. Surely, I thought, good science speaks for itself. Over the following two years, as I gained experience with scientific writing, it became clear to me that my work would not speak for itself unless I made it do so.

Storytelling plays a particularly important role in my thesis. The thesis is built around individual research articles that were designed and conducted independently from one another. This contrasts with what is the norm in theses written under a regular PhD programme, in which each research article, from the outset, is designed as a component of a larger, cohesive whole.

Nonetheless, the research questions explored in each of the articles that constitute this thesis share a common thrust: understanding some of the main obstacles that governments have to overcome in their efforts to manage climate change.

Notwithstanding progress in some areas, several of the fundamental challenges faced by governments persist, and no solutions appear to be in sight. In a most inspiring piece published in 2015, Harriet Bulkeley and Peter Newell point to what, in my view, is the overriding problem: the «prevailing context of neo-liberalism». Vladimir Janković and Andrew Bowman put it in more explicit terms: «the premise of an exogenous material threat as the key policy driver has been relegated to an academic concern [and] justifications for action have become increasingly endogenous to the market [in the form of] opportunities in the so-called carbon economy».

The eight articles that constitute this thesis explore some of the challenges associated with managing uncertainty, reducing (regressive) distributional effects, transferring cleaner-energy technologies and engaging with non-state actors. The «prevailing context of neo-liberalism» referred to by Bulkeley and Newell is disturbingly present at the heart of all these challenges.

The ninth article that I would have liked to include in this PhD thesis is one connecting my findings with the conclusions arrived at by Bulkeley and Newell. As soon as this thesis is out of the way, I intend to write that article.

Acknowledgements

Ahead of writing this page, I felt compelled to conduct a literature review of sorts: reading the acknowledgements written by Mathilde Pedersen, Caroline Schaer and Ulrich Hansen, previous PhD students who had the same supervisor as myself, Ivan Nygaard. Ivan is described as «enthusiastic», «available», «helpful», and «optimistic», and his guidance is hailed as «great» and «truly exceptional». I agree with these qualifiers, and would like to add two more adjectives: “generous” (my thesis required a certain amount of activism) and “patient” (I took some time to find the right framing). Thank-you very much, Ivan, for all your help.

Sincere thanks go to John Christensen and the UNEP DTU Partnership. I am most grateful for having been given the opportunity to complete this thesis.

I would also like to thank my co-supervisor and all the colleagues with whom I wrote the various articles that constitute this thesis. I learnt a great deal from each and every one of them.

Ditte Rytter Krofa and Stefan Røpke guided me through the intricacies of paragraph 15, article 2 of the Danish legislation on PhD theses. With their trademark kindness and efficiency, Pia Riis Kofoed-Hansen and Ghita Hjarne took care of all administrative matters. I am indebted to the four of them.

Family, friends and colleagues encouraged me throughout the process. I thank them wholeheartedly for their support.

I postponed this thesis for You, to be able to give you as much of my time as possible, when You needed my help the most. Now that the thesis is complete, it is only fitting that I dedicate it to You.

Contents

Abstract

The Paris Agreement, under the United Nations Framework Convention on Climate Change, lays out the international community's blueprint for curbing global warming. It is a blueprint articulated around the individual contributions that each party to the Convention is prepared to make, in light of its capabilities and the so-called principle of common-but-differentiated responsibilities. This thesis explores how national governments are responding to the challenges associated with determining the nature and scope of those contributions, and implementing them.

The thesis focuses on four challenges that are common to most, if not all, governments: integrating uncertainty into national-level policies and plans; reducing regressive distributional impacts associated with measures to mitigate, and adapt to, climate change; increasing low income-country access to the technologies needed to curb climate change; and governing climate change transnationally. Each challenge is explored through two articles, thus allowing for a more nuanced analysis.

Limited or no performance requirements for certain aspects of the policy-making process is at the heart of some of the challenges faced by governments. Two examples serve to illustrate this point. First, national-level policy planning relies on projections of greenhouse-gas emissions. For the most, these projections fail to reflect current knowledge with regard to uncertainty management. Minimum quality standards could help reverse this trend, thus increasing the robustness of national policy plans and, indirectly, strengthening the international climate change regime. Second, because climate change governance increasingly involves actors other than national governments – from businesses, to subnational and supranational governmental entities, to non-governmental organisations –, the need to introduce performance requirements extends beyond national governments. Specifically, the Paris Agreement, and subsequent decisions by the parties to the Convention, effectively suggest that non-state actors will help deliver on the goals of the Convention, making up for potentially insufficient delivery by state actors. Irrespective of the ability of non-state actors to live up to these expectations, in most cases their actions are not subject to basic accountability mechanisms. Such lack of transparency, which performance requirements could counter, risks undermining the otherwise sensible goal of harnessing non-state actor ingenuity and resources, to complement state actor action.

In areas where evaluative evidence is available, such as technology transfer or distributional impacts, limited uptake of that evidence in the policy-making process represents a second type of challenge faced by governments. The thesis studies a number of cases in these two areas, and notes avoidable programme-design shortcomings. Reasons for the prevalence of these shortcomings are likely to be structural: policy evaluations struggle to determine counterfactuals and establish attribution, and governance arrangements and regulatory frameworks often need revision.

Resumé

Parisaftalen under FN's klimakonvention fastlægger det internationale samfunds plan for at begrænse den globale opvarmning. Planen er formuleret omkring de individuelle bidrag, som hver part i konventionen er parat til at yde, baseret på den enkeltes evner og det såkaldte princip om fælles men differentieret ansvar. Denne afhandling undersøger, hvordan nationale regeringer reagerer på udfordringerne forbundet med at bestemme typen og omfanget af disse bidrag og på implementeringen af dem.

Afhandlingen fokuserer på fire udfordringer, der er fælles for de fleste, hvis ikke alle, regeringer: integration af usikkerheder i politikker og planer på nationalt niveau; reduktion af regressive fordelingsvirkninger forbundet med foranstaltninger til at begrænse og tilpasse klimaforandringer; øgning af adgang til teknologier, der er nødvendige for at begrænse klimaforandringerne, for lavindkomstlande; og "transnational governance" for klimaforandringer. Hver udfordring udforskes gennem to artikler, hvilket giver mulighed for en mere nuanceret analyse.

Begrænsede eller ingen krav for visse aspekter af den politiske beslutningsproces er kernen i nogle af de udfordringer, regeringer står overfor. To eksempler kan illustrere dette. For det første bygger politisk planlægning på nationalt plan på fremskrivninger af udledning af drivhusgasser. Ofte afspejler disse fremskrivninger ikke den aktuelle viden med hensyn til styring af usikkerhed. Minimumsstandarder for kvalitet kan hjælpe med at vende denne tendens og dermed øge robustheden i nationale politiske planer og indirekte styrke den internationale indsats mod klimaforandringer. For det andet, fordi indsatsen mod klimaforandringer i stigende grad involverer andre aktører end nationale regeringer – fra virksomheder, til subnationale og overstatslige enheder, til ikke-statslige organisationer – strækker behovet for at indføre præstationskrav sig ud over de nationale regeringer. Specifikt antyder Parisaftalen og efterfølgende beslutninger truffet af parterne i konventionen effektivt, at ikke-statslige aktører vil hjælpe med at opfylde konventionens mål og kompensere for potentielt utilstrækkelige indsatser fra statslige aktører. Uanset ikke-statslige aktørers evne til at leve op til disse forventninger er deres handlinger i de fleste tilfælde ikke underlagt grundlæggende ansvarlighedsmekanismer. En sådan mangel på gennemsigtighed, som performancekrav kunne imødegå, risikerer at underminere det ellers fornuftige mål om at udnytte ikke-statslige aktørers opfindsomhed og ressourcer til at supplere staters handlinger.

På områder, hvor der foreligger evaluerende bevismateriale, såsom teknologioverførsel eller distributionskonsekvenser, repræsenterer begrænset anvendelse af dette bevismateriale i den politiske beslutningsproces en anden type udfordring, som regeringerne står overfor. Denne afhandling undersøger en række sager inden for disse to områder og finder undgåelige mangler ved programdesign. Årsagerne til udbredelsen af disse mangler er sandsynligvis strukturelle: evalueringer af politik kæmper med at bestemme "counterfactuals" og etablere "attribution", og regeringsførelse og lovgivningsmæssige rammer har ofte brug for revision.

1. Introduction

The United Nations Framework Convention on Climate Change (hereinafter, the Convention) was adopted in 1992 and entered into force in 1994. Its objective is to «stabilize greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system» (UNFCCC, 1992, p. 4).

In 2009, the parties to the Convention agreed to interpret this objective as a 2°C increase in global mean temperature by 2100, compared to the global mean temperature in pre-industrial times (UNFCCC, 2009). To have a probability greater than 66 percent of meeting this target, global annual emission levels in 2030 should be no higher than 41 $GtCO_2e$ (range: 39-46) (UNEP, 2019).

Assuming that all parties to the Convention deliver on their current emission reduction commitments, the resulting levels of greenhouse-gas emissions in 2030 is expected to fall woefully short of the levels required to meet the objectives of the Convention (Rogelj *et al.*, 2017). Indeed, even under a full compliance scenario, additional emission reductions worth between 12 and 15 $GtCO_2e$ annually would be needed in 2030 to reach 41 $GtCO_2e$ (UNEP, 2019). This shortfall is roughly equivalent in magnitude to the combined annual emission levels of the European Union, the Russian Federation, and the United States of America in 2030, in a scenario in which current policies are extended to 2030 (UNEP, 2017).

The Paris Agreement (UNFCCC, 2015a), adopted in 2015 and effective since late 2016, is the international community's blueprint for achieving the emission reduction levels required in 2030 and beyond, referred to above. The broad implementation provisions for the Paris Agreement (UNFCCC, 2015b) make explicit reference to «technology development and transfer» (*ibid*, pp. 10-12). So-called technology transfer has been a cornerstone of the Convention since its adoption (Metz *et al.*, 2000). Yet, both the research and public policy discourses on technology transfer have been framed around narrow, market-oriented definitions, giving limited consideration to the broader socio-cultural and institutional issues that determine the diffusion of a given technology (Haselip *et al*., 2015).

In addition to "technology development and transfer", Decision 1/CP.21 singles out a number of other enablers for the success of the Paris Agreement, such as "finance" and "capacity building", among others (UNFCCC, 2015b). However, two equally central issues are mentioned in an implicit manner only. These issues are transnational governance and the distributional impacts of climate-change management policies

The transnational nature of climate-change governance has been a reality for at least two decades (Hale, 2016). The Paris Agreement institutionalised this reality, by «[inviting] non-Party stakeholders [...] to scale-up their efforts and support actions to reduce emissions [of greenhouse gases]» (UNFCCC, 2015b, p. 19). As the expectations on non-party stakeholders grow, it is timely to consider the extent to which these expectations are realistic. Indeed, the so-called global stocktake of the Paris Agreement, scheduled for 2023 in its first cycle, will put to the test the extent to which non-party stakeholders can live up to the hopes placed on them.

Equity is «one of the guiding principles» of the Convention (Winkler, 2020, p. 124), and is enshrined as such in the Paris Agreement, which calls for both intergenerational equity and a fair allocation of the mitigation burden across countries.[1] One might argue that equity within the same country and generation is implicit in these calls. Yet, avoiding such negative outcomes requires conscious and sustained efforts, thus suggesting that a more explicit reference to this type of equity would be warranted. Indeed, countering negative distributional outcomes is widely recognised as key to the long-term success of any climate change-management policy. Avoiding regressive distributional impacts would be especially important in the context of «countries [ratcheting] up their ambition to meet the Paris Agreement targets» (Markkanen and Anger-Kraavi, 2019, p. 838).

While transnational governance and distributional impacts are reflected in the Paris Agreement, if somewhat cursorily, uncertainty management is not. Yet, the nature of climate change is such that uncertainty management is inescapable (Morgan *et al*., 1999). In the context of the Paris Agreement, the issue is of especial relevance with regard to nationally determined contributions and, indirectly, the global stocktake referred to above. While acknowledging that the specificities of the latter are yet to be worked out, the guidance available concerning how to integrated uncertainty in nationally determined contributions is arguably insufficient (UNFCCC, 2018).

In this thesis, I explore some of the key policy-related challenges faced by national governments in their efforts to manage climate change. My main research question is this:

Main research question

How are national governments responding to the challenges associated with the implementation of the Paris Agreement?

To shed light on this broad question, I explore two challenges from a national-level perspective (the treatment of uncertainty in policy-making, and the consideration given in policy design to distributional impacts), and two from a global-level perspective (development aid-funded technology-transfer programmes, and non-state actor action). Without claiming to be representative, this selection of four challenges is arguably broad enough to reflect the wide array of policy issues that governments have to consider. Each of the four challenges is treated in two separate studies (Table 1.1), thus allowing for a more nuanced analysis.

Against this background, and to answer the main research question above, I explore four narrower questions, or sub-questions:

Research sub-questions

1. To what extent can the effectiveness of non-state actor actions be assessed and increased?
2. In the context of promoting the transfer of cleaner-energy technologies, to what extent are development aid-funded programmes effective?
3. To what extent is uncertainty incorporated in national-level climate change-mitigation policies and plans?
4. To what extent are national-level strategies to mitigate climate change conducive to avoiding distributional impacts?

Table 1.1 lists the various articles that constitute this thesis. Individually for each of the four sub-questions above, Tables 1.2 to 1.5 synthesise the objectives, conceptual frameworks, research methods and conclusions of the articles associated with each sub-question.

Table 1.1: Articles that constitute this thesis

Article	Reference	Status
1	Szabó, S., Pinedo, I., Moner-Girona, M., **Puig, D.**, Negre, M., Huld, T., Mulugetta, Y, Kougias, I., Szabó, L. and Kammen, D. (2020). Bringing green electricity to low-hanging fruit communities: the way to accelerate to reach affordable and universal energy access. *Nature Energy.*	Submission in early March 2020
2	**Puig, D.** and Bakhtiari, F. (2020). Determinants of successful delivery by non-state actors: an exploratory study. *International Environmental Agreements: Politics, Law and Economics.*	Under review
3	**Puig, D.**, Bakhtiari, F. (2020). A new model for accounting for non-state action. *Climate Policy.*	Under review
4	**Puig, D.** and Bakhtiari, F. (2019). Incorporating uncertainty in national-level climate change-mitigation policy: possible elements for a research agenda. *Journal of Environmental Studies and Sciences 9*(1), pp. 86-89.	Published
5	**Puig, D.**, Haselip, J.A. and Bakhtiari, F. (2018). The mismatch between the in-country determinants of technology transfer, and the scope of the technology transfer initiatives under the United Nations Framework Convention on Climate Change. *International Environmental Agreements: Politics Law and Economics 18*(5), pp. 659-669.	Published
6	**Puig, D.**, Morales-Nápoles, O., Bakhtiari, F. and Landa, G. (2018). The accountability imperative for quantifying the uncertainty of emission forecasts: evidence from Mexico. *Climate Policy 18*(6), pp. 742-751.	Published
7	de Coninck, H. and **Puig, D.** (2015). Assessing climate change mitigation technology interventions by international institutions. *Climatic Change 131*(3), pp. 417-433.	Published
8	Scrieciu, S.Ş., Belton, V., Chalabi, Z., Mechler, R. and **Puig, D.** (2014). Advancing methodological thinking and practice for development-compatible climate policy planning. *Mitigation and Adaptation Strategies for Global Change 19*(3), pp. 261-288.	Published

The remainder of this thesis is structured around four additional sections and three annexes. Section 2 describes the various conceptual frameworks that are relevant to the research question (and sub-questions) listed above. Section 3 describes the research methods applied in the various articles. Section 4 summarises the individual articles. Section 5 presents my conclusions, and a number of suggestions for further work. Annex 1 includes the full text of all individual articles.

Annex 2 lists additional, related publications that I have authored or co-authored. Annex 3 outlines the editorial and stylistic choices that I made when I set off to write this thesis.

Table 1.2: Articles related to sub-question 1

Sub-question 1: To what extent can the effectiveness of non-state actor actions be assessed and increased?				
Article	**Objective**	**Literature and concepts**	**Research method**	**Conclusions**
2	Develop a taxonomy to characterise the determinants of delivery for non-state actor actions focused on adaptation or disaster-risk reduction.	The literature on transnational climate change governance focuses on mitigation (Hale, 2016), as experience with adaptation and disaster-risk reduction is limited. Research on the determinants of delivery by this type of non-state actors is barely taking off (Chan and Amling, 2019).	Questionnaire- and interview-based data collection, coupled with a review of the scientific literature.	The determinants of delivery for non-state actor actions include socio-economic, regulatory and institutional factors that are well outside the sphere of influence of non-state actors.
3	Determine the extent to which the expectations placed on non-state actors, notably with regard to supplementing state action, are supported by the evidence, and suggest alternative governance arrangements, drawing on experience in sectors other than climate change.	The literature on transnational climate change governance characterises the plethora of schemes that have spun over the past three decades (Bulkeley *et al*., 2014). Only recently has criticism begun to emerge about the growing institutionalisation of non-state actors (Michaelowa and Michaelowa, 2017).	Systematic review of the scientific literature and of technical reports, coupled with interview-based data collection.	The expectations placed on non-state actors are not justified by the scant evidence available, which instead points toward a comparatively more modest role for non-state actor action.

Table 1.3: Articles related to sub-question 2

Sub-question 2: In the context of promoting the transfer of cleaner-energy technologies, to what extent are development aid-funded programmes effective?				
Article	**Objective**	**Literature and concepts**	**Research method**	**Conclusions**
7	Assess the extent to which four intergovernmental agency programmes aimed to support cleaner-energy technologies address fundamental technology transfer and diffusion functions, with a focus on innovation.	The literature on sustainability transitions includes various approaches to analyse the mechanisms that make it possible to change from one socio-technical regime to another (Markard *et al*., 2012). Among these, an innovation systems framework has been put forward to study cleaner-energy technology diffusion (Blanco *et al*., 2012). This framework is built around actor roles, innovation "functions", and linkages between actors (Markard and Truffer, 2008).	Secondary data analysis (including both scientific literature and of technical reports), and application of a theoretical framework on "technology innovation".	While all programmes reviewed had a strong focus on technology transfer, they gave limited attention to innovation capabilities with users, government, and universities.
5	Explore the extent to which development aid-funded technology-transfer programmes achieve their objectives, by comparing the in-country determinants of technology transfer with the outcomes of several programmes aimed to promote cleaner-energy technologies.	Anchored in scholarship on sustainability transitions, a stream of the literature analyses barriers for technology diffusion (Painuly, 2001), and studies technology typologies (Nygaard and Hansen, 2015a), and technology barriers (Nygaard and Hansen, 2015b).	Secondary data analysis (including both scientific literature and technical reports), coupled with questionnaire-based data collection.	The key drivers for the adoption of cleaner-energy technologies are outside of the scope of any individual development-aid-funded programme.

Table 1.4: Articles related to sub-question 3

Sub-question 3: To what extent is uncertainty incorporated in national-level climate change-mitigation policies and plans?				
Article	**Objective**	**Literature and concepts**	**Research method**	**Conclusions**
4	Make the case for incorporating uncertainty in the analysis that underpins policy-making for climate-change management, identify gaps in the literature, and suggest a research agenda for the future.	A sub-set of the literature on uncertainty analysis seeks to guide national-level public-policy for climate-change management (Morgan, 2009). Partly anchored in policy evaluation research, this literature is richest on uncertainty quantification, and poorest on the interface between uncertainty analysis and policy design (Morgan *et al*., 1999).	Narrative review of the scientific literature and of technical reports.	Notwithstanding prevailing research gaps, most climate change-mitigation policy fails to incorporate uncertainty to an extent that is commensurate with the current level of knowledge about uncertainty management.
6	Underscore the importance of incorporating uncertainty in emission forecasts, especially when forecasts are used to derive official emission-reduction targets.	The literature on uncertainty quantification reports on techniques such as Bayesian networks, Monte Carlo simulations, or expert judgement (Morgan, 2009). The latter is particularly suitable to explore plausible outcomes in the absence of monitoring data or model outputs (Cooke, 1991).	Structured expert judgement elicitation, and energy-economy modelling.	When the uncertainty associated with future levels of economic output is taken into account, forecasts of plausible future levels of greenhouse-gas emissions span a large range.

Table 1.5: Articles related to sub-question 4

Sub-question 4: To what extent are national-level strategies to mitigate climate change conducive to avoiding distributional impacts?				
Article	**Objective**	**Literature and concepts**	**Research method**	**Conclusions**
1	Calculate high-resolution, geo-referenced estimates of expenditure in energy services, and estimates of up-front and operation-and-maintenance costs of rural electrification systems, to determine the distributional impacts of these systems by fuel type (renewable versus non-renewable).	The literature on cost-benefit analysis is increasingly incorporating the study of distributional effects (Serret and Johnstone, 2006). Although some of the reported applications focus on energy issues, few have targeted rural electrification programmes (Szabó *et al.*, 2011).	Computer-based model of several electrification scenarios, consistent with the Intergovernmental Panel on Climate Change's "shared socio-economic pathways".	Renewable energy-powered electrification is the cheapest option for parts of the unelectrified population worldwide, and it is affordable (although slightly more expensive than diesel-oil) for a smaller share of unelectrified communities.
8	Propose a methodological framework for climate-change management that prioritises approaches that are supportive of development goals, integrate multiples values, and incorporate uncertainty.	Most of the literature on growth models in public policy contrasts utilitarianism with rights ethics (Beinhocker, 2007). Whereas utilitarianism has a long-standing tradition, often articulated through cost-benefit analysis, rights-ethics approaches are in their early days, and thus lack a consolidated theoretical underpinning.	Argumentative review of the scientific literature, coupled with case studies.	Multi-criteria decision analysis can underpin policy-making approaches that overcome the shortcomings of utilitarian public-policy frameworks, not least with regard to preventing regressive distributional impacts.

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Endnotes

1 The so-called nationally determined contributions, which outline party commitments for the near term, are arguably the best channel to introduce equity in the intergovernmental response to climate change. Nonetheless, most national governments are likely to need guidance on how to practically do so (Winkler *et al*., 2018).

2. Research field

This thesis draws upon four main research fields: transnational governance, sustainability transitions, uncertainty analysis, and equity in climate change. In this chapter, I present the specific strands of the literature within each of these fields that are of direct relevance to the thesis. Specifically, the following sections outline how individual concepts and frameworks are applied in the various articles, and how connections between these concepts and framework are established.

2.1 Engaging with non-state actors

While the institutionalisation of non-state action in national and international policy processes continues apace, there is no shared understanding about the characteristics of "non-state actors" or "non-state actor action".[1] Common to most interpretations in the scientific literature are three notions (UNEP, 2015). First, "action" refers to initiatives that contribute to managing climate change, over and above related initiatives led by national governments. Second, "non-state actor" refers to any combination of entities, possibly including national-level governments. Third, national-level governments are not the sole drivers of the "action" undertaken by "non-state actors".

Non-state actor action manifests itself at various geographic scales. Non-state actors working across national boundaries, often referred to as "international cooperative initiatives", have been the subject of extensive research efforts.[2] Such cross-border non-state actor action is a manifestation of transnational governance[3], which has been defined as «networks operating in the transnational sphere [that] steer constituents toward public goals» (Andonova *et al*., 2009, p. 56). Transnational governance interacts with traditional forms of governance, in a so-called polycentric complex, the effectiveness of which is often preconized, even though it remains unproved (Jordan *et al*., 2015).

Possibly influenced by the success of transnational governance in areas other than climate-change management (Hanefeld, 2011), early scholarship assumed that the impacts of a polycentric climate change regime would be largely positive and grow over time (Ostrom, 2010). In line with this thinking, it was argued that a polycentric approach to climate-change management was poised to create more opportunities for experimentation and learning, while building «the mutual trust necessary for improved climate outcomes» (Cole, 2015, p. 115).

Although these claims might be justified, the evidence required to substantiate them is limited (Bulkeley *et al*., 2014). Indeed, recent assessments conclude that the data available is insufficient to quantify the effectiveness of non-state actor actions (Hsu *et al*., 2019), irrespective of whether direct or indirect impacts are considered.[4] Article 3 presents the main findings in the literature on effectiveness of transnational climate-change governance, which touches upon three main topics:

- **Effectiveness benchmarks**. Because effectiveness can be measured against a range of different benchmarks, clarity on the benchmark chosen is essential. Several benchmarks are reported in the literature, including a non-state actor's own set of targets (Widerberg and Pattberg, 2015), an independent (*ibid*) or aspirational target (Dzebo, 2019), or a counterfactual, such as a future situation under a "business as usual" scenario (*ibid*). Irrespective of the benchmark chosen, any measurement of effectiveness will be contingent upon the role that the non-state actor action concerned plays in the prevailing climate change-governance context. When the action fills a governance gap, effectiveness is concerned with the extent to which the public good is delivered (Bulkeley *et al*., 2014). Conversely, in a situation where the action is driven by agendas other than climate-change management, effectiveness is concerned with the extent to which the various agendas at play, not least of all climate-change management, can be made compatible (*ibid*). Finally, Bulkeley and Newell (2015) note that any benchmark used to assess the effectiveness of non-state actor actions ought to include non-climate change co-benefits, if the assessment is to be of relevance to decision makers.

- **Methodological approaches**. Only a handful of methods for assessing effectiveness have been put forward. Echoing earlier scholarship, Widerberg and Pattberg (2015) advocate for a multi-dimensional assessment of the performance of non-state actor actions, structured around three elements: effectiveness, legitimacy and institutional fit. They assess effectiveness as a function of (i) the suitability of the partners in the non-state actor action, given the action's intended outputs, and (ii) the extent to which the required technical and financial resources are available (*ibid*). Chan and Amling (2019, 433) use a similar semi-quantitative model: they assess whether the outputs of a given non-state actor action are consistent with the function(s) that the action in question seeks to deliver, using a set of twelve predefined «functional categories». Examples of functions include knowledge dissemination and policy planning, among others. Finally, Dzebo (2019) develops a method inspired in that by Liese and Beisheim (2014). He maps four determinants of effectiveness, namely actors, processes, institutional design, and context, against the outputs and outcomes (mapping impacts proves unfeasible) of the non-state actor actions analysed. A few other assessments have touched upon effectiveness, albeit indirectly.[5]

- **Orchestration**. The governance of non-state actor action can take several forms, including so-called horizontal, hierarchical and orchestrated governance (Hale and Roger, 2014). From the point of view of studying the effectiveness of non-state actor action, comparatively more research has gone into orchestrated governance.[6] Abbott and Snidal (2009, p. 558) argue that there is an «orchestration deficit», and call for increased reliance on this type of governance regime. Reducing costs and increasing benefits compared to other governance regimes would be the key reasons for such call (Abbott, 2012). In his assessment of the effectiveness of non-state actor actions focused on climate-change adaptation, Dzebo (2019) supports this claim, noting that orchestration is among the key determinants of effectiveness. In their analysis of the so-called Global Climate Action Agenda, Chan and Amling (2019, p. 429) nuance this view, by suggesting that a focus on orchestrating promising (mostly mitigation-focused) actions may have led to «neglect of underperforming actions—many of them adaptation actions in developing countries». In a similar vein, Bäckstrand and Kuyper (2017, 785) report that orchestration entails «democratic shortfalls» associated with (limited) participation and accountability, thus reducing the effectiveness of orchestration as a governance regime.

Article 3 analyses the significance of the above findings with regard to the role that the Convention has given to non-state actors. Drawing on this analysis, and inspired on evidence from transnational governance in areas other than climate change, Article 3 puts forward a possible new model for accounting for non-state actor action.

Article 2 develops a taxonomy for assessing the likelihood that non-state actors deliver on their objectives. The taxonomy is based on data collected from a selection of non-state actor actions focused on climate-change adaptation and disaster-risk reduction, and thus may only apply to this type of actions. The data was collected using two complementary survey forms, coupled with interviews. The content of the survey forms reflects the issues raised in the literature on non-state actor action effectiveness (see above). Specifically, the survey forms collect information related to both the enablers of, and barriers to, delivery documented in the literature. Examples of the former include the existence of a permanent secretariat, or the convening power of the core partners (Chan and Amling, 2019 ; Dzebo, 2019); examples of the latter include the extent to which there is overlap with state actor action, or the degree to which the partners in the action boast the required technical and coordination skills (Widerberg and Pattberg, 2015). Given the claim that indirect impacts by non-state actors may be more important than direct impacts, the analysis includes two types of often-mentioned potential indirect impacts: ability to trigger complementary action by state actors, and ability to raise additional private-sector funding.

The resulting taxonomy is compared with three sets of criteria documented in the literature, which were developed in a semi-empirical fashion. Article 2 provides an empirical counterfactual to these three sets of criteria, and highlights that "effectiveness" covers a broader range of issues, compared to the range reported in the literature.

2.2 Transferring cleaner energy technologies

The Intergovernmental Panel on Climate Change defines "technology" as «a piece of equipment, technique, practical knowledge or skills for performing a particular activity» (Metz *et al*., 2000, p. 460). Further, it defines "technology transfer" (from high-income to low-income countries) as «the broad set of processes covering the exchange of knowledge, money and goods amongst different stakeholders that lead to the spreading of technology for adapting to or mitigating climate change» (*ibid*).

The sustainability-transitions framework seeks to interpret both the nature and the scope of the "broad set of processes" referred to in this definition (Markard, Raven and Truffer, 2012). Although developed in a European Union context, the sustainability-transitions framework is increasingly being used in studies related to climate change-management in low-income countries (Hansen *et al*., 2018). Examples of such studies include an assessment of the suitability of the framework to the socio-economic and institutional realities of low-income countries (Ramos-Mejía *et al*., 2018), and a review of the role of national policies in accelerating cleaner-energy transitions in an African country (Bhamidipati *et al*., 2019), among others.

Among the various approaches to sustainability-transitions thinking, Markard, Raven and Truffer (2012) single out four:

- **Transition management** is «a governance approach […] that discriminates between different types of governance activities that influence long-term change [and] can be used both to analyze and to structure or "manage" ongoing governance processes in society» (Loorbach, 2010, p. 163).
- **Strategic niche management** is an approach aimed to facilitate the introduction of more sustainable technologies through the creation of so-called technological niches, namely «protected spaces that allow the experimentation with the co-evolution of technology, user practices, and regulatory structures» (Schot and Geels, 2008, p. 537).
- **Multi-level perspective** is a framework that «conceptualizes overall dynamic patterns in socio-technical transitions» (Geels, 2011, p. 26), understood as the major shifts in «technology, policy, markets, consumer practices, infrastructure, cultural meaning and scientific knowledge» (Geels, 2012, p. 471) that are inherent to the introduction of a new technology.
- **Technological innovation systems** is an approach that can be used to explain how a technology is created, used and diffused as a result of the interactions among a range of actors, and taking into account the specific societal and regulatory context in which these actions are embedded.

The technological innovation systems approach, which is used in Article 7, draws on systems-innovation research (Malerba, 2002), and industrial-economics research (Weber and Truffer, 2017). The approach is structured around three elements, namely technologies, actors and institutions. "Actors" refers to businesses (or business sub-units), governmental and non-governmental agencies, research entities, and individual technology users, for example (Markard and Truffer, 2008). Institutions refers to laws and regulations, socio-cultural and technical norms, and shared expectations, for example (*ibid*). According to this approach (Bergek *et al.*, 2008), innovation is accomplished through the fulfilment of seven functions: (i) knowledge development and diffusion, (ii) influence on the direction of search, (iii) entrepreneurial experimentation, (iv) market formation, (v) legitimation, (vi) resource mobilisation, and (vii) development of positive externalities. Formalising innovation-related functions in such an explicit manner makes it possible to identify weak aspects in the technology innovation system (*ibid*).

Drawing on the technological innovation-systems approach, Article 7 assesses the extent to which innovation is promoted in the context of four development aid-funded programmes aimed to transfer cleaner-energy technologies to low-income countries. The framework maintains the elements outlined above, namely technologies, actors, institutions and functions. For each of the four programmes analysed, Article 7 investigates whether (i) the innovation capacities of key actors are developed, and (ii) the various functions are performed. In an effort to be comprehensive, the actors considered are: the financial sector, users and consumers, government, research institutes and universities, and companies and entrepreneurs. The functions considered are those proposed by Bergek and colleagues (2008), namely knowledge development, resource mobilisation, market formation, influence on the direction of research, legitimation, entrepreneurial experimentation, and development of external economies.

Article 5 is also anchored in the literature on technological innovation systems and sustainability transitions more broadly. Specifically, the article draws on two concepts introduced in earlier studies: technology typologies (Nygaard and Hansen, 2015a), and technology barriers (Painuly, 2001 ; Nygaard and Hansen, 2015b). For a number of low-income countries, Article 5 identifies barriers to, and enablers of, technology transfer. By drawing conclusions on the effectiveness of development aid-funded programmes with regard to promoting the transfer of cleaner-energy technologies, the analysis in Article 5 adds to related literature on the role of development aid in fostering sustainability transitions (Hansen and Nygaard, 2013 ; Wieczorek, 2018).

2.3 Managing uncertainty

In the context of this thesis, "uncertainty" refers to «a state of incomplete knowledge that can result from a lack of information or from disagreement about what is known or even knowable» (IPCC, 2014a, p. 128).[7] Such a broad scope calls for a taxonomy that facilitates the study of all issues of relevance. Article 4 puts forward a possible taxonomy, structured around five sets of policy-relevant actions:

- **Characterising uncertainty**. As a first step, the sources of uncertainty that are relevant in a given context need to be identified and described. A conceptual framework can make this task easier, by providing an overview of all potential sources, and categorising uncertainties by type (epistemic versus stochastic versus ambiguity) and level (from "shallow" to "deep" uncertainty). One such frameworks exists, which can be used in the context of model-based analyses to characterise uncertainty (Kwakkel *et al.*, 2010). However, not all analyses of uncertainty are based on (computer-supported) models: some are structured around qualitative scenario-building approaches. A framework catering to the latter approach is currently missing.

- **Reducing uncertainty**. In some situations, notably when uncertainty stems from ambiguity, uncertainty can be reduced without having to resort to large investments in additional research (Fleming and Howden, 2016). In these situations, and although there is no single approach for reducing uncertainty, it is possible to generalise certain "good practices" that are applicable in specific contexts. For example, Montibeller and von Winterfeldt (2015) put forward a protocol for reducing uncertainty in applications of multi-criteria decision analysis. Similar protocols for other decision-support tools, notably cost-benefit analysis, are not available.

- **Quantifying uncertainty**. At the global and supranational levels, efforts to quantify the uncertainty ranges associated with estimates of future levels of greenhouse-gas emissions go back at least three decades. As a result, a suite of techniques are available (Katz, 2002), which today are well-established. The opposite is true for the national and subnational levels: experience is limited and, although some guidance is available (Morgan, 2009), the techniques reported remain generic. Arguably, the techniques currently used should be developed further, to facilitate analyses targeting a specific sector (for example, electricity generation) or a specific decision-support tool (for example, cost-benefit analysis).

- **Communicating uncertainty**. Efforts to characterise, reduce and quantify uncertainty are futile if the results of these efforts are not communicated to the public in general, and decision-makers in particular, in a manner that suits their specific needs. This is seldom the case, and reversing the situation will require changes in the way scientists interact with the public and with decision makers (Fischhoff, 2012). Fischhoff and Davis (2014) have developed a protocol that can guide such transition. However, awareness about the need to communicate uncertainty appears to remain very limited, as evidenced but the lack of documented uses of this protocol or, indeed, any other related efforts.

- **Integrating uncertainty into policy**. Focusing on Swedish policy-making for climate-change management, Knaggård (2014) explores whether uncertainty analysis is incorporated into policy. Perhaps unsurprisingly, given the overview provided in the preceding paragraphs, her findings are mostly in the negative. The literature includes no attempts to conduct similar analyses, or protocols to guide such attempts.[8]

Among the five categories above, uncertainty quantification has received most attention (Morgan, 2009), possibly because it is the research area that is more amenable to direct application. Because the time horizons considered and, to a lesser extent, the determinants of uncertainty vary so much (IPCC, 2014b), research on uncertainty quantification can be divided according to whether it focuses on the global and supranational contexts, or the national and subnational contexts.

At the global and supranational levels, research on uncertainty quantification is dominated by developments around so-called integrated assessment models (Stanton *et al*., 2009 ; Farmer *et al*., 2015). By allowing for out-of-equilibrium dynamics, and introducing bounded rationality, among other features, so-called agent-based models would reflect uncertainties better, compared to integrated assessment models (Nay *et al*., 2014 ; Lamperti *et al.*, 2018). In light of this, and in the context of the regular assessment reports by the Intergovernmental Panel on Climate Change, calls have been made to replace integrated assessment models with agent-based models (Stern, 2016).

At the national and subnational levels, research on uncertainty quantification is increasingly focusing on the extent to which, collectively, the emission-reduction commitments by parties to the Convention are sufficient to meet the goals of the Convention.[9] This research relies on computer-based models, notably integrated-assessment models and energy-system models[10], which have developed relatively little over the past two decades (Stern, 2016). However, model input data and, more broadly, analytical paradigms are evolving. For example, Benveniste and colleagues (2018) run Monte Carlo simulations on twenty national-level economic-growth scenarios, articulated around the five socio-economic pathways used in the latest assessment report by the Intergovernmental Panel on Climate Change. Article 6 takes a somewhat similar approach, in the sense that it uses probabilistic estimates of likely future growth rates in gross domestic product.

Indeed, over the last five-to-ten years, reliance on probabilistic methods has been gaining ground (Rogelj *et al*., 2013). The use of expert judgement elicitation in Article 6 falls within this wave of research. For variables the value of which can be expressed as a continuous function, expert judgement elicitation makes it possible to quantify the uncertainty around plausible future levels of the variable of interest, which in turn can be used as input to computer-based models (Morgan, 2009). Specifically, so-called structured expert judgement uses a more advanced treatment of the individual experts' judgements, compared to other types of expert judgement elicitation (Cooke, 1991). Although analytically demanding, the use of expert judgement elicitation, and probabilistic methods more generally, makes it possible to reflect uncertainties in a more robust manner, compared to deterministic methods (Puig, 2015). Not least, country-specific analyses provide more robust estimates, compared to more generic, multi-country analyses (*ibid*).

2.4 Managing distributional impacts

In the context of this thesis, "distributional impacts" refers to the relative distribution of the costs and benefits of a given action across income groups in a community.[11] In a climate change-management context, the notion of distributional impacts has most often been studied through the lens of equity (Tol *et al*., 2004).[12]

Applied research on the distributional impacts of climate change-management policies can be categorised according to its geographic scope: supranational, national and subnational. At the supranational level, the equity implications of intergovernmental agreements are the main subject under study. This literature draws on economics, philosophy and political science, among other disciplines. Most national-level studies are anchored in public-policy theories, and focus on two main issues: the trade-offs associated with reducing the (regressive) distributional impacts of policies, and how decision-support tools may be of help in assessing these trade-offs. Finally, subnational-level research explores, often quantitatively, a specific investment's relative distribution of costs and benefits across income groups. In a climate-change context, most of the subnational-level literature targets power generation and agricultural-support programmes.

Supranational level

Focusing on the supranational level, Markandya (2011) examines options to incorporate equity in the outcomes of international climate-change negotiations. He reviews the two main strands in the literature, namely utilitarian and rights-based approaches, to find that few of the proposals made have an ethical basis (*ibid*). He claims that, among the few proposals that reflect ethics, reaching an equal per-capita allocation over 25-to-35 years, although imperfect, may be the most satisfactory proposal of all (*ibid*). He goes on to suggest that uncertainty can be used «as a frame» for considering distributional impacts, in light of inter- and intra-generational differences in income levels and the magnitude of the impacts borne (*ibid*, p. 1056). Exploring the same theoretical space, other authors zoom in on one specific policy instrument, such as cap-and-trade programmes,[13] or a given policy-design issue, notably the discount rate.[14]

Regrettably, research appears to not have translated into policy. Examining the full set of national-level commitments that make up the international response to climate change, Robiou du Pont and colleagues (2017, p. 43) find that, when screened against five «equity approaches», low-income country commitments are more ambitious than those of their high income-country counterparts.

National level

At the national level, managing distributional impacts amounts to incorporating ethics into a public policy paradigm that, at present, continues to be dominated by traditional (neoclassical) economic thinking (Barker, 2008). Scholarship in this area falls under one of two main strands:

- Studies that consider the ethical implications of policies and plans for climate-change management. Stern (2014) explores these implications in the context of national-level emission quotas or "budgets". He concludes that such an approach «is likely to lead to policy impasse and inaction [which] is the most inequitable outcome of all», and suggests that a framing around «'equitable access to sustainable development' […] recognizes the importance of ethics, the dynamic nature of the necessary economic transformation, and is more likely to lead to agreement» (*ibid*, p. 496).
- Studies of modelling approaches that are amenable to taking ethics into account, alongside economic, environmental, financial and other consideration.[15] For example, Doukas and Nikas (2020) review three alternative approaches, namely portfolio analysis, multi-criteria decision analysis and fuzzy cognitive maps. They find that, when it comes to uncertainty and distributional impacts, multi-criteria decision analysis is potentially better suited than all other options (*ibid*).

Article 8 engages with the literature on global- and national-level studies sketched above. It does so by putting forward a methodological framework that builds upon three of the aforementioned streams of research. First, in its theoretical underpinning, the framework is consistent with the emerging body of literature that seeks to integrate ethics into the decision-making paradigms of national governments, which continue to be dominated by utilitarian, representative-agent modelling approaches.[16] Second, the framework brings together (i) global-level policy questions, such as the effect of the choice of discount rates on distributional impacts, and (ii) the national-level decision-making paradigms referred to in the previous sentence. Third, the framework includes a generic decision-support tool, based on multi-criteria decision analyses, which is intended to facilitate the practical application of the framework.

Ultimately, Article 8 has one main added value: it translates specialised concepts and debates into notions that are usable by practitioners. To do so, choices had to be made with regard to ethical issues (notably, discounting) and methodologies (multi-criteria decision analysis). Arguably, these choices help propel the debate, by putting forward specific proposals that researchers can engage with in a more direct manner, compared to other, more generic or theoretical scholarship.

Subnational level

As noted above, at the subnational level most research on the management of distributional impacts is issue-specific. Providing access to electricity to rural communities in low-income countries is one of these issues: the choice between fossil- versus renewable energy-fuelled electricity generation entails trade-offs in terms of cost, time horizons, emissions of greenhouse-gases and, crucially, affordability by users.

A handful of studies have considered the trade-offs between greenhouse-gas emission levels and the pace, scale and cost of an electrification programme. These studies reach seemingly contradicting conclusions. For example, focusing on India, Pachauri (2014) finds that rising electricity access rates would have little impact on greenhouse-gas emissions.[17] However, other studies reach different conclusions (see, for example, the assessments by Moss and Leo [2014] and Dagnachew and colleagues [2018]).

Using a highly disaggregated geo-referenced dataset, Article 1 studies affordability by users in all countries in sub-Saharan Africa and Asia where rural electrification is limited. This approach complements the scholarship referred to above by providing bottom-up estimates of costs, time horizons, and greenhouse-gas emissions, which are more detailed and robust than previous estimates. Not least, Article 1 goes beyond existing research by identifying the communities for which renewable energy-fuelled electrification is the cheapest option, even in situations in which fossil-fuelled electrification is relatively inexpensive. This makes it possible to map out the areas in which electrification programmes could focus entirely on renewable energy.

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Endnotes

1 "Institutionalisation" refers to the adoption of decisions and resolutions, notably within international governmental fora but also at the level of national governments, by which non-state action is expected to contribute to meeting the goals of the Convention, supplementing state action.

2 This interest responds to the expected larger impact attributed to such actions, compared to that of non-state actor actions localised in a narrower geographic setting (Bakhtiari, 2018).

3 Transnational governance is linked to the globalisation trends initiated nearly fifty years ago, partly spurred by the liberalisation in international financial markets that took place at that time (Höhne *et al*., 2016).

4 Direct impacts refers to climate-change management actions that are additional to those provided by state actors, whereas indirect impacts refers to catalytic actions such as providing information or finance in ways that support the work of state actors.

5 Michaelowa and Michaelowa (2017, pp. 131) state that «[as] it is too early for an evaluation of [the effectiveness of non-state actor actions], we focus on their design and the direct mitigation benefits that can be expected thereof». Specifically, they screen non-state actor actions against three "design criteria": the extent to which (i) explicit targets have been set; (ii) incentives are available; and (iii) monitoring, reporting and verification procedures have been adopted. Arguably, their results provide a measure, if only indirect, of the effectiveness of the non-state actor actions analysed.

6 In its Supplementary Information Note 1, Article 2 sketches the concept of orchestrated governance:

> «Orchestrated governance implies a decision-making process in which a governmental entity, be it a national government or an international organisation, catalyses the development of a nonstate actor action. They do so by reducing transaction costs, or mistrust among partners, or by assisting weaker partners. As soon as the non-state actor action is operational, the governmental entity pulls out, or plays a role similar to that described under 'horizontal governance'.»

7 Lack of information stems from (i) unpredictable variability in the system under study, or (ii) incomplete knowledge about that system (Kwakkel *et al*., 2010). Disagreement stems from ambiguity, which can be intentional, or associated with (unintended) flaws in the knowledge-production process or in the decision-making process (Fleming and Howden, 2016).

8 Article 3 (Table 1 in Section 1) represents one notable exception, in that the Mexican government used the outcomes of that research to define the country's greenhouse-gas emission-reduction targets. Nonetheless, only some elements of the research were used – the central value of our projections of gross domestic product growth

rates. This choice can be seen as undermining the overall goal of the research, which called for using probabilistic projections (as opposed to any individual point estimate).

[9] The Paris Agreement constitutes the implementation blueprint for the Convention. The Agreements calls on all parties to put forward individual emission-reduction commitments, as part of their so-called nationally-determined contributions to implementing the Convention (UNFCCC, 2015). Some of these commitments are expressed in quantitative terms.

[10] For example, Fawcett *et al*., (2015) and Rogelj *et al*., (2016) use integrated assessment models, whereas den Elzen *et al*., (2016), Vandyck *et al*., (2016) and Rogelj *et al*., (2017) use energy-system models combined with macroeconomic general-equilibrium models.

[11] It is worth noting that, in addition to income, the concept of distributional impacts is relevant to a number of other parameters, such as ethnicity, age and geographical distribution, among others (Johnston and Serret, 2006).

[12] Klinsky and colleagues (2017) claim that equity should be a core component of all climate-change research. Subjective as it may be, the statement gives a measure of the stakes in the debate about distributional impacts.

[13] For example, Méjean and colleagues (2015) examine cap-and-trade programmes. They claim that a broadening of development policies, to include climate-change concerns, could reduce distributional impacts across countries and generations (*ibid*).

[14] For example, Caney (2016, p. 53) explores the «normative force of the considerations that are employed to determine the social discount rate», in light of the importance that discounting has with regard to distributional impacts. His findings caution against delaying action on climate change, with the sole exception of discounting framed around so-called growth-discounting considerations (*ibid*).

[15] There is broad agreement about the limitations of the main modelling approaches used thus far to underpin the planning of national-level policies to manage climate change (Stern, 2016).

[16] On this topic, a review (in two parts) by Nicholas Stern and an editorial essay by Terry Barker provide a good overview of both the rationale for, and the main findings in, this burgeoning field of research:

Stern, N. (2014). Ethics, equity and the economics of climate change paper 1: science and philosophy. *Economics and Philosophy, 30*(3), 397-444.

Stern, N. (2014). Ethics, equity and the economics of climate change paper 2: economics and politics. *Economics and Philosophy, 30*(3), 445-501.

Barker, T. (2008). The economics of avoiding dangerous climate change. An editorial essay on The Stern Review. *Climatic Change 89*(3-4), 173-194.

[17] In line with this finding, a global-level study by the International Energy Agency reports that universal electricity access by 2030 would increase carbon-dioxide emissions by a mere 0.7 percent (IEA, 2017).

3. Research methods

The articles that constitute this thesis rely on seven main research methods (Table 3.1): three types of literature reviews, expert judgement elicitation, computer-based modelling, interviews and surveys, and secondary data analysis. With the exceptions of articles 5 and 6, a single method dominated the design and implementation of the research in each article.

Collaboration with teams in a number of European research centres made it possible to implement some of these methods, notably computer-based modelling and expert judgement elicitation. Similarly, the topics studied required contributions from researchers specialised in a variety of disciplines, ranging from economics, to political science, to engineering.

Table 3.1: Overview of research methods, by article

	Articles							
	1	2	3	4	5	6	7	8
Literature review								
- argumentative								●
- narrative		•		●				
- systematic			●					
Quantitative methods								
- expert judgement						●		
- modelling	●					●		
Qualitative methods								
- interview and survey		●	•		●			
- secondary data analysis	•				●		●	

Key: ● major role ; • complementary role

The remainder of this chapter outlines the approach followed to apply the research methods listed in Table 3.1 above. Details concerning the specific methodology used in each article can be found in the articles themselves. The following paragraphs present the rationale for choosing a given method and implementation approach, and the merits of using a combination of methods, wherever relevant.

3.1 Literature review

Four of the articles that constitute this thesis rely, to a greater or lesser extent, on reviews of the literature (Jesson *et al.*, 2011). Article 3 is a systematic review of the literature on the effectiveness of non-state actor action; Article 4 is a narrative review of the literature on applied uncertainty management; and Article 8 is an argumentative review of the literature on the analytical paradigms that underpin national-level policy plans for the management of climate change. The research reported in Article 2 relied on a narrative review of the literature on non-state actor action, which informed the design of the interview questions and survey forms applied, which were the main methodological tools used in Article 2.

Systematic review

The systematic literature review presented in Article 3 seeks to shed light on the following research question: to what extent is it possible to assess the effectiveness of non-state actor action? A somewhat restrictive set of criteria was used to query the peer-reviewed literature, and identify an initial set of seventeen documents, from which eight documents (seven articles and one book chapter) were finally selected.[2] Through backward and forward snowballing, nine more documents were identified (six articles, one book chapter, and two books). With the use of qualitative data analysis software (Atlas.ti 8), five overriding issues quickly became apparent, around which the review was structured (Miles *et al*., 2014).

The results of the review were conclusive: the empirical evidence is insufficient to assess the effectiveness of non-state actor action. Indirectly, this finding suggests that the growing institutionalisation afforded to non-state actors is hard to justify. These results were expected. Indeed, they motivated the choice of methodology: it was felt that a systematic literature review would be the most appropriate type of review with regard to backing this kind of findings (Booth *et al*., 2016).[3]

Narrative review

Article 4 provides an overview of the literature on uncertainty management in the context of national-level policy planning for climate-change management.[4] To prepare this overview, a narrative review of the literature was conducted (Jesson *et al*., 2011). Twelve search strings were implemented, with a view to identifying relevant documents.[5] In all instances, search results included over one thousand hits. Alternative search strings providing a smaller number of seemingly comprehensive results could not be identified. In light of this, as a first step, only the documents that appeared in at least nine searches were selected.[6] Drawing on this core group of documents, through backward and forward snowballing, additional relevant documents were identified. Reiterating this process with the newly identified documents, the twenty-four documents referenced in the article were considered for the review.

A narrative review (*ibid*) was chosen because identifying gaps in the literature was the main goal of Article 4. To do so, a framework or, at the very least, a comprehensive breakdown of all the issues of relevance was needed. Two possible frameworks were tested, which proved inadequate.[7] As a result, qualitative data analysis software (Atlas.ti 8) was used to facilitate the process of identifying connections between the various salient issues. This analysis resulted in a stylised taxonomy of all the steps one might consider when analysing uncertainty – from first to last in a temporal scale – around which the review of the literature was structured.

Argumentative review

Article 8 puts forward a methodological approach for use in policy planning in the area of climate-change management. This approach is informed by an argumentative review (*ibid*) of selected literature on the economics of climate change, namely the work of authors who question the dominant neoclassical paradigm and contend that economics should integrate moral-philosophy considerations.

The departure point for the review was an article by Dietz and Stern (2008): through backward and forward snowballing, a set of references were identified, on which the review was based. The main inclusion criterion was: "relevance to the development of an applied methodology for planning climate-change policies".

As suits argumentative reviews (*ibid*), supporting an argument that had been established from the outset (in this case, the need for economics to integrate moral-philosophy considerations) was the main objective of the work. For this reason, no statistical treatment of the selected articles was conducted, nor did the work involve any attempt to include all documents that met certain quality criteria, as would be the case in a systematic review. Instead, the review sought to report the most up-to-date and authoritative views on the various issues that were of relevance to the development of the methodological approach put forward in Article 8.

Because multi-criteria decision analysis is a key component of the methodological approach, a parallel effort was undertaken to include related literature. In this case, a book by Belton and Stewart (2002) was used as the departure point for selecting literature (again, through backward and forward snowballing).

3.2 Expert judgement

One of the articles that constitute this thesis used expert judgement to quantify the uncertainties associated with projections of greenhouse-gas emissions in Mexico (Meyer and Booker, 2001). Experts were asked to provide probability distributions for (i) future growth rates of gross domestic product and (ii) oil and gas prices in Mexico. The probabilistic estimates thus obtained were used as input to a computer-based energy-economy model (Callonec *et al.*, 2013), from which projections of greenhouse-gas emissions were obtained. To avoid redundancies, hereinafter the discussion focuses on gross domestic product only.[8]

Model-based projections of gross domestic-product growth-rates are routinely calculated, albeit for time horizons spanning no more than six to twelve months. Since the projections of interest referred to one decade (and longer) hence, the study could not rely on model-based projections. For this reason, eliciting expert judgement was the approach chosen. Simply stated, the rationale of expert judgement elicitation is that estimates by experts (i) reflect the knowledge of the various expert involved and (ii) synthesise the evidence available. This practice is common in a wide range of areas, when monitoring data is not available and modelling tools are inadequate. The extent to which any one expert can meaningfully assess likely future trends for a highly uncertain variable such as gross domestic product remains contested. Proponents of expert judgement elicitation argue that the probability distributions elicited from experts are not intended as predictions of the future, but rather as informed guesses about the plausible range within which future values of the variable may lie. Not least, expert judgement elicitation represents a more transparent and replicable method, compared to the alternatives.

Expert judgement elicitation has been formalised through a number of different methods. We relied on a method called structured expert judgement, which integrates the responses of the various experts into a single probability distribution (Cooke, 1991). It does so by weighting the individual expert responses according to the scores (high or low) that each expert obtains when responding to a series of so-called calibration questions, the answers of which cannot be known at the time of responding to the questions, but are knowable shortly thereafter.[9] To implement this method, a three-day workshop was needed – to introduce the experts to the method, collect responses to the calibration questions, and run the elicitation itself.

Changes in gross domestic product are linked to developments in a number of other macro-economic indicators, notably trade balances (with the United States, in this case) and labour market taxation levels, among others. Stated differently, an assessment of likely future changes in gross domestic-product growth rates has to consider plausible future changes in these indicators.[10] For this reason, an econometric model was developed that quantified the dependence between gross domestic product and several other macro-economic parameters (Loría, 2013). This model was provided to the experts that took part in the elicitation. The rationale for including the results of the econometric model in the elicitation protocol was simply to give the experts a projection that ignores potential discontinuities. Indeed, a key strength of eliciting expert judgement on a variable such as gross domestic product is that the expert can judge – among other issues – whether or not discontinuities may be realistic and, if so, how large they might be.

The elicitation protocol was structured around three "economic growth scenarios": low, medium and high. In practice, this meant that a fixed value was set for all the macro-economic variables that influence gross domestic-product growth rates, and thus experts could disregard the former and focus on the latter. The alternative option would have involved eliciting probability distributions for the likely future values of all variables – from gross domestic product growth rates to all other related macro-economic variables. Not only would this elicitation have been overly demanding on the experts, but it would have also required a cumbersome post-hoc dependency analysis. Finally, rather than eliciting probabilities for a single year, probabilities were elicited for two periods: 2014-2020 and 2021-2030. Doing so allowed the experts to provide more robust estimates, which they expressed as percentiles of the average gross domestic-product growth rate in the period concerned.

3.3 Modelling

The article that studies renewable energy-powered universal electrification used a bottom-up model, akin to most so-called accounting models (Puig *et al*., 2013). The model was coded in Visual Basic, using Microsoft Excel as user interface.

The model was built around both existing and newly created datasets.[11] Gridded population, electrification-access rates, and location of the electricity grid are among the main existing datasets used. With regard to newly created datasets, and because highly disaggregated data on electricity affordability is lacking, a proxy for "ability to pay for electricity" was created by comparing consumption with current expenditure data. The values obtained for this proxy were then compared to annual operating costs, which made it possible to gauge the "affordability" of a given electrification option (namely, diesel oil or solar photovoltaic technologies). Other model outputs include estimates of unelectrified population, electrification costs, and greenhouse-gas emissions associated with different electrification options. Some of these estimates are more detailed than previously reported (for example, the costs associated with transporting diesel are calculated individually for each grid, and included in the overall cost estimate).

In many ways, the main addition to the literature is the model itself, because it brings together data that had not been cross-analysed before, and it provides outputs that are directly usable in a policy context. In this regard, and in contrast to the Mexican case described below, in this modelling exercise the estimates obtained are the key research output. Specifically, the high-level of disaggregation of the model estimates makes it possible to introduce much needed nuances in the debate about rural electrification.

The article that reports uncertainty estimates for projections of greenhouse-gas emissions in Mexico relied on a general-equilibrium energy-economy model (Callonec *et al*., 2013).[12] The Mexican Ministry of Environment and Natural Resources, which was involved in the calculation of these estimates, had some experience with this model. Familiarity with it was a deciding factor in the choice of model.[13] Although familiarity is an important consideration, the relative weight placed on this factor is questionable on two accounts at least. First, the complexity of the model eventually discouraged the Mexican administration from adopting it for other analyses. Arguably, this is an undesirable outcome, because it entails (i) spending additional resources in the adoption of a new model for future analyses, and (ii) reducing the comparability among the results of the various analyses, because they rely on different models. Second, a general-equilibrium model is ill-suited to assess the uncertainty around projections of greenhouse-gas emissions, which was the main goal of the research. Indeed, central aspects of general-equilibrium models, such as (theoretical) economic efficiency, reduce the robustness of the resulting estimates, thus complicating the analysis of the uncertainty associated with those estimates.

The issues above arose during the research, and the option of using an alternative model was contemplated. Specifically, a so-called bottom-up accounting model was considered, because of its simplicity and because its outputs are more amenable to an analysis of uncertainty (Heaps, 2008). This model could have used instead of the general-equilibrium model or as a complement to it. In the end, calendar and budgetary constraints prevented this option from being implemented. Nevertheless, the discussions with government officials concerning this option revealed a tension that speaks about the difficulty of integrating science into the policy process. Simply stated, the appeal of using one additional model (or several) lies in the increased insight that two sets of estimates offer with regard to understanding better the differences in the estimates. In other words, the estimates themselves are less interesting than the clues that two modelling exercises offer with regard to elucidating sources of uncertainty, which is the first step toward quantifying and, whenever possible, reducing those uncertainties. Although the government officials involved in the research fully understood these considerations, they felt that a linear narrative (probabilistic projections derived from a "sophisticated" model) would carry more weight with their managers, who were senior decision makers in the Mexican administration.

The Mexican government's interests in the context of international climate-change negotiations play a non-negligible role in the final design of the research. Mexico's greenhouse-gas emission-reduction commitments before the international community are generally seen as sensible, in comparison with the commitments made by similar countries. At some level, assessing the uncertainty around projections of greenhouse-gas emissions, which was the main objective of the research, served the political purpose of providing a scientific underpinning to the purported ambition of those commitments. Other tools could have been considered to provide such underpinning, notably a review by peers, akin to that undertaken by South Africa in the context of its climate change-mitigation scenarios. Notwithstanding other considerations, the technocratic approach adopted – namely, the use of a fairly sophisticated general-equilibrium model – arguably reflects a risk-averse attitude on the part of the Mexican government, in what otherwise remains a laudable pioneering initiative.

3.4 Surveys and interviews

Some of the articles that constitute this thesis were built upon data newly collected through surveys and interviews (Miles *et al*., 2014).[14] In all instances where surveys and interviews were used, the two methods were applied together. The following paragraphs reflect on the use made of these complementary research methods. Because rationales and strategies differ across issues, the description is split between non-state actor action and technology transfer.

The vast majority of non-state actors disclose a limited amount of information concerning their activities (Fenhann *et al*., 2018). Early studies could rely on this scant evidence base. However, all subsequent research (that is, research undertaken over the past five to ten years) has required a systematic and purpose-developed data collection effort. For the most, these empirical investigations have targeted non-state actors themselves as the providers of the information (Hsu *et al*., 2018).[15] In line with this practice, for one of the articles that constitute this thesis, the survey targeted core partners in a range of non-state actor actions.[16] Conversely, for a second article, researchers were the target of the surveys and interviews that were conducted. This category of information providers appears to be missing in the literature on non-state actor action. Arguably, as more and more studies become available, meta-analyses based on data collected from researchers are likely to become increasingly common in the area of non-state actor action.

Non-state actors work on a wide range of topics, at all possible governance levels, and in many different countries, thus within a multiplicity of socio-cultural environments (*ibid*). For this reason, and compared to surveying a less diverse phenomenon, surveying non-state actors is challenging. Specifically, developing a questionnaire that applies to, and is understood equally by, all intended recipients is a complicated task, which can be more successfully completed by consulting (a selection of) those recipients. Such a consultation, which ultimately aimed to increase the comparability of the responses to be elicited through the questionnaire, was undertaken by means of two rounds of phone interviews.[17]

Feedback from the interviewees highlighted the disconnect between policy and practice. For example, the interviewees perceived themselves as running individual "projects" with a finite time frame, as opposed to running a "non-state actor action", a concept that they seldom used and some had trouble defining. Similarly, discussions about "climate change governance" or "overlaps between state and non-state action" were seen as much too abstract by most interviewees. In short, the exchanges that took place during the process for preparing the questionnaire were as informative as the responses to the questionnaires.

Non-state actor actions are essentially partnerships. Therefore, to fully characterise their work, one has to collect two types of data: information on the partnership itself, and information on the individual partners. To this end a questionnaire in two parts was developed. The first part of the questionnaire focused on the non-state actor action itself, and was filled out jointly by all core partners in the action.[18] The second part of the questionnaire focused on the individual core partners in the action.[19] The non-state actors lacking an established permanent secretariat had unreasonably great difficulties responding to the first part of the questionnaire. This finding echoes claims that coordination structures such as a permanent secretariat increase the efficiency and effectiveness of non-state actor actions (Chan *et al*., 2018 ; Dzebo 2019).

One of the articles focused on technology transfer sought to collect comparable information about enablers of, and barriers to, the transfer of cleaner-energy technologies. This kind of information is available in governmental documents (the so-called technology needs assessments), although the degree of completeness of these assessments varies from one country to another (Haselip *et al*., 2015). For this reason, a questionnaire was used to complement the information available in these governmental documents. As per the description in the previous paragraphs, the design of the questionnaire was informed by the feedback provided – through phone interviews – by the recipients of the questionnaire. Reacting to the large amount of detail in the final version of the questionnaire, most interviewees suggested that the technology needs assessment process would benefit from incorporating the guidance that the detailed questionnaire provided.

3.5 Secondary data analysis

The article that analyses four development aid-funded technology-transfer programmes relied on secondary data (Largan and Morris, 2019). These data were obtained mostly from grey literature, including both descriptions of the individual programmes' aims, prepared before the programmes were launched, and assessments of performance, conducted two or more years into a programme's period of operations. Although most of this literature is publicly available, some had to be obtained by contacting the institutions that run the programmes. Additionally, personal contacts were used to seek clarification and details not included in any of the written documents analysed.

The technological innovation systems approach (Markard and Truffer, 2008) was used to both determine and organise the information drawn from the sources referred to above. Querying this information along the lines of the various *actors* involved, which is one of the dimensions in the technological innovation systems approach, was possible without making assumptions. However, doing so for the remaining two dimensions in the technological innovation systems approach was challenging. These dimensions are, respectively, determining the extent to which *interlinkages* between actors were strengthened, and assessing the ability of any one actor to perform one or more innovation-related *functions*.

Concerning the interlinkages between actors, two criteria were used to assess changes with regard to a baseline, defined as the situation prevailing before the project started its operations. The first criterion was the establishment of a previously inexistent dialogue between any given group of actors. To evaluate this criterion, the information included in the grey literature referred to above was sufficient in all instances. The second criterion was the reinforcement of an existing dialogue. For some of the programmes, evaluating this criterion required interpreting the data, in which case personal contacts with the managers of the programmes were used, to contrast the interpretation made.

Concerning the innovation-related functions introduced above, assumptions had to be made as to the degree to which the various functions were performed more efficiently and effectively as a result of the actions undertaken by the various programmes studied. When the data analysed revealed that a given function was performed at a higher level, compared to the baseline level, the change was assumed to be due to the programmes. This assumption, which reflects the classic attribution problems faced by most policy evaluations, seemed plausible in this case, as no other discernible forces acted to affect how a given function was performed.

A second article, also focused on technology transfer, relied on secondary data analysis, namely the article that explores the extent to which development aid-funded technology-transfer programmes achieve their objectives. Here too, grey literature was the source of data for the analysis. However, unlike the case described above, the various documents on which the article draws were both standardised in their content, and easily locatable.[20]

As outlined in Section 4.3, these reports describe the outcomes of a prioritisation process, through which national governments in low-income countries selected the climate-change mitigation (and adaptation) technologies that the country needs most. Explicitly for all reports, although more so in some than others, the reports describe the enablers of, and barriers to, the adoption of the various technologies, as summarised by government officials in the countries concerned.[21] These descriptions are the secondary data on which the article drew.

In several instances, the descriptions of enablers and barriers were somewhat generic, often referring to lack of financial resources as the main obstacle that technology adoption would face. While acknowledging the importance of financing, providing a more nuanced view on technology transfer was the goal of the research project. To this end, the text in the reports was analysed using word-mining techniques: essentially, the paragraphs including a reference to a given technology were isolated and the nouns and verbs in that paragraph were associated to the technology in question. The resulting lists were screened, to exclude irrelevant words (notably the verb to be and the name of the country, which appeared often). With the final list of words, a hypothesis was made as to what the potential barriers and enablers for the technology in question might be. This hypothesis was then included in a survey form, which was sent to the government officials who, individually in the various countries studied, led the technology prioritisation process. The responses to this form were later contrasted with the types of support offered by development aid-funded technology-transfer programmes, to determine the extent to which expectations (from development-aid recipient countries) were aligned with what those programmes are in a position to offer, given the logic of development-aid spending.

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Endnotes

1 A number of ready-to-use expert judgement-elicitation tools are available online. For example, the so-called Sheffield Elicitation Framework (or SHELF, for short) is available at: http://www.tonyohagan.co.uk/shelf/

2 The search string was: (TITLE-ABS-KEY ("climate change") AND TITLE-ABS-KEY ("effectiveness") AND TITLE-ABS-KEY ("nonstate actor" OR "non-state actor")). The inclusion criteria were: a focus on transnational initiatives. The exclusion criteria were: a focus on the effectiveness of the international climate-change regime, or of state-actor actions.

3 In addition, Article 3 includes (in Supplementary Information Note 1) a narrative review of the literature on emission reduction potentials attributable to non-state actor action. This review, which aimed to analyse the assumptions that underlie those estimates and – crucially – the logic behind the various assumptions, is used as a complement to the systematic review that constitutes the bulk of the research reported in Article 3.

4 A 2009 report, commissioned by the now-discontinued United States Climate Change Science Program, provided an overview of applied research on uncertainty management (Morgan, 2009). The report has not been updated, and no other comparable overview has been published. Besides, most guidance available is of relevance to global and supranational assessments, as opposed to national-level policy making. Filling this gap in the literature was the main purpose of Article 4.

5 Our inclusion criteria were: applied research, of relevance to practitioners in national governments (as opposed to research that is relevant in the context of supranational assessments). Our exclusion criteria were: research that reports on narrow details of any one methodology, especially when linkages with other comparable methodologies are not presented.

6 Six documents met this criterion, among which the following three met our inclusion and exclusion criteria:

Fischhoff B, Davis A.L. (2014) Communicating scientific uncertainty. *Proceedings of the National Academy of Sciences 111*(Supplement 4), 13664-13671.

Knaggård Å (2014) What do policy-makers do with scientific uncertainty? The incremental character of Swedish climate change policymaking. *Policy Studies 35*(1), 22-39.

Kwakkel, J.H., Walker, W.E. and Marchau, V.A. (2010). Classifying and communicating uncertainties in model-based policy analysis. *International Journal of Technology, Policy and Management, 10*(4), 299-315.

7 To identify a conceptual framework around which the review of the literature could be structured, the twenty-four documents were mapped out against the dimensions of two already existing frameworks. Initially, the so-called kaleidoscope framework of policy change was used (Resnick *et al.*, 2018), because the idea of systematically exploring all aspects of the policy process aligns well with the motivations of the article. The framework is depicted as Figure 1 in the article, where it is referred to as “model” (and not as a “framework”).

However, it was found that each of the findings could be placed in nearly all the dimensions of the kaleidoscope framework. Stated differently, the framework did not help categorise the findings, which was the main objective of this task. As a result, a second framework was considered (Kwakkel *et al*., 2010), which has as its making objective guiding model-based uncertainty analysis.

Location, one of the dimensions that make up this framework, made it possible to categorise some of the findings – but not all, notably issues related to incorporating uncertainty in the policy process. Not least, (by design) this framework is biased toward model-based quantitative assessments, thus making it difficult to accommodate qualitative assessments, such as those used in areas like land-use management. For this reason, the idea of using this framework was abandoned.

8 In recent years, comparing the (nearly always deterministic) individual projections obtained through different computer-based energy-economy models has been one of the most commonly used approaches to assessing the uncertainty associated with projections of greenhouse-gas emissions. To the extent that the assumptions made and the input data used are comparable, the assessments thus obtained mainly reflect the uncertainty associated with the various modelling paradigms. To contrast these assessments, a different methodology was used, namely quantifying the uncertainty around plausible future values of two drivers of emissions in Mexico: gross domestic-

product growth rates, and oil prices. (In an industrialised country like Mexico, greenhouse-gas emission levels correlate positively with gross domestic-product growth rates. The same is true for oil and gas prices, although in a counterintuitive fashion: when prices are high, oil and gas become export commodities, and net emissions are reduced.) With the help of a general-equilibrium energy-economy model, (probabilistic) estimates for likely future values of these two drivers were used to calculate the uncertainty associated with projections of greenhouse-gas emissions in the country.

9 For example, experts are asked about inflation rates some months hence, or about export rates for a given sector, also in the near-term. In some instances, these so-called calibration questions also include questions referred to the past.

10 This is true irrespective of the assessment method used – expert judgement elicitation or some other method.

11 Details on the structure of the model and the newly created datasets can be found in the Supplementary Information Note to Article 1.

12 In the model used, gross domestic product is an endogenous variable. For this reason, the probabilistic projections obtained through expert judgement elicitation could not be used as inputs to the model. Instead, for each set of projections, the model had to be recalibrated in such a way as to be consistent with the gross domestic product values given by the probabilistic projections.

13 A coincidence of two additional non-technical factors played a role in the choice of model. First, the model is maintained and updated by a French research institution. Second, some elements of the research were funded by the French Development Agency. Although choosing the model developed by the French research institution was never a pre-condition for the funding to be forthcoming, the French Development Agency actively promoted the model, as a means to indirectly support domestic research.

14 For some articles, we combined data newly collected through surveys and interviews with secondary data analysis (Section 3.5).

15 Nonetheless, a handful of studies have targeted as information providers (i) state actors or (ii) the beneficiaries of the work of non-state actors. Admittedly, the "state" and "non-state" actor categories are often undiscernible, as exemplified in the survey reported by Hjerpe and Nasiritousi (2015). As for the surveys of "beneficiaries", it is worth noting that they are more common in high-income countries, where communities have comparatively more resources to organise themselves and, therefore, it is easier for researchers to targets such communities. The survey reported by Ingold and colleagues (2010) provides an example of this type of studies.

16 We were interested in learning about the delivery mechanisms by the non-state actor actions. This information is only available from the core partners in the actions. As such, reaching out to state actors or beneficiaries would have served no purpose.

17 The description provided in this paragraph refers to the article that surveyed core partners in a number of non-state actor actions. For details on the survey form that was used to gather information from researchers, the reader is referred to Supplementary Information Note 1 in Article 3.

18 The first part of the questionnaire included questions about the type of governance arrangement, or the type of delivery mechanism, among others. A consensus response from all core partners was sought. For actions with more than five or six core partners, that consensus response was prepared by a representative selection of partners.

19 The second part of the questionnaire included questions that are specific to each core partner, such as the incentives for joining the non-state actor action, or the relative importance of the non-state actor action in the portfolio of activities of a given core partner. This part of the questionnaire was filled out by each core partner individually.

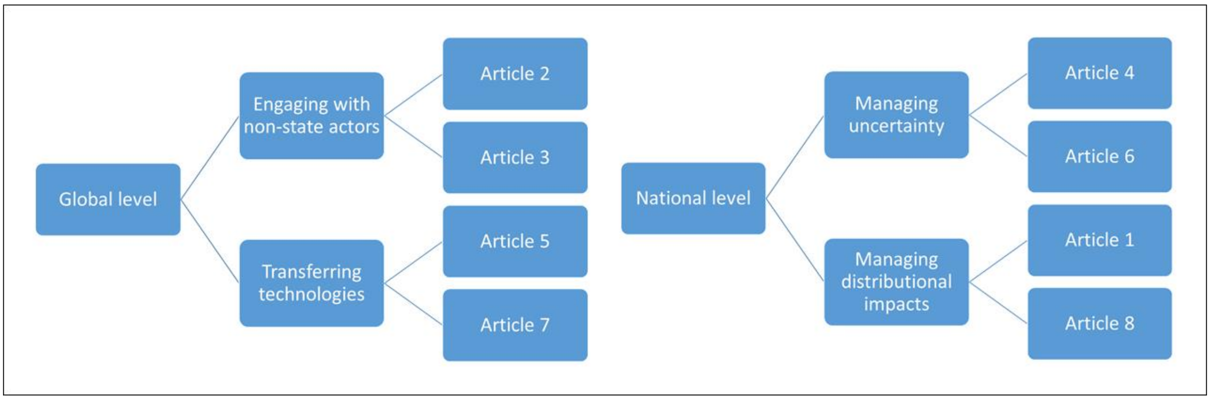
[20] These documents are the so-called technology needs assessment reports. They are freely accessible online: https://tech-action.unepdtu.org/tna-database/

[21] In most instances, the summary (like the rest of the so-called technology needs assessment report) was prepared by consultants. Nonetheless, the views presented are considered official governmental views, in that governments led the technology prioritisation process, drawing on input from the main stakeholders in the country (UNFCCC, 2009).

4. Summaries of the articles

This chapter consists of summaries of the eight articles that constitute the thesis. As indicated in chapter 1, the articles touch upon four thematic areas across two governance levels (Figure 4.1). For ease of reference, the summaries are presented by theme.

Figure 4.1: Overview of articles, by governance level and theme



4.1 Engaging with non-state actors

This section summarises the following articles:

- Article 2: Puig, D. and Bakhtiari, F. (2020). Determinants of successful delivery by non-state actors: an exploratory study. *International Environmental Agreements: Politics, Law and Economics*. [under review]
- Article 3: Puig, D., Bakhtiari, F. (2020). A new model for accounting for non-state action. *Climate Policy*. [under review]

4.1.1 Summary of Article 2

Article 2 develops a taxonomy for assessing ex-ante the likelihood that delivery by non-state actor actions may be successful. The rationale for the taxonomy is twofold. First, it brings together the scant literature on criteria of successful delivery by non-state actor actions. Second, it gives an empirical underpinning to the intuitive notion that some barriers to successful delivery can be identified ex-ante, with a view to improving the delivery methods of non-state actor actions.

The taxonomy is based on the feedback gathered through a series of semi-structured interviews. Interviewees were selected among the lead partners in six non-state actor actions focused on adaptation to climate change or disaster-risk reduction. The feedback obtained through the interviews pointed toward three sets of issues, which the article terms “societal conditions”, “domain conditions” and “action conditions”. “Societal conditions” refers to issues that take years to change and have a clear, albeit indirect influence on the work of non-state actor actions. Examples of these issues include near-term vulnerability to the impacts of climate change, or the extent to which public-private partnerships are used to implement policy. “Domain conditions”, refers to three types of issues, all of which have a direct influence on the work of the non-state actor action. First, the capabilities and competences of the core partners in a non-state actor action. Second, the policy and regulatory environment within which a non-state actor action operates. Third, the agendas of the stakeholders that operate within the same economic and regulatory environment. Finally, "action conditions" refers to the choice of delivery method made by a non-state actor action, the specific design of the method, and the way in which the different partners in the action interact with one another to apply that method.

The taxonomy is consistent with the findings of three related studies. The main difference lies in the larger scope of the taxonomy, compared to the scope of the criteria in those three studies. Similarly, the taxonomy is consistent with the so-called multi-level perspectives framework for "technological transitions". A comparison with this framework is relevant because "technological transitions" amount to disruptions in established socio-economic regimes, which are akin to the impact that a successful non-state actor action may have, albeit at a smaller scale. The comparison with the multi-level perspectives framework suggests that the taxonomy presented in Article 2 encompasses a comprehensive set of issues.

4.1.2 Summary of Article 3

Article 3 puts forward a new model for accounting for non-state actor action in the area of climate change. This model entails that the role of a non-state actor actions vis-à-vis the United Nations Framework Convention on Climate Change (hereinafter, the Convention) be contingent on the type of sector in which a given non-state actor action is active.

In sectors dominated by a small number of large companies, non-state actor action is likely to be more effective if integrated into mainstream state actor action. The suggestion is informed by two sets of evidence. First, such an approach is being implemented with some success to avoid deforestation and forest degradation, or to reduce greenhouse-gas emissions from niche sectors such as hydrofluorocarbon-emitting industries and aviation. Second, experience from non-state actors active in areas other than climate change, notably immunisation against vaccine-preventable diseases, indicates that, in highly homogeneous sectors, an integrated approach is more efficient, compared to state and non-state actors working independently. Reluctance on the part of non-state actors to lose visibility and to enter into binding commitments tend to be the main barriers to implementing such an approach.

In sectors such as agriculture or end-use energy efficiency, for example, which are made up of a large number of heterogeneous actors, the case for integrating state and non-state action is less clear. In these sectors, non-state action could be seen primarily as a valuable policy laboratory, where new approaches can be tested and innovation is spurred. Importantly, emission reductions from these sectors would not be accounted for.

The proposals in the article are motivated by two considerations. First, an examination of the estimates of emission reduction potentials associated with non-state actor actions highlights that some of the assumptions made differ strikingly. Second, and consistent with the first point, a review of the literature underscores that it is not possible at present to calculate the size of the impact (direct or indirect) that non-state actor actions can make. For these reasons, the article cautions against the growing institutionalisation of non-state actor actions in the Convention, and advocates for the conservative model outlined above.

4.2 Transferring cleaner-energy technologies

This section summarises the following articles:

- Article 7: de Coninck, H. and Puig, D. (2015). Assessing climate change mitigation technology interventions by international institutions. *Climatic Change 131*(3), pp. 417-433.
- Article 5: Puig, D., Haselip, J.A. and Bakhtiari, F. (2018). The mismatch between the in-country determinants of technology transfer, and the scope of the technology transfer initiatives under the United Nations Framework Convention on Climate Change. *International Environmental Agreements: Politics Law and Economics 18*(5), pp. 659-669.

4.2.1 Summary of Article 7

Article 7 studies four inter-governmental agency programmes that seek to support the diffusion of climate change-mitigation technologies, to assess the extent to which these programmes promote technological innovation. Further, among the technology innovation functions that are currently underserved, the article suggests which might be fulfilled by the Convention's so-called technology mechanism.

To assess whether and how much a programme contributes to technology innovation, the article draws on a framework that identifies the actors involved in innovation systems, and maps the relationships among these actors. Specifically, for each of the four international programmes studied, the article analyses two sets of elements. First, the extent to which the programme has been successful at increasing the capabilities of individual actors. Here, capabilities refers to the knowledge and skills that allow a given actor to perform its functions in the technological innovation system. Second, the extent to which interlinkages between actors have been established or strengthened, as relevant.

The article concludes that, while all four programmes promote technology transfer, they give limited attention to the innovation capabilities of users, governments and universities. Specifically, functions that could be strengthened include knowledge development, legitimation and market formation. Given its stated objectives, the Convention's technology mechanism could fulfil some of these neglected functions, notably knowledge development by universities and other research bodies, and the improvement of technological innovation systems by national governments.

4.2.2 Summary of Article 5

Article 5 explores the extent to which development aid-funded technology-transfer programmes achieve their objectives. It does so by comparing the in-country determinants of technology transfer, as identified by low income-country government-agency staff, with the outcomes of development aid-funded programmes aimed to promote the diffusion of cleaner-energy technologies. The comparison reveals a disconnect between what low income-country governments perceive as the key enablers of, and barriers to, technology transfer, and what bilateral and multilateral technology-transfer programmes can offer, given budgetary constraints and the logic of development-aid spending.

The article takes as a departure point the information collected in so-called technology needs-assessment reports, which are official government statements of national priorities with regard to climate-change mitigation (and adaptation) technologies. Because these reports do not include some of the data required for the comparison referred to above, a survey was conducted, to fill the data gaps. Further, the survey was used to clarify some of the information included in the technology needs-assessment reports, which helped increase the comparability of the data drawn from these reports. The resulting dataset, while limited to a reduced number of countries, sheds light on the determinants of effectiveness of development aid-funded technology-transfer programmes.

To reflect the wide range of cleaner energy-technologies used in low-income countries, the survey was structured around four technology clusters: "household consumer goods", such as energy-efficient refrigerators; "industry retrofits", such as heat pumps; "new industry investments", such as combined-cycle gas turbines; and "large infrastructure projects", such as geothermal energy. Governmental targets (for the "new industry investments" cluster) and long-term cost savings (for the remaining three clusters) emerged as the main drivers of the adoption of any of these technologies. The main barriers cited include regulatory inefficiencies (for the "large infrastructure projects" cluster), and high costs and lack of financial incentives (for the remaining three clusters). Finally, the main enablers cited were foreign direct investment (for the "large infrastructure projects" cluster) and subsidies (for the remaining three clusters).

Few development aid-funded programmes to promote technology transfer reflect the findings outlined above. Indeed, only regulatory-framework reform is frequently included in the design of development aid-funded technology-transfer programmes. The Convention, notably through the Climate Technology Centre and Network, has the possibility to influence the design of future technology-transfer programmes, so that they reflect better barriers and enablers.

4.3 Managing uncertainty

This section summarises the following articles:

- Article 4: Puig, D. and Bakhtiari, F. (2019). Incorporating uncertainty in national-level climate change-mitigation policy: possible elements for a research agenda. *Journal of Environmental Studies and Sciences 9*(1), pp. 86-89.
- Article 6: Puig, D., Morales-Nápoles, O., Bakhtiari, F. and Landa, G. (2018). The accountability imperative for quantifying the uncertainty of emission forecasts: evidence from Mexico. *Climate Policy 18*(6), pp. 742-751.

4.3.1 Summary of Article 4

Article 4 puts forward elements for a research agenda on incorporating uncertainty in national-level climate change-mitigation policy. Incorporating uncertainty refers to three sets of issues: characterising and, to the extent possible, reducing uncertainty; (scientist) communicating uncertainty (to policy makers); and reflecting uncertainty in the design of policy measures to manage climate change. The research agenda sketched in the article is informed by an overview of the literature, touching upon the three sets of issues above. The rationale for the article is that, in spite of the recurrent rhetoric about the importance of managing uncertainty, national-level practices remain rudimentary, as evidenced by the planning and target-setting processes described in the various so-called nationally-determined contributions and other national-level policy documents.

The overview of the literature reveals that most initiatives aimed to characterise and reduce uncertainty are circumscribed to the research community, and fail to be taken up in the national-level policy-making process. Even more so, this is the case for uncertainty communication: researchers have theorised about it, in broad terms in the context of post-modern science and more specifically in the context of the so-called science-policy interface, but theories have not translated into practice. Finally, the paucity of literature focused on reflecting uncertainty in the design of policies to manage climate change suggests that, beyond the policy-evaluation literature, theory is lacking and practice is simply non-existent.

Article 4 concludes with the following suggestions for research priorities. First, the development of frameworks to characterise uncertainty in contexts other than computer model-based analyses to support policy design, notably analyses based on qualitative scenarios. Second, the development of techniques to quantify uncertainty that suit the specificities of key sectors (for example, land-use planning), or commonly used decision-support tools (for example, cost-benefit analysis or multi-criteria decision analysis). Third, the development of protocols to reduce uncertainty that are specific to each of the most commonly used decision-support tools. In addition, the article calls for the use of an existing framework to communicate uncertainty, and for the undertaking of reviews of the extent to which uncertainty has been reflected in national policy.

4.3.2 Summary of Article 6

Article 6 presents probabilistic forecasts of greenhouse-gas emissions for Mexico, and compares them with Mexico's governmental deterministic forecasts. The goal of the article is to underscore the importance of incorporating uncertainty in emission forecasts, especially when forecasts are used to derive official emission-reduction targets.

In an industrialised country like Mexico, economic output is a key driver of greenhouse-gas emissions. Using structured expert judgement, probabilistic forecasts of gross domestic product growth rates were obtained. To keep the elicitation process manageable, while taking due account of the strong dependencies between gross domestic product and a number of other macro-economic variables, the elicitation was structured around different scenarios of economic growth, defined through a purpose-developed econometric model. Using a general-equilibrium model, the resulting probabilistic forecasts of gross domestic-product growth rates were used to produce probabilistic forecasts of greenhouse-gas emissions in Mexico in 2020 and 2030. Because, in the model used, gross domestic product is not an exogenous variable, the model had to be recalibrated for each percentile elicited in each scenario. In the case of the so-called neutral scenario, the median value of the resulting forecasts of greenhouse-gas emissions was consistent with the governmental deterministic forecasts. Compared to this median value, the median values of the so-called pessimistic and optimistic scenarios were, respectively, 14 percent lower and 16 percent higher. In short, the range of plausible future levels of greenhouse-gas emissions in Mexico in 2030 is rather large. For this reason, any deterministic value effectively represents an arbitrary choice, and one that may prove to be off the mark.

Mexico is one of several low-income countries that define their official greenhouse-gas emission-reduction targets through deterministic forecasts of emission levels in 2030. The article argues that, for the reasons outlined above, such practice yields estimates that are not robust and, as a result, it undermines the integrity of the international climate change regime, which rests on the robustness of the individual forecasts provided by the parties to the Convention. The article suggests that, with regard to the processes that parties to the Convention use to prepare national forecasts of greenhouse-gas emissions, minimum disclosure and quality standards should be developed and applied. Further, the article calls for greenhouse-gas emission-reduction targets that reflect key uncertainties. This goal could be achieved, for example, by expressing targets as a range of greenhouse-gas emission levels, associated with a small number of socio-economic scenarios: should certain socio-economic developments come to pass, notably in terms of gross domestic product-growth rates and energy prices, a higher or lower value of the emission-reductions target would apply.

4.4 Managing distributional impacts

This section summarises the following articles:

- Article 1: Szabó, S., Pinedo, I., Moner-Girona, M., Puig, D., Negre, M., Huld, T., Mulugetta, Y, Kougias, I., Szabó, L. and Kammen, D. (2020). Bringing green electricity to low-hanging fruit communities: the way to accelerate to reach affordable and universal energy access. *Nature Energy*. [submission in early March 2020]
- Article 8: Scrieciu, S.Ş., Belton, V., Chalabi, Z., Mechler, R. and Puig, D. (2014). Advancing methodological thinking and practice for development-compatible climate policy planning. *Mitigation and Adaptation Strategies for Global Change 19*(3), pp. 261-288.

4.4.1 Summary of Article 1

Article 1 studies unelectrified communities in 71 countries across Africa, south Asia and east Asia. Through a high-resolution (1 km^2) geo-referenced model, it maps out the communities for which renewable energy-powered electrification is cheaper than diesel oil-powered systems. Further, it maps out communities for which renewable energy-powered electrification is affordable (compared to what they spend today in energy), even if diesel-oil powered systems are cheaper in these communities.

The rationale for the article is twofold. First, given the poor credit ratings of national governments and public utilities in the countries concerned, which are inadequate to raise the amounts of debt required to finance electrification in these countries, electrification programmes are financed by development-aid budgets and, increasingly, by private mini-grid and off-grid service providers. Second, in rural settings, where returns on investment are uncertain, diesel oil-powered systems are often preferred over renewable energy-powered systems, because financing the higher up-front costs associated with the latter is comparatively more challenging. Yet, because operation and maintenance costs for renewable energy-powered systems tend to be lower, the associated (negative) distributional impacts are also lower – an aspect that is not necessarily considered at the stage of planning the investment.

To produce high-resolution geo-referenced estimates of unelectrified communities, proxies are used. For each grid in the dataset, two sets of cost estimates are calculated, corresponding to one of two techno-economic scenarios consistent with the so-called shared socio-economic pathways scenarios 1 and 3, respectively. Essentially, these scenarios describe favourable or adverse conditions for the deployment of renewable energy-powered electrification systems. Using a second set of proxies, energy expenditure is calculated for each grid in the analysis. This estimate allows us to identify the communities in which renewable energy-powered electrification could be an option, even if it is more expensive than diesel-oil powered systems.

The article seeks to convey a number of policy-relevant messages. First, investment decisions for electrification programmes should not neglect operation and maintenance costs, as these can compromise the viability of programmes in the long term. Second, the design of electrification programmes should avoid blanket approaches and instead seek to reflect local realities, which requires high-resolution geo-referenced analyses. Third, electrification programmes ought to factor in the ancillary benefits of renewable energy-powered systems, namely reduced local air pollution and avoided greenhouse-gas emissions.

4.4.2 Summary of Article 8

Article 8 makes the case for a new paradigm to planning for climate-change management – one that considers distributional effects and trade-offs between multiple development objectives, incorporates uncertainty, and avoids economic optimisation. Further, the article puts forward a methodological approach that is consistent with this paradigm. This approach is structured around three elements: a number of guiding principles and good-practice evaluation standards, a generic criteria-tree for evaluating policy options, and a set of prioritisation processes and models based on multi-criteria decision analysis. The following paragraphs outline the key features of each of these three elements.

The guiding principles referred to above relate to three sets of issues. First, the multi-dimensional nature of global warming requires that a wide range of values and priorities are considered. Second, climate change-management policies and development objectives can and should be mutually reinforcing. Third, climate change-management policies need to take fully into account non-market goods and services, uncertainty, and the long-term dynamics of environmental, socioeconomic and technological systems. Reflecting these principles, a number of good-practice evaluation standards are recommended, touching upon (i) baseline formulation, (ii) macroeconomic assumptions, (iii) technological innovation, (iv) no- and low-regrets options and co-benefits, (v) monetary valuation and non-marketed impacts, (vi) discounting future costs and impacts, (vii) risk and uncertainty, (vii) institutional barriers to, and enablers of, policy, and (viii) fiscal sustainability.

The generic criteria tree referred to above has two objectives. First, it raises awareness among decision-makers about the need for public policy to strike a societally acceptable balance between climate change priorities, environmental concerns and socio-economic development objectives. Second, it provides decision-makers a tool to assess the extent to which a proposed policy achieves that balance. To do so, the criteria tree is designed in such a way as to allow for independent assessments across criteria (and groups of criteria). It is important to note that the criteria tree was formulated through an iterative process, involving a dozen world-class experts working together over an extended period.

Finally, the prioritisation process referred to above, based on multi-criteria decision analysis, is described. The article contends that multi-criteria decision analysis is better suited to take into account distributional effects, because it is amenable to incorporating (i) diverse analytical methods and the views of multiple stakeholder groups, and (ii) no-regrets approaches that are robust across a wide range of (uncertain) plausible future outcomes.

5. Conclusions

This thesis set out to investigate how national governments are responding to the challenges associated with the implementation of the Paris Agreement. The findings of the various articles point to two sets of overall challenges, to which governments ought to respond: limited or no performance requirements for certain aspects of the policy-making process, and limited up-take of evaluative evidence in new or revised policies and plans. Section 5.5 discusses these challenges, and reflects on the approaches that governments are following to deal with them. Preceding this discussion, sections 5.1 to 5.4 answer the four sub-questions introduced in chapter 1.

5.1 Engaging with non-state actors

Transnational climate-change governance, and non-state actor action in particular, are receiving growing attention, both in policy circles and in academia (Bulkeley *et al.*, 2018). This attention stems from the fast pace at which non-state actor action has grown in recent years, which raises three main questions (Jordan *et al.*, 2015). First, the way in which state and non-state actor actions can be mutually supportive. Second, the type of impact that a "polycentric" governance regime is likely to have in the context of climate-change management. Third, the extent to which non-state actors deliver on their objectives. The two articles focused on engaging no-state actors dwell on the third point above. Indirectly, these articles also touch upon the first point, in that they consider governance-related aspects of the relationship between state and non-state actor actions.

The first article seeks to characterise the issues that determine the extent to which a non-state actor action is likely to deliver on its objectives. The article concludes that many of these issues fall outside of the control of the core partners in a non-state actor action. Examples of such issues include institutional and regulatory frameworks, or the extent to which, in a given jurisdiction, public-private partnerships are a common tool for policy implementation. Drawing on empirical evidence, the article puts forward a taxonomy of the determinants of delivery by non-state actor actions. This taxonomy is contrasted with non-empirically-based proposals made in earlier studies, namely those by Widerberg and Pattberg (2015), Michaelowa and Michaelowa (2017) and Chan and Amling (2019). The article finds that the taxonomy spans a wider range of issues, compared to the set of issues reported in the literature. Not least, the article makes the case for using this kind of taxonomies to assess ex-ante the likelihood that a non-state actor action will be successful in delivering on its objectives. Other studies have advocated for ex-ante assessments, although from a predominantly theoretical point of view (Andonova *et al.*, 2009 ; Andonova *et al.*, 2017 ; Bulkeley *et al.*, 2018).

The second article focuses on the overlap (or lack thereof) between international cooperative initiatives and state actor action. Drawing on a review of the literature on non-state actor effectiveness, the article advocates for a new model to govern the interactions between state- and non-state-actor actions. In this model, non-state actor action would be integrated into state actor action (in sectors dominated by a small number of large companies), or it would be seen as a "policy laboratory" only, with no impact on the accounting of emission reductions (for all other sectors and types of non-state actors). Emerging practice in sectors such as forestry and land-use change, and experiences with non-state actor action in domains other than climate-change management, briefly introduced in the article, suggest that the proposed new model may help reduce overlaps between state and non-state actor action. The article joins Michaelowa and Michaelowa (2017) and Chan and colleagues (2018) in providing a pessimistic view on the size of the contribution that non-state actor action can make to achieving international climate-change goals. As such, it departs from earlier literature in this area[1], which was overwhelmingly optimistic.

Limited accountability requirements on non-state actors have translated into scant reporting on their activities, which hampers efforts to assess ex-post the impact of those activities. Against this background, the two articles referred to above study evidence that is of relevance to ex-ante assessments of effectiveness. The results of this work call for a new approach to non-state actor action, in which the role afforded to non-state actors varies from one action to another, to reflect the particularities of the sector and countries involved. This model contrasts with the one-size-fits-all approach currently applied.

5.2 Transferring cleaner-energy technologies

Achieving a widespread use of cleaner-energy technologies, in high- and low-income countries alike, is a precondition for curbing global warming. In the context of low-income countries, development aid plays a key role with regard to catalysing a market-based technology transition. The two articles focused on transferring cleaner-energy technologies analyse the barriers to, and enablers of, technology transfer, and the extent to which development aid-funded programmes catalyse innovation, a key element in the long-term viability of technology adoption. Ultimately, the goal of these two articles is to explore the extent to which development aid-funded programmes are effective at promoting the transfer of cleaner-energy technologies.

The first article uses the technological innovation systems framework to analyse four development aid-funded programmes aimed to promote technology transfer, to assess the extent to which these programmes are successful at spurring innovation. The article shows that, in the case of the four programmes studied, there is limited focus on activities that catalyse innovation, even though this is a stated objective of all the programmes. In terms of actors, these programmes strengthen the innovation capacities of both companies and financiers, but have little impact on the innovation capacities of researchers, governments and users of the technology. In terms of the functions performed by these actors, the programmes analysed strengthen functions such as "resource mobilisation", but pay less attention to "knowledge development", "legitimation of policies", and "market formation". The article concludes that in the context of public sector-driven programmes, the transfer of cleaner-energy technologies necessitates of the type of coordinating role that an intergovernmental entity can provide. This conclusion is aligned with the findings reported in recent studies (see, for example, Glachant and Dechezleprêtre [2017] and Bouwer [2018]).

The second article studies the in-country drivers of cleaner-energy technology transfer in low-income countries. It compares the enablers of, and barriers to technology transfer, as identified by developing-country government-agency staff, with the outcomes of typical development aid-funded programmes aimed to diffuse cleaner-energy technologies. A first conclusion coming out of this comparison is that few development aid-funded programmes target, or indeed are in a position to influence, important determinants of technology transfer. These determinants include issues such as fiscal incentives to promote savings by households, or differential energy pricing for industrial energy use, among others. A second conclusion relates to the disconnect between what developing-country governments perceive as the key enablers of, and barriers to, technology transfer, and what bilateral and multilateral technology-transfer programmes can offer, given budgetary constraints and the logic of development-aid spending. Drawing on research on sustainable transitions in energy-related sectors, one can hypothesise that this type of mismatch could be due to (i) limited engagement with the full range of actors that influence transitions, and (ii) limited integration (in the design of the programme) of the full set of socio-economic processes involved in transitions.[2]

Development aid-funded programmes are credited for having contributed to catalysing sustainability transitions, notably by supporting entrepreneurship (Meijerink and Huitema, 2010) and protecting niches for specific technologies (Hansen and Nygaard, 2013). The two articles that focus on the transfer of cleaner-energy technologies add to the emerging literature that explores the relationship between development aid-funded programmes and sustainability transitions by studying programmes that are driven by the international climate-change regime, and notably the so-called Technology Mechanism under the United Nations framework Convention on Climate Change (hereinafter, the Convention).

5.3 Managing uncertainty

Climate change is riddled with uncertainties. As a result, for climate-change policies to be robust to as broad a range of plausible future outcomes as possible, uncertainty analysis has to be a component of the policy-planning process. Regrettably, this is seldom the case and, to reverse the trend, additional emphasis on a number of issues will be required (Morgan, 2009). Characterising and quantifying the uncertainty associated with national-level emission-reduction targets are two of the issues requiring heightened attention. The two articles focused on managing uncertainty touch upon uncertainty characterisation and quantification. The first article analyses the public-policy implications of using deterministic forecasts of greenhouse-gas emissions, compared to using probabilistic forecasts. In doing so, it sheds light on the implications that uncertainty management might have with regard to international climate-change negotiations. The second article provides and overview of the literature in this area, and puts forward elements for a research agenda on incorporating uncertainty in governmental climate change-mitigation plans. Ultimately, both articles seek to make the case for a new approach to policy-making in the area of climate-change management – one in which uncertainty analysis becomes an integral part of the process.

The first article suggests a breakdown for the various strands of literature in an area that can be loosely described as applied research on uncertainty management in a climate change-mitigation context. In summarising this literature, two main problems become apparent. First, a number of gaps can be found in the literature. For example, although analytical frameworks exist for computer model-based planning processes, similar frameworks usable in qualitative scenario-based planning process, which are more commonly relied upon than the former, are missing. Second, pick up by public policy of the findings in the literature is likely to be limited, as evidenced by the lack of documented uses, both in the scientific and grey literatures, of uncertainty management tools and methods. The article concurs with earlier work calling for heightened efforts to manage uncertainty and, crucially, to strengthen communication in this area between scientists and policy makers (Fischhoff, 2012). The overview provided by the article and, not least, the breakdown that the article introduces, may be of help in this regard.

The second article quantifies the uncertainty associated with national-level projections of greenhouse-gas emissions in Mexico in 2030. In doing so, it shows that, when the uncertainty associated with likely future levels of economic output is taken into account, forecasts of plausible future levels of greenhouse-gas emissions span a large range. This finding suggests that, when forecasts of greenhouse-gas emissions do not reflect uncertainty, they convey a sense of accuracy that is more perceived than actual, and is potentially misleading.[3] Instead of relying on a range of generic projections of gross domestic product, as done by Benveniste and colleagues (2018), the analysis in the article is based on three sets of purpose-developed projections of gross domestic product for Mexico, each corresponding to a different socio-economic scenario for the country.[4] This specificity gives the resulting estimates a higher degree of plausibility, compared to the estimates obtained through studies such as that by Benveniste and colleagues (2018), which use a comparable approach.

The two articles that focus on uncertainty reaffirm calls for increased attention to the management of uncertainty in the context of climate-change mitigation (Morgan, 2009). The articles add to research in this area by highlighting (i) the range of issues that national governments ought to consider in their efforts to manage uncertainty, and (ii) the implications, at the level of international climate-change negotiations, of limited up-take of scientifically sound uncertainty-management practices by national level-policy planners.

5.4 Managing distributional impacts

Avoiding regressive distributional impacts should be a core public-policy goal. In the context of climate-change management, research on distributional impacts focuses on different sets of issues, depending on the governance level concerned. At the supranational level, approaches to safeguarding equity across generations and countries, today and in the future, is a central research priority. At the national level, most research focuses on the interplay between moral philosophy and economics, in that it has the potential to underpin a shift in decision-making paradigms, away from neoclassical economics and toward frameworks that lend themselves better to reflecting ethical considerations. At the subnational level, a variety of research studies report on sector- and issue-specific analyses that quantify potential regressive effects, with a view to raising awareness about, and helping eliminate, these effects. The two articles that focus on distributional impacts touch upon several of these issues. Specifically, the first article complements subnational-level research by examining how certain design aspects of rural electrification programmes can bring about negative distributional impacts. The second article draws on research focused on global-level equity issues and national-level decision-making paradigms, to put forward a framework for planning climate change-management policies that are more just and more robust.

The first article quantifies the costs of, and greenhouse-gas emissions associated with, electrification programmes fuelled by renewable energy, and compares these estimates with the corresponding estimates for fossil-fuelled electrification programmes. It finds that, with respect to the former, normalised emission levels for the latter are higher by one order of magnitude, a conclusion that is aligned with that of Dagnachew and colleagues (2018), for example, and contrasts with that of Pachauri (2014). Not least, the article reports two findings that challenge current practices with regard to investment in electrification programmes (namely, practices that have an unwarranted focus on up-front costs, to the detriment of operation and maintenance costs, which are key to the long-term viability of the programme). The first of the two findings referred to above is that, for many communities, renewable energy-fuelled electrification programmes are cheaper, everything considered. The second of the two findings referred to above is that, although for some communities these programmes are more expensive than a fossil-fuelled programme, renewable energy-fuelled programmes remain affordable: they represent a level of expenditure in energy that is comparable to the level that these communities currently incur. By quantifying these parameters at a highly disaggregated level, the article substantiates earlier literature on the costs of rural electrification, such as the work of Szabó and colleagues (2011).

The second article draws on the work of Barker (2008) and Stern (2014), to put forward a methodological framework targeting practitioners and seeking to support the planning of climate change-management policies. A first conclusion in the article, stemming from a review of the literature, is that policies ought to take into account non-market goods and services, incorporate uncertainty, and reflect the dynamic nature of technology learning and technology costs. A second conclusion is that, among the range of decision-support tools that can be used in public policy, multi-criteria decision analysis is especially well suited to accommodate the type of analysis associated with non-market goods and services, uncertainty and technology dynamics. The generic criteria tree reported in the article, which seeks to facilitate applications of multi-criteria decision analysis in a climate-change context, effectively translates into the climate-change arena the theoretical principles from multi-criteria decision-analysis theory (Belton and Stewart, 2002) that can be used to identify trade-offs between climate-change objectives and developmental priorities. Facilitating the integration of the former into the latter is the overriding aim of the framework.

The two articles that focus on distributional impacts highlight that managing these impacts requires explicit efforts, over and above those undertaken in most policy-making settings (Johnston and Serret, 2006). The analysis reported in the first article above complements the literature in this area by illustrating that, for highly variable issues such as energy service affordability, highly disaggregated geo-referenced data provides the analysis of distributional impacts with much needed granularity.[5] The second article adds to the literature by (i) integrating the global- and national-level research sketched above, and (ii) translating theoretical concepts into a tool that practitioners can use. With regard to the latter, the tool has been utilised in a governmental policy-planning effort in Mexico (SEMARNAT, 2014) and has informed similar efforts in Peru.

5.5 Implementing the Paris Agreement

Returning to the overall question of how are national governments are responding to the challenges associated with the implementation of the Paris Agreement, the evidence drawn from the eight articles that constitute this thesis suggests that inadequate accountability mechanisms are at the heart of several of the challenges that governments face in their efforts to implement the Paris Agreement. Here “inadequate accountability mechanisms” refers to limited or no performance requirements for certain aspects of the policy-making process, and limited uptake of evaluative evidence in the policy-making process – in areas where such evidence has been available for some years.

Performance requirements

Referring to non-state actor action, Article 2 laments that «anything goes». Article 6 makes a similar point with regard to managing uncertainty, and argues that shifting to scientifically sound practices is an «accountability imperative». Indeed, the empirical evidence points toward the need for introducing minimum quality standards in both areas. In the case of non-state actor action, such requirements could mandate clearer objectives and regular, detailed reporting; in the case of uncertainty management, requirements could entail limiting the choice of policy-planning approaches to those that stand scientific scrutiny.

In both instances, the lack of requirements responds to a combination of factors, from institutional inertia, to limited awareness and capacity, to inclusiveness.[6] Notwithstanding, the price tag of this practice is arguably too high: as shown above, the complexity introduced by the plethora of non-state actor actions, and the potentially misleading deterministic projections used by governments, both risk undermining the credibility of the international climate-change regime. Increased coordination, it has been claimed, is needed (Dorsch and Flachsland, 2017).

Improved programme design

The articles focused on (i) promoting technology transfer and (ii) managing distributional impacts highlight that sub-optimal programme design remains a concern even in areas in which substantial experience has accumulated. In some instances, design shortcomings affect core elements of the programme. This is the case for the technology transfer programmes reported in Article 5, where we observe a mismatch between on-the-ground needs and the programmes' offer. Similarly, Article 1 illustrates that, in some communities, the poorest members cannot afford the "electricity for the poor" provided by development aid-funded rural-electrification programmes. Design shortcomings also affect secondary aspects of some programmes, such as the promotion of innovation (Article 7) or the level of emphasis afforded to ethics in decision-making paradigms (Article 8).

Two hypothesis can be formulated about the reasons for the prevalence of these design shortcomings. First, the challenges inherent to policy evaluations may result in some of the issues referred to above being overlooked.[7] As evaluation methods improve, for example by adopting advanced versions of the so-called theory of change approach, evaluations are likely to capture these and other programme design issues, thus making it easier to fine-tune future policy actions. Second, irrespective of the quality of a given policy action, its performance will be negatively affected if structural elements such as governance arrangements and regulatory frameworks are inadequate. Yet, as much as the notion of integrating climate-change concerns into development policies is well-established, it is clear that much remains to be done in this regard.

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Endnotes

[1] Hsu and colleagues (2018) provide a summary of this literature.

[2] See, for example, Moradi and Vagnoni (2018) and Næss and Vogel (2012) on urban mobility, Wainstein and Bumpus (2016) on power generation, or Withmarsh (2012) and Berkeley *et al*., (2017) on private transport.

[3] Indeed, for countries that have defined their emission-reduction targets as percent-wise reductions of future levels of emissions, the target will only correspond to the emission-reductions effort originally envisaged if the level of emissions in the target year happens to coincide with the level forecasted. Such coincidence is unlikely, given the multiplicity of uncertain factors that affect forecasts.

[4] For an industrialised country like Mexico, economic growth (measured, in this case, through the rate of growth in gross domestic product) is a key driver of greenhouse-gas emissions. Projections of gross domestic product-growth rates are obtained using a well-established protocol for the elicitation of expert judgement.

[5] For example, a meta-analysis by Ohlendorf and colleagues (2018) focused on climate-change mitigation reveals that high-resolution geo-referenced assessments are uncommon. Conversely, as study by Hallegatte and Rozenberg (2017) highlights the usefulness of disaggregated data (in this case, a combination of climate change-impact data and household survey data focused on climate-change adaptation).

[6] Inclusiveness refers to the Convention's practice of avoiding prescriptive frameworks. Doing so is credited for having helped increase engagement. However, the lack of frameworks and associated guidance has reduced comparability across practices, while making it possible for sub-optimal practices to be used.

[7] For example, policy evaluations continue to struggle to determine counterfactuals and establish attribution.

ANNEX 1

Article 1

Szabó, S., Pinedo, I., Moner-Girona, M., Puig, D., Negre, M., Huld, T., Mulugetta, Y, Kougias, I., Szabó, L. and Kammen, D. (2020). Bringing green electricity to low-hanging fruit communities: the way to accelerate to reach affordable and universal energy access. *Nature Energy*.

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Title

Bringing green electricity to low-hanging fruit communities: the way to accelerate to reach affordable & universal energy access

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Abstract

[TEXT TO COME]

Manuscript

1. Introduction

In sub-Saharan Africa (SSA), about 56 percent of the population, lack access to modern forms of energy; the corresponding figures in South and East Asia are eleven percent and three percent[1] [1,2]. The resulting economic, social and environmental impacts contribute to perpetuating poverty in these regions [3]. For this reason, providing electricity to unelectrified communities has been a long-standing policy priority in both aid-donor and aid-receiving countries – an ambition that has been incorporated into the United Nations-sponsored Sustainable Development Goals[2]. Yet, progress with electrification has been slow, focusing mostly on centralized generation and grid extension, which cannot address the needs of rural and scattered communities [4]

To meet the needs of the unelectrified population and the growing demand of the population that already has access to electricity, at least 900 GW of new electricity-generation capacity needs to be installed over the next thirty years, a tenfold increase compared to recent trends [5,6]. The required levels of installation rates (and investment) increase further if universal access is to be achieved for all unelectrified communities. In this context, it is worth recalling that lack of access to modern energy services is concentrated in rural areas where 80 percent of energy-poor people live. Investments will have to come from development-aid budgets [7] or so-called independent power producers (IPPs) [5], which are mostly privately capitalized, because the credit ratings of national governments and public utilities in the regions concerned are inadequate to raise the amounts of debt required to finance universal electrification. However, such investments can only materialize if the following conditions are met [5,7–10]: credible power-sector planning is introduced; the financial risk is reduced through the involvement of development-finance institutions and other risk-mitigation measures; and regulatory frameworks are fine-tuned.

At present, a large part of those already having access to electricity can afford electricity tariffs (by one estimate, as many as 90 percent do [11]). However, affordability levels stagnate at about 25 percent of the population that lacks access to electricity [11]. To make electricity affordable to all, potential short- and mid-term investment returns need to be specified for the full range of electrification options and, spatially, at the level of individual communities.

This article maps unelectrified communities in which current energy expenditure levels make renewable energy-powered off-grid electrification affordable. Solar photovoltaic (PV) off-grid electrification is advantageous from two points of view. First, it reduces maintenance and running costs, compared to diesel oil-powered electricity generation, thus making the technology affordable to a larger share of the population in the long term. Second, it reduces emissions of local air pollutants and contributes to mitigating emissions of global warming-greenhouse gases. For 71 countries, we identify the unelectrified communities where solar-powered electricity generation is a feasible option even when diesel-oil prices are low.

[1] For comparison, while Africa's population is similar in size to China's, Africa has one-tenth of China's installed electricity-generation capacity [2].

[2] Under Sustainable Development Goal 7 ("ensure access to affordable, reliable, sustainable and modern energy for all"), an aspirational target has been set to "ensure universal access to affordable, reliable and modern energy services" by 2030 (UN-DESA, 2020).

In the period 2007-2017, off-grid represented only a minor share of total installed capacity, not exceeding 10 MW in the countries for which data is available, the only exceptions being Bangladesh, Ethiopia, India and Indonesia. We argue that, on the grounds outlined above, there is ample scope for extending solar energy-powered off-grid electrification.

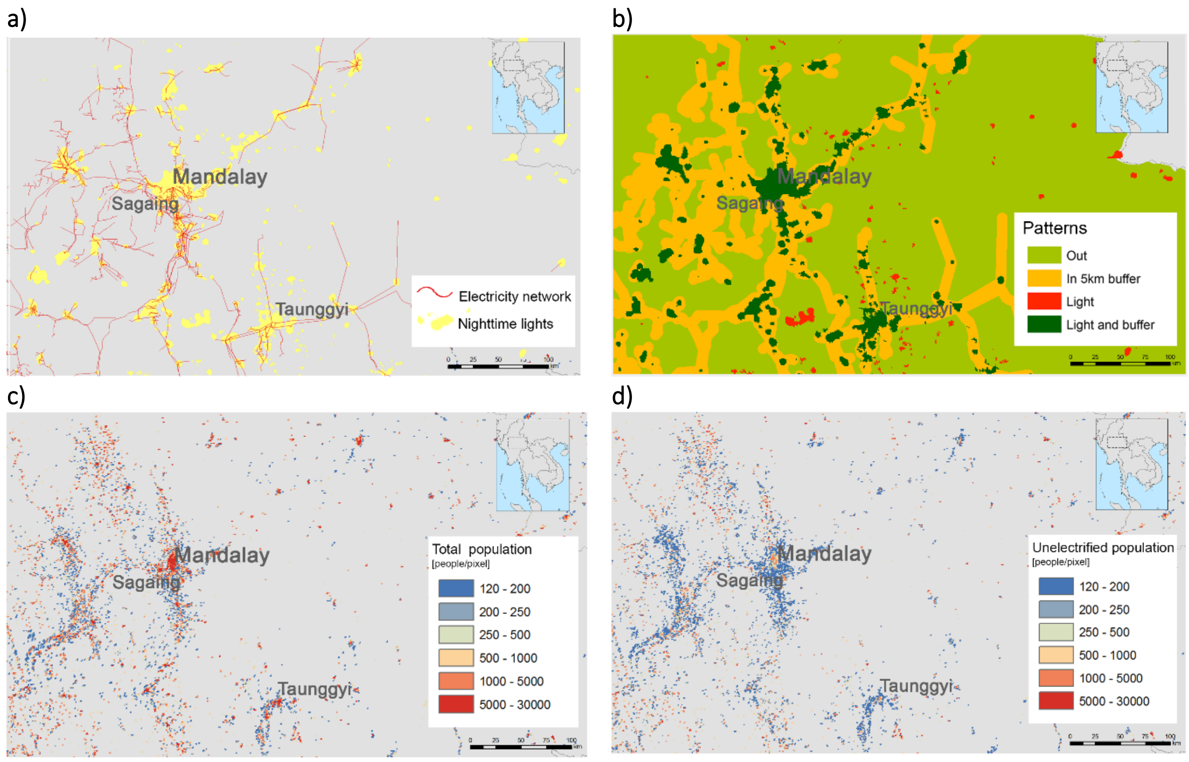
2. Methodology

Building on earlier work [4,12], we study 71 countries in Africa, south Asia and parts of east Asia, which are home to the vast majority (85 percent) of unelectrified communities worldwide (Supplementary Material). As such, the article attempts to provide a comprehensive assessment of universal electrification.

To analyse and quantify the spatial distribution of population without access to electricity, we rely on geo-referenced datasets in different formats and spatial resolutions but with high temporal coherence. The following paragraphs describe the assumptions behind the spatial disaggregation of the data for unelectrified populations.

Figure 1. Example of model outputs: Myanmar's Mandalay region

a) Electricity network and nightlight data
b) Spatial classification of the area according to proximity to the electricity grid and presence of nightlights
c) Distribution of population (people/per cell)
d) Distribution of unelectrified population (people/per cell)



Sources: (European Commission Joint Research Centre (JRC) and Columbia University Center for International Earch Science Information Network (CIESIN), 2015; National Renewable Energy Laboratory, n.d.; OpenStreetMap Foundation (OSMF) & Contributors, 2017; The World Bank, 2017; US NOAA National Geophysical Data Center and US Air Force Weather Agency, 2014; World Bank and the International Finance Coorporation, n.d.) and author's model output.

To estimate the unelectrified population in each cell (grid size: 1 km^2), we use the geo-referenced dataset of human settlements [13] and national unelectrified figures published by the World Bank.

First, we defined zones according to the patterns associated with the absence or presence of nightlights [14] and/or electricity grids[3] (Figure 1a). Areas with nightlights outside the electricity grid buffer are shown in red (Figure 1b). These areas correspond to communities that have off-grid access to electricity. Yellow-coloured areas are those that fall within a maximum of 5 km from the existing electricity grid. These areas correspond to communities with no connection to the grid today, but for which connection is feasible. Dark green-coloured areas show the communities close to the already existing electricity grid (5 km buffer) and with detected night lighting. These areas correspond to electrified areas. Areas with no nightlights far from the existing electricity grid are coloured in light green.

Second, we experimentally set zonal electrification rates (Table I) that reflect the differences among countries while maximising the correlation with national-level figures (Figure 2). Table I gives assumptions about the electrification rate, by country group and type of zone. The values were calculated through an iterative process that maximises the correlation between (i) the reported national-level figures for lack of access to electricity and (ii) the result of summing up the values of every cell for the entire country. The estimates are based on a cross-source analysis of the most populous countries in each country group, and reflect a generalisation of findings in key high-impact countries (Kenya, India and Ethiopia).

Table I: Criteria used to calculate the non-electrified population depending on the type of zone and corresponding country group

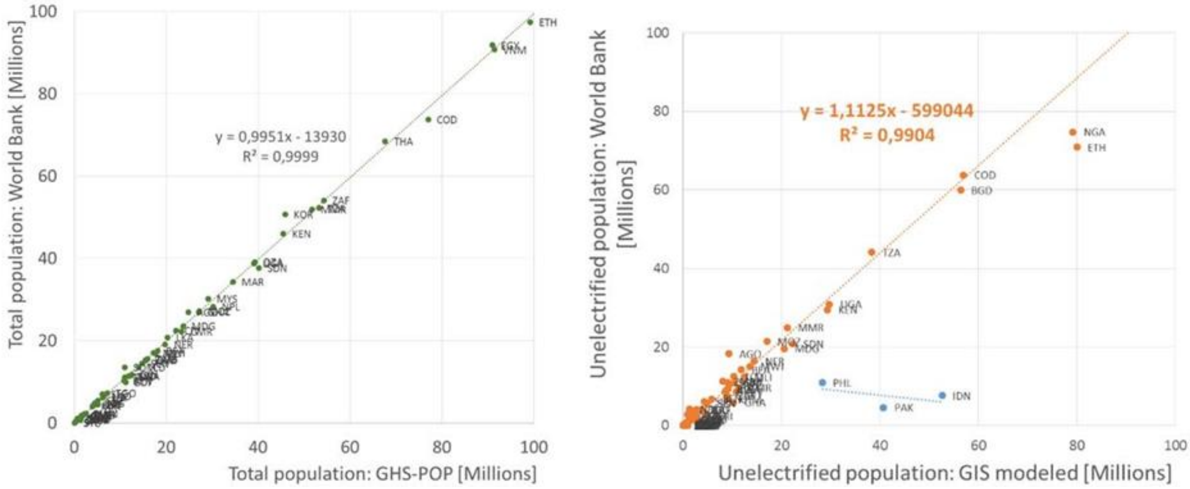
Country group	**Type of zone**			
	In 5km buffer (orange)	In light area (red)	Inside both (dark green)	Out (light green)
	Electrification rate (% of population with no access to electricity)			
South East Asia	40	5	5	100
North Africa	10	20	0	10
Sub Saharan Africa	90	40	5	100
South East Asia electrified	0	0	0	10

Source: authors

Figure 2 shows that the country-level estimates correlate well with the corresponding World Bank figures [15].

[3] In some countries, this corresponds only to transmission lines (66 or 100 kV), whereas in other countries both transmission and distribution lines (11 kV) were available.

Figure 2 Correlation between national level data and spatial distribution of total population (a) and correlation between national-level and model output unelectrified population



Source: own calculations and World Bank data

Using the proxies described above to spatially disaggregate the national figures of unserved population, we estimate the unelectrified population per cell ($1km^2$). To illustrate the type and level of disaggregation of the model's outputs, we present here the results for a square area located in the region of central Mandalay (Myanmar). Figure 1c shows the distribution of population in the area, which hosts approximately 16 million people, out of the total 51 million people in the country. Just below ten percent of the population in this area live in the three largest urban areas: Mandalay (1.2 million people), Taunggyi (260,000), and Sagaing (70,000). Figure 1d shows the result of spatially disaggregating the unelectrified population in each pixel using the electrification rate corresponding to the zone and the country group described in Table 1. Nearly 6 million people, out of the 16 million living in this area, lack access to electricity.[4]

3. Costs of solar energy- versus diesel oil-powered electrification

Drawing on previous efforts to map the production costs of off-grid technologies in Africa [4], we calculate site-specific electricity costs for the two main electrification technologies: solar PV mini grids and diesel-oil mini grids. Such a calculation allows us to assess both the maximum rate of deployment for photovoltaic technologies (namely, for high diesel oil prices) and the minimum rate of deployment (namely, for low diesel oil prices).

3.1 Techno-economic conditions for photovoltaic and diesel-oil systems

We distinguish between two types of deployment conditions for photovoltaic systems. We term these scenarios "favourable" and "adverse", respectively. They correspond to an overall framework, market situation and landscape that is positive or negative for solar PV installations. "Favourable" conditions for PV are consistent with SSP1[5]. In this scenario, diesel prices remain at their 2012

[4] Our estimate for Myanmar is 15 percent lower than the corresponding estimate by the World Bank.

[5] SSP1 refers to the first "pathway" in a set of scenarios labelled Shared Socioeconomic Pathways. These scenarios provide narratives of plausible future changes in socio-economic parameters [22]. They are used to foster comparability among prospective climate change-management studies. SSP1 describes a future that shifts strongly towards low-emission technologies and a sustainable management of natural resources.

levels, which are considered high (Methods) and include national-level taxes and subsidies. Costs associated with solar PV mini grids (Table II) are in line with current estimations of component costs [16,17].

Table II: Current component costs for PV mini grids

Parameter	Value
PV module cost	0.95 USD/Wp
Balance of system cost	1.15 USD/Wp
Li-on battery cost	400 USD/kWh
System lifetime	20 years
Battery lifetime	10 years
Discount rate	5%
Consumption during daytime	2/3
Days with power loss	5%

Source: Moner-Girona et al [16], Huld et al [17]

"Adverse" conditions for PV are consistent with SSP3.[6] In this scenario, we assume that investment decisions favour low-cost diesel. For this reason, we use the price of February 1, 2016, right after one of the lowest values of Brent in the last five years [18,19] (Methods). Under these conditions, decisions about electrification are likely to be dominated by three factors. First, PV mini grids exhibit higher up-front costs, compared to diesel-oil mini grids[7]. Second, high population growth rates in this scenario result in stronger demand for quick and cheap electrification, compared to the "favourable" PV conditions. Third, high demand leads to an increase in diesel prices in the mid-term, at which point investments in diesel-oil mini grids are already locked in.[8]

3.2 Least-cost options for photovoltaic and diesel-oil systems

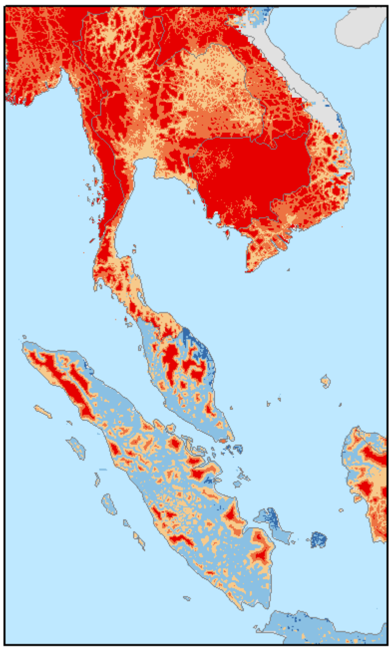
For each of the two technologies, we estimate the costs and annual emissions associated with providing access to electricity to the entire unelectrified population in each 1 km^2 cell. We assume an annual consumption level of 1,250 kWh per household [20] (Methods). For each cell, we compare technology-specific costs. **Figure 3** shows the comparison for south-east Asia, one of the regions under study: red-coloured areas are those where PV mini grids are cheaper, whereas blue-coloured areas those where diesel-oil mini grids are cheaper. The higher the contrast, the larger the difference in cost estimates.

[6] Under SSP3, regionalization wins over integration, current high-fertility countries experience high population growth, and oil price volatility becomes the norm.

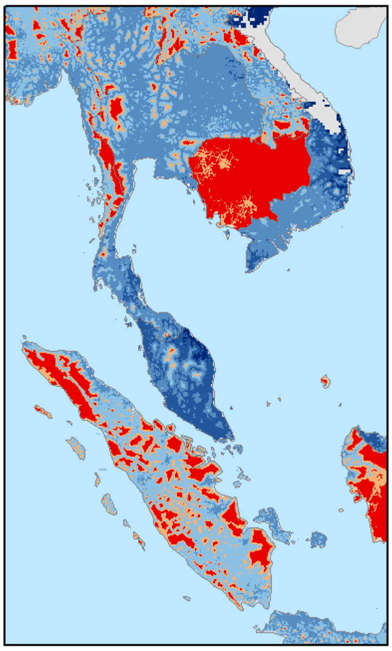
[7] In this reasoning, higher interest rates result in lower, more discounted future operation costs associated with fuel purchase

[8] For the increasing diesel prices, we use the national retail diesel prices of 2012 (GID, n.d.).

Figure 3: Competitiveness of PV (red) versus diesel-oil (blue) mini grids in the Indochinese peninsula under the “favourable” (a) and “adverse” (b) conditions scenarios



a)



b)

Source: own calculations

3.3 Environmental performance for photovoltaic and diesel based systems

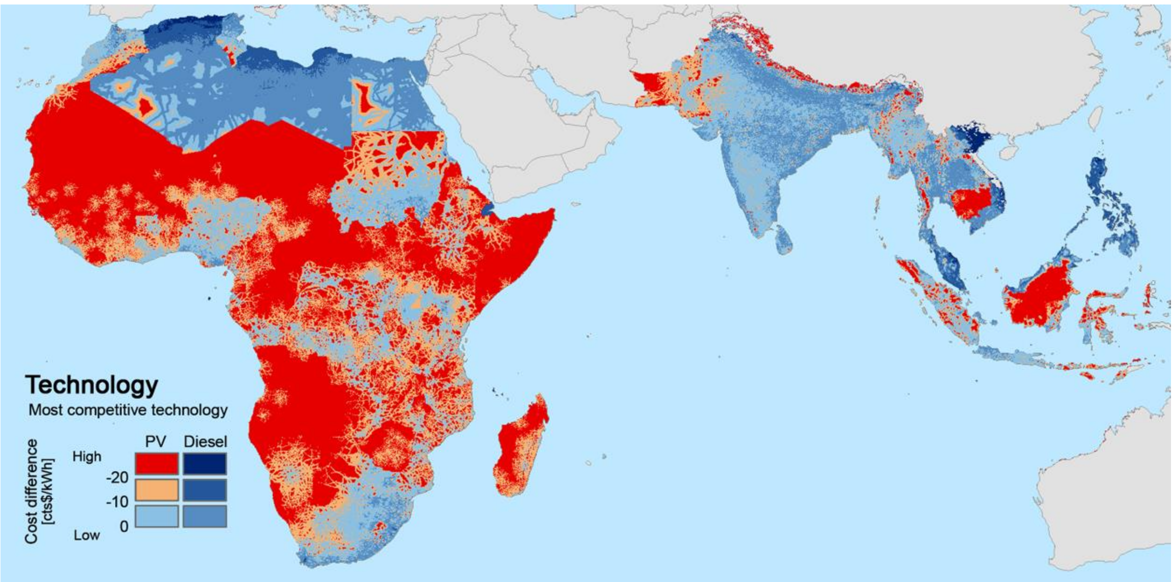
Considering the human health and environmental impacts of the two prevailing rural electrification systems, PV-based systems outperform their diesel-based counterparts. Indeed, in the PV adverse scenario, carbon-dioxide emissions are higher by a factor of six, and local air quality is also comparatively lower.

3.4 Areas in which photovoltaic mini grids are the cheapest option under both scenarios

Figure 4 illustrates the results under the “adverse” conditions scenario. The dark red-coloured areas show the regions in which photovoltaic mini grids produce 1 kWh for a cost that is at least 20 USD cent/kWh cheaper than that of diesel-oil mini grids. The red-coloured areas are those where photovoltaic mini grid investments constitute a no-regrets option[9].

[9] Note that the model does not account for planned extension of the electricity grid.

Figure 4 Location-specific estimates of the relative cost of solar PV versus diesel-oil mini grids in the "adverse" conditions scenario



Source: own calculations

The analysis covers 71 countries, with an unelectrified population of roughly 1,200 million people. Energy poverty is concentrated in 27 of those countries, where 89 percent of this population lives. Focusing on the latter (we term these countries "high priority" countries), we find that for 125 million people (11%) photovoltaic mini grids represent the least-cost electrification option. Simply stated, photovoltaic mini grids is the no-regrets option for providing electricity to 125 million people in 27 "high priority" countries. Country-level data is provided in Table III.

Table III: Adverse conditions scenario: population living in photovoltaic mini grids as "no regrets-option" in "high priority" countries

Country	Unelectrified population (million people)	Population living in areas where PV is a no-regrets option (million people)	Population living in areas where PV is a no-regrets option (percent of total unelectrified population)
Republic of Korea	0,0009	0	0
Philippines	31,7	0	0
Bangladesh	71,5	0,003	0
Myanmar	26,1	0,1	1
Sudan	26,2	0,6	2
Nigeria	93,2	0,9	1
India	294,8	1,1	0
Cameroon	13,0	1,3	10
Mozambique	20,4	1,8	9
Uganda	34,7	1,9	6
Pakistan	54,8	2,0	4
Zambia	9,5	2,6	27
DRC	66,2	2,7	4
Ethiopia	94,0	27,7	30
Kenya	34,0	3,7	11
Indonesia	54,1	4,0	8
Burundi	10,6	4,1	39
Tanzania	44,7	4,4	10
Niger	17,2	4,4	26
South Sudan	12,2	5,6	46
Chad	12,5	5,8	47
Zimbabwe	11,8	7,0	59
Madagascar	25,0	7,1	29
Angola	10,9	8,5	78
Mali	14,8	9,0	62
Malawi	16,1	9,4	58
Burkina Faso	13,8	9,6	70

Source: own calculations

4. Affordability levels for photovoltaic mini grids

The estimates presented thus far correspond to the share and spatial location of unelectrified communities for which photovoltaic mini grids represent a no-regrets option purely from the point of view of costs. However, comparatively lower costs will not necessarily lead to successful electrification interventions unless affordability considerations are taken into account.

Electrification programmes incur two types of costs: up-front costs, and operation and maintenance costs (O&M). Further to an initial period, the latter are borne by the beneficiaries of these programmes. It follows that, if programme beneficiaries cannot afford O&M costs, the programme will not achieve its objectives. Universal access targets the electrification of the poorest areas in the world; accordingly, low O&M costs are imperative. When considering also the human health and environmental impacts associated with the use of diesel-oil based technologies, it is worth exploring the share of unelectrified communities that could afford photovoltaic mini grids.

In light of the above, our cost estimates are broken down into two components: up-front and O&M costs. We assume that the former will be borne by a governmental entity, whether it is a national government or an overseas aid agency, and the latter will be borne by the beneficiaries. Contrary to this assumption, financial appraisals tend to focus on up-front costs (REF), even if ignoring O&M costs may result in a system that is underutilized at best[10].

Drawing on field data, and using conservative assumptions, we estimate that O&M costs associated with photovoltaic mini grids represent one-tenth of the total costs [16]. For diesel-oil mini grids, we estimate that 1 USD cent/kWh covers the initial capital cost[11], with O&M costs (production and transport cost) accounting for the rest.[12]

To assess affordability, we estimate two parameters: the running costs of electricity and the amount of money households can spend in energy. Our estimates of the latter assume that, provided that the same level of service is obtained and the overall amount of money available is not exceeded, the choice of fuel is inconsequential.[13]

In Figure 5, we compare the modelled cost of electricity (and the fraction associated with O&M) with the potential daily expenditure in electricity in a poor household. The latter is drawn from the World bank's Global Consumption Database, a freely accessible database on household consumption patterns in developing countries (for more detailed description, please refer to Methods). Some of the expenditure values in the Global Consumption Database are comparatively low. If no modeled cost is reported (either PV or diesel) it means that, under PV adverse conditions, no household is allocated to that technology, because the competitor is cheaper for all the locations within that country.

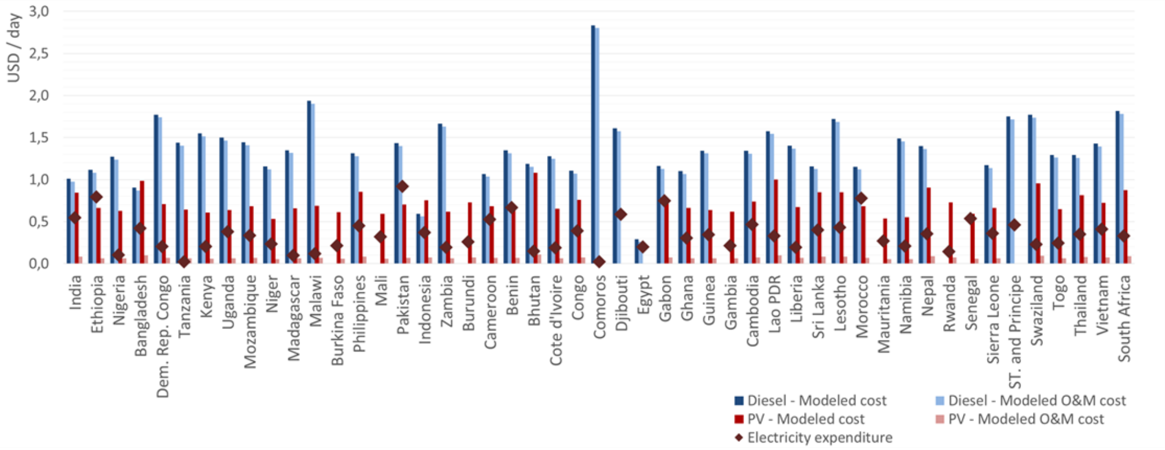
[10] A large number of IPP-financed projects are in this situation (REF).

[11] This cost component accounts for the commercial price and the average lifetime for the 4-15kW diesel generators.

[12] This cost component accounts for diesel-oil consumption associated with the production phase, accounting the price increased due to the transport from distribution to consumption location.

[13] This assumption ignores substitution between energy and other goods purchased by households.

Figure 5	Modelled total and O&M costs versus expenditure on electricity per day per poor household. The costs are calculated under PV adverse conditions scenario



Source: own calculations

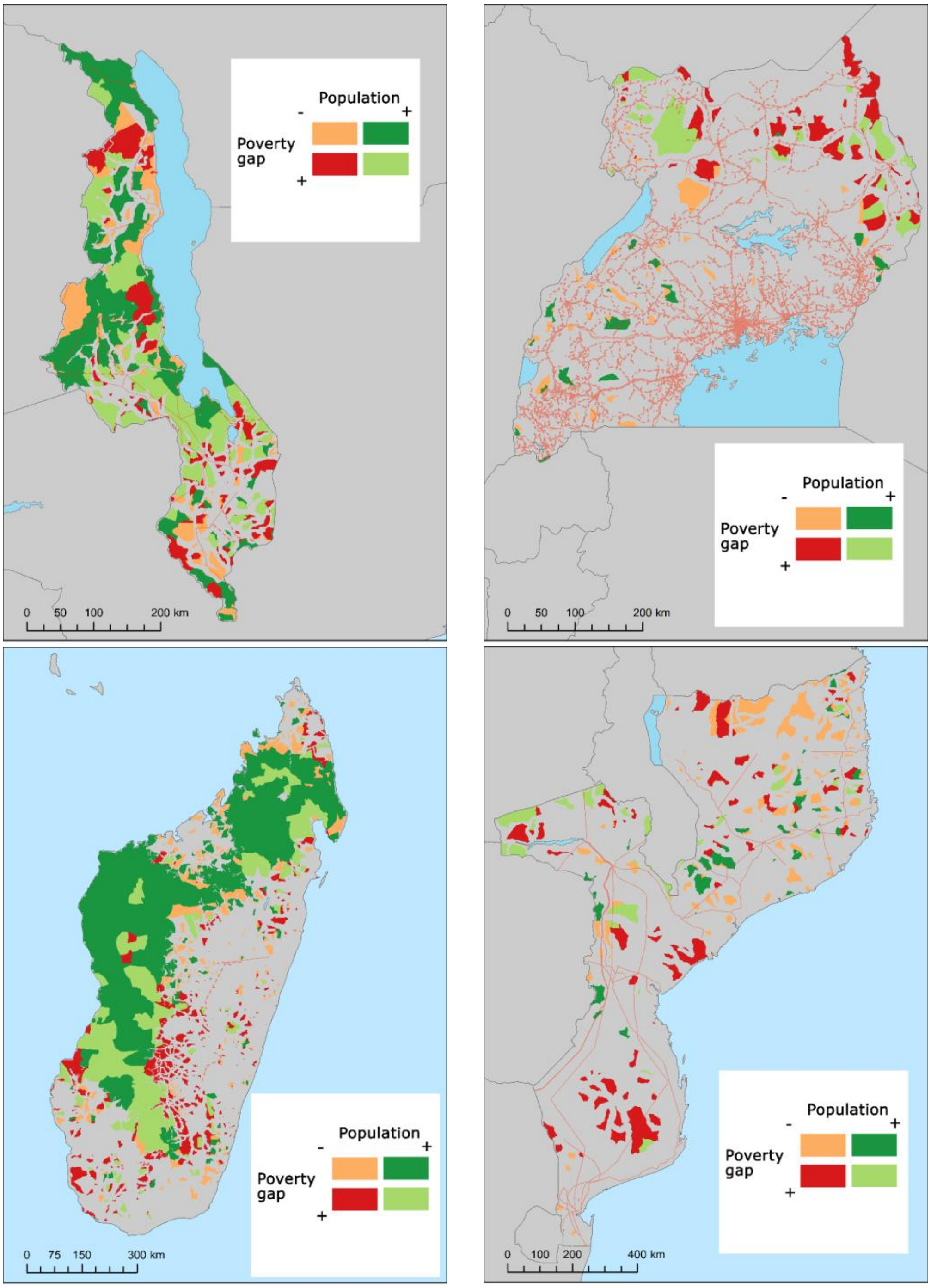
Figure 5 illustrates two points. First, the differences between countries with regard to estimated O&M costs per poor household. Second, the relevance of considering affordability when contextualising the chances of achieving universal access targets in poor areas.

Lacking disaggregated affordability data, to identify and rank "low hanging fruit" PV areas we rely on sub-national data draen from the so-called poverty gap.[14] Figure 6 shows the results for Madagascar, Malawi, Mozambique and Uganda, as examples. We assign each administrative area to one of four categories, defined according to whether or not PV mini grids are affordable, considering the size of the population in each administrative area and their ability to pay.[15]

[14] The so-called poverty gap index can be defined as the average shortfall between actual household welfare levels and the poverty line, expressed as a fraction of the poverty line [21].

[15] The threshold used in each map to distinguish the two poverty gap classes (large or small) corresponds to the mean of the poverty gap in "photovoltaic areas" in each country (Madagascar: 35.6 percent, Malawi: 28.9 percent, Mozambique: 32.4 percent, and Uganda: 17 percent). The threshold used in each map to distinguish the two groups of population covered (more and less population) corresponds to the mean of the number of inhabitants allocated in "photovoltaic areas" in each country (Madagascar: 5,000 inhabitants, Malawi: 18,000 inhabitants, Mozambique: 5,300 inhabitants, and Uganda: 9,000 inhabitants).

Figure 6 Classification of "low-hanging-fruit PV" areas (green) in (i) Malawi (ii) Uganda (iii) Madagascar and (iv) Mozambique (clockwise). Dark green corresponds to areas with more population and, on average, wealthier than the norm, whereas dark red corresponds to areas less populated and poorer than the norm



Source: own calculations

Identifying these areas has the potential to increase the impact of electrification projects, by integrating into the project design the economic vulnerability of the different rural consumers. Simply by developing a comprehensive spatial database with the distribution of poverty within and across countries, the method used to produce the maps above is replicable elsewhere.

6. Conclusions

For 71 countries, and at a high level of resolution, we identify the communities that can afford photovoltaic mini grids. These communities are no-regrets options for PV investors, because PV is the cheapest option, even under unfavourable conditions. Together, these areas are home to a large number of people who can afford the electricity tariffs associated with PV mini grids. Investing in photovoltaic technologies, as opposed to diesel-oil technologies is justified on two accounts: O&M costs, and human health and environmental concerns.

At present, national investment decisions for electrification are short-sighted, as they often put too much weight on up-front costs, even when the size of the O&M costs may eventually render the investment futile. The findings reported in this article are of direct relevance to governments in low-income countries, and development-aid agencies. Specifically, the methodology used, which is extensively documented in annexes, can inform the design of future electrification programmes, especially those targeting rural areas with low purchasing power. Ultimately, our findings suggest that both public- and IPP-led investments in electrification will lack robustness and credibility if they are framed around decisions that neglect O&M costs, and human health and environmental concerns.

We believe that investing in photovoltaic mini grids in the communities that we label no-regrets areas could serve a dual purpose. First, these communities would be provided with affordable and sustainable electricity. Second, such an investment could help turn the tide with regard to the investment decision parameters sketched above.

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Article 2

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Pre-print (second round of review comments)

Title

Determinants of successful delivery by non-state actors: an exploratory study

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Abstract

Parties to the United Nations Framework Convention on Climate Change are giving an increasingly prominent role to non-state actor action. As a result, significant research efforts have gone into assessing the extent to which non-state actors can complement the role of state actors. However, the literature shows a paucity of studies assessing ex-ante the likelihood that a given non-state actor action may deliver on its intended objectives. The article develops a framework to help conduct such an assessment. The framework helps identify potential barriers to delivery, with a view to anticipating possible solutions and integrating these in the design of the non-state actor action. It is suggested that the Convention should sponsor this kind of ex-ante assessments, to increase the quality of useful actions, and make it easier to weed out ineffectual initiatives.

Manuscript

1. Introduction

Transnational governance has been defined as the set of «processes in which nonstate actors adopt rules that seek to move behavior toward a shared, public goal in at least two states» (Roger and Dauvergne, 2016).[1] By nonstate actors, Roger and Dauvergne refer to non-governmental entities,

[1] Transnational governance can be defined by opposition to what might be called 'intergovernmental governance', which refers to the set of rules that govern the collective efforts of at least two state actors pursuing a shared, public goal (Roger and Dauvergne, 2016). Thus, 'intergovernmental governance' would be restricted to national-level governments, and would exclude explicitly non-state actors.

thus entirely excluding governmental entities, whether they are national, sub-national or supra-national entities. In this article, non-state actor action refers to any combination of entities that are not exclusively governmental entities (Supplementary Information 1).

The surge in transnational governance schemes «can be traced back to the incipient globalisation that followed the liberalisation of trade markets in the mid-1970s» (Bakhtiari, 2017). Founded in 1990, the Climate Alliance, a coalition of sub-national governments, is possibly the first transnational governance scheme focused on climate change-management (*ibid*).

In 2015, through its Paris Agreement, the United Nations Framework Convention on Climate Change (UNFCCC) declared that «non-party stakeholders» (that is, parties other than the signatory parties to the UNFCCC, thus including non-state actors) may contribute to achieving the UNFCCC's mitigation and adaptation goals (UNFCCC, 2015).[2] The so-called global climate action summit, held in September 2018 in San Francisco, lent momentum to a further institutionalisation of the role of non-state actors in international climate change negotiations. There are no indications to suggest that this trend will reverse in the near future (Bulkeley *et al*., 2018).

Against this background, the proliferation of transnational climate change-governance schemes should come as no surprise. Yet, in spite of the political support that these schemes enjoy, there is no commonly agreed definition of what constitutes a non-state actor action (Supplementary Information 1). This hampers efforts to inventory and study non-state actor actions (Fenhann *et al*., 2018). Notwithstanding, it is clear that most climate change-related non-state actor actions focus on climate change mitigation, with just a few covering adaptation to climate change and disaster-risk reduction (CIP, 2018).[3]

Irrespective of whether they focus on climate-change mitigation, adaptation, or disaster-risk reduction, studies of non-state actor action can be characterised according to the types of impact – direct or indirect – that they explore. We define direct and indirect impacts as follows:

- Direct impact refers to the delivery of tangible climate change-management outcomes within a given period of time. A tangible outcome is understood as changes in technologies or practices that, in themselves, result in reductions in greenhouse-gas emissions, or increases in resilience to the impacts of climate change. These outcomes are the direct consequence of the operations of the non-state actor action, and are additional to any other related efforts to deliver climate change-management outcomes (notably, efforts led by state actors). Stated differently, within the selected period of time, the climate change-management outcomes attributable to the non-state actor action would not have been delivered, neither partially nor totally, had the non-state actor action not been in operation.
- Indirect impact refers to the changes in practices, improvements in technical capacities and increases in financial resources or information flows which, over a given period of time, facilitate the delivery of direct climate change-management outcomes by other actors, notably

[2] In decision 1/CP.21, through which the Paris Agreement is implemented, paragraph 117 «welcomes the efforts of non-Party stakeholders to scale up their climate actions», whilst paragraph 118 «encourages Parties to work closely with non-Party stakeholders to catalyse efforts to strengthen mitigation [...] action» (UNFCCC, 2015). Paragraph 134 in the same decision «invites [...] non-Party stakeholders [...] to scale up their efforts and support actions to reduce emissions» (*ibid*).

[3] Most non-state actor actions focus on climate change mitigation because, compared to adaptation to climate change and to disaster-risk reduction, mitigation action has a much longer history.

state actors. Stated differently, within the selected period of time, the work of the non-state actor action increases the pace with which other (state or non-state) actors can deliver climate change-management outcomes that they would have attempted to deliver as a part of their regular operations.

Most research on non-state actors focuses on direct impacts. Estimates of the level of greenhouse-gas emission reductions that these actions could achieve make up a distinct research stream (Hsu *et al.*, 2018). Next to this type of work, governance constitutes a second area of research, contributing both theoretical (Andonova *et al.*, 2009) and empirical (Andonova *et al.*, 2017) studies that target all governance levels, from local, to national, to global.[4] Additional research on direct impacts by non-state actor actions includes studies focused on international climate change negotiations (Hermwille, 2018), specific actors such as cities (Bulkeley and Schroeder, 2012), or the geographic distribution of the actions (Chan *et al*., 2018), among other topics.

The study of indirect impacts has attracted less attention, in spite of calls to consider such impacts (van der Ven *et al*., 2017). In general, indirect impacts are characterised as being «catalytic and political – contributing to normative change, building the capacities of political actors and altering coalition-building and conflict dynamics […] in addition to, or even instead of, quantifiable emissions reductions» (Bulkeley *et al*., 2018).[5] This characterisation could be expanded beyond "quantifiable emission reductions", to include increases in resilience to the impacts of climate change, or reductions in disaster risk.

In reality, the divide between direct and indirect impacts is somewhat artificial, as few, if any, non-state actor actions achieve one type of impact only (CIP, 2019). For example, the Global Resilience Partnership, a non-state actor action whose primary goal is to deliver direct impacts, has also contributed to increasing the ability of bilateral donors to coordinate their climate change adaptation portfolios (an indirect impact) (GRP, 2019). Similarly, CDP's initial work to foster private sector disclosure of climate change-related data (an indirect impact) has led to actual reductions in greenhouse-gas emissions by many CDP members (CDP, 2019).

Few authors have put forward criteria that can be used to assess the extent to which a non-state actor action is likely to deliver on its objectives, irrespective of the main type of impact – direct or indirect – that is concerned. Widerberg and Pattberg (2015) developed three sets of criteria exploring, respectively, the effectiveness, legitimacy and "institutional fitness" of non-state actor actions. For example, one of the two effectiveness criteria focuses on the extent to which a given non-state actor action has access to the required type and amount of resources. Michaelowa and Michaelowa (2017) screen non-state actor actions against three "design criteria": the extent to which (i) explicit targets have been set; (ii) incentives are available; and (iii) monitoring, reporting and verification procedures have been adopted. Finally, Chan and Amling (2019) rely on twelve pre-defined "functional categories" to assess whether the outputs of a given non-state actor action are consistent with the function(s) that the action in question seeks to deliver. Examples of functions include knowledge dissemination and policy planning, among others.

We study a selection of six non-state actor actions, to gain insights on the determinants of successful delivery. We choose non-state actor actions whose direct impacts concern adaptation to climate change or disaster-risk reduction. We make this choice because, compared to research on non-state

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[4] Although some of these studies explore both direct and indirect impacts, most focus on direct impacts.

[5] It is worth noting that indirect impacts can be both positive and negative (van der Ven *et al.*, 2017).

actor actions focused on climate-change mitigation, adaptation and disaster-risk reduction are under-studied areas.[6] With regard to indirect impacts, we examine two widely cited types of impacts: mobilising private sector funding, and catalysing related, complementary action by state actors.

We rely on semi-structured interviews, complemented with a survey. We use the interviews to learn the interviewees' points of view with regard to the determinants of successful delivery by non-state actor actions. The survey, which focuses on factual data about the various non-state actor actions studied, helps us put into perspective the feedback provided by the interviewees. We use these data to sketch a framework for assessing the likelihood that delivery by non-state actor actions may be successful. Our findings allow us to make a number of recommendations with regard to the role that the UNFCCC can play to increase the efficiency and effectiveness of non-state actor actions.

The remainder of the article is structured around four additional sections. Section 2 summarises the type of data that we have collected, and the process that we followed to collect it. Section 3 describes our findings, the implications of which are discussed in Section 4. Concluding considerations are presented in Section 5.

2. Methods

This section is structured around two sub-sections. First, the process followed to select the non-state actor actions is outlined. Following this, details of the data collection process are provided. This process entailed both a set of interviews and a survey, as referred to in the previous section.

2.1 Selection of non-state actor actions

The literature includes several databases of non-state actor actions, which differ substantially in scope (Höhne and Drost, 2015). At least two reasons account for this. First, there is no single definition of non-state actor action (Supplementary Information 1). Second, the purpose of a database determines the selection of non-state actor actions included in it (Widerberg and Stripple, 2016). As a result, we had to rely on multiple sources to identify the non-state actor actions that were relevant to our research. As stated above, we chose to focus on adaptation and disaster-risk reduction.

A literature search returned nine non-state actor actions focused exclusively on adaptation to climate change or disaster-risk reduction. Semi-structured interviews with the managers of each of these nine actions were used to get three types of feedback. First, the interviewees helped us judge the extent to which the actions were consistent with our definition (Supplementary Information 1). Second, feedback from the interviewees was critical to determine whether the actions had been active for long enough to be able to respond to our questions, as this information is seldom disclosed in the documentation that non-state actor actions make publicly available. Third, interviewees helped us identify additional non-state actor actions that could be of potential interest to us and had not been captured through our literature search.

[6] Studies of non-state actor actions that focus on adaptation to climate change are scarce, partly because practice is still limited. Dzebo and Strippe (2015) authored one of the first such studies, which remains the only review focused solely on adaptation. Most subsequent studies of adaptation-focused non-state actor actions also cover their mitigation-focused counterparts. A review by Michaelowa and Michaelowa (2017) provides an example of this.

This screening process allowed us to discard four actions: three of them were at the early stages of their work, and one of them did not fit our definition. In addition, the screening process allowed us to identify one additional action that did meet our eligibility criteria. In sum, at the end of the screening process we had identified six non-state actor actions that were eligible for the analysis. Three of these actions focus on adaptation to climate change and the remaining three focus on disaster-risk reduction (Table 1).

Table 1: Non-state actor actions surveyed

Non-state actor action	Focus area
Business Alliance for Water and Climate	Climate change adaptation
Crisis Anticipation Window	Disaster-risk reduction
Forecast-based Financing	Disaster-risk reduction
RegionsAdapt	Climate change adaptation
Rural Resilience Initiative	Disaster-risk reduction
Urban Community Resilience Assessment	Climate change adaptation

2.2 Data collection

Reporting by non-state actor actions remains limited at best (Fenhann *et al.*, 2018). As a result, the little data available is neither comprehensive nor comparable across non-state actor actions. For this reason, we conducted a survey among the six non-state actor actions identified, and interviewed the core partners in each action.

The survey consisted of two questionnaires, to which we referred as “Form A” and “Form B” (Supplementary Information 2). For each non-state actor action, we collected one response to Form A, jointly prepared by the core partners in the action, because the questions in this form capture the main features of the non-state actor action itself. Form B was filled out individually by each of the core partners in a non-state actor action, because the questions in this form capture issues that are specific to an individual organisation. In short, for each non-state actor action surveyed, we collected one response to Form A, and as many responses to Form B as core partners in the action.[7]

In both forms, some of the questions allowed for responses that could be defined in advance. Examples of this type of questions include the countries in which a non-state actor action is active, or the descriptor (governmental agency, private sector, non-governmental advocacy group, or academia) that best characterises a partner in the non-state actor action. These questions were phrased as multiple-choice questions. However, a second set of questions were not amenable to a multiple-choice phrasing. The incentive that an organisation may have in joining a non-state actor action, or the delivery mechanisms of the action are examples of this type of questions.

[7] Further to an initial contact by e-mail, survey respondents were briefed on the phone about the scope and goal of the survey. They submitted their responses by e-mail. A second phone conversation was used to ensure that the responses provided were fully aligned with the type of response sought. This helped increase, across respondents, the comparability of the responses received.

Nonetheless, to introduce a minimum level of convergence in the responses without leading respondents and thus potentially losing granularity, the questionnaire included certain examples. These examples reflected the preliminary feedback provided by respondents themselves (see footnote 7). Respondents were encouraged to provide a succinct response, without necessarily limiting themselves to the examples included in the questionnaire.

For each non-state actor action, we interviewed one of the core partners in the action. We asked for their views on the determinants of successful delivery, understood as the enablers of delivery of the action's intended objectives.

We encouraged our interviewees to consider as broad a range of issues as possible, including issues that are out of the control of the partners in the action. Our goal with this suggestion was twofold. First, to avoid unduly narrow responses that only consider issues that are within the boundaries of the non-state actor action. Second, to introduce as light and non-constraining a framework as possible.

3. Results

This section is structured around two elements. First, we present an overview of the results of our survey of six non-state actor actions. Second, we report on the interviews that we conducted, the goal of which was to shed light on the determinants of successful delivery by the non-state actor actions studied.

3.1 Survey results

Supplementary Information 3 provides a narrative synthesis of the results of the survey, including the stated objectives (Table SI3.1) and purported net benefits (Table SI3.2) of each of the individual non-state actor actions surveyed. Table 2 gives a tabular overview of the survey results. Together, these elements provide context to the feedback collected through our interviews (Section 3.2).

Three of the non-state actor actions surveyed focus on planning for climate change adaptation, whereas the remaining three focus on mobilising and channelling funding for disaster-risk reduction. In general, we find that, compared to the former, the latter (i) have a clearer niche vis-à-vis related work by state actors, (ii) use innovative delivery mechanisms, and (iii) represent a major part of the portfolio for at least one of the core partners in the action.

All six non-state actor actions have delivered on their intended direct impacts.[8] With regard to indirect impacts, we consider two widely cited types: mobilising private sector funding, and catalysing related, complementary action by state actors. Only the three non-state actor actions focused on disaster-risk reduction have been successful at mobilising private sector funding. Two of the actions focused on disaster-risk reduction have been successful at catalysing related, complementary action by state actors.

Four out of the six non-state actor actions surveyed report on their activities mainly as a response to donor requirements. In other words, in spite of longstanding calls for heightened disclosure (Höhne and Drost, 2015), reports targeting stakeholders other than donors are rare. Of the remaining two

[8] That a non-state actor action delivers on its stated objectives says nothing about the level of ambition of those objectives, or about the effectiveness and efficiency with which delivery occurred.

non-state actor actions, one action reports annually to international climate change negotiators, whereas the second action produces no reports.

Table 2: Overview of the responses to the survey

	Business Alliance for Water and Climate	Crisis Anticipation Window	Forecast-based Financing	RegionsAdapt	Rural Resilience Initiative	Urban Community Resilience Assessment
Nature of the objectives	Qualitative	Qualitative	Qualitative	Qualitative	Qualitative (although some are quantitative)	Qualitative
Intended benefits	Support planning	Mobilise and channel funding	Mobilise and channel funding	Support planning	Mobilise and channel funding	Support planning
Overlap with state actor action	Some	None	None	Some	None	Some
Catalyse complementary state actor action	No	No (but progress made)	Yes	No	Yes	No
Mobilisation of private sector funding	Not attempted	Yes	Yes	No	Yes	No
Reporting	Annual reports to the UNFCCC COP	To fulfil donor requirements	To fulfil donor requirements	None (although members report individually to the secretariat and to CDP)	To fulfil donor requirements	To fulfil donor requirements

Note: UNFCCC COP stands for conference of the parties to the United Nations Framework Convention on Climate Change

Table 3: Overview of the responses to the survey (continued)

	Business Alliance for Water and Climate	Crisis Anticipation Window	Forecast-based Financing	RegionsAdapt	Rural Resilience Initiative	Urban Community Resilience Assessment
Governance arrangements	Horizontal	Horizontal	Hierarchical (for the setting up of the action) and horizontal (for running the action)	Horizontal	Orchestrated	Horizontal
Innovative delivery mechanisms	No (knowledge dissemination)	Yes (risk reduction)	Yes (risk reduction and risk transfer)	No (knowledge dissemination)	Yes (risk reduction and risk transfer)	No (local-level technical assistance)
Type of organisation	Heterogeneous (non-governmental organisations and businesses)	Homogeneous (non-governmental organisations)	Heterogeneous (UN agency and non-governmental organisations)	Homogeneous (sub-national governments)	Heterogeneous (UN agency and non-governmental organisations)	Homogeneous (non-governmental organisations)
Relative importance of the action vis-à-vis other activities	Modest part of the portfolio for all partners	Large part of the portfolio for at least one partner	Large part of the portfolio for at least one partner	Modest part of the portfolio (except for two African members)	Large part of the portfolio for at least one partner	Modest part of the portfolio for all partners
Delivery mechanisms	No mentioning of "quality control"	No mentioning of "quality control"	"Quality control" is among the main activities	No mentioning of "quality control"	"Quality control" is among the main activities	No mentioning of "quality control"

3.2 Interviewee responses

Individually for each of the non-state actor actions studied, the following paragraphs present the feedback gathered through our interviews. Repetitions in the feedback reflect the similar objectives and delivery methods of the non-state actor actions studied.

3.2.1 Business Alliance for Water and Climate

Business Alliance for Water and Climate fills two kind of gaps. First, it generates and channels otherwise unavailable knowledge about climate change-induced water stresses that affect businesses. Second, it guides private companies in their interactions with international negotiations about climate change adaptation. These functions fall at the interface between public policy and business strategy, and thus their fulfilment is of interest to both public and private sector actors.

At the international level, Business Alliance for Water and Climate responds to both peer and political pressure on developed-country multinational companies. Peer pressure has marketing and efficiency implications, both of which have some impact on profit-making and thus attract senior management attention. Political pressure stems, in this case, from the willingness of the French government, as host to the 2105 conference of the parties to the UNFCCC, to display non-state actor action in the area of climate change. Both types of pressure are important drivers and enablers of Business Alliance for Water and Climate.

At the operational level, Business Alliance for Water and Climate relies on three assets. First, the credibility of the core partners, which strengthens their convening power. Second, the capabilities and competences of the core partners, which allow them to drive the action from the technical and strategic points of view. Third, the availability of the resources required to coordinate the work of the companies that have joined the action.

3.2.2 Crisis Anticipation Window

Crisis Anticipation Window mobilises funding to prevent disasters, and channels it to a network of non-governmental organisations that are active in disaster-prone regions. Much like Forecast-based Financing (see below), the objectives of Crisis Anticipation Window are aligned with the policies of donor countries and the needs of beneficiary countries. This alignment is seen as a fundamental pre-condition for success. Need is a second pre-condition for success: Crisis Anticipation Window is needed because no state actor delivers the same kind of disaster-risk management assistance. This situation gives the non-state actor action a “license-to-operate” vis-à-vis donors and, especially, beneficiaries.

To fill the delivery gap referred to above, Crisis Anticipation Window had to create a specialised delivery model, based on a network of non-governmental organisations that are well established is disaster-prone regions. The innovative nature of this delivery model, coupled with a selection of core partners that house the required technical and project management skills, and the coordination capabilities needed to act on extremely tight schedules, are further elements that account for the success of the non-state actor action.

To mobilise private sector funding, Crisis Anticipation Window capitalised on both its “brand” and the extent to which its delivery mechanisms are effective. Brands are a function of the values associated with them, the extent to which the population shares those values, and the level of visibility that a potential private sector funder may achieve. In practice, the first two factors become necessary-but-not-sufficient conditions, with visibility playing the determinant role.[9] Effectiveness, which is a function of the technical and organisational skills accessible to the core partners, attracts two types of potential private sector funders. First, those that may be able to benefit directly from the skills of the partners in the non-state actor action, because they are active in a related field. Second, those that are active in a completely different field, and see effectiveness is a pre-condition for making charitable contributions. The private sector funders of Crisis Anticipation Window fall under the second category.

3.2.3 Forecast-based Financing

For donor countries, preventing disaster in least-developed countries, the goal of Forecast-based Financing, is a strong political choice (both in its own right and from the point of view of the more efficient use of resources that it represents, compared to post-disaster relief). For beneficiary countries, disaster-prevention efforts by non-state actors are among the few options that the poorest communities in these countries have to protect their livelihoods.[10] Therefore, Forecast-based Financing is aligned with both donor policies and beneficiary country needs, which strengthens greatly its ability to deliver successfully.

With regard to implementation, Forecast-based Financing relies on two assets. First, a tight distribution of labour among highly specialised and well-coordinated core partners, which makes it possible for the non-state actor action to provide immediate responses when disasters are about to strike. Second, an innovative methodology, which has proven successful and, as a result, has attracted the interest of state actors. Indeed, a number of state actors have adopted the methodology. To catalyse this change, Forecast-based Financing had to (i) establish a close dialogue with state actors,[11] and (ii) devote resources to transferring skills. In turn, and as a pre-condition to adopting the methodology, state actors had to strengthen institutional capacities and regulatory frameworks.

Forecast-based Financing was successful at mobilising private sector funding. Two reasons account for this success. First, the perceived public-relations benefits of being associated to the Forecast-based Financing "brand". Second, the belief on the part of the private sector funders that the work conducted by Forecast-based Financing was a good quality and thus represented a good use of charitable funds. Section 3.2.2 above gives additional details on the impact of "brands" and "effective delivery" in the context of mobilising private sector funding.

3.2.4 RegionsAdapt

The decision to join RegionsAdapt, which is left to sub-national governments, is contingent on three interrelated factors. First, the availability of staff who have the time and expertise required to engage in this non-state actor action, which focuses on knowledge-sharing. Second, the benefits (in

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[9] In the context of the visibility sought by potential private sector funders, it is interesting to note that Forecast-based Financing and Rural Resilience Initiative, which have a narrow focus, have raised larger amounts of private sector funds, compared to Crisis Anticipation Window, which has a broader focus. As indicated by our interviewees, the broader the focus, the more reduced the visibility and thus the more difficult it becomes to mobilise private sector funding.

[10] This non-state actor action targets least-developed countries, where the poorest can seldom expect assistance from domestic governmental agencies.

[11] The closer the dialogue, the more effective the non-state actor action is likely to be and, in the mid- to long-term, the higher the chances that state actors choose to adopt successful non-state actor approaches.

terms of both learning and visibility) that the sub-national government expects to obtain from joining. Third, a high level of citizen awareness about the near-term impacts of climate change. RegionsAdapt is most successful in sub-national jurisdictions where these three pre-conditions are met.

From the point of view of its design, RegionsAdapt capitalises on its ability to provide a public good that the relevant national governments provide only partly or not at all, namely documenting and disseminating knowledge about adaptation to climate change. It does so through a learning mechanism (based on the exchange of information among the various beneficiaries of the action) and a networking element (through the coordination role provided by the core partners in the action).

From the point of view of its implementation, RegionsAdapt relies mostly on the coordination and agenda-setting capabilities of the core partners. Although these partners are knowledgeable on climate change adaptation, the specialised expertise need not reside with them: it often resides in the sub-national governments that choose to join the action, precisely to share their expertise with other sub-national governments, and learn from them about other adaptation-related issues. As a result, core partner ability to coordinate and engage members (rather than deep technical expertise) are key determinants of success for RegionsAdapt.

3.2.5 Rural Resilience Initiative

Rural Resilience Initiative provides a range of risk reduction and risk transfer opportunities to poor communities in developing countries, with a focus on farmers. Most of the determinants of success mentioned by the other non-state actor actions studied apply to Rural Resilience Initiative. Specifically, Rural Resilience Initiative is consistent with donor policies and beneficiary country needs, and it benefits from highly skilled and well-coordinate core partners. Nonetheless, the key to its success lies on the quality and scope of the services it delivers, which go beyond basic risk-management approaches and have broken new ground in the field (Spiegel and Satterthwaite, 2013). The level of excellent of its operations is also the main reason for the success of Rural Resilience Initiatives at mobilising private sector funding and catalysing related state actor action. For details on the services of Rural Resilience Initiative, the reader is referred to the wealth of online material, notably the annual reports prepared by the core partners in the initiative.

3.2.6 Urban Community Resilience Assessment

Urban Community Resilience Assessment relies on development aid to support informal communities in large urban areas. Therefore, the extent to which this type of support is consistent with the priorities of development aid agencies, and its relative importance vis-à-vis other climate change adaptation activities in the portfolio of development agencies are key determinants of success.

For the local authorities benefitting from Urban Community Resilience Assessment, the support that they receive is of immediate practical application. However, "values", even more than "outputs", are the key drivers of engagement by these local authorities. Indeed, given the one-off nature of Urban Community Resilience Assessment, and the limited selection of informal communities that it can reach, given its limited budget, the appeal of the action lies in the principles it stands for. Therefore, to some degree, the likelihood of success of Urban Community Resilience Assessment is influenced by the extent to which its principles are cherished by the local authorities concerned.

When it comes to on-the-ground delivery, Urban Community Resilience Assessment relies on the capabilities and competences of the core partners, notably their technical expertise and their ability to administer development aid funds. Not least, the non-state actor action relies for its success on the gap it fills: the public good it provides, which would not be provided by public authorities.

4. Discussion

Drawing on the feedback gathered through our interviews (Section 3.2), we sketch a framework for assessing the likelihood that delivery by non-state actor actions may be successful (Section 4.1). We compare this framework with related criteria documented in the literature on non-state actor action (Section 4.2) and with the so-called multi-level perspectives framework for "technological transitions" (Section 4.3).[12] These theoretical exercises suggest that our proposed framework (i) integrates the various sets of criteria that can be found in the literature, and (ii) spans across the full range of issues that play a role in the entry of new actors in a given socio-economic regime, thus suggesting that our framework is comprehensive.

4.1 A framework to assess the likelihood of successful delivery

The responses from our interviewees touch upon three distinct sets of issues. A first set of issues relates to conditions that tend to change slowly and only as a response to forces that are beyond the sphere of influence of the non-state actor action. Examples of these conditions are the extent to which state actors provide climate change adaptation or disaster-risk reduction services to vulnerable communities, or the extent to which development aid agencies are willing to support non-state actors that provide these services.

A second set of issues relates to the type of policy and regulatory environment within which a non-state actor action operates, the extent to which the core partners in the action have the skills required to operate in that environment, and the interactions with other actors that are active in the same environment. One example of these issues is the partnerships that the non-state actor actions surveyed establish with actors that have a strong presence in the regions of interest. Crisis Anticipation Window and Urban Community Resilience Assessment are cases in point. A second example of these issues is the degree to which state actors are in a position to change regulatory and institutional frameworks, in spite of vested interests and institutional inertias, to adopt relevant non-state actor action approaches. Forecast-based Financing is possibly the best example of this.

A third set of issues relates to the workings of the non-state actor action itself, the main elements of which are the choice of delivery method and the interactions between core partners to implement the delivery method chosen. Rural Resilience Initiative provides a paradigmatic example of the importance of the delivery method. With their focus on servicing a relatively large membership, RegionsAdapt and Business Alliance for Water and Climate are examples of the importance that the interaction among partners has for the success of the non-state actor action.

The three sets of issues described above can be generalised into the following three dimensions, which constitute our framework for assessing the likelihood that delivery by non-state actor actions may be successful:

- The first dimension, which we label "societal conditions", refers to issues that take years to change and have a clear, albeit indirect influence on the work of non-state actor actions.

[12] In section 4.3, we argue that, when "technology" is understood in a broad sense, the multi-level perspectives framework is relevant in the context of non-state actor action.

Examples of these issues include near-term vulnerability to the impacts of climate change, societal support (in donor countries) for development aid, or the extent to which civil society is involved in policy-making and public-private partnerships are used to implement policy, among other issues.

- The second dimension, which we label "domain conditions", refers to three types of issues, all of which have a direct influence on the work of the non-state actor action. First, the capabilities and competences of the partners in the non-state actor action, and the extent to which they complement one another. Second, the policy and regulatory environment within which the non-state actor action operates. Third, the agendas of the stakeholders that operate within the same economic and regulatory environment.
- The third dimension, which we label "action conditions", refers to the choice of delivery method made by the non-state actor action, the specific design of the method, and the way in which the different partners in the action interact with one another to apply that method.

4.2 Comparing the three dimensions in our framework with the criteria in the literature

In Section 1, we refer to three sets of criteria that can be used to assess the likelihood that a non-state actor actions delivers on its objectives. In the following paragraphs, and individually for each of these three sets of criteria, we analyse the extent to which the various criteria overlap with the range of issues covered by our framework. This comparison reveals that our framework is fully consistent with the criteria in the literature. The main difference is that our framework covers a broader set of issues (Table 3).

4.2.1 "Effectiveness, legitimacy and institutional-fit" criteria

Widerberg and Pattberg (2015) put forward three criteria, each with two sub-criteria attached. We analyse each sub-criterion individually.

Sub-criterion 1: does the mix of partners in the non-state actor action "reflect the problem it addresses"? Since the focus is on the mix of partners, the notion of "reflecting the problem" is akin to the notion of capabilities and competences, under our "domain conditions".

Sub-criterion 2: is the required technical and financial capacity available? Here, too, there is overlap with the capabilities and competences element under our "domain conditions".

Sub-criterion 3: is the target group represented and is decision-making power equally distributed among partners? The first element in this sub-criterion relates to the need to consider other stakeholders' agendas (under our "domain conditions"). The second element relates to the concept of interactions between partners (under our "action conditions"), although equal distribution of power unduly rules out other legitimate types of interactions.

Sub-criterion 4: do the partners and the broader public have access to information? At the level of principles, access to information relates to our "societal conditions", whereas it relates to capabilities and competences (under our "domain conditions") when it comes to the skills and resources needed to access and distribute information.

Sub-criterion 5: does the non-state actor action have a clear institutional niche? Although related to our "societal conditions", the concept of institutional niche fits better with the need to consider other stakeholders' agendas (under our "domain conditions"), because the partners in the action have some control (at the design stage) over the extent to which the output of the non-state actor action will complement the outputs by other stakeholders.

Sub-criterion 6: is the non-state actor action responding to a governance gap? Although related to the choice and design of the delivery method (under our "action conditions"), the concept of governance gap fits better with our "societal conditions".

4.2.2 "Design" criteria

Michaelowa and Michaelowa (2017) put forward three "design criteria": the extent to which (i) explicit targets have been set; (ii) incentives are available; and (iii) monitoring, reporting and verification procedures have been adopted. They screen individual non-state actor actions against each of these criteria.

The existence of explicit targets relates to the delivery method, which falls under our "action conditions". The same is true with regard to the adoption of monitoring, reporting and verification procedures. However, the notion of "adoption" does not necessarily include design and implementation considerations. Stated differently, procedures may have been adopted that are not workable because the partners in the action lack the required technical and coordination capabilities, or the resources available are incommensurate with the task at hand.

The availability of incentives is linked to our "action conditions", in the sense that incentives can (and should) be introduced by design in the delivery method. In addition, the availability of incentives is linked to our "domain conditions", because the policy and regulatory environments shape the impact that any incentives will have.

4.2.3 "Function-output fit" criteria

Chan and Amling (2019) map functions against outputs.[13] They assign as many functions as relevant to a non-state actor action, and analyse the extent to which the outputs of that action are likely to fulfil all the functions concerned.

The outputs considered by Chan and Amling relate mainly to one type of "domain condition", namely the capabilities and competences of the partners in the non-state actor action. The output labelled "provision of professional advice" is the most obvious example.

To a lesser extent, the outputs considered by Chan and Amling also relate to one aspects of "action conditions", namely the choice of delivery method. However, their assessment stops with the categorisation of the method (see footnote 13), thus falling short of assessing the effectiveness of the delivery method.

[13] Examples of functions include "knowledge production", "norm and standard setting" or "policy planning", among others. Examples of outputs include "publications", "funding" or "events", among others.
Chan *et al.*, (2015) provide a listing of functions and outputs (see Table 1 and Table 2, respectively, in Annex 1).

Table 3: Comparing the criteria in the literature with the feedback from the interviewees

	Widerberg and Pattberg (2015)	Michaelowa and Michaelowa (2017)	Chan and Amling (2019)
Societal conditions	Considered (partly)		
Domain conditions			
- capabilities and competences	Considered (partly)		Considered
- economic and regulatory environment		Considered (indirectly)	
- agendas of other stakeholders	Considered		
Action conditions			
- choice and design of the delivery method		Considered	Considered (partly)
- interactions between partners	Considered (narrowly)		

Note: explanations are provided in sections 4.2.1 to 4.2.3.

4.3 Comparing the three dimensions in our framework with the multi-level perspectives framework for "technological transitions"

The literature on "technological transitions" describes how technology-related transformations in society come about. These transformations involve «changes in technology, but also changes in elements such as user practices, regulation, industrial networks, infrastructure, and symbolic meaning» (Geels, 2002). Four main analytical frameworks for technological transitions have been proposed (Markard *et al*., 2012). Compared to the other three frameworks, the so-called multi-level perspectives framework is better suited to incorporate non-technological elements (Geels, 2011). We argue that the multi-level perspectives framework is applicable to the analysis of non-state actor action (Supplementary Information 4).

The multi-level perspectives framework is structured around the concepts of landscapes, socio-technical regimes and niches. Geels (2011) defines these concepts. Landscapes refers to both the «technical and material backdrop that sustains society» and the related «demographic trends, political ideologies, societal values, and macro-economic patterns». Socio-technical regimes refers to «semi-coherent sets of rules that orient and coordinate the activities of the social groups that reproduce the various elements of socio-technical systems». Technological niches develop through three core processes: «the articulation (and adjustment) of expectations or visions», «the building of societal networks and the enrolment of more actors», and «learning and articulation processes on various dimensions». For a graphic depiction of these concepts, the reader is referred to Figure 2 on page 28 in Geels (2011).

To a great extent, the three concepts above – landscapes, socio-technical regimes and niches – overlap with the three dimensions in our framework. We observe two main differences: the time frame associated with "landscapes" is longer than that associated with our "societal conditions", and "niches" focuses nearly exclusively on the method itself, whereas our "action conditions" also include the interactions between partners implementing that method. Nonetheless, to the extent that the multi-level perspectives framework can be considered both relevant (Supplementary Information 4) and all-inclusive (Markard *et al*., 2012), the comparison highlights that our framework is itself comprehensive.

5. Conclusions

We find that successful delivery by non-state actor actions depends on the alignment of several parameters. Some of these parameters are under the direct control of non-state actor actions. The extent to which the core partners in the action have access to the resources and skills required to implement the action is a prime example of this type of parameters. However, most parameters escape the control of the non-state actor action. Key among these are how vested interests and institutional inertias impact the work of the non-state actor action. Therefore, we conclude that there is no silver bullet to successful delivery by non-state actor actions. Nevertheless, our framework, tentative as it may be, helps identify potential barriers, which in turn is useful to anticipate possible solutions and integrate these in the design of the non-state actor action.

The parties to the UNFCCC have given non-state actors an increasingly prominent role in complementing state actor action. However, in the name of avoiding rigid frameworks that could stifle non-state actor ingenuity, there is no oversight as to how this role is performed: with regard to non-state actor action, seemingly, anything goes. This has resulted in an overabundance of non-state actor actions (over 20,000 are registered in the NAZCA platform), which have brought about an inflation in estimates of emission-reduction potentials (Hsu *et al*., 2019). In light of this, and delegating on a third party if necessary, the UNFCCC may want to prepare and apply a framework such as that presented in this article, with a view to identifying non-state actor actions that are unlikely to deliver direct or indirect impacts. Surely, a benchmark can only help raise the bar for useful actions, and make it easier to weed out ineffectual initiatives.

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Supplementary Information

Supplementary Information 1

There is no commonly agreed definition of non-state actor action (UNEP, 2018). In this article, non-state actor action refers to an agreement between two or more partners, through which 'public goods' in the area of climate change are delivered as per the following broad terms:

- The agreement includes an overall goal (qualitative) or target (quantitative), and specifies the roles and responsibilities of each partner with regard to achieving it. The agreement is contractual or non-contractual, and comes with or without accountability and enforcement mechanisms.
- Partners can be any kind of organisation – governmental or non-governmental, and for profit or non-for profit – as long as the partnership is not made up of national-level government agencies only. The organisations involved may work at any geographical level – sub-national, national, or supra-national. The partners are based in two (or more) different countries.
- 'Public goods' are climate-change management actions for which there is insufficient or no delivery. These actions are either neglected altogether, or conducted by governments only when public budgets to do so can be mobilised. The deployment of technologies that reduce emissions of greenhouse gases, or reduce vulnerability to climate change, are examples of such 'public goods'.
- Delivering the 'public goods' mentioned above may be the primary objective of the non-state actor action, or simply a by-product of a different primary objective.

Compared to the core activities of the organisations involved, governmental or non-governmental, non-state actor actions are characterised by an element of exceptionality: the partnerships required, the approach used, the objectives pursued, or any combination of these, are uncommon and, for this reason, stand out as an 'exceptional' activity for the organisation to conduct. In light of this, determining whether an activity constitutes a non-state actor action in some instances will be a judgemental matter.

Different types of governance arrangements govern the work of non-state actor actions. Drawing on Hale and Roger (2014), we consider three types of governance arrangements:

- Horizontal governance implies a decision-making process in which all partners play an equal role in the creation and operation of the non-state actor action. This is especially significant with regard to any governmental entities that may take part in the non-state actor action: even though, in other contexts, governmental entities typically set and enforce decisions, in the context of the non-state actor action they share the decision-making powers with all other partners.
- Orchestrated governance implies a decision-making process in which a governmental entity, be it a national government or an international organisation, catalyses the development of a non-state actor action. They do so by reducing transaction costs, or mistrust among partners, or by assisting weaker partners. As soon as the non-state actor action is operational, the

governmental entity pulls out, or plays a role similar to that described under 'horizontal governance', above.

- Hierarchical governance implies a decision-making process in which a national government or an intergovernmental organisation grant authority to one entity (or several), to implement a pre-defined set of activities on behalf of that national government or intergovernmental organisation. In this arrangement, the implementing entity is fully accountable to those that grant the authority to it. Delegation responds to a range of issues, notably related to the expertise or moral authority of the implementing entity, or to reduce costs and facilitate implementation.

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Supplementary Information 2

Our survey forms (Form A and Form B) are include below. The actual responses received are available from the corresponding author, upon reasonable request.

Form A: Data concerning the non-state actor action

Objective of this data collection form

Through this form, we seek to collect **data concerning the non-state actor action itself**. Data concerning the individual partners to the action is collected through Form B.

Who should fill this form

The partner that acts as a secretariat to the non-state actor action should fill this form. If no partner plays this role, **all partners in the non-state actor action (or a representative selection)** should agree on one collective set of answers to the questions in the form.

Questions

A.1 Governance arrangements

Please state the governance arrangement that applies to the non-state actor action. The options are: horizontal, orchestrated, or hierarchical. These concepts are defined in a separate document.

A.2 Performance of the non-state actor action against selected criteria

Net benefits

Please explain how the non-state actor action contributes to increasing resilience or reducing vulnerability, compared to a situation in which the non-state actor action did not exist.

Overlaps with ongoing state-actor actions

Please state if there is overlap between the work of the non-state actor action, and related ongoing work by state actors.

If there is overlap, please indicate how much, and in which specific aspects and geographic areas, as relevant.

If there is no overlap, please indicate whether this is by design, or because the non-state actor action is active in an area where (in the countries concerned) state actors are inactive.

Private sector funding

Please indicate whether the non-state actor action has resulted in a *net increase* in private sector financing for adaptation or disaster-risk reduction, compared to a situation in which the non-state actor action did not exist.

If your answer is positive, please indicate whether the additional funds are channelled through the non-state actor action itself, through some other non-state actor mechanisms, or through a state-actor action.

State-actor action

Please indicate whether there is strong evidence that the work of the non-state actor action has catalysed (or will catalyse, in the near future) additional state-actor action in the same area.

If you answer is positive, please indicate whether it is likely that the (new) state-actor action will overlap with the non-state actor action, will complement it, or will replace it.

A.3 Basic information about the non-state actor action

Name:

Please type your answer here.

Start year:

Please type your answer here.

Objective:

Please describe the overall objective of the non-state actor action.

Type of objective:

Please specify if the objective is qualitative or quantitative.

Time frames:

Please indicate whether a specific target year has been attached to the achievement (in full) of the objectives of the non-state actor action (as opposed to an open-ended objective, such as that associated with an action focused on exchanging experiences). For example, a non-state actor action seeking to set-up micro-finance mechanisms for farmers in a rural area in Botswana may strive to reach a pre-defined share of all farmers in that area by, say, 2020.

Delivery mechanism:

Please state the main delivery mechanism(s). Brief descriptions such as 'provide technical assistance', 'mobilise financing', 'exchange experiences', or 'facilitate consensus', would be sufficient.

In addition, please state if you always rely on one delivery mechanism (for example, 'exchange experiences'), or if the delivery mechanism that you use is defined on a case-by-case basis.

Target countries:

Please list the countries in which the non-state actor action is active. If there are more than ten, please provide the name of the top five (that is, the five countries in which the non-state actor action is performing better).

Target sectors:

Please indicate the sector or sectors in which the non-state actor action is active. Sector refers both to economic activities (such as rice farming), and developmental activities (such as training).

Key partners:

Please list the core partners in the non-state actor action.

Membership:

Please indicate if the membership of the non-state actor action is closed, or open.

Closed membership refers to a situation in which the partners are identified before initiating the work, on the basis of the skills needed to deliver on the stated objectives of the action, and no additional partners are added during the implementation process.

Open membership refers to a situation in which, by design, the non-state actor action seeks to expand its membership (for example, in the case of a non-state actor action aimed at exchanging experiences among stakeholders that face similar problems).

Permanent secretariat:

Please indicate if the non-state actor action has a permanent secretariat.

Regular reporting:

Please indicate if the non-state actor action reports, on a regular basis, on the extent to which it is on track to achieve its objectives.

In addition, please indicate if the reporting is done at the initiative of the non-state actor action, or to fulfil the requirements of a wider structure (for example, because the action is a part of broader initiative aimed to connect cities, membership to which is subject to regular reporting on performance by the individual members).

Beneficiaries:

Please list the main beneficiaries of the work of the non-state actor action.

In addition, please state if increasing the number of beneficiaries is a stated goal of the non-state actor action (as opposed to a situation in which the non-state actor action is set-up to serve a pre-defined set of beneficiaries, such as farmers in a specific rural area in Botswana, and replicating the work in other areas or countries is not envisaged).

Form B: Data concerning the individual partners in the non-state actor action

Objective of this data collection form

Through this form, we seek to collect **data concerning the individual partners in the non-state actor action**. Data concerning the action itself is collected through Form A (sent in a separate document).

Who should fill this form

A non-state actor action may have several partners. In the cases where there are five or less, we hope to receive **one separate form for each partner**. When there are more than five partners in the action, we hope that a representative selection of, say, five or six partners can be identified, and each of them can send us a separate form.

Questions

B.1 Details about the partner

Name of the organisation

Please type your answer here

Type of organisation

Please specify the label that better describes your organisation:

- governmental (specify between sub-national, national, or supra-national governmental entity)
- private sector

- non-governmental advocacy group
- academia

To the extent that it reflects reality, please provide one response only.

Portfolio

Please explain the role that the non-state actor action plays vis-à-vis the rest of the activities that your organisations conducts. For example, you can measure this in terms of visibility (is the non-state actor action what gives your organisation most visibility), or in terms of staff time (is the non-state actor action what takes most time from your staff).

B.2 Contribution to the non-state actor action

Delivery mechanisms

Please explain what you specifically do, compared to what other partners do to achieve the goals of the non-state actor action. Brief answers such as 'scientific analysis, 'financial analysis', process management (consultation and facilitation), and similar would be enough. More than one answer is of course possible.

Agency

Please explain what you bring to the table, which allows you to be 'someone' at the table. Brief answers such as 'expertise', 'funding', or 'convening power' would be enough. To the extent that it reflects reality, please provide one response only.

Incentives

Please indicate what your incentive is for participating in the non-state actor action. Brief answers such as any of the following would be enough:

- fulfil the mission of my organisation
- reputational value
- return on investment
- knowledge
- influence future policy developments
- avoid mandatory regulatory requirements
- promote mandatory regulatory requirements
- etc.

To the extent that it reflects reality, please provide a maximum of two answers.

Investment

Please indicate what kind of contribution your organisation makes to the non-state actor action. This could be, for example, ‘staff time’, or ‘financial contributions’, among others. More than one answer is of course possible.

In addition, please quantify the extent of your investment (for example, the number of staff-hours per month, or the financial disbursements made over a period of one year).

Supplementary Information 3

This Supplementary Information Note gives an overview of the responses obtained to selected questions in our survey forms (Form A and Form B). The overview focuses on the issues that are more often covered in the literature (Höhne and Drost, 2015), to facilitate comparisons.

Table SI3.1 summarises the objectives of each of the six non-state actor actions surveyed. Respondents were asked to provide succinct statements that are as factual as possible. This request was prompted by the recognition that the descriptions that are publicly available, while typically lengthy, tend to be short on the specifics of the non-state actor action. For the reader who is unfamiliar with the six non-state actor actions surveyed, these descriptions provide a snapshot of what each of the actions seeks to achieve.

SI3.1 Nature of the objectives

The broad objectives laid out in the main text (Table 2) are articulated around concrete delivery plans. For example, the Urban Community Resilience Assessment focuses on a household sample of pre-defined size in three specific cities, and RegionsAdapt has a fixed number of working groups. Nonetheless, for each of the six non-state actor actions surveyed, the individual outputs associated with the respective delivery plans can only be characterised in qualitative terms. To some extent, the Rural Resilience Initiative is an exception to this finding, in that some of its region- or issue-specific objectives are set (in advance) in quantitative terms. For example, in its current implementation cycle, the Rural Resilience Initiative has a target of 500,000 insured farmers by 2020.

SI3.2 Intended benefits

The qualitative nature of the objectives of the various non-state actor actions is illustrated further by the descriptions of the benefits that each of these actions seeks to bring about (Table SI3). These descriptions are all open-ended, lacking quantification. Respondents working on the three actions focused on disaster-risk reduction argued that an open-ended statement of benefits is unavoidable, because these actions deal with climate change variability, which influences the size, type and location of the outputs that the actions deliver. Stated differently, variability makes it difficult for the core partners in these non-state actor actions to be conclusive about the precise benefits that the actions will bring about. In the case of the three actions focused on adaptation to climate change, the qualitative nature of the statement of benefits was attributed to the inclusive and non-prescriptive approach to planning for climate change adaptation that is inherent to the work of these actions. Such an approach can be well-defined with regard to process, but is open-ended with regard to outputs, thus resulting in an equally open-ended statement of benefits.

Notwithstanding the uniformity of the responses concerning the statements of benefits by the various actions (namely, that all the statement are qualitative), a closer look at these statements highlights a divide between non-state actor actions focused on adaptation to climate change and those focused on disaster-risk reduction. Indeed, while the former concern themselves with supporting planning efforts (by companies, sub-national governments or local governments), the latter mobilise and channel funding. This finding may not be surprising, given the markedly different needs associated with supporting, respectively, climate change adaptation and disaster-risk reduction. Nevertheless, this difference (a focus on planning versus funding) correlates well with the differences observed concerning the design of the action. Such diversity in design choices is most visible in connection with, for example, the expertise required from the various partners in the action (see below).

SI3.3 Interplay with state actor action

When asking for the benefits that an action brings about, we emphasised that we were interested in benefits that are additional to those attributable to other stakeholders, notably state actors. Related to this, in a subsequent question we asked about the extent to which the outputs of the non-state actor action were likely to overlap with related work by state actors. Implicit in the question is the recognition that such overlaps cannot be discounted, as evidenced by the findings of the multiple studies of non-state actor actions focused on climate change mitigation (Hsu *et al.*, 2019). The responses received to this question echoed the divide referred to above: the non-state actor actions focused on disaster-risk reduction reported no overlap, whereas their climate change adaptation counterparts reported partial overlap.

A further question touching upon the interplay between state and non-state actor action concerns the extent to which non-state actor actions catalyse related, complementary action by state actors. Two of the actions focused on disaster-risk reduction reported that their work did have a catalytic impact, whereas the rest of the actions surveyed reported no catalytic impact, albeit with slight differences in the conclusiveness of the responses provided.

SI3.4 Private sector funding

Next to the purported ability to catalyse related, complementary action by state actors, the supposed capacity to mobilise private sector funding is a second much-touted indirect impact attributed to non-state actors (Chan *et al*., 2018).[14] We asked whether such a net increase in private sector funding had been forthcoming, and obtained affirmative responses from the three non-state actor actions focused on disaster-risk reduction. We also asked whether the funding was channelled through one or more of the partners in the initiative, or through a third party, notably a national- or supranational-level government agency that otherwise would not have been involved in the non-state actor action. We found that, in all cases, the funding was channelled through one of the core partners in the action.

SI3.5 Reporting

As indicated above, reporting by non-state actor actions is limited (Fenhann *et al.*, 2018). For this reason, our survey included a question regarding whether or not the actions report regularly on the extent to which they are on track to achieve their objectives. In all six cases, the responses obtained were positive. We asked a follow up question, namely whether the reporting requirements were self-imposed, in an attempt to increase the transparency of the activities of the non-state actor action, or whether they were the result of accountability requirements imposed by the funders of the non-state actor action. Four of the six actions surveyed responded that their reporting is driven by donor requirements. RegionsAdapt responded that, although members to the action report to the action's secretariat (and to CDP, a non-governmental organisation), the secretariat does not prepare and publish a report consolidating all the input received. Finally, the Business Alliance for

[14] The private sector funding mobilised would be additional to the funding levels that would be available in the absence of the non-state actor action.

Water and Climate responded that it reports to the Conference of the Parties to the United Nations Framework Convention on Climate Change.

It is worth noting that, in all cases, the reporting focuses on appraising the extent to which the envisioned goals of the non-state actor action have been achieved. Although useful from a generic accountability point of view, such an appraisal seldom assesses the level of ambition of those envisioned goals. Stated differently, donor-driven reporting tends to overlook the question of how critical a role a given non-state actor action plays in delivering the public good concerned, compared to the role of all other actors active in the same area, and how efficiently and effectively that role is played. Indeed, we found that none of the actions include this kind of appraisal in their reports.

SI3.6 Governance

Governance arrangements influence the efficiency and effectiveness of non-state actor actions (Hale and Roger, 2014). For this reason, we asked about the governance arrangements (Supplementary Information 1) that apply to the each of the six non-state actor actions. Four of the actions responded "horizontal", thus indicating that all core partners share equal decision-making responsibility. The Rural Resilience Initiative responded "orchestrated", with the World Food Programme acting as the lead partner in the initiative. Finally, the secretariat of Forecast-based Financing responded «a combination of horizontal and hierarchical». Initially, the German government worked with the German Red Cross to set up Forecast-based Financing (hierarchical governance). Once established, the core partners in the action (the German Red Cross, the World Food Programme and two non-governmental organisations) chose to distribute the decision-making power equally among all partners (horizontal governance).

SI3.7 Innovation

For of each of the six non-state actor actions surveyed, we asked about the specifics of their delivery mechanisms. Our goal was to assess the extent to which those mechanisms can be considered innovative. Here, innovative refers to untested refinements of approaches that had proven successful in related contexts. The three non-state actor actions focused on disaster-risk reduction reported delivery mechanisms that fit our definition of "innovative": Crisis Anticipation Window relies on novel risk reduction methods, and Forecast-based Financing and Rural Resilience Initiative rely on similarly original risk reduction and risk transfer methods. Conversely, the remaining three non-state actor actions surveyed used tried-and-tested delivery methods: Business Alliance for Water and Climate and RegionsAdapt work with classic knowledge dissemination approaches, and Urban Community Resilience Assessment provides local-level technical assistance, using classic development-aid approaches.

SI3.8 Type of organisation

For each of the non-state actor actions surveyed, we identified the core partners and asked them to indicate whether they are governmental agencies, non-governmental organisation, businesses or research institutions. RegionsAdapt, Urban Community Resilience Assessment and Crisis Anticipation Window are homogeneous in their constituency: sub-national governments only, in the case of RegionsAdapt, and non-governmental organisations only, in the cases of both Urban Community Resilience Assessment and Crisis Anticipation Window. The remaining non-state actor actions surveyed have a mixed constituency, including supra-national government agencies, non-governmental organisations and businesses. In all cases, the number of core members ranges from two to four.

SI3.9 Portfolio

We asked each core partner in a given non-state actor action to assess the importance of the non-state actor action vis-à-vis the rest of the activities it conducts. With two exceptions, the core partners in the three actions focused on adaptation to climate change noted that the action represented a modest component in their portfolio of activities. The two exceptions named above are two sub-national African governments involved in RegionsAdapt. For the remaining non-state actor actions, at least one of the core partners declared that the action made up for a substantial part of its activities. For example, Forecast-based Financing is a major component in the portfolio of the Red Cross and Red Crescent Climate Centre, a non-governmental organisation that is a core partner in Forecast-based Financing, but it is a small part of the work of the German Red Cross, the World Food Programme, and Welthungerhilfe, the remaining core partners in this non-state actor action.

SI3.10 Delivery mechanisms

As indicated above (Section 2), our survey form included a number of possible responses to certain questions, to illustrate the type of feedback that we were seeking. These possible responses reflect issues that had been raised by the respondents themselves, during the preliminary discussions that informed the development of our survey forms. At the time of collecting actual responses to the finalised questionnaires, we encouraged the respondents to use additional categories, if our examples did not fully capture all the issues of importance in a given question. Respondents did use additional categories, mainly for the question concerning delivery mechanisms (that is, what an individual core partner does, which the other core partners do not necessarily do in the context of the non-state actor action).

Responses such as “provision of technical expertise”, “partnership formation” and “advocacy and fundraising”, which were included as examples in our questionnaire, were common among all core partners surveyed. Interestingly, some of the core partners in Rural Resilience Initiative and in Forecast-based Financing alluded to “quality control”, noting that it was a central component of their work. This type of delivery mechanism was not included in our list of possible responses, and was not mentioned by the core partners in any of the other non-state actor actions surveyed. Stated differently, although quality assurance may not be absent in the work of the remaining non-state actor actions, the core partners in these actions place no emphasis on it.

Table SI3.1: Objectives of the non-state actor actions surveyed

Non-state actor action	Objective
Business Alliance for Water and Climate	Increase the number of companies committed to water and climate stewardship objectives; ensure broad private sector uptake of, and action on, water security measures in a climate change adaptation context; and track progress from committed companies as to their success in achieving these goals.
Crisis Anticipation Window	Enable non-governmental organisations to respond to potential disasters by providing the funding needed to set up preparedness and response actions before a crises strikes, in hopes to mitigate the harm and/or loss associated with the predicted impacts of the disaster.
Forecast-based Financing	Based on weather forecasts for extreme events, implement an efficient financing mechanism to mitigate the humanitarian impacts of climate change.
RegionsAdapt	Inspire and support regional governments to take action, collaborate and report on climate change adaptation. By joining RegionsAdapt, regional governments commit to (i) adopt or review plans on adaptation within a two-year period, (ii) implement an adaptation action in one of the thematic areas of the initiative, and (iii) report on the progress of their initiatives through CDP's States and Regions platform.
Rural Resilience Initiative	Achieve food security for, and build the resilience of, the most vulnerable rural communities against climate change and weather shocks, through a community-oriented, risk management-focused and markets-based approach.
Urban Community Resilience Assessment	For selected informal urban communities in three large cities, include individual citizen and community capacities into broader assessments of urban resilience, and identify concrete actions to increase individual and community resilience, such as district-level emergency guides, shelter maps and evacuation routes.

Table SI3.2: Net benefits associated with each of the non-state actor actions surveyed

Non-state actor action	Benefit brought about by the action
Disaster risk reduction	
Crisis Anticipation Window	Reduced vulnerability of the targeted populations, by releasing funding on the basis of need (forecasts), as opposed to «politics or the media».
Forecast-based Financing	Increased resilience of the targeted populations, by shifting development aid and humanitarian assistance from post- to pre-disaster.
Rural Resilience Initiative	Reduced vulnerability of the targeted populations to extreme weather events (through better resource management [risk reduction], and access to insurance [risk transfer], livelihood diversification options and microcredit [prudent risk taking], and savings mechanism [risk reserves]).
Adaptation to climate change	
Business Alliance for Water and Climate	Improved adaptation planning by water-intensive businesses, through the exchange of knowledge, the development of good practices, and the identification of short- and mid-term improvements in manufacturing processes.
RegionsAdapt	Improved adaptation planning by sub-national member governments (through exchange of information and the development of joint, mutually beneficial activities by members).
Urban Community Resilience Assessment	Increased resilience of the targeted 100-to-500 households in informal communities in the cities of Surat (India), Semarang (Indonesia) and Rio de Janeiro (Brazil), through the preparation of identification of adaptation planning options for these households.

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Supplementary Information 4

The multi-level perspectives framework concerns itself with disruptions in established societal regimes (Geels, 2002). Societal regime refers to any combination of technologies, know-how and institutional dynamics that comes to play to meet a certain societal function. Disruptions to the regime arise when existing or newly established partnerships, through an innovative approach, succeed in serving a previously underserved societal function, or in displacing (partially or completely) the options that traditionally served that function. Successful delivery by non-state actor actions is a form of regime disruption, because it fills a gap (in the case of unserved societal functions), or it changes the way and, in some cases, the extent to which, state actors serve a societal function.

From the point of view of climate-change management, technology has been defined as the "hardware", "software" or "orgware" required for performing a particular activity (Boldt *et al*., 2012). In this context, "hardware" is understood as equipment and products, "software" refers to know-how, experiences and practices, and "orgware" alludes to the types of, and dynamics between, institutions that need the "hardware" and the "software". Although the multi-level perspectives framework is best known for its applications in the area of "hardware", it has also been applied to both "software" and "orgware".[i] Our use of the framework in the context of delivery by non-state actor actions adds to the sub-set of the literature that applies the framework to "software" and "orgware".

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[i] For example, the framework has been applied to institutional dynamics in the wake of the financial crisis (Geels, 2013), city planning (Hodson *et al*., 2017), and popular culture (Geels, 2007), among other areas. Indeed, it has been argued that approaches such as that of the technological transitions framework are much needed complements to traditional tools, notably model-based analysis (Geels, 2016).

Article 3

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Title

A new model for accounting for non-state action

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Abstract

The Paris Agreement represented a decisive step up in the institutionalisation of non-state actors within the international climate-change regime. We review the literature on effectiveness of non-state action, to assess the extent to which non-state actors can add to state action, either as supplements or facilitators. We find that the empirical evidence cannot justify the current blanket approach to institutionalising non-state action. Not least, we find gaps in the evidence, which reinforce the need for taking a conservative approach, away from acritically embracing non-state actor action. We propose a new model for non-state action, whereby emission reductions attributable to non-state actors are only accounted in instances where non-state action is fully integrated in state action whereas. When this is not the case, the corresponding emission reductions would not be accounted for, and non-state action would mainly serve the purpose of testing new approaches and spurring policy innovation.

Key policy insights

- Although, for decades, non-state actors have been integral elements in climate-change governance, only recently, through the Paris Agreement has this role been given more prominence.
- The empirical evidence suggests that the role afforded to non-state action ought to be differentiated, depending on the sector and country concerned.

- In economic sectors dominated by few, large companies, non-state actor action would be more effective if fully integrated into state actor action.
- In highly heterogeneous sectors, involving many companies, non-state actor action could be seen primarily as a policy laboratory.
- In the context of the international climate-change regime, the so-called global stocktake will put to the test the robustness of the current approach to non-state actor action.

Manuscript

1. Introduction

Increasingly, environmental pressure groups, businesses, and local and regional governments are undertaking voluntary actions that contribute to reducing emissions of global-warming greenhouse gases. As a result, these entities have gained prominence in global climate change governance (Bakhtiari, 2018). They work alone or, more often, in coalition with others, sometimes across national boundaries (CIP, 2020). When coalitions are formed, national government entities may take part, sharing decision-making power with the other members of the coalition (*ibid*).

To distinguish them from the national (and, in the case of the European Union, supranational) governmental entities that are parties to the United Nations Framework Convention on Climate Change (UNFCCC), non-governmental organisations, businesses and local or regional governments are sometimes referred to as "non-party stakeholders". Outside of the UNFCCC context, non-party stakeholders are referred to as non-state actors, transnational actors, subnational actors, or combinations of these, depending on the main element of interest. Hereinafter, we refer to them as "non-state actors".

In 2015, the parties to the UNFCCC «[invited] non-Party stakeholders […] to scale-up their efforts and support actions to reduce emissions [of greenhouse gases]» (UNFCCC, 2015). Since then, the prominence of "non-party stakeholders" has only increased in international climate change negotiations (Bulkeley *et al*., 2018).[1] In light of this, it is timely to consider whether non-state actor actions can live up to the expectations placed on them.

We review the literature on effectiveness of non-state actor action, with a dual purpose. First, we assess the extent to which the evidence base is sufficient to justify the expectations placed on non-state actor action. Second, we suggest a new model for non-state actor action in the area of climate change. The implications of our model vis-à-vis the international climate change regime are discussed.

[1] Indeed, the December 2019 conference of the parties to the UNFCCC re-states the expectations placed on non-state actors (UNFCCC, 2019).

2 Effectiveness of non-state actor action

Research in transnational climate-change governance has developed apace with interest in non-state actors at the inter-governmental level. This section summarises the scholarship on the effectiveness of non-state actor action.

2.1 The scope of effectiveness

The concept of "effectiveness of non-state actor action" has been examined from different perspectives, notably governance, analysis and policy. From a governance point of view, the significance of effectiveness is linked to the main agenda being pursued – public or private. When providing an undelivered public good is the main purpose of a non-state actor action, effectiveness is concerned with the degree to which the public good is being delivered (Bulkeley *et al*., 2014). Conversely, when the provision of a public good is a secondary objective, tributary to a non-state actor's own agenda, effectiveness is concerned with the extent to which the achievement of the non-state actor's primary goal is compatible with delivering a public good (*ibid*).

From an analytical point of view, effectiveness is a function of the benchmark chosen, as noted by a number of scholars. For example, a benchmark could be a non-state actor's own target (Widerberg and Pattberg, 2015), a target set by another party (*ibid*), or an aspirational target (Dzebo, 2019). Effectiveness could also refer to a counterfactual, such as a future situation under a "business as usual" scenario (*ibid*). Depending on the benchmark chosen, the assessed level of effectiveness is likely to vary. From a policy point of view, and linked to the choice of benchmark, Bulkeley and Newell (2015) argue that any assessment of effectiveness ought to reflect all the benefits brought about by the non-state actor action, both in the area of climate-change management and – crucially – in all other areas, and term the latter set of benefits "co-benefits".

2.2 Measuring effectiveness

Scholarship on the impact of non-state actor action includes studies that range from assessments of necessary-but-not-sufficient conditions, to studies that explicitly seek to measure effectiveness.[2] Multi-dimensional metrics, as called for by Zelli and van Asselt (2013), are a common feature of all studies.

Michaelowa and Michaelowa (2017) argue that, because most non-state actor actions are barely getting off the ground, «it is too early for an evaluation of [the effectiveness of non-state actor actions]». Therefore, they choose to conduct an assessment of necessary-but-not-sufficient conditions. To do so, they screen non-state actor actions against three "design criteria" that they deem indispensable for an action to deliver on its stated goals: the extent to which (i) explicit targets have been set; (ii) incentives are available; and (iii) monitoring, reporting and verification procedures have been adopted. Their results suggest that the degree to which non-state actors deliver on their intended objectives is limited, and thus non-state actors «cannot be expected to fill the "mitigation gap"» (*ibid*).

Widerberg and Pattberg (2015) analyse the performance of nine non-state actor actions across three sets of parameters: potential effectiveness, legitimacy and institutional fit. They measure potential effectiveness as a function of (i) the suitability of the partners in the non-state actor action, given the action's intended outputs, and (ii) the extent to which the required technical and financial resources are available. Arguably, these metrics come close to representing necessary-but-not-sufficient

[2] It is worth noting that, due to lack of ex-post data on performance (Hsu *et al*., 2019), most studies focus on potential effectiveness as a function of design. Exceptions to this are a handful of small-scale studies, such as those by Khan and Sovacool (2016), Croci and colleagues (2017), and Steffen and colleagues (2019).

conditions, in the sense that effectiveness entails a much wider range of issues, and thus calls for an analysis based on a much broader range of parameters. With regard to potential effectiveness, their findings are optimistic, in that most of the non-state actor actions assessed meet the criteria in the methodology used (*ibid*).

Chan and colleagues (2018) analyse the effectiveness of fifty-two non-state actor actions working in a range of areas, including the energy and agriculture sectors, and adaptation to climate change, among others.[3] To do so, they assess whether the outputs of a non-state actor action are commensurate with the function that the action intends to perform. While outputs (twenty-six types) were identified during the analysis, functions had been clustered in advance, drawing on existing studies. The assessment assumes that, when outputs represent a reasonable fit for the function sought, the non-state actor action is more likely to be effective. Implicit in this assumption is that outputs lead to outcomes and impacts. They conclude that «most climate actions [produce] outputs that fit some (36%) or all (29%) of their main functions» (ibid).

Dzebo (2019) assesses the effectiveness of forty non-state actor actions focused on adaptation to climate change. The assessment method draws on a framework developed by Liese and Beisheim (2014), and considers both outputs and outcomes. Outputs are screened against the goals of the non-state actor action concerned, to gauge the degree of consistency between one another. Outcome delivery is assessed through published or grey literature, complemented with interviews. Finding are analysed through the perspective of four determinants of effectiveness, namely actors, processes, institutional design, and context, to determine which of these determinants plays a bigger role in achieving effectiveness. The study finds that, although two-thirds of the initiatives are effective in terms of outputs, only one-third are effective in terms of outcomes.

Studies such as those summarised above reach similar conclusions with regard to the design features that effective non-state actor actions share. Three such features appear to be critical. First, targets ought to be specific (Widerberg and Pattberg, 2015 ; Hsu *et al*., 2015 ; Chan *et al*., 2018), and commensurate with the possibilities of non-state actors (Dzebo, 2019). Second, core partners in the non-state actor action need to have high organisation and coordination skills (Chan *et al*., 2018 ; Dzebo 2019). Third, a permanent secretariat, backed by a coherent management strategy, should be in place from the outset (*ibid*).

2.3 Orchestrated governance

Orchestrated governance implies a decision-making process in which a governmental entity, be it a national government or an international organisation, catalyses the development of a non-state actor action. Compared to other types of governance regimes, orchestrated governance has been hailed as being especially effective (Abbott and Snidal, 2009): allegedly, orchestration increases «the benefits of institutional complexity» and reduces its costs (Abbott, 2012).[4] It does so by lending credibility to non-state actor-driven initiatives, helping align goals with resources and skills, and facilitating learning, among other catalytic functions (*ibid*). Nonetheless, who the lead orchestrator is appears to matter: as Abbot and colleagues (2015) note «[where] states rather than [inter-governmental organisations] initiate orchestration, certain factors we hypothesized would foster

[3] Chan and colleagues collected publicly available data for fifty-two actions. This data collection effort was complemented by a survey sent to representatives of all non-state actor actions studied. Twenty-five responses were obtained (out of fifty-two possible).

[4] "Institutional complexity" refers to the coexistence of public, private and hybrid governance arrangements, which are often referred to as the "climate-change governance complex" (see section 2.4).

[intergovernmental organisation] orchestration – notably goal divergence among member states – actually discourage it».

In his assessment of non-state actor actions focused on climate-change adaptation, Dzebo (2019) finds that orchestration is a key determinant of output-effectiveness. Nevertheless, he notes that orchestrated initiatives do not necessarily score better than the rest in terms of outcome-effectiveness. In a similar vein, in their analysis of the so-called Global Climate Action Agenda, a set of orchestrated non-state actor actions, Chan and Amling (2019) find high output-effectiveness. However, they also note that a focus on mitigation may have led to «neglect of underperforming actions—many of them adaptation actions in developing countries» (ibid). More generally, they note that, among all the orchestrated actions that they analyse, «output performance» is lower for actions focused on climate-change adaptation, compared to actions focused on climate-change mitigation (*ibid*). They claim that orchestrators tend to favour mitigation-focused actions, with which there is more experience and, therefore, a higher chance of success.

Departing from the empirically descriptive views presented above, Bäckstrand and Kuyper (2017) take a theoretically normative view to analyse two orchestrated non-state actor actions. Focusing on the «democratic legitimacy of orchestration», they conclude that the two actions analysed «have substantive democratic shortfalls» (*ibid*). Specifically, they consider four parameters – participation, deliberation, accountability and transparency –, and conclude that participation and deliberation increase with top-down orchestration (in their study, the Lima-Paris Action Agenda), whereas «transparency and accountability mechanisms are nascent at best, nonexistent at worse» for the two actions analysed (*ibid*). Finally, the study makes a call for giving more emphasis to normative questions in future studies of non-state actor action.[5]

2.4 Non-state actors within the climate change “governance complex”

Most of the literature considers non-state actor action in isolation from the institutional processes and inducements associated with action undertaken by parties to the UNFCCC. By exploring the ways in which both types of actions interact with one another, Andonova and colleagues (2017) shed light on the way in which such interactions affect the effectiveness of (state and) non-state actor action.

Using regression analysis, they find a correlation between «the openness of domestic institutions [and the stringency of] national climate policies» on the one hand, and the prevalence and effectiveness of non-state actor action on the other (Andonova *et al.*, 2017).[6] There are two corollaries to this aggregated finding, which are relevant to the study of the effectiveness of non-state actor action.

First, non-state action would be most effective in participatory democracies with liberalised economies, where national climate change policies are lenient and/or federal governance arrangements apply. In such context, non-state actor action can compensate to some degree for weak national climate-change policies (Andonova, 2014). In a federal setting, non-state action could more easily spur innovation and promote policy experimentation (Andonova *et al.*, 2017).

[5] Although Bäckstand and Kuyper (2017) do not single out any specific normative questions that they think would deserve priority attention, we understand that they refer to issues related to ethics and justice.
[6] Openness of institutions is defined as the «ability [of non-state actors, both domestic and international] to engage in public deliberation, contestation, and mobilization» (Andonova, Hale and Roger, 2017).

Second, even in the countries referred to above, and much less globally, non-state action cannot substitute for lacklustre climate change-mitigation action by national governments.[7] This is in line with the findings of a quantitative assessment by Michaelowa and Michaelowa (2017) referred to above, which concludes that «the lack of mitigation ambition on the government level cannot be "made up" by mitigation achieved through [non-state actions], as too few of the latter have a mitigation-oriented design».

In recent years, research on the effectiveness of non-state actor action in the context of the broader climate change "governance complex" has focused on the Paris Agreement. For example, van Asselt (2016) suggests that non-state actors have a central role to play in the Paris Agreement's assessment and review process,[8] even though he expresses reservations about parties to the UNFCCC formally affording non-state actors such a role. Kuyper and colleagues (2018) echo the view that non-state actors can increase the effectiveness of efforts to implement the Paris Agreement, by increasing transparency and compliance. In addition, they argue that non-state actors can help reduce the economic cost associated with achieving the Paris Agreement's goals (*ibid*).

2.5 Evidence concerning impacts

Vis-à-vis state actor actions aimed to mitigation climate change, the actions that non-state actors undertake are credited for having two main types of impacts (Bulkeley *et al*., 2018). Measurable reductions in greenhouse-gas emissions, additional to those achieved by national governments, are referred to as direct impacts. Secondary effects, such as catalysing access to information or finance in ways that support emission-reduction programmes by governmental entities, or impacts (positive or negative) on societal behaviour, for example, are referred to as indirect impacts.

2.5.1 Direct impacts

A number of studies estimate the level of reductions in greenhouse-gas emissions that could be expected from non-state actor actions (Hsu *et al*., 2018). Partly, the interest in these estimates stems from the realisation that current emission-reduction commitments by national governments amount to a level of reductions in greenhouse-gas emissions that falls woefully short of what is required to curb global warming (Rogelj *et al*., 2017).

As any other estimate, the findings of these studies need to be interpreted in light of the assumptions that underlie them. Two assumptions are of special importance, given the impact that they may have on the resulting estimates:

- **The extent to which each of the various non-state actor actions considered will deliver on its commitments.** This point matters because the number of non-state actions studies consider is growing (Hsu *et al*., 2018). On this issue, it is increasingly clear that some non-state actor actions are more likely than others to meet their objectives (Chan *et al*., 2018).[9] In studies that assess direct impact, authors frequently assume complete implementation, in spite of the scant evidence available. (Hsu *et al*., 2018).

[7] It has been suggested that non-state actor action can have negative consequences for the provision of public goods (Chan *et al*., 2019)

[8] This view is in line with that of earlier scholarship focused on non-state actors' influence on the international climate change regime (see, for example, Dannenmaier [2011]).

[9] Chan and colleagues (2018) consider cooperative initiatives. Without attempting to prove it, and based on the literature summarised in sections 2.1 to 2.4, we claim that the same conclusion applies to other types of non-state actor actions.

- **The extent to which greenhouse-gas emission reductions attributable to non-state actor actions overlap with emission reductions attributable to governmental programmes.** Understanding the size of the overlap matters greatly, because part of the appeal of non-state actor action lies in the overlap being very small. On this issue, published studies reach seemingly contradicting conclusions, motivated by the markedly different logic behind the assumptions that each study makes (Supplementary Information 1). Although most studies attempt to estimate overlaps, some still neglect to do so.[10]

As the number of studies grows, it can be expected that more attention will be devoted to analysing the plausibility of the assumptions that underlie the estimates produced by each study. Irrespective, lacking robust evaluative evidence, at present it is not possible to be conclusive about the actual (ex-post) direct impact that non-state actors make to reduce emissions of greenhouse gases (Hsu *et al*., 2019).[11]

2.5.2 Indirect impacts

Anchored in policy innovation theory (Hoffmann, 2011), the notion that «[w]hile the direct impacts of [non-state actor] actions are potentially large, their indirect impacts may be even greater» (Chan *et al*., 2015) has raised in the literature. In recent years, calls have been made to appreciate more fully the potential of indirect impacts, and to account more systematically for indirect impacts through the reporting systems used by non-state actors (Bulkeley *et al*., 2014 ; van der Ven *et al*., 2017 ; Hsu *et al*., 2019).

Notwithstanding, the literature also cautions about the possibility that indirect impacts may have unintended negative consequences (van der Ven *et al*., 2017). From the point of view of an individual non-state actor action, two main types of negative effects have been noted: crowding-out of funding (Balboa, 2016) and so-called rebound effects, whereby overall net emissions outweigh gains achieved through efficiency improvements (Druckmann *et al*., 2011). When non-state actor actions are considered as a group, a key negative consequence noted relates to how the plethora of actions contributes to governance complexity and fragmentation, with the risk that this undermines governance legitimacy and accountability more broadly (Kuyper *et al*., 2018).[12] In addition, governance complexity and fragmentation potentially hampers much needed coordination within the international climate change governance system (van Asselt and Zelli, 2014).

In sum, the indirect impact of non-state actors is subject to trade-offs, which are best analysed in terms of the governance risks that such impact might entail (Chan *et al*., 2019). Given these trade-offs, and because of the facilitative nature of indirect impacts, which focus on processes more than discrete outputs, indirect impact by non-state actors are «difficult (if not impossible) to quantify» (Hsu *et al*., 2019).

[10] In areas such as cities and sectors such as buildings, overlaps between non-state actor actions may be an issue.

[11] Few ex-post studies exist (see endnote 2), and the extent to which their findings can be generalised is unclear.

[12] For instance, when mostly developed country-based multinational corporations exploit emerging governance complexity, questions may be raised as to where the benefits of non-state actions accrue (Chan *et al*., 2018).

3. Conclusions

Section 2 presented an overview of the literature on effectiveness of non-state actor action. Drawing on this overview, in this section we outline conclusions that can shed light on the question posed in our introduction, namely whether the evidence base is sufficient to justify the expectations placed on non-state actors. We have structured our selection of conclusions around the concepts of direct and indirect impacts (Section 2.5), and orchestration (Section 2.3).

At present, estimating the actual (ex-post) direct impacts of non-state actor action is not possible. The literature includes a number of studies that assess the extent to which the outputs of non-state actor actions can be deemed consistent with the stated goals of the actions analysed. One study explores the likelihood that the outputs of non-state actor action may lead to the desired outcomes. However, methodological difficulties, notably those associated with the choice of a suitable benchmark, prevent us from assessing the extent to which non-state actor actions achieve their intended direct impacts.[13] In participatory democracies with a degree of decentralisation and weak climate change-management policies, direct impacts by non-state actors might compensate – if only modestly – for limited state actor action.[14]

At present, estimating the indirect impacts of non-state actor action is not possible. Nevertheless, the view that indirect impacts may be greater than direct impacts has been gaining advocates in recent years. At the national level, indirect impacts by non-state actors are likely to entail actions that strengthen and help implement state actor action. These actions would have more opportunities to flourish in countries with strong climate change-management policies. With regard to the international climate-change regime, indirect impacts by non-state actors might entail actions aimed at increasing transparency and compliance in the context of the Paris Agreement. The extent and type of the non-state actor engagement that parties to the UNFCCC will seek remains unclear.

Among all governance forms in which non-state actors play a lead role, orchestration is preconized as being comparatively more successful.[15] With regard to outputs, some authors support this claim. However, it is unclear whether orchestrated governance is more effective also at the level of outcomes (and impacts). Not least, orchestration may introduce both selection and performance biases. Selection bias refers to orchestrators favouring non-state actor actions that are more likely to deliver on their objectives, possibly at the expense of other actions that may be equally necessary, but require more effort to be brought to fruition. Performance bias refers to the beneficiaries of orchestrated actions having few or no options to influence the design of the action, and the limited extent to which these actions report on their work and, more generally, are accountable to the communities most directly concerned.

In sum, the evidence available is insufficient to assess the actual impacts, direct or indirect, of non-state actor actions. A number of other aspects related to non-state actor action remain equally unclear, notably the trade-offs associated with the type of governance form chosen. In light of this, the across-the-board institutionalisation afforded to non-state actors appears unwarranted.

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[13] These difficulties are not exclusive to non-state actor action: assessing the effectiveness of state actor action faces similar challenges. Notwithstanding, these difficulties effectively limit our understanding of the direct impacts of non-state actor action.

[14] The opposite would be true for countries with restrictive institutions and weak civil-society engagement in policy making.

[15] For a summary of the literature that supports this claim, see section 2.3.

4. Discussion

From the Gold Standard's norm-setting function, to the CDP's reporting mechanism, among several other possible examples, non-state actors have already made vital contributions to climate-change management. Indeed, for several years now, non-state actors de facto have been integral elements of climate-change governance, both nationally and internationally. As such, it is only fitting that non-state actors have been formally incorporated into the Paris Agreement.

Notwithstanding, the evidence summarised in Section 3 calls for a more cautious approach, compared to the current situation, in which non-state actor action is often embraced uncritically by national governments. In this context, a more cautious approach could entail differentiating, if and as necessary, across sectors, and across social, political and economic realities. Stated differently, non-state actors cannot be expected to play all roles in all sectors, and they cannot be expected to be equally prominent in all countries.

In the following paragraphs, we offer a possible differentiation across sectoral lines. A premise of this differentiation is that, from the point of view of accounting for greenhouse gas-emission reductions, overlaps between state and non-state actor action occur (Table SI1-A in Supplementary Information Note 1) and they are undesirable. Indeed, to the extent that supplementing the mitigation of state actors is one of the expectations placed on non-state actors, overlaps are detrimental.[16]

Our proposal, sketched in Table 1, can be summarise as follows. In economic sectors dominated by few, large companies (for example, oil and gas, cement or iron and steel), non-state actor action could be fully integrated into state actor action. Stated differently, to the extent that both state and non-state actors are working to reduce emissions in a sector constituted by a small number of large companies, the two efforts should be fully integrated. If nothing else, doing so would help eliminate the overlaps between state actor-led and non-state actor-led action, which plague efforts to assess progress with greenhouse-gas mitigation (Supplementary Information 1).

Conversely, in highly heterogeneous sectors, involving a large number of companies (for example, agriculture, or end-use energy efficiency), non-state actor action could be seen primarily as a policy laboratory, where new approaches are tested and innovation is spurred (see also Abbott [2012]). This approach has proven successful in non-climate change-related, public good-driven sectors, notably public health (Supplementary Information 2).

[16] As outlined in the introduction to this article, over the years, the parties to the UNFCCC have adopted a range of decisions that concern non-state actors. The implications of these decisions are subject to interpretation. Specifically, the extent to which these decisions call for non-state actor action to supplement state actor action is debatable. We believe that, without ruling out other roles for non-state actors, the decisions do call for non-state actors to supplement state actor action, as evidenced by the treatment that non-state actor action receives in, for example, the so-called emissions gap report. In this report, which quantifies emission reductions attributable to state actor action, emission reductions attributable to non-state actor action are presented separately, as a supplement to the former. This analysis, and the presentation of it, is not coincidental: it reflects international climate change negotiations and, indirectly, the interpretation made of the decisions adopted by the parties to the UNFCCC, referred to above.

Table 1: A new model for accounting for non-state action

Structure of the sector	Function	Transparency requirements	Linkages between state and non-state actor actions
A small number of large companies	Emission reductions	High and compulsory	Fully integrated
A large number of small companies	Policy laboratory	Limited	Independent from one another

Such a distinction, involving two categories of non-state actions, one integrated within governmental action, and one acting as a policy laboratory, would have implications for the accounting of reductions in greenhouse-gas emissions globally. Emission reductions attributable to the first category of actions would be subject to stringent transparency requirements, and would be accounted in global estimates of greenhouse-gas emission reductions. Conversely, emission reductions attributable to the second category of actions, which most often lack basic transparency mechanisms (CIP, 2020), would not be accounted in global-level estimates. A continuation of the current approach, where the estimates of greenhouse-gas emission reductions attributed to non-state action are both unreasonably large (Supplementary Information 1) and routinely accounted in global estimates (Hsu *et al*., 2018), risks undermining the credibility of the international climate change regime.

The type of model sketched above is already dominant in sectors like hydrofluorocarbon emitters and aviation, which benefit from dedicated governance schemes (CIP, 2020). Similarly, in the context of reducing greenhouse-gas emissions associated with deforestation and forest degradation, steps in this direction have already been taken (*ibid*).[17] However, these cases are the exception, rather than the rule: even in highly cohesive sectors, where coordination between non-state actors and government would be easy, non-state action takes place alongside and, in some sense, in competition with, governmental action. To some degree, this conflict arises because integration of non-state action within mainstream governmental action could plausibly entail both a binding commitment and a loss of visibility, a price that many non-state actors may be unwilling to pay (Supplementary Information 3).[18]

In this article, we have sought to show that the limited evidence base precludes even a basic assessment of the effectiveness of non-state actor action. In light of this, we have suggested a new model for non-state actor action in the area of climate-change management – one that is conservative with regard to the expectations placed on non-state actors, as called for by the current gaps in knowledge. In doing so, we add to the literature in two complementary ways. First, we provide the first review of the scholarship on the effectiveness of non-state actor action. Second, we contribute to a nascent literature that seeks to identify a realistic policy space for non-state actor action (see, for example, Hsu *et al*., [2019]).

Our findings have practical application, not least at the international level, in the context of the so-called global stocktake of the Paris Agreement. A key question for the global stocktake will be: in the current situation, which we characterised as governments uncritically embracing non-state actor

[17] The success of the handful of initiatives going in this direction is mixed. Whether this is due to the integrative approach that we preconize, or to poorly designed delivery mechanisms remains unclear.
[18] With the right inducements, this set of perverse incentives could be turned on its head. For example, by endorsing them at some level, the UNFCCC could reward non-state actors that abide to certain minimum transparency requirements, or actively seek to integrate their work to that of state actors, if and as relevant.

action, how can one tell if non-party stakeholders are supplementing efforts made by parties? Table SI1-A (Supplementary Information 1) highlights that a robust answer to this question will only be forthcoming if and when evaluative (ex-post) evidence on the effectiveness of non-state actors is available.

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Supplementary Information

Supplementary Information 1

The text in this Supplementary Information note contains summaries from a number of studies, selected findings of which are summarised in Table SI1-A. In these studies, “non-party stakeholders” are referred to using a variety of terms, notably “international cooperative initiatives” (or, simply, “initiatives”) and “non-state actor actions”. In the summaries presented below, the original terminology has been maintained.

From a pioneering study by Blok *et al*. (2012) to a recent assessment by Hsu *et al*. (2018), in recent years a number of estimates have been reported of the emission reduction potential associated with non-state actors. These estimates are not fully comparable, because they cover different sub-sets of actions (for example, city-level actions, or large international initiatives only), and because they have been calculated using different methodologies. Reported estimates of 2030 annual emission-reduction potentials attributable to “non-state actors” range from between 17 and 25 Gt CO_2e to less than 5 Gt CO_2e (Hsu and Widerberg, 2018).

Estimates of emission reduction potentials need to be interpreted in light of the assumptions made to calculate the estimates. Assumptions can be analysed in terms of their plausibility, in which case all assumptions are concerned. They can also be analysed in terms of the impact that the individual assumptions may have in the resulting estimates of emission reduction potentials, in which case a smaller number of assumptions will typically be of interest. When the latter approach is taken, two issues appear to dominate.

First, most studies assume that actions by non-state actors will meet their objectives fully. Yet, in more or less explicit terms, all studies state that actions by “non-state actors” are unlikely to deliver fully on their commitments. Indeed, the studies’ estimates of emission reduction potentials represent a theoretical counterfactual (“what would happen”), more than a prediction (“what will happen”). Stated differently, the estimates of potentials represent the level of emission reductions that would be reached in the unlikely event that all actions by “non-state actors” actually delivered in full on their commitments.

Second, most studies find it challenging to estimate the extent to which actions by non-state actors overlap with actions by governmental entities. Individually for a selection of studies, Table 1 lists estimates of the overlap between emission reductions attributable to action by governmental entities versus those attributable to action by non-state actors. Among all estimates of emission reduction potentials published, Table 1 only includes those that cover multiple sectors. The next section in this Supplementary Information note provides, individually for each study, additional background on the assumptions behind the estimates of overlap.

The disparity of the estimates of overlap obtained, which range from 0 to 80 percent, is striking. This diversity does not stem from the specific selection of actions by “non-state actors” on which a given study focuses, as evidenced by a comparison of the results by Roelfsema *et al*. (2015) with the results by Graichen *et al*. (2017), since the latter studied most of the initiatives considered by the former.

Instead, the diversity appears to be determined by the logic that underlies the assumptions made. This logic is as diverse as the resulting estimates of overlap: for example, UNEP (2015) uses a simple but replicable method, Blok *et al*. (2012) and Hsu *et al*. (2015) rely on expert judgement, and Roelfsema *et al*. (2015) and Roelfsema *et al*. (2018) choose a single but intuitive criterion (namely, if a non-state actor focuses on emission sources that are targeted by a governmental emission-reductions programme, the study assumes complete overlap). Most of the studies listed on Table 1 acknowledge that the information available, concerning both state actor and non-state actor action, is insufficient to allow for a robust assessment of overlaps.

Table SI1-A: Overlap between direct impacts from actions by “non-state actors” and action by governmental entities

Study	Initiatives analysed	Estimated annual emissions reductions potential (Gt CO_2e)	Estimated overlap (percent share of estimated potential)
Blok *et al*. (2012)	A selection of 21 “major initiatives”	10 (in 2020)	Between 30% and 50% [(a)]
Erikson and Tempest (2014)	None (the study estimated the technical abatement potential by cities worldwide)	3.7 (in 2030)	Insignificant
Roelfsema *et al*. (2015)	A selection of 17 “major international initiatives”	2.5 (in 2020) 5.5 (in 2030)	Up to 70%
UNEP (2015)	A selection of 15 “major initiatives”	2.9 (in 2020)	Below 33%
Hsu *et al*. (2015)	Eight of the “commitments” made at a 2014 United Nations summit on climate change	2.5 (in 2020)	Not quantified
Graichen *et al*. (2017)	A selection of 19 “international initiatives”	8 (in 2030)	Insignificant
Roelfsema *et al*. (2018)	A selection of 11 “major international initiatives”	2.5 (in 2020) 5.0 (in 2030)	Up to 70% in 2020 Up to 80% in 2030
Hsu *et al*. (2018)	Individual commitments by 5,910 cities, 74 states and regions, and 2,175 companies Commitments by 21 “international cooperative initiatives”	1.5-2.2 (in 2030) 15-23 (in 2030)	Not quantified [(b)]

Notes:

(a) The study provides two sets of case-by-case estimates of overlaps: around 50% (for “high-ambition pledges”) and between 0% and 30% (for “low-ambition pledges”). The estimates are “based on [the author’s] knowledge of the pledges”, derived from work on the ‘Climate Action Tracker’ and the ‘emissions gap’ report by the United Nations Environment Programme.

(b) It only includes emission-reduction commitments that are unambiguously more ambitious than potentially overlapping efforts in the same geography.

Additional details about the studies summarised in Table 1

1. Assumptions made in Blok *et al*. (2012)

In a "Supplementary Information" note, the study provides two sets of case-by-case estimates of overlaps between state and non-state actor action – one for "high-ambition pledges" and one for "low-ambition pledges". For "high-ambition pledges", the study estimates that twelve initiatives are additional by a factor of 50% (the remaining initiatives are additional by a factor of 100% (three), 30% (also three), 70% (two) and 0% (one)). For "low-ambition pledges", the study estimates that eleven initiatives are additional by a factor of 70% (the remaining initiatives are additional by a factor of 100% (six), 90% (two) and 50% (two)). These estimates are "based on [the author's] knowledge of the pledges". This approach is taken because "[p]ledges of countries are only in rare cases specified by sector, so it is not apparent from the pledges how exactly they will overlap with the initiatives".

2. Assumptions made in Erikson and Tempest (2014)

The study states that, in 2013, when the analysis was conducted, national-level emission reduction commitments by parties to the UNFCCC targeted the industry and power sectors. In contrast, city-level greenhouse-gas abatement policies and actions focused on the building and local transport sectors.

3. Assumptions made in Roelfsema *et al*. (2015)

The study assumes that, when non-state actor action targets areas are also included in the national-level commitments made by parties to the UNFCCC, non-state actor action will not result in emission reductions that are additional to those included in national-level commitments. The study indicates that this assumption "differs from the general expectation" that, compared to emission reductions by state actor action, emission reductions by non-state actor actors will be additional.

4. Assumptions made in UNEP (2015)

With regard to the assessment of overlaps between state and non-state actor action, the study proceeds as follows:

- Considers an estimate of the economy-wide emission reductions potential.
- Calculates the share of this potential that is not used by the elements in national-level pledges (made by parties to the UNFCCC) that have already been translated into policies and actions [1].
- Assumes that non-state actor actions and the fraction of state actor actions that are yet to be translated into specific policies and actions will compete for the "unused" share of the economy-wide emissions reduction potential [2].
- Assumes that the relative overlap between state and non-state actor action is equivalent to the ratio between [1] and [2].

- Contrasts the above “top-down” analysis with a number of “bottom-up” sector-specific analyses, which lead to a similar estimate.

5. Assumptions made in Hsu *et al*. (2015)

In a “Supplementary Information” note, the study provides a case-by-case assessment of the commitments analysed. For one initiative (“phasing down climate potent HFCs”), the note states that «100 percent overlap with national commitments» is assumed. For the “New York declaration on forests”, the note lists the signatory countries that have included related forestry-sector goals as part of their (state actor-led) emission reduction commitments. This information is used to estimate the overlap between state actor action and the “New York declaration on forests”.

6. Assumptions made in Graichen *et al*. (2017)

The study assumes that implementation of the objectives of the non-state actor actions analysed will not displace emission reductions that state actors have pledged to achieve, or otherwise would have achieved. Stated differently, the estimates reported in the study represent emission reductions that would be additional to those attributable to state actor action.

7. Assumptions made in Roelfsema *et al*. (2018)

The study assumes that, when non-state actor action targets areas are also included in the national-level commitments made by parties to the UNFCCC, non-state actor action will not result in emission reductions that are additional to those included in national-level commitments. The study indicates that a more precise assessment would require a complex case-by-case analysis, which the study did not undertake.

8. Assumptions made in Hsu *et al*. (2018)

In its analysis of individual city, region and company commitments, the study assumes that these commitments are fully implemented. To address overlap between subnational and non-state action with national policy, it assumes that «additional reductions only take place for [regions, cities and companies] if their aggregated reductions relative to 2015 are higher than reductions implied by national policy implementation». To address overlaps among subnational and non-state actors, it determines the extent to which the commitments target the same set of emissions, and then compares the ambition of the various actions that are overlapping.

In its analysis of international cooperative initiatives, the study accounts for three kinds of overlap: overlaps from actors with targets in more than one initiative; overlaps where initiatives target the same emissions; and overlaps between initiatives that target sectors, such as energy, buildings, transport, and energy efficiency, that will likely overlap with municipal and regional efforts. The analysis also assumes that initiatives meet their goals, including goals to grow their membership.

Throughout, it assumes that «both national governments and other actors do not change the pace of their existing climate policies and actions in response to these subnational and non-state efforts».

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Supplementary Information 2

In the area of human health, hybrid governance schemes have been successful at ramping up the delivery of health services. These schemes illustrate that, in some cases, state and non-state actor action are more effective when they are full integrated. Examples can be found at both the international and national levels.

At the international level, the Global Alliance for Vaccines and Immunisation (GAVI), and the Global Fund to Fight Aids, Tuberculosis and Malaria (the Global Fund) are two cases in point. Notwithstanding differences in other aspects of their operations, both GAVI and the Global Fund share one important feature with regard to their approach: joint delivery by state and non-state actors, who are accountable to each other through elaborate governance mechanisms. Indeed, both GAVI and the Global Fund are credited for having a major impact primarily because they bring together governmental and non-governmental actors into a large-scale, tightly collaborative effort (England, 2009). Nevertheless, they also coexist with, and complement, other programmes that are eminently state actor-led or non-state actor-led.

At the national level, the development of Thailand's antiretroviral-therapy policy provides an example of joint delivery between state and non-state actors (Tantivess and Walt, 2008). In this case, and in addition to lobbying government to take policy action on antiretroviral therapy, non-state actors supported all aspects of the policy process, effectively complementing the work of state actors. Interestingly, the role of non-state actors evolved over time, always supplementing the role of their state-actor counterparts. With time, the Thai non-state actors extended their activities beyond the national borders, to conduct similar roles in neighbouring countries. Similarly, international non-state actors eventually joined domestic actors to help implement Thailand's policy.

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Supplementary Information 3

Within a single industry sector, what hinders the establishment of a hybrid governance arrangement focused on mitigating greenhouse-gas emissions and, crucially, integrating all major actors in the sector, governmental and non-governmental alike, following the approach successfully adopted by GAVI and the Global Fund (Supplementary Information 2)? Arguably, the binding nature of the commitment and the loss of visibility are two central elements to the answer of this question.

With regard to the binding nature of the commitment, it is worth recalling that GAVI and the Global Fund operate under an elaborate governance mechanism (Hale and Held, 2011). This framework spells out the specific responsibilities of each actor involved, including the nature and time frame of the products or services that each actor has committed to delivering, the budget allocated to each actor, the accountability relations between actors, and the reporting requirements applicable to each actor. These terms are more demanding than the terms applicable to most non-state actions that are active today. Similarly, peer pressure associated with delivery is higher, in that an integrative initiative like GAVI or the Global Fund effectively includes all major actors, which have committed publicly to delivering and fear the reputational damage associated with not doing so, especially if they peers deliver successfully.

With regard to the loss of visibility, it is worth recalling that public relations is one of the driving forces of most organisations involved in a non-state actor action (CIP, 2020). The tightly integrative arrangement exemplified by GAVI and the Global Fund arguably reduces visibility of the parts, to the benefit of the whole.

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Article 4

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Incorporating uncertainty in national-level climate change-mitigation policy: possible elements for a research agenda

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Abstract

Decision making for climate change management seldom incorporates uncertainty in the analysis that underpins the policy process. First, uncertainty is seldom characterised fully, and attempts to reduce uncertainty—when this is possible—are rare. Second, scientists are ill-equipped to communicate about uncertainty with policy makers, and policy makers most often favour pretended certainty over nuance and detail. Third, the uncertainty analysis that may have been conducted most often fails to actually influence policy in a significant manner. The case is made for (i) characterising and, to the extent possible, reducing uncertainty, (ii) communicating uncertainty, and (iii) reflecting uncertainty in the design of policy initiatives for climate change management. Possible elements for a research agenda on each of these areas are proposed.

Keywords Government accountability · Decision-support tools · Science-policy interface

Policy making for climate change management is riddled with uncertainties. Therefore, incorporating uncertainty in the policy-making process is a precondition for designing and implementing efficient and effective climate change-management policies (Morgan 2009). In a stylised representation of the concept, 'incorporating uncertainty' could encompass three steps: (i) characterising and, to the extent possible, reducing uncertainty; (ii) communicating the remaining uncertainty to policy makers, in a manner that is adapted to their needs; and (iii) reflecting uncertainty in the design of policy initiatives for climate change management.[1]

Over the past 15 years, uncertainty characterisation and reduction (the first step above) has been the subject of extensive research with regard to global estimates of warming levels and the costs arising from the impacts associated with such warming (Heal and Kriström 2002; Dessai et al. 2007). In recent years, research on uncertainty characterisation and reduction has also focused on national-level estimates of future emission volumes (Rogelj et al. 2017; Puig et al. 2017; Benveniste et al. 2018).[2] However, the latter has not influenced national-level processes for setting emission-reduction targets, as evidenced by the types of targets presented in the Nationally Determined Contributions put forward by parties to the United Nations Framework Convention on Climate Change (UNFCCC) (UNFCCC 2016).

Uncertainty communication (the second step above) is an under-researched topic (Fischhoff 2012). The handful of studies available focus on the general public—not government—as the target audience, and the media—not scientists—as the communicator (Broomell and Kane 2017). A 2014 protocol for uncertainty communication provides practicable guidance that can be used in a context where scientists communicate with governments (Fischhoff and Davis 2014). This protocol appears to never have been used for policy making in the area of climate change management, as evidenced by the complete lack of literature documenting such use.

Determining the extent to which uncertainty is reflected in the design of policy initiatives for climate change management (the third step above) is challenging. In her assessment of Swedish climate change

[1] Guidance exists for dealing with uncertainty in the area of climate change management. Yet, this guidance is insufficient in most cases, and under-used at best. In light of this, the article (i) makes the case for using this guidance to incorporate uncertainty in the analysis that underpins the policy process, and (ii) proposes possible elements for a research agenda in this area.

[2] This interest stems from the critical role that the individual emission reduction commitments by parties to the United Nations Framework Convention on Climate Change (UNFCCC) play in the Paris Agreement.

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policies, Knaggård (2014) finds that 'scientific uncertainty played a very marginal role in the development of Swedish climate politics'. No other comparable assessments appear to have been conducted, in Sweden or elsewhere. Knaggård's results, and the paucity of literature in this area, suggest that climate change decision makers fail to reflect uncertainty customarily in the policies they design and implement.[3]

Against this background, it seems justified to claim that, in the context of climate change management, policy making fails to incorporate uncertainty in a comprehensive and systematic manner. In addition to institutional inertia, two reasons account for this failure. Firstly, the appeal that (pretended) certainty has for senior decision makers, as described in the post-normal science literature (Funtowicz and Ravetz 1993; Mathijssen et al. 2008). Secondly, and far more prosaic, the resources that are required to incorporate uncertainty in the decision-making process, which are challenging to mobilise, especially in low-income countries (UNFCCC 2016).

Reversing this situation is difficult, even in countries that have the resources and the political determination to do so (Petersen et al. 2011). Notwithstanding, the case for incorporating uncertainty in the policy-making process is strong on at least two accounts. Firstly, it is the duty of governments to ensure that policy is based on the best available evidence (Gluckman 2016). In the context of climate change management, fulfilling this duty is tantamount to incorporating uncertainty in the policy-making process, among other considerations.[4] Secondly, in as much as uncertainty is inextricably linked to the analysis that underpins national-level processes for setting emission-reduction targets, and because such targets are at the heart of the Paris agreement under the UNFCCC, disregarding uncertainty undermines the robustness of the Paris Agreement.[5] Given the stakes, UNFCCC-sponsored guidance on this issue appears warranted (Puig et al. 2017).

Heightened research efforts will be required to progress toward incorporating uncertainty in national-level climate change-mitigation policy. Key among these are the following (Table 1):

- A conceptual framework exists that supports the characterisation of uncertainty in the context of model-based analyses (Kwakkel et al. 2010).[6] However, climate change-mitigation policy cannot always rely on modelling, because modelling tools are underdeveloped (such as is the case for land-use planning), or because the country has limited tradition (and thus expertise) with modelling. In these situations, a broader framework to guide the characterisation of uncertainty is needed, possibly structured around qualitative scenarios (Enserink et al. 2013). Such broader conceptual framework is missing.
- A handful of reviews has been published, documenting techniques that can be used to quantify uncertainty. However, they are suboptimal with regard to designing national-level climate change-mitigation policies: some of these reviews are mainly relevant in the context of regional integrated assessment modelling (Katz 2002; Unwin et al. 2011), whereas those that lend themselves better to application in a national-level planning context, arguably lack detail (IPCC 2006; Morgan 2009). Additional research is needed, to shed light on what the best techniques might be for quantifying uncertainty at the level of a specific sector (such as electricity generation) or decision-support tools (such as cost-benefit analysis).
- National-level policy-planning for climate change management is rarely confronted with irreducible uncertainties, such as those that are common in climatology. For the most, this type of policy planning faces two kinds of uncertainties: those that can be reduced only through years' worth of additional research (for example, the impact on fuel demand attributable to fossil fuel taxation), and those that can be reduced reasonably easily (for example, the choice of options available to pursue a given

[3] In most countries, policy making for climate change management is informed by the results of consultations with key stakeholders. This refers to all stages in the policy process, from identifying priorities and setting objectives, to defining and implementing potential actions, to monitoring progress with implementation. In so far as these consultations help identify uncertainties, the consultations contribute to reflecting uncertainty in the policy-making process. Similarly, it is now customary for modelling results to benefit from sensitivity analyses, which help evaluate the extent to which projections of a variable of interest may change, depending on which assumption is used, across the full range of plausible future values for an uncertain variable. Whilst these and other similar practices constitute relevant efforts to reflect uncertainty in climate change-management policies, they are far from comprehensive, given the much broader set of uncertainties that reasonably could be considered (Walker et al. 2013).

[4] When the resources needed to obtain 'the best available evidence' are not on hand, it is the government's duty of care to explicitly acknowledge this, whilst adopting a no-regrets approach to policy making. In this setting, a 'no-regrets approach' to policy making refers to adopting measures that meet two requirements: they are consistent with the information about which there is a high degree of certainty, and they preclude as few future courses of action as possible (Kwakkel et al. 2016). Ideally, this approach to policy making should be complemented with regular evaluations of performance against the policy's intended objective.

[5] In the Paris agreement, the accounting of future emission levels relies on the UNFCCC parties' deterministic estimates of future emission-reduction volumes by the individual parties. If those estimates turn out to be overly optimistic (or pessimistic), a key pillar of the negotiations is compromised. In light of this, it has been suggested that national-level emission reduction targets should be attached to scenarios, and expressed in probabilistic terms (Puig et al. 2017).

[6] Model refers to a computer-based representation of reality, simple as it may be, as opposed to a less explicit or tangible alternative.

Table 1 Research gaps for incorporating uncertainty in national-level climate change-management policy

Topic	State of research today	Potential research priorities
Characterising uncertainty	Conceptual framework for use in computer-based models (Kwakkel et al. 2010)	Broader framework, catering to both computer-based and other types of models
Quantifying uncertainty	Descriptions of generic techniques (Morgan 2009)	Adaptations of the generic techniques, to suit the specificities of key sectors (for example, transport) or decision-support tools (for example, cost-benefit analysis)
Reducing uncertainty	Protocol suitable for multi-criteria decision analysis (Montibeller and von Winterfeldt 2015)	Protocols for other types of decision-support tools
Communicating uncertainty	Protocol for uncertainty communication (Fischhoff and Davis 2014)	Application of the protocol to different types of policy-planning processes, to build a body of knowledge in this area
Reflecting uncertainty in the design of policies	Review of the extent to which Swedish climate change-management policies reflect uncertainty (Knaggård 2014)	Additional reviews, to improve methodologies and foster the integration of uncertainty in policy design

objective). A protocol exists to reduce uncertainties in applications of multi-criteria decision analysis (Montibeller and von Winterfeldt 2015). Additional research is needed to develop similar protocols for other types of decision-support tools, notably for cost-benefit analysis (Puig and Bakhtiari 2017).

– As mentioned above, a protocol for uncertainty communication has been developed, which attempts to promote communication between scientists and policy makers (Fischhoff and Davis 2014). There is no documented use of the protocol in the area of national-level policy-planning for climate change management. Application of the protocol across different types of policy-planning processes for climate-change management would contribute to building a body of knowledge in this area, ultimately helping improve communication between scientists and policy makers.[7]

– A review of Swedish policy making appears to be the only study of the extent to which uncertainty is being reflected in the design of national-level policy measures for climate change management (Knaggård 2014). Additional research in this area is needed, to gain the insights required to improve the methodological frameworks used to conduct this kind of evaluations, and understand the barriers to increased uptake of uncertainty evidence in national-level policy-planning for climate change management.

[7] It is worth noting that uncertainty reduction may, in some instances, hamper uncertainty communication (Puig and Bakhtiari 2017). This observation only strengthens the case for developing uncertainty reduction protocols, and gaining experience with uncertainty communication (for example, by applying the Fischhoff and Davis protocol referred to above).

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Article 5

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ORIGINAL PAPER

The mismatch between the in-country determinants of technology transfer, and the scope of technology transfer initiatives under the United Nations Framework Convention on Climate Change

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Abstract

Despite decades of international political emphasis, little is known about the in-country determinants of technology transfer for climate change mitigation. We draw upon the conclusions of a series of standardised, official governmental statements of technology priorities, coupled with questionnaire-based data collection, to shed light on the nature of those determinants. We find that there is a disconnect between what developing country governments perceive as the key enablers of, and barriers to, technology transfer, and what bilateral and multilateral technology transfer programmes can offer, given budgetary constraints and the logic of development aid spending. We show that the well-established notion of making climate change mitigation actions an integral part of sound development plans is especially relevant for technology transfer. We offer pointers as to how this might be done in practice, in the context of the 'technology action plans' developed as part of the United Nations-sponsored technology needs assessment process.

Keywords United Nations Framework Convention on Climate Change · Technology needs assessment · Technology mechanism · Development aid for climate change

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1 Introduction

In the context of multilateral climate change negotiations, scaling up the adoption of lower-carbon energy technologies in developing countries is referred to as ‘technology transfer’ (Metz and Turkson 2000). While, over the years, the concept of technology transfer has become central to these negotiations, both the debate about, and the approach to, technology transfer has been ‘characterised by a highly narrow and instrumentalist (and sometimes even naïve) understanding of technology, and the conditions under which technology transfer occurs’ (Haselip et al. 2015a).

Reflecting the shortcomings noted above, the extent to which the plethora of past and ongoing technology transfer initiatives have been effective and efficient at scaling up the adoption of cleaner energy technologies in developing countries is unknown (Chatterji 2016). Identifying the in-country determinants of technology transfer, and mapping them against the outcomes of these initiatives, is a prerequisite to evaluate the efficiency and effectiveness of the initiatives. We explore this question, focusing on a selection of energy-related technologies, and a small group of developing countries, to offer some indicative results as a means to stimulate debate and identify areas for more in-depth research. With the aim of drawing broadly applicable findings that are relevant to multilateral climate change negotiations, we do so from an aggregated point of view, by structuring our research around four technology clusters—household consumer goods, industry retrofits, new industry investments, and large infrastructure projects. We find that there is a disconnect between what developing country governments perceive as the key enablers of, and barriers to, technology transfer, and what bilateral and multilateral technology transfer programmes can offer, given budgetary constraints and the logic of development aid spending. Given that our analysis is informed by the conclusions of non-OECD country-driven processes (principally the TNAs, as discussed in Sect. 2), our analysis is focused on non-OECD country perspectives, albeit from our own developed-world perspective.

The disconnect referred to above reflects governance deficiencies that are common in many developing countries, and have the unintended consequence of undermining sectoral policy goals, by unduly contra-positioning development priorities to those sectoral goals (Bulkeley and Newell 2015). In the area of climate change mitigation, a large part of the solution to this deficiency entails striking a balance between the additional cost of lower-carbon energy technologies (compared to the cost of traditional alternatives), and the imperative to adopt inexpensive technologies, with a view to stretching limited budgets as far as possible. The so-called technology action plans, a set of detailed, national-level blueprints for the adoption of lower-carbon energy technologies, prepared under a United Nations-sponsored initiative to promote technology transfer in developing countries, offer an opportunity to strike this balance. With regard to the role of technology transfer, the credibility of the international climate change regime may suffer if this opportunity is missed (UDP 2015).

2 Background

‘Technology transfer’ is a key tenet of the 1992 United Nations Framework Convention on Climate Change (UNFCCC). Article 4 in the UNFCCC requires its signatory parties to “promote and cooperate in the development, application and diffusion, including transfer, of technologies, practices and processes that control, reduce or prevent anthropogenic emissions of greenhouse gases not controlled by the Montreal Protocol in all relevant sectors".

An emphasis on the role and importance of technology within the UNFCCC stems partly from the success of the 1989 Montreal Protocol, which relied on a narrow 'hardware' focus to achieve a relatively rapid and widespread technology switching, following the ban on chlorofluorocarbons.[1] However, unlike chlorofluorocarbons, greenhouse gases are emitted by virtually all sectors in the economy, directly or indirectly, through a wide range of technologies. For this reason, technology switching is far more complex in the area of climate change, as it involves more than just a limited number of manufacturing processes within a relatively small industry that has few large producers.

Acknowledging that a narrow focus on manufacturing processes would be unsuitable for the ubiquitous nature of climate change, the Intergovernmental Panel on Climate Change (IPCC) defined 'technology transfer' rather broadly (Metz and Turkson 2000):

> The broad set of processes covering the exchange of knowledge, money and goods amongst different stakeholders that lead to the spreading of technology for adapting to or mitigating climate change. [The] word 'transfer' [is used] to encompass both diffusion of technologies and cooperation across and within countries.

Indeed, much of the academic debate reveals a paucity of detailed, operational definitions of technology transfer (Karakosta et al. 2010; Popp 2011). In this article, we use the IPCC definition, which emphasises the importance of cooperation. This is an aspect that the academic literature is increasingly focused on, using the term 'cooperation' in order interrogate the political and economic dynamics behind such exchange.

In response to Article 4 in the UNFCCC, various multilateral and bilateral funding mechanisms have been set up to accelerate technology transfer for climate change mitigation (and adaptation) (de Coninck and Puig 2015).[2] For example, in the year between July 2014 and June 2015, the Global Environment Facility, a multilateral fund, approved USD 221.4 million worth of investments in lower-carbon energy technologies in developing countries. The Green Climate Fund (GCF) and the Climate Technology Centre and Network (CTCN) are expected to play key roles in providing or (in the case of the CTCN) enabling finance for technology transfer.

The extent to which these multilateral institutions have promoted 'technology transfer' is unclear. Research on the determinants of technology transfer has focused on two main aspects: evidence on the mechanisms that help promote technology transfer across a wide spectrum of technologies (Ockwell and Mallett 2012), and evidence on the conditions that facilitate the adoption of a specific technology, often in a particular socioeconomic context (Audretsch et al. 2016). These two streams of work have supported, respectively,

[1] Chlorofluorocarbons were used in refrigerants, propellants and solvents. They were responsible for the destruction of the ozone layer, a portion of the Earth's stratosphere that absorbs most of the Sun's medium-frequency ultraviolet radiation, which is damaging to life. For a discussion on the relative role and importance of commercial patents as a driving force behind multilateral agreements to tackle ozone and greenhouse gas emissions see, for example, Seidel and Ye (2015).

[2] Multilateral and bilateral funds are channelled through grants, or a range of financial products. Grants are often aimed at increasing technical and institutional capacities in developing countries. Financial products, typically in the form of equity, concessional debt, or guarantee instruments and risk sharing, often seek to leverage larger volumes of private sector financing for capital and infrastructure investment.

international climate change negotiations, and the development of financial plans for lower-carbon energy technologies.

Notwithstanding its usefulness, this work overlooks an intermediate level that can be characterised by clusters of technologies sharing key market attributes, notably with regard to the affordability of these technologies by the relevant stakeholders. As such, we use the term 'clusters' to capture the basic market categories common to all national-level economics, where the 'intermediate' level focuses on policies that correspond to this national level. Research at this intermediate level is much needed, because this is the level at which national planning for climate change takes place (Boldt et al. 2012).[3] In this sense, our analysis is focused through a political economy lens, where we assume that private sector actors (investors, technology suppliers and consumers) are the principle drivers in the uptake and diffusion of lower-carbon energy technologies in a given economy (Ockwell and Byrne 2015). Thus, the question is how governments and state agencies can create, steer and scale up markets for these technologies, by incentivising economic actors to increase investment in the supply and demand.

By extension, it is appropriate for us to anchor this article in the broader literature on technology innovation systems and sustainability transitions, where there is growing academic discussion about the drivers, mechanisms and implication of the uptake and diffusion of lower-carbon technologies in non-OECD countries, outside the context of the UNFCCC. The contours of this debate are well articulated in a special issue on sustainability transitions in developing countries edited by Hansen et al. (2017) and in Ockwell and Byrne's (2016) edited book. A key theme within this debate is the limitation of some of the analytical approaches (e.g. technology innovation systems) to understanding the topic in non-OECD contexts, and how studies often focus on one technology and/or the macroeconomic level, and hence fail to take into account the socioeconomic contexts surrounding the processes of technology transfer. By focusing our analysis on technology clusters in the context of the UNFCCC (as opposed to individual technologies and/or countries as a whole), we aim to contribute to these wider debates.

Our research question is 'for a range of "technology clusters" that are relevant to most developing country plans for climate change, what are the determinants of technology transfer?' Drawing upon conclusions of official statements of national climate change technology priorities, we provide tentative answers to this question. In doing so, we sketch some of the requirements for promoting the actual transfer of lower-carbon energy technologies.

This article is structured around four additional sections. Section 3 introduces the 'technology needs assessment process', from which our data are drawn. Section 4 outlines our methodology. Section 5 presents our findings. In a final section, we raise points for discussion, indicating areas of possible future research.

[3] The Paris Agreement, the international blueprint for climate change management, requires parties to the UNFCCC to formally report their actions to manage climate change. These reports are known as Nationally Determined Contributions (or NDCs for short). The approach used in this paper, focused on the 'intermediate level' of planning outlined above, is directly relevant to the type of analysis around which the NDCs are structured.

3 The TNA project

Among the various multilateral efforts aimed at promoting technology transfer, the 'technology needs assessment (TNA) process' is a long-standing one. The TNA process was conceived as a means to 'track evolving needs for new equipment, techniques, practical knowledge and skills to mitigate greenhouse gases and adapt to the adverse impacts of climate change'. Since 2001, and with support from international organisations, more than 85 developing countries have completed an assessment of their technology needs for climate change. The latest generation of TNAs was mandated by the UNFCCC's Poznan Strategic Programme on Technology Transfer, in 2008. According to this programme, the TNAs enable developing countries to 'demonstrate commitment' to technology transfer, as a step towards accessing public finance for it.

The TNA process is organised around three main steps: (1) identify and prioritise mitigation (and adaptation) technologies for key sector and/or sub-sectors at the national level; (2) identify, analyse and break down barriers to technology diffusion, and detail an 'enabling framework' for that diffusion; and (3) articulate 'technology action plans' (TAPs).[4] The first step results in the so-called TNA reports, from which most of our data are drawn. The TAPs resulting from the third step, which are framed around concrete opportunities for technology switching, are a second source of data for our work.

The TNA process reflects national priorities and concerns.[5] By relying on TNA data, our findings are consistent with these—as opposed to conclusions derived from an externally developed economic optimisation model, or a particular governance model. As such, our data reflects a diversity of technology priorities and rationalities regarding the barriers to technology transfer, and the means to overcome them. What these priorities and rationalities have in common, however, is that they are all nationally determined analyses, and statements of official, sovereign intent.

For the technology-prioritisation process, the TNA process used multi-criteria decision analysis. Multi-criteria analysis is a decision-support tool that enables participants to identify, select and evaluate options on the basis of agreed-upon criteria. Unlike cost–benefit analysis, multi-criteria decision analysis does not depend upon a monetisation of values, thus enabling participants to capture and value a wider range of issues (one of which may be the monetary value of a technology's costs and benefits) and discuss their relative importance. This multi-criteria analysis was conducted as a participatory process, involving various stakeholders, as selected by the national governments responsible for implementing the TNA.

4 Methodology

Based on the conclusions of the TNA reports, we identify key determinants of successful technology transfer. These determinants are a combination of the barriers that would have to be removed, and the enabling factors that would have to be introduced, which, taken together, increase the likelihood of technology transfer taking place. We cluster these

[4] All reports are available online at: http://www.tech-action.org/.

[5] For some countries, the results of the TNA project are clearly reflected in the NDC. The extent to which this is so depends, among other issues, on (1) how recent the TNA ranking is, and (2) whether or not the NDC is detailed enough to highlight specific technology-related priorities.

determinants by type of market—household consumer goods, industry retrofits, new industry investments, and large infrastructure projects—and identify the key determinants in each cluster. When defining the clusters, our main consideration was how the technology upgrading would be financed, combined with a simple division of consumer categories. This reflects the main issue as expressed in the TNA reports. For the 'households' cluster, the main determinant is having sufficient disposable income (and a willingness to pay); for the 'industry retrofits' cluster, it is mostly about returns on capital investment. For the 'new industry investments', the main issue is access to investment in new production facilities and longer-term returns, and the 'large infrastructure projects' cluster is mostly concerned with access to sovereign loans (i.e. government history of debt repayments or defaults).

Countries participating in the TNA process were provided with specific guidance developed for the project, including a standardised assessment methodology prepared by the UNEP DTU Partnership (Haselip et al. 2015b). Nonetheless, individual TNA reports are not always directly comparable, as countries were given a significant degree of flexibility with regard to conducting the technology-prioritisation process and barrier analysis, as befit their technical capabilities and preferences.

For the analysis presented in this paper, we have complemented the data from the TNA reports with a survey on enablers of, and barriers to, technology transfer (Supplementary Information 1). The survey was sent to the TNA project coordinators in the countries participating in the first phase (2011–2014), who were typically government officials and the national climate change focal points within relevant ministries, thus assumed to have an informed overview of the key determinants of technology transfer in their countries. This survey allowed us to (1) increase the comparability of the TNA report data across countries, and (2) collect data that was missing in the TNA reports. The resulting dataset (Supplementary Information 1), while limited to a reduced number of countries, allows us to draw some tentative conclusions that reflect the realities in the countries surveyed, and possibly beyond (Sect. 5).

5 Findings

We characterise the determinants of technology transfer through three survey questions—drivers, enablers and barriers (Supplementary Information 1). Responses for each of these questions are elicited by country and technology. Here, we present aggregated findings by technology cluster.

Table 1 summarises key survey results by technology cluster. In the following paragraphs, we compare these results with the typical design of bilateral and multilateral technology transfer programmes.

With regard to the drivers of technology transfer, we find that 'cost savings' dominate in three out of four technology clusters. In the fourth cluster ('new industry investments'), meeting government targets appears to be the main driving force. This suggests that technology transfer is more likely to occur where energy prices are not unduly low, and government has introduced certain performance targets for large energy consumers. Whilst this is perfectly consistent with current wisdom, it has not deterred funders of technology transfer programmes from deploying these programmes in countries where

Table 1 Summary of survey results, by technology cluster

Target groups	Drivers	Enablers	Barriers
Household consumer goods			
Households and service industry	Long-term cost savings (increased disposable income)	Subsidies and, to a lesser extent, information campaigns	High up-front costs
Industry retrofits			
Service industry and manufacturing companies	Long-term cost savings (increased profits)	Targeted subsidies or grants, and investment by foreign companies	High capital costs, and high taxes on imported equipment
New industry investments			
Power companies with majority of foreign capital	Governmental targets[a]	Targeted subsidies, including feed-in tariffs	Lack of financial incentives[b]
Large infrastructure projects			
Central government	Long-term cost savings (reduced spending)	Foreign direct investment[c]	Inefficiencies that discourage investment[d]

[a] 'Make a profitable investment' also cited

[b] 'Unclear regulatory frameworks' also cited

[c] 'Bilateral or multilateral loans' also cited

[d] 'Poor credit rating' and 'public opposition' also cited

these two pre-conditions are not met, as evidenced by the geographic scope of most such programmes.[6]

In three out of four technology clusters, subsidisation is cited as the main enabler of technology transfer. While bilateral and multilateral technology transfer programmes often rely on an element of subsidisation, this is seldom the dominant aspect in these programmes. This is because subsidy-based programmes contradict the predominant market-based (or neoliberal) logic that drives decision making among multilateral lenders. From this perspective, subsidy-based programmes are generally viewed as expensive, and not seen as a sustainable option upon programme completion. Instead, other options, such as technology-specific credit facilities (possibly combined with a small subsidy to cover the costs of the technology), represent what is widely viewed as a more sustainable alternative (CPI 2012). This highlights a fundamental disconnect between what countries perceive to be the main enabler for technology transfer, and what bilateral and multilateral programmes can offer, given the political economy around, and known limitations of, subsidy-based programmes (UNEP 2005).

In the fourth cluster ('large infrastructure projects'), foreign direct investment is perceived as the most likely enabler of technology transfer.[7] Two issues are worth noting here. Firstly, 'bilateral and multilateral loans' were only cited in the context or large hydropower dams—not for carbon capture and storage, or for geothermal energy. Secondly, the fact that technology transfer for certain large infrastructure projects may depend on foreign direct investment underscores the need to widen the traditional technology transfer debate, which continues to be heavily focused around development aid-funded implementation modalities. However, without wishing to drift into the realm of speculation, it seems fair to say that multilateral initiatives could do more to secure investment for specific technologies, supporting national funding agencies that are less willing to take on the financial and non-financial risks associated with certain large-scale infrastructure projects such as hydropower or wind farms located in remote areas with contested land tenure and access rights. The Lake Turkana project in Kenya is a case in point where various sources of finance (public, private, domestic and foreign) came together to build what was the largest single wind farm in Africa (310 MW), at the time of construction (2017).

In two out of four technology clusters, issues related to affordability are cited as the main barriers to technology transfer. Specifically, the barriers cited are high up-front costs ('household consumer goods' cluster), and high capital costs, also combined with high import taxes ('industry retrofits' cluster). In the case of the 'household consumer goods' cluster, breaking down these barriers requires macro-economic policies that encourage savings, thereby increasing disposable income. However, increasing disposable incomes does not necessarily lead to the purchase of more energy efficient consumer goods. Rather, changes in consumption also depend on shifts in consumer willingness to pay, which is partly a function of changing cultural practices, education and concern about the non-financial (environmental and social) costs of consumption. Related to this is the rapidly evolving landscape of technologies and business models for service provisions, such as mobile and pay-as-you-go technologies, which are being applied to off-grid solar PV system, for example.

[6] The Global Environment Facility reports on funding for technology transfer. The latest report dates to 2014, and includes a full list of beneficiary countries (UNFCCC 2014a).

[7] To the extent that some NDC targets are conditional on external support, it may be expected that some countries single out large infrastructure projects as key targets for such external support.

In the case of the 'industry retrofits' cluster, increased profitability can help break down the cost barrier. Profitability is a function of several parameters, some linked to the investment structures within the industry concerned, and some linked to the fiscal and industrial policies in the host country. Few bilateral and multilateral technology transfer programmes attempt to bring about these types of changes, as evidenced by the scope of most such programmes (UNFCCC 2014b).

In the remaining two clusters, the main barriers cited relate to the regulatory framework: lack of financial incentives ('new industry investments' cluster), and regulatory inefficiencies ('large infrastructure projects' cluster). This is an area that bilateral and multilateral technology transfer programmes have prioritised, in some countries and sectors more than in others (UDP 2015). Increased emphasis on these issues might thus be warranted.

6 Discussion

In its broad definition of technology transfer, the IPCC captures the multiple dimensions of the concept (Metz and Turkson 2000). Conversely, international climate change negotiations under the UNFCCC arguably fail to recognise these complexities, as evidenced by the narrow focus of the Poznan Strategic Programme on Technology Transfer, which lacks a holistic framework that embeds technology transfer within a country's broader socioeconomic context (UNFCCC 2008). Indeed, the UNFCCC's Technology Mechanism, with its Climate Technology Centre and Network, predominantly takes a narrow project focus.[8]

Expectations about the Technology Mechanism by some developing country governments are similarly narrow, in the sense that (limited) developed country funding levels are typically brandished as the main obstacle to technology transfer in the TNAs. This is a simplification of the issue, in that it overlooks the fundamental role that the regulatory and institutional frameworks play with regard to successful technology transfer. More generally, the funding argument may mask key developmental deficiencies, notably those related to the suitability of a country's fiscal and investment frameworks, including transparency and rule-of-law, which translate into differing risk profiles.

The 'technology action plans' (TAPs) prepared as the final outputs of the technology needs assessment process represent a valuable opportunity to correct the shortcomings referred to above. These plans outline targeted actions that, by helping remove barriers to the adoption of climate change (adaptation and) mitigation technologies, can facilitate the uptake of those technologies. Here, it is important to reiterate that the TAPs are nationally determined plans that reflect the will and preference of the governments (informed by their appointed stakeholders), not externally calculated optimisation models based on a host of assumptions. To stimulate technology transfer beyond current levels, it is necessary to articulate and present opportunities, beyond a discussion of hardware and funding, to include revisions in related policy and the broader enabling framework (UNFCCC 2014b, 2016). This brings us back to the primacy of the political economy of technology transfer processes, in which private investors, technology suppliers and consumers are the key actors that governments and state agencies must engage with to create, steer and scale up markets for low-carbon energy technologies.

[8] Limited funding to-date for the Climate Technology Centre and Network is one of the reasons for this.

If technology is to play a truly meaningful role in the mitigation of greenhouse-gas emissions, the UNFCCC rhetoric about ‘technology transfer’ and ‘sustainable development’ has to be made operational, and has to be scaled up significantly in the coming decades. This would mean framing technology transfer as an intrinsic and core element of broader development plans—an aspiration that is at least as old as the notion of ‘technology transfer’ itself, but towards which relatively little progress has been achieved thus far.

Therefore, thinking beyond the life of the TNA/TAP process, multilateral mechanisms that aim to scale up access and investment in low-carbon energy technologies should also think about the developmental benefits of the technological transition they aim to support. Here, it is important to acknowledge how the basic political economy of low-carbon technology ‘transfer’ has shifted in recent years, to operate increasingly on market lines. On the supply side, especially for the large-scale infrastructure cluster, it is private investors who are driving the transition in low-income countries (Nygaard et al. 2017). As such, donors now play a predominantly supporting role in many low-income countries, to kick-start and de-risk projects that otherwise operate on commercial grounds (Rodríguez-Manotas et al. 2018). This movement—from projects to markets—creates new challenges and opportunities for governments, and their development partners, to optimise the enabling framework for low-carbon energy technologies. This includes the enactment of laws, policies and regulations to accelerate the large-scale diffusion of low-carbon energy technologies through market-creation incentives; create local employment by capturing larger shares of value in the global value chains in the supply of technologies; and ensure that wider development objectives are met through private sector engagement, as enshrined in SDG7, SDG8 and SDG9.

In order to avoid ‘missing the boat’ in capturing these developmental benefits of the technology transition, non-OECD governments should appeal to their development partners (multilateral or bilateral) for support in working with relevant ministries and their policy makers, regulators, public utilities, local research institutions and private sector actors. Here, the basic aim should be to identify elements of a reformed enabling framework for specific technologies, with an emphasis on securing a greater share of the market value chain in the local economy.

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Article 6

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TITLE

The accountability imperative for quantifying the uncertainty of emission forecasts: evidence from Mexico

ACADEMIC ABSTRACT

Governmental climate change mitigation targets are typically developed with the aid of forecasts of greenhouse-gas emissions. The robustness and credibility of such forecasts depends, among other issues, on the extent to which forecasting approaches can reflect prevailing uncertainties. We apply a transparent and replicable method to quantify the uncertainty associated with projections of gross domestic product growth rates for Mexico, a key driver of greenhouse-gas emissions in the country. We use those projections to produce probabilistic forecasts of greenhouse-gas emissions for Mexico. We contrast our probabilistic forecasts with Mexico's governmental deterministic forecasts. We show that, because they fail to reflect such key uncertainty, deterministic forecasts are ill-suited for use in target-setting processes. We argue that (i) guidelines should be agreed upon, to ensure that governmental forecasts meet certain minimum transparency and quality standards, and (ii) governments should be held accountable for the appropriateness of the forecasting approach applied to prepare governmental forecasts, especially when those forecasts are used to derive climate change mitigation targets.

KEYWORDS

Uncertainty, projections, structured expert judgement, accountability, emission-reduction targets, gross domestic product growth rates

POLICY INSIGHTS

- No minimum transparency and quality standards exist to guide the development of greenhouse-gas emission scenario forecasts, not even when these forecasts are used to set national climate change mitigation targets.
- No accountability mechanisms appear to be in place at the national level to ensure that national governments rely on scientifically sound processes to develop greenhouse-gas emission scenarios.
- Using probabilistic forecasts to underpin emission reduction targets represents a scientifically sound option for reflecting in the target the uncertainty to which those forecasts are subject, thus increasing the validity of the target.
- Setting up minimum transparency and quality standards, and holding governments accountable for their choice of forecasting methods could lead to more robust emission reduction targets nationally and, by extension, internationally.

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1. Introduction

The vast majority of the parties to the United Nations Framework Convention on Climate Change (UNFCCC) have committed to specific greenhouse-gas (GHG) emission-reduction targets by 2030 (INDCs 2017). The level of ambition of each party's individual commitment, and the extent to which commitments are actually implemented, will determine whether the UNFCCC goal can be met (UNEP 2016, UNFCCC 2016).

Several of the largest developing-country parties to the UNFCCC have defined their GHG emission-reduction targets relative to a forecast 'baseline' level in 2030 – that is, the emission level that would be reached in 2030 if the policies and measures directed at meeting the target were not implemented (INDCs 2017).[1] For these parties, two factors determine the level of ambition of their individual targets (Puig *et al.* 2013): the stringency of the target, measured as the extent to which the target represents a departure from those 'baseline' emission levels; and the robustness and credibility of the forecasts that describe the 'baseline' emission levels, measured in terms of the appropriateness of the forecasting approach used.[2]

While both determinants matter with regard to measuring the level ambition of the individual targets, the former receives far more scrutiny than the latter (UNEP 2016, UNFCCC 2016). Nonetheless, the latter is by no means negligible. Consider a percentagewise emission reduction target that applies to a forecast of 'baseline' GHG emission levels in a certain future year: depending on whether that forecast is high or low, the emission reductions target will represent, respectively, a low or a high level of actual emission reductions in that future year.

Therefore, eminently technical issues, such as the appropriateness of the assumptions made, and methods used, to calculate emission forecasts, have a major influence on the outcomes of the largely non-technical decisions made by parties to the UNFCCC at their annual conferences.[3] Yet, in spite of the stakes, no requirements or even generic (voluntary) approaches exist to inform GHG emissions forecasting, although a limited amount of guidance can be drawn from two United Nations-sponsored initiatives (IPCC 2006, CGE 2016).

This raises two questions about forecasts of GHG emissions. Firstly, to what extent do the assumptions made, and methods used, by governments to prepare official forecasts stand scientific scrutiny? Secondly, to what extent are governments held accountable for the appropriateness of the forecasting approaches on which they rely?

Both questions are under-researched. Limited evidence from both developed and developing countries indicates that (i) forecasting assumptions are undisclosed or poorly documented, and (ii) forecasting methods are undisclosed or rudimentary (Clapp *et al*. 2009, Clapp and Prag 2012, BURs 2017). We have been unable to

[1] In addition to Mexico, several other countries have defined their Nationally Determined Contribution (NDC) targets in terms of emission reductions against a future 'reference' level. In Latin America, Colombia, Costa Rica and Peru, among others, have followed the same approach. In Africa, the list includes Ethiopia, Ghana and Kenya, for example. In Asia, Indonesia, Thailand and Vietnam are the largest among the countries having followed this approach.
[2] NDCs are framed around different types of targets, notably reductions relative to a baseline level (as is the case in Mexico), reductions per unit of gross domestic product, or implementation of specific policies and measures. While uncertainty analysis is relevant to all types of NDCs, several approaches can be used to conduct such analysis. The approach presented in this paper, centred in quantifying the uncertainty around projections of gross domestic product, is directly applicable to NDCs structured around the emissions intensity of the economy (that is, NDCs whose targets are defined as emission reductions per unit of gross domestic product).
[3] While the choice of assumptions made, and projections used, is at least partly a political matter, the extent to which those choices are appropriate from a scientific standpoint is what we term an eminently technical issue. The latter (appropriateness) is the main subject of our analysis.

identify any literature that documents accountability requirements on governments with regard to their choice of forecasting approaches, which suggests that such requirements are lacking.

We examine the methods used by the Mexican government to obtain forecasts of GHG emissions.[4] This allows us to answer, for the case of Mexico, the two questions introduced above. In addition, we contrast Mexico's governmental deterministic forecasts of GHG emissions with our probabilistic forecasts for the country.[5] This allows us to judge the robustness of the governmental forecasts.[6]

The Mexican government's efforts in this area deserve praise, in that they go beyond what appears to be standard practice (Puig 2015). Nonetheless, our findings highlight a number of shortcomings of the Mexican government's approach to GHG emission forecasting.[7]

We conclude by hypothesizing about the implications that our findings may have with regard to assessing the collective effect of national-level GHG emission reduction targets. This leads us to make two recommendations. Firstly, transparency standards should be introduced, to ensure a minimum level of quality with regard to the forecasting approaches used, and promote comparability among forecasts from different governments. Secondly, emission reduction targets should be derived from probabilistic forecasts which, unlike deterministic forecasts, reflect some of the uncertainty associated with future GHG emission levels.

The remainder of the paper is structured in five sections. Section 2 introduces three GHG emission scenarios prepared by the government of Mexico. The text focuses on the assumptions made in each scenario concerning future gross domestic product (GDP) growth rates. Section 3 summarises the main findings of an elicitation of expert judgement aimed at obtaining estimates of short- and mid-term GDP growth rates for Mexico. Section 4 presents GHG emission forecasts for Mexico, obtained using an energy-economy model calibrated to follow economic pathways consistent with the estimates of GDP growth rates described in section 3. Section 5 analyses the accountability implications of the government of Mexico's approach to GHG emission forecasting. Section 6 discusses the impact on international climate change negotiations of improving the way national government forecasts of GHG emissions are prepared.

2. Greenhouse-gas emission scenarios in Mexico

Limiting emissions of GHGs has become a major public policy concern in most countries. With its 2012 General Law on climate change, Mexico has become a leader among developing countries with regard to planning for climate change mitigation (Nachmany *et al.* 2015).

Over the past decade government, academia and the private sector in Mexico, all have prepared GHG emission scenarios in support of various planning processes (Puig 2015). Methods and assumptions vary across these scenarios and, as a result, forecasts of likely future levels of GHG emissions differ.

[4] The work presented in this paper was conducted as a part of two bilateral development cooperation programmes. Development priorities on the part of the donor countries account for the choice of beneficiary country (Mexico).
[5] In the context of this paper, probabilistic forecast refers to a forecast that is expressed as a continuous variable, with a probability of occurrence attached to each of its possible values. This contrasts with the concept of deterministic forecast, which is defined as a forecast expressed as a single value, with an implicit certainty of occurrence.
[6] Our analysis focuses on one source of uncertainty: gross domestic product growth rates. For a country with the industrialisation level found in Mexico, and as highlighted in section 2, economic growth is a major determinant of uncertainty in GHG emission forecasts.
[7] The literature on this topic is extremely limited. A recent similar analysis, conducted in South Africa, suggests that the shortcomings identified in this paper may be common to other countries (Durbach *et al.* 2017).

For an industrialised country like Mexico, a key forecasting assumption is the choice of projections of GDP growth rates (Puig *et al.* 2013).[8] In the period between 2012 and 2015 the government of Mexico issued three sets of forecasts of GHG emissions. Each set relies on a different projection of GDP annual growth rates:

- **Fifth 'National Communication' to the United Nations Framework Convention on Climate Change** (SEMARNAT 2012). The forecasts presented are based on the assumption that, in the period between 2006 and 2020, the average annual growth rate for GDP will be 2.3 per cent. This rate is said to be based on "historical trends", with no further information given about it. No projection of GDP growth rates is provided for the period 2021-2030, even though the document does include forecasts of GHG emissions for that period.

- **'National Strategy on Climate Change'** (SEMARNAT 2013). At present this document constitutes the only official source of forecasts of GHG emissions for Mexico. The forecasts presented are based on the assumption that, in the period between 2010 and 2030, the average annual growth rate for GDP will be 3.6 per cent. This is the rate used to calculate Mexico's official projections for electricity demand (SENER 2012). The document describing the electricity demand projections considers three growth scenarios for GDP – low, medium and high – and states that the medium scenario, corresponding to an annual growth rate of 3.6 per cent, is believed to be more likely. No information is provided as to why this is so, or how the 3.6 per cent figure was calculated.

- **'Intended Nationally Determined Contribution', submitted to the United Nations Framework Convention on Climate Change** (INDC Portal 2017).[9] The forecasts presented are based on the assumption that, in the periods between 2014 and 2020, and 2021 and 2030, the annual growth rates for GDP will be, respectively, 3.37 per cent and 3.85 per cent (Jorge Gutiérrez, Mexico's National Institute of Ecology and Climate Change, personal communication, 2015). These figures were obtained through an expert judgement elicitation conducted in 2014 (Supplementary Information SI.1). The elicitation was framed around three economic scenarios. In the 'neutral' (or 'medium economic growth') scenario, GDP would grow by a median annual rate of 3.36 per cent in the period between 2014 and 2020, and by 3.88 per cent in the period between 2020 and 2030.

In addition to mitigation-scenario forecasts of GHG emissions, the three documents referred to above present reference-scenario forecasts.[10] For a given year (2020 or 2030), these reference-scenario forecasts differ by between two and thirty percent, depending on the combination of scenarios considered (Table 1). Since GHG emission forecasts across all three reference scenarios ought to be largely comparable, the variations observed

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[8] Within the time frames considered, the growth rate for gross domestic product is the major source of uncertainty when it comes to forecasting future GHG emission levels in a country with the industrialisation level found in Mexico. The impact of technical innovations that can reduce the GHG emissions intensity of the economy would only be relevant if longer time frames – several decades – were involved. Such technical innovations would typically entail larger than currently experienced increases in (i) the share of renewable energy sources in the fuel mix, or (ii) in energy efficiency across the economy. Given the time frames of the analysis, this type of considerations are excluded.

[9] Mexico's non-conditional NDC target represents a 25 percent reduction in GHG emissions by 2030, compared to Mexico's official 'reference' emission levels in the same year.

[10] There are two main types of GHG emission scenarios: reference scenarios and mitigation scenarios. In contraposition to mitigation scenarios, reference scenarios assume no additional policy efforts, compared to present-day emission-reduction policies.

For a given future year, the forecasts derived from different scenarios will be comparable if the scenarios consider the same sectors in the same regions, have the same (or analogous) base years, and share key assumptions. In most instances mitigation scenarios consider different sets of emission-reduction policies. Therefore, in general, full comparability across mitigation scenarios is rare. Reference scenarios, on the other hand, ought to be largely comparable if the above premises are met.

Contrasting forecasts from comparable scenarios makes it possible to assess the impact on forecasts of the forecasting assumptions and forecasting methods chosen. In this article, we compare reference scenario forecasts.

respond to differences in forecasting assumptions (in particular, estimates of GDP growth rates) and forecasting methods.

Irrespective of whether they correspond to reference or mitigation scenarios, the robustness of (the Mexican) forecasts of GHG emissions depends to a great extent on the robustness of the projections of GDP growth rates used to calculate those forecasts (Puig *et al.* 2013). Because projections of GDP growth rates are surrounded with uncertainty, quantifying that uncertainty represents one of the best ways of increasing the robustness of the projections (Morgan *et al*. 2009). By extension, this makes it possible to increase the robustness of the associated forecasts of GHG emissions.

Table 1: Assumptions about GDP growth rates, by Mexican government planning scenario

Policy process in support of which the scenario was prepared	Assumed annual growth rate for GDP	Analytical method behind the assumption	Reference scenario forecasts ($MtCO_2e$)	
			2020	2030
Fifth National Communication (2012)	2.3 % (2006-2020)	Following "historical trends"	872	996
National Strategy on Climate Change (2013)	3.6 % (2010-2030)	Unspecified	960	1,276
Intended Nationally Determined Contribution (2015)	3.37 % (2014-2020) 3.85 % (2021-2030)	Expert judgement elicitation	792	973

3. Quantifying the uncertainty associated with gross domestic product growth rates

We use structured expert judgement to quantify the uncertainty associated with projections of GDP growth rates in Mexico (Cooke 1991). To keep the elicitation process manageable, while taking due account of the strong dependencies between GDP and a number of other macro-economic variables, we structure the elicitation around different scenarios of economic growth (Morales-Nápoles 2014).

3.1 Developing scenarios of economic growth

We use an econometric model for GDP in Mexico, which was built specifically for this work (Loría 2013). The outputs of the model underpin three economic scenarios: 'pessimistic' (low economic growth), 'neutral' (medium economic growth) and 'optimistic' (high economic growth). Each scenario is defined by a plausible combination of values for variables such as interest rates, unemployment, and inflation in Mexico, and economic growth in the United States.[11]

[11] Economic growth in the United States is a key determinant of economic growth in Mexico.

The scenario approach is chosen because of the strong interdependencies among variables. By capturing those interdependencies through scenarios (as opposed to eliciting experts on all individual variables potentially influencing GDP), it is possible to avoid a cumbersome post-hoc dependence analysis.

3.2 Eliciting expert judgements on gross domestic product growth rates

We rely on the so-called Cooke method of expert judgement elicitation, which involves external validation of experts' opinions (Supplementary Information SI.1 summarises the main features of the model) (Cooke 1991).[12] We elicit probability distributions from nine experts, through a three-day workshop.[13] The variable elicited are GDP growth rates (the 5th, 50th and 95th percentiles). Experts are asked to provide uncertainty estimates for each of the three scenarios referred to above.[14]

Through the scenarios, experts are explicitly confronted with a wide range of plausible economic growth pathways. This allows us to obtain a similarly wide range of estimates, thus characterising more fully the uncertainty around likely future trends in GDP growth rates (Table 2). Rather than focusing on individual years, we elicit uncertainty around average rates in the time periods 2014-2020 and 2021-2030 (Supplementary Information SI.1).

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[12] Cooke's method combines the various assessments from experts into one single probability distribution. It does this through differential weighting of experts' assessment, on the basis of measures of each expert's performance when responding to a set of so-called calibration questions (Supplementary Information SI.1).

[13] A total of 19 variables were assessed, of which 13 were calibration variables.

[14] The reader may notice in the second column of table S1 that the calibration scores of experts 6 and 9 are >0.05, which is typically the threshold level to render expert opinions as statistically accurate. Moreover, the equal weighting of expert opinions is also slightly above 0.05, while the performance-based combination has a higher calibration score (0.614) than the equal-weight combination, and every individual expert. One example of calibration variable and variable of interest is presented in SI.1. The format of other seed questions and variables of interest follows the format of those presented in the supplementary information. The format chosen for this research is not different from that used in other areas where the method has been applied in the past. See for example Cooke et al (2007) for an example of seed variables vs. variables of interest in epidemiology.

Table 2: Results of the expert judgement elicitation for GDP growth rates (by scenario of economic growth and percentile), and corresponding ThreeME-model forecasts of GHG emission levels

Percentile	GDPannual growth rates (percent)		Reference scenario forecasts ($MtCO_2e$)	
	2014-2020	2021-2030	2020	2030
'Pessimistic' scenario				
5th	1.23	1.60	582	583
50th	2.44	2.79	613	694
95th	3.20	3.69	633	781
'Neutral' scenario				
5th	1.79	2.85	596	663
50th	3.36	3.88	638	801
95th	4.10	4.50	658	883
'Optimistic' scenario				
5th	3.85	3.13	651	790
50th	4.58	4.84	671	937
95th	5.80	5.90	889	1,102

Notes: Projections of annual growth rate for GDP are obtained through expert judgement elicitation. 'Reference scenario forecasts' refers to emissions of all GHGs covered in the Kyoto protocol to the United Nations Framework Convention on Climate Change, and excludes the net impact of agriculture, land-use change and forestry, and emissions from waste management. Forecasts are obtained using the ThreeME general-equilibrium model.

Retrospective assessments of performance highlight that, irrespective of the forecasting method used, forecasts can be wrong, sometimes by a large margin (Morgan *et al*. 2009). Structured expert judgement is no exception: it is not possible to know ex-ante the quality of the assessments elicited from experts.[15] Caution is especially needed in the context of highly uncertain variables, such as that of interest in this paper (namely, the uncertainty associated with future estimates of annual GDP growth rates). Notwithstanding, the results obtained represent a

[15] Structured expert judgement recognises these challenges, and goes some way toward addressing them (Supplementary Information SI.1). To do so, structured expert judgement often relies on a-priori data (namely, the experts' assessments, analysed together with the values of calibration variables). In recent years, methods that rely on a-posteriori data have been proposed and tested (Kaack *et al.* 2017).

transparent and replicable estimate, which can inform the policy-making process, provided that the uncertainty around it is properly communicated to decision-makers.

3.3 Comparing our results with the projections used in Mexican government forecasts

The estimates of annual growth rate for GDP used in the 2012 (SEMARNAT 2012) and 2013 (SEMARNAT 2013) Mexican government scenarios are consistent with the estimates associated with, respectively, our 'pessimistic' and 'neutral' scenarios (Table 1 and Table 2). We note that the methods used by the government of Mexico to obtain the projections of GDP growth rates used in the 2012 and 2013 documents referred to above do not stand scientific scrutiny (Table 1) (Oppenheimer *et al*. 2016).

The estimates used in the 2015 Mexican government scenario (INDC Portal 2016) were derived from our 'neutral' scenario, and are nearly identical to those associated with that scenario (Table 3). Structured expert judgement, the method used to obtain the estimates in all our scenarios, is transparent and replicable (Aspinall 2010).

Table 3: Calculated annual growth rates in reference-scenario forecasts of GHG emissions, and assumptions about GDP growth rates, by scenario

Scenario	Reference scenario forecasts ($MtCO_2e$)		Annual growth rates (percent)		Ratio
	2020	2030	Emissions (2020-2030)	GDP (2021-2030)	
INDC (2015)	632	798	2.4	3.85	0.61
ThreeME pessimistic	613	694	1.2	2.79	0.45
ThreeME neutral	638	801	2.3	3.88	0.59
ThreeME optimistic	671	937	3.4	4.84	0.70

Notes: 'Reference scenario forecasts' refers to emissions of all GHGs covered in the Kyoto protocol to the United Nations Framework Convention on Climate Change, and excludes the net impact of agriculture, land-use change and forestry, and emissions from waste management. 'Ratio' refers to the quotient of GHG emissions growth rates and GDP growth rates. For each of the three scenarios considered, ThreeME forecasts correspond to estimate obtained using the 50th percentile for the projection of GDP growth rates.

Acronyms: INDC stands for 'Intended Nationally Determined Contribution', and ThreeME refers to the forecasts obtained through the ThreeME model.

4. Calculating probabilistic reference-scenario forecasts of greenhouse-gas emissions

We use the Multi-sector Macroeconomic Model for the Evaluation of Environmental and Energy policy (hereinafter the ThreeME model) to obtain forecasts of GHG emissions in Mexico for the years 2020 and 2030 (Landa *et al*. 2016, Callonec *et al*. 2013).[16] We run the model several times, each time using a different

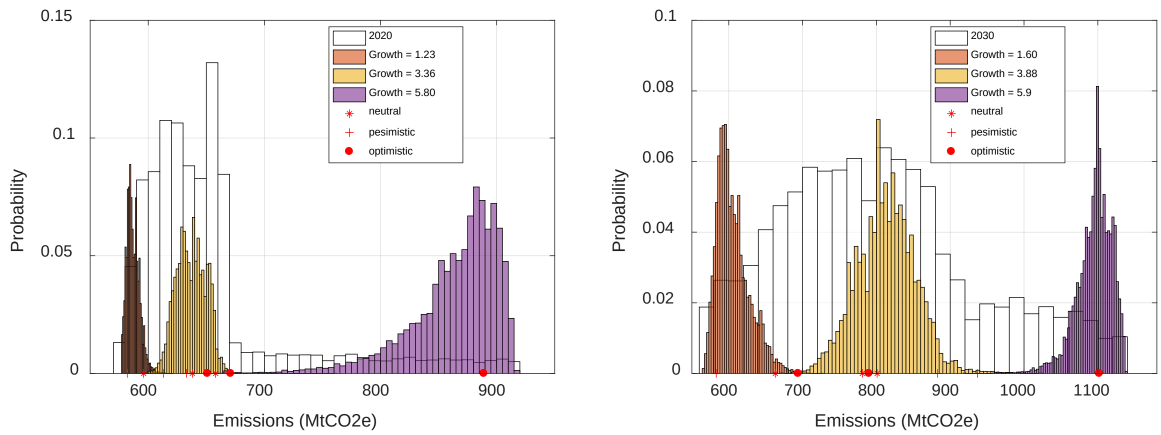
[16] A dedicated two-year calibration and verification exercise was conducted, to ensure that the ThreeMe model could be meaningfully used to assess likely future levels of GHG emissions in Mexico (Supplementary

economic pathway. Each of the pathways used is consistent with one of the various estimates of GDP growth rates that we obtained through expert judgement elicitation (Supplementary Information SI.1). This allows us to produce a range of forecasts of GHG emissions that reflects the uncertainty associated with the full range of GDP growth rate estimates obtained through structured expert judgement (Table 2). For 2030 the range of forecasts spans from 583 $MtCO_2e$ ('pessimistic' scenario, 5th percentile) to 1,102 $MtCO_2e$ ('optimistic' scenario, 95th percentile).

The ThreeME model excludes emissions from agriculture, land-use change, and waste management (Supplementary Information SI.2). Since the three Mexican government scenarios referred to above include emissions from these sectors, the ThreeME model forecasts are not directly comparable to either of the forecasts resulting from those scenarios. To make comparisons possible, emissions from agriculture, land-use change, and waste management have to be excluded from the governmental scenario forecasts. This can only be done for the 2015 scenario, as this is the only scenario that provides sector-specific forecasts (INECC 2016). We find that the 2015 Mexican government forecasts are fully consistent with the ThreeME forecasts corresponding to the median estimate in the 'neutral' scenario (Table 3).

To obtain probability distributions for GHG emissions in Mexico, we analyse the statistical dependence of the ThreeME forecasts (Table 2). The rank correlation of the 18 estimates is approximately 0.96. In this case, a Gaussian copula is a valid model for statistical dependence between GDP growth rates and GHG emissions (Joe 2014). The marginal distributions of GDP growth rates and GHG emissions for 2020 and 2030 can be calculated on the basis of the combined distributions obtained through structured expert judgment, assigning equal probability to the three scenarios (section 3.2). Summary results are presented in the main text (Figure 1), while a fuller description of the approach is included in annexes (Supplementary Information SI.3).[17]

Figure 1: **Unconditional and conditional uncertainty distributions associated with, GHG emission forecasts obtained with the ThreeME model and structured expert judgment.**



Source: Own elaboration

Information SI.2). This exercise benefited from input by a number of (mostly Mexican) forecasters, and users of emission forecasts in Mexico (mostly governmental agencies) (Landa *et al.* 2016).

[17] We chose a combination of scenario-based analysis and probabilistic methods, which makes quantification easier, and thus can be more relevant from a policy standpoint.

5. Accountability considerations of governments' choice of forecasting approach

Our results show that the range – and, therefore, the uncertainty – of plausible values for GHG emission levels in Mexico in 2030 is large (Table 2, Figure 1). We conjecture that GHG emission forecasts for most other industrialised countries are characterised by similarly large uncertainty ranges.

Had we analysed more sources of uncertainty, in all likelihood the resulting uncertainty range would have been even larger. Notwithstanding, experience shows that, when it comes to model assumptions, annual growth rates for GDP are, with energy prices, the main sources of uncertainty in GHG emissions scenarios in industrialised countries.[18]

Several tools are available to estimate plausible future values for some uncertain variables (Morgan *et al.* 2009). Expert judgement elicitation is one such tools. In addition to being transparent and replicable, the appeal of expert judgement elicitation lies in the probabilistic nature of its outputs, which facilitates the use of probabilistic forecasting methods.

Concerns have been voiced over the "abuse" of expert judgement elicitation in support of decision-making for public policy (Morgan 2014). Clearly, like any other analytical tool, expert judgement elicitation has its limitations. Notwithstanding, when 'best guesses' are the alternative, well-conducted expert judgement elicitation is a better choice.

The government of Mexico quantified the uncertainty associated with trends in GDP growth rates, one key driver of GHG emissions. However, this uncertainty was not incorporated into the official forecast of GHG emissions. This is because deterministic (as opposed to probabilistic) forecasting methods were used.

Forecasts of GHG emissions that fail to incorporate uncertainty are defective scientifically and, when they are used to calculate targets, they are inappropriate from a policy standpoint.[19] Yet, there appear to be no requirements on governments with regard to the need to incorporate uncertainty in governmental forecasts, as evidenced by the lack of literature on this topic. In fact, by taking the initiative to quantify the uncertainty in GDP growth rates (and oil and gas prices), the government of Mexico went beyond what appears to be standard practice (Clapp *et al.* 2009, Clapp & Prag 2012).

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[18] For industrialised countries where land-use change is not a major source (or sink) of GHG emissions, and barring unprecedented demographic changes, variations in gross domestic product and energy prices are the main drivers of emissions. Estimating the impact of changes in energy prices in Mexico's emissions of GHGs is challenging. Firstly, energy prices are typically volatile, which makes them notoriously difficult to forecast. Secondly, when international oil prices are high, domestic oil consumption in Mexico is replaced partly by natural gas, as oil is a major export commodity for the country. The extent to which that replacement takes place, and the impact of oil prices on the overall energy consumption level in Mexico are similarly difficult to forecast. We conducted some of the work required to estimate the impact of oil and gas prices in GHG emissions in Mexico (Supplementary Information 1). However, the results are not robust enough to warrant inclusion in the paper.

[19] Consider a country that defines its emission reductions target in absolute terms (that is, a target of emitting X million metric tons of carbon dioxide-equivalent in a given future year). From a policy point of view, uncertainty analysis plays no role in this target: meeting it is all that matters. Consider now a country that, like Mexico, defines its emission reductions target in relative terms (typically, the level of emission reductions in a given future year, below a certain 'reference level'). Often, that 'reference level' is defined as the level of emissions associated with less stringent emission reduction policies, compared to those being considered. To the extent that we are uncertain about that 'reference level', uncertainty analysis becomes important, not only from a scientific perspective, but also from a policy standpoint. This is because uncertainty prevents us from obtaining a precise estimate of the future value of the 'reference value', which in turn prevents us from determining whether the policy target is stringent (because it represents a large departure from the 'reference level'), or not. In the context of international emission reduction commitments, and to the extent that several countries have defined their emission reduction targets in relative terms, uncertainty analysis is thus relevant not only from a scientific perspective, but also from a policy point of view.

We argue that governments should be held accountable for their choice of forecasting approach. This would entail closer scrutiny of both the assumptions made, and the methods used, to produce governmental forecasts. Specifically, this would call for science-based governmental forecasts, including a quantification of the uncertainty associated with the forecasts.

It is for scientists to select the most appropriate analytical methods, to prepare the best projections that science can offer, and to communicate them properly to decision makers (Fischhoff & Davis 2014). In turn, the role of decision-makers is to ensure that public policy relies on transparent and replicable analytical processes, reflecting the full implications of the findings emerging from those processes. Specifically, in the context of the work described in this paper, it is for decision-makers to ensure that uncertainty estimates are incorporated in a meaningful way in the target-setting process.

6. Conclusions

In most instances, GHG emission-reduction commitments by parties to the UNFCCC are based on governmental forecasts of GHG emissions. Therefore, indirectly, the integrity of the international climate change regime rests on the robustness and credibility of those forecasts. Yet, the extent to which forecasts are robust and credible is generally unknown: forecasting approaches are often undisclosed, and accountability requirements on governments appear to be lacking. Against this background, the need for minimum transparency and quality standards for forecasting approaches appears self-evident.[20]

We argue that the UNFCCC should champion the development of such standards. They would foster comparability between emission-reduction commitments from different parties, which could help ensure that individual UNFCCC party commitments are “fair and ambitious”. Fairness and ambition are two of the fundamental tenets of the international climate change regime: sacrificing the flexibility that parties currently enjoy with regard to the forecasting approaches that they use for target-setting seems a price worth paying to safeguard those premises.

We further argue that GHG emission-reduction commitments by parties to the UNFCCC should reflect the uncertainty associated with future levels of GHG emissions. This could mean that individual UNFCCC party emission-reduction targets are derived from probabilistic forecasts of GHG emissions. For example, UNFCCC party targets could be expressed as a range of GHG emission levels, given by pre-defined quantiles of their uncertainty distribution. This could be associated with a small number of socio-economic scenarios: should certain socio-economic developments come to pass (notably in terms of GDP growth rates and energy prices), a higher or lower value of the emission reductions target would apply.

With the Paris Agreement, the international climate change regime has strengthened its accountability requirements. Specifically, the so-called transparency framework under the Paris Agreement calls for increased scrutiny and disclosure of national reporting to the UNFCCC. As the provisions of the transparency framework come into effect, the need for reflecting uncertainty in national GHG emission reduction targets is likely to become more apparent. Characterising and quantifying uncertainty, and communicating uncertainty to decision makers are areas where additional research is required.

Additional research would be required to achieve the above goals. Specifically, guidance is needed to determine, by type of variable, which methods are appropriate to forecasts uncertainty distributions. Should analysts rely on, for example, multi-model comparisons, expert judgement elicitation, or both? Similarly, guidance is needed with regard to the approaches available to aggregate different uncertainties into a single distribution. Doing so is

[20] The same, or similar, standards could be applied to non-state actor actions relevant to climate change mitigation. Indeed, (limited) accountability is one of the main shortcomings associated with most non-state actor actions (Bakhtiari 2017).

useful from an analytical viewpoint, and arguably indispensable from the point of view of facilitating the communication of uncertainty to decision makers.

In short, uncertainty quantification cannot remain the domain of climate scientists working with long-term, global models. Analysts who support national-level climate-change policy formulation should routinely incorporate uncertainty quantification in their work. Doing so is a precondition for truly successful implementation of the Paris Agreement's transparency framework (Winkler *et al*. 2017 ; Jacoby *et al*. 2017 ; Karlsson-Vinkhuyzen *et al*. 2017). Further analyses, in countries other than Mexico, would contribute to highlighting this point.

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SUPPLEMENTARY INFORMATION

SI.1 Expert judgement elicitation

We used expert judgement elicitation to quantify the uncertainty around estimates of future trends in key drivers of greenhouse-gas emissions (Morales-Nápoles 2014). The drivers analysed were (annual growth rates of) gross domestic product, as well as oil (West Texas intermediate) and gas (Henry Hub) prices. For this research two expert judgment elicitation sessions were conducted in Mexico, both in 2014. Two different groups of experienced Mexican macro-economists were engaged.

We relied on the so-called classical (or Cooke's) method for elicitation of structured expert judgment. A complete discussion of the classical method is out of the scope of this paper. Nonetheless, a summary of the method's main features is provided. For a complete overview the reader is referred to (Cooke 1991).

The classical method for structured expert judgement seeks to achieve rational consensus. Simply stated, experts are asked to assess their uncertainty concerning certain continuous quantities in the form of a number of percentiles (most commonly the 5^{th}, 50^{th} and 95^{th} percentiles) for their uncertainty distribution. The percentiles are assessed for uncertain quantities (*variables of interest*) but also for quantities whose value is known to the analysts (or will be known within the time frame of the research), but is not known to the experts at the moment of the elicitation. These are called *seed* or *calibration variables* and are used to ensure empirical control of the experts' uncertainty assessments.

Examples of a seed variable and a variable of interest (concerning economic growth in Mexico) follow:

a) *Seed variable*: Quarterly growth rates of gross domestic product in Mexico have been below -5% in four instances between the first trimester of 1994 and the third trimester of 2013. What was the average value of the 28-day Mexican Federal Treasury Certificates (CETES) interest rate in these four trimesters? Indicate the 5^{th}, 50^{th} and 95^{th} percentiles of your uncertainty distribution.

b) *Variable of interest*: Consider a scenario in which, at the end of 2020, the Mexican (commercial) interest rate is between 3.5 and 4.0 percent, the unemployment rate is between 5.4 and 5.6 percent, the inflation growth rate is between 3.0 and 3.3, and growth rates of gross domestic product in the USA are between 2.8 and 3.3 percent. Please provide your estimate of the mean gross domestic product growth rates in Mexico up to 2020.

Seed variables are used to compute two measures of performance: the *calibration* and *information* scores. Simply stated, the calibration score measures the degree to which experts are statistically accurate, while the information score measures the degree to which experts' uncertainty estimates are concentrated, relative to a background measure.

SI.1.a Calibration

Assume we have answers from $e = 1, \dots, k$ experts on $i = 1, \dots, N$ calibration variables. Assume further that we assess three quintiles: 5^{th}, 50^{th} and 95^{th} for each uncertain quantity. For each quantity, each expert divides his/her belief range into four inter-quantile intervals, for which the corresponding probabilities of occurrence are: $p_1 = 0.05$ for a realization value $\leq 5^{th}$ percentile, $p_2 = 0.45$ for a realization value $\in (5^{th}, 50^{th}]$ percentile, $p_3 = 0.45$ for a realization value $\in (50^{th}, 95^{th}]$ percentile, and $p_4 = 0.05$ for a realization value $> 95^{th}$ percentile. The empirical version of $\boldsymbol{p} = (p_1, \dots, p_4)$ for expert e, is denoted $\boldsymbol{s(e)} = (s_1, \dots, s_4)$, where

$$s_1(e) = \frac{\#\text{ realization in seed variables } \leq 5^{\text{th}} \text{ percentiles assessed by expert } e}{N}$$

$$s_2(e) = \frac{\#\text{ realization in seed variables } \in (5^{\text{th}}, 50^{\text{th}}] \text{ percentiles assessed by expert } e}{N}$$

$$s_3(e) = \frac{\#\text{ realization in seed variables } \in (50^{\text{th}}, 95^{\text{th}}] \text{ percentiles assessed by expert } e}{N}$$

$$s_4(e) = \frac{\#\text{ realization in seed variables } > 95^{\text{th}} \text{ percentiles assessed by expert } e}{N}$$

One way to measure the difference between $\boldsymbol{p}$ and $\boldsymbol{s(e)}$ is through relative information or entropy, which is a measure of the average information content that one is missing when one does not know the value of the random variable (Shannon & Weaver 1959).

$$I(\boldsymbol{s}(e), \boldsymbol{p}) = \sum_{j=1}^{4} s_j \ln\left(\frac{s_j}{p_j}\right) \tag{1}$$

Experts' assessments are treated as statistical hypotheses. Consider for each expert the null hypothesis

H_0: the inter quintile interval containing the true value for each variable is drawn independently from the probability vector $\boldsymbol{p}$.

The quantity $2\ N\ I(\boldsymbol{s}(e), \boldsymbol{p})$ where $I(\boldsymbol{s}(e), \boldsymbol{p})$ is given in equation (1) is asymptotically χ_3^2 (the degrees of freedom are the number of inter quintile intervals minus 1). This quantity can be used to test H_0 and it defines the calibration score:

$$CS(e) = P\{2\ N\ I(\boldsymbol{s}(e), \boldsymbol{p}) \geq r\} \tag{2}$$

where r is the value for expert e computed as in equation (1). The probability can be evaluated by a χ_3^2 distribution. The calibration score $CS(e)$ is the probability that a deviation at least as large as r could be observed on N realizations if H_0 were true. Values of calibration close to zero mean that it is unlikely that the experts' probabilities are correct.

SI.1.b Information

Recall that the information score measures the degree to which a distribution is concentrated with respect to a background measure. In the classical model uniform or log uniform background measures are used. An intrinsic range is calculated for the background measure $[q_l, q_h]$, where $q_l = q_5 - k(q_{95} - q_5)$ and $q_l = q_5 + k(q_{95} -$

q_5). k is typically chosen as 0.10 (10% overshoot). q_5 is the lowest 5th percentile assessed across experts for a particular item and q_{95} the largest 95th percentile assessed across experts for the same item. The information score is then computed as

$$IS(e) = \frac{1}{N}\sum_{i=1}^{N} I(f_{e,i}, g_i) \tag{3}$$

where g_i is the background density for item i (usually uniform or log uniform) and $f_{e,i}$ the density for expert e on item i. $I(f_{e,i}, g_i)$ is the mutual entropy between the densities of interest.

SI.1.c Combination

In the classical model the combination of experts' assessments is called a *Decision Maker* (DM). This is a weighted average of individual estimates. When the weights are determined based on the performance of experts in the seed variables, we speak of performance-based DM. The DM distributions are thus:

$$DM_\alpha(i) = \frac{\sum_{e=1}^{k} w_\alpha(e)\, f_{e,i}}{\sum_{e=1}^{k} w_\alpha(e)} \tag{4}$$

where the weighs $w_\alpha(e) = 1_{\{CS(e)>\alpha\}} CS(e) IS(e)$. Values of $\alpha < 0.05$ would fail to confer the study the required level of confidence. Note that the DM can also be evaluated in terms of calibration and information. For this reason the DM is referred to as 'virtual expert'. In the performance based DM the value of α is chosen such that the calibration score of the DM is maximized.

SI.1.d Econometric analyses and scenarios

To estimate gross domestic product growth rates, probability distributions were elicited from nine experts through a three-day workshop. A total of 19 variables were assessed, of which 13 were calibration variables. The variables of interest all referred to estimates of gross domestic product growth rates in 2020 and 2030.

To estimate trends in oil and gas prices, probability distributions were elicited from eight experts. A total of 26 calibration variables and 24 variables of interest were assessed. These variables also referred to 2020 and 2030.

An econometric model was built for each variable of interest (that is, gross domestic product, and energy commodity prices) (Loría 2013). The results of the econometric models were used to develop several sets of scenarios. The scenario approach was chosen because of the strong interdependencies among variables. By capturing those interdependencies through scenarios (as opposed to eliciting experts on all individual variables potentially influencing gross domestic product, and energy commodity prices), it was possible to avoid a cumbersome post-hoc dependency analysis.

For gross domestic product, six scenarios were built. They targeted both 2014-2020 and 2021-2030, and were defined around three combinations of macro-economic conditions – 'pessimistic' (low economic growth), ‘neutral’ (medium economic growth) and ‘optimistic’ (high economic growth). The scenarios were structured around different plausible combinations of values for interest rates, unemployment, inflation and economic growth in the United States (the latter is a key determinant of growth in Mexico). The variable elicited was gross domestic product (GDP) growth rates (the 5th, 50th and 95th percentiles).

For energy commodity prices twelve scenarios were built – six for oil prices and six for gas prices. The scenarios targeted the periods 2014-2020 and 2021-2030, and were defined around three combinations of economic growth and international oil trade conditions. These were also labelled ‘pessimistic’, ‘neutral’ and ‘optimistic’. In this case the scenarios were structured around plausible combinations of values for economic growth in China, economic growth in India and oil imports in OECD countries. For the analysis of oil prices West Texas Intermediate was used as a reference, whereas the Henry Hub spot price was used for the analysis of natural gas prices. As for gross domestic product, experts were asked to provide the 5th, 50th and 95th percentiles.

SI.1.e Results of the expert judgment elicitation for gross domestic product growth rates

Supplementary Table 1 presents the results of the performance assessment of the 9 experts participating in a 2014 workshop for assessing the uncertainty associated with projections of economic growth in Mexico. The second column presents the calibration score (equation (2)) of each expert. Typically a value <0.05 would cast doubts regarding the credibility of the exercise. As shown in Supplementary Table 1, two individual experts (6 and 9) have calibration scores > 0.05. The calibration score of experts 3, 5 and 7 is marginal, while that of experts 1, 2, 4 and 8 is <0.0001. The “virtual experts”, that is, the combination of expert opinions according to equal weights (column 7 in Table S1) and global weights (column 8), both present a calibration score > 0.05. The equal weight combination shows a calibration score larger than all individual experts, except for expert 6, who is the individual expert with the highest calibration score. On the other hand, the global weight combination outperforms the calibration score of the highest calibrated individual expert by a factor of 2.2. It also outperforms the equal weight combination (by about an order of magnitude). Note that the equal weight combination has the lowest information score across all experts, including the performance-based combination.

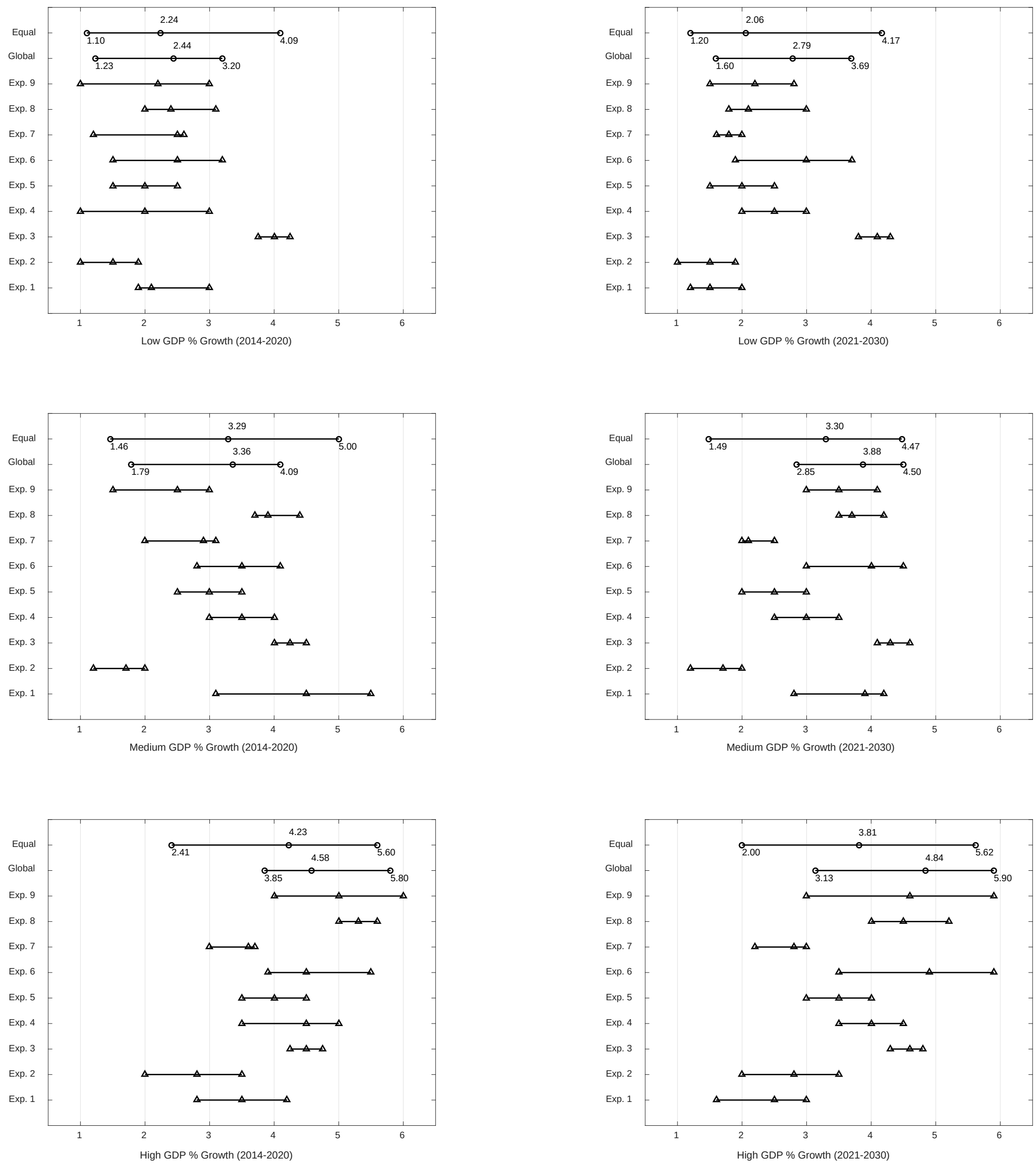
Columns 3 and 4 present the mean relative information (equation (3)) computed with all variables (column 3) and with calibration variables only (column 4). Across both columns individual experts have information scores that are in the interval (1.006, 1.944). The ratio of the information score per expert in calibration variables to all variables is within 28%, which shows that experts are consistent in expressing their uncertainty between seed variables and variables of interest. Column 5 presents the weights of individual experts, which correspond to the product of columns 2 and 4. Column 6 presents the ratio of the information score on calibration variables of individual experts to the equal-weight combination. For all experts, including the performance-based combination, this ratio is > 2. Based on the results presented in Supplementary Table 1, the performance-based combination is recommended as the best representation of the uncertainty regarding growth rates of gross domestic product in Mexico in 2020 and 2030. The results of expert opinions are shown in Supplementary Figure 1.

Supplementary Table S1: **Results of the performance assessment for nine experts participating in a 2014 workshop to assess the uncertainty associated with projections of economic growth in Mexico**

Expert ID	Calibration	Mean relative information		Weight	Information relative to Equal	Normalized weight	
		all variables	calibration variables			Equal	Global
Exp. 1	<0.0001	1.608	1.935	<0.0001	4.45	0.111	
Exp. 2	<0.0001	1.03	1.006	<0.0001	2.31	0.111	
Exp. 3	0.0001	1.666	1.651	0.0002	3.80	0.111	
Exp. 4	<0.0001	1.302	1.484	<0.0001	3.41	0.111	
Exp. 5	0.0015	1.223	1.301	0.0020	2.99	0.111	0.004601
Exp. 6	0.2766	1.081	1.285	0.3554	2.96	0.111	0.8353
Exp. 7	0.0002	1.825	1.944	0.0003	4.47	0.111	
Exp. 8	<0.0001	1.698	1.913	<0.0001	4.40	0.111	
Exp. 9	0.0530	1.078	1.285	0.0682	2.96	0.111	0.1601
Equal	0.0632	0.3378	0.4348	0.0275	1.00		
Global	0.6140	0.7797	0.924	0.5673	2.13		

Supplementary Figure 1 shows that the equal-weight combination presents (as expected) largest uncertainties across experts. However, the performance-based combination presents uncertainty levels comparable to those of the individual experts expressing larger uncertainties.

Supplementary Figure 1: The 5th, 50th and 95th percentiles of expert opinions regarding economic growth in Mexico in 2020 and 2030



Sources: own elaboration, based on the results of the expert judgement elicitation

SI.1.f Results of the expert judgment elicitation for oil and gas prices

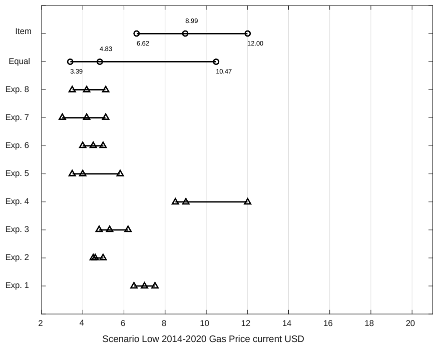
Supplementary Table 2 presents the results of the performance assessment of the 8 experts participating in the 2014 workshop for uncertainty analysis of energy commodity prices. This table is equivalent to Supplementary Table 1 above.

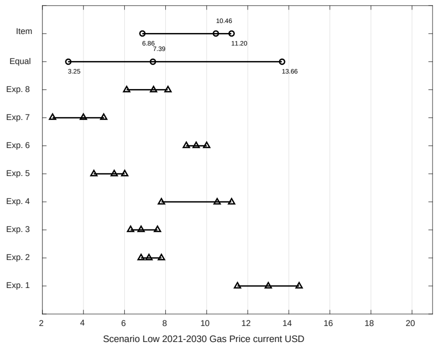
Column 2 shows the calibration scores per expert and decision maker. In this case only expert 4 has a calibration score > 0.05. While the equal-weight decision-maker is highly calibrated, the information scores of individual experts can be up to a factor of 4.5 larger than the one observed for this DM (column 7). The calibration score of the item weight combination is still > 0.05 and larger than that of each individual expert. The information score for the performance-based combination on all items is slightly smaller than that of individual experts (column 3). For calibration items alone, the information score of the performance based DM is bigger than that of expert 4. The performance-based combination is mostly that of expert 4 (98%) and experts 2 and 7 contributing the remaining 2%. In this case there is no evidence not to recommend the performance-based decision maker as the preferred choice. Results for variables of interest are presented in Supplementary Figure S2.

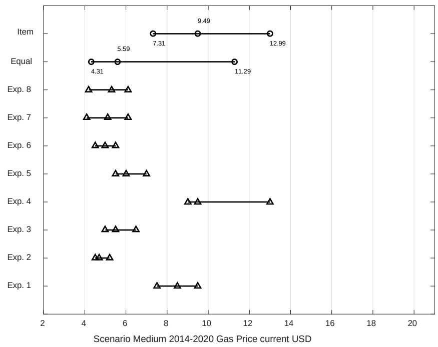
Supplementary Table 2: **Results of the performance assessment for 8 experts participating in a 2014 workshop to assess the uncertainty associated with projections of international oil and gas prices**

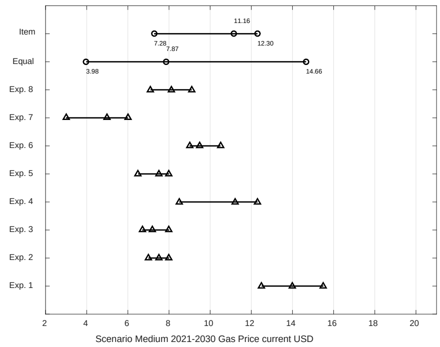
Expert ID	Calibration	Mean relative information		Weight	Information relative to Equal	Normalized weight	
		all variables	calibration variables			Equal	Global
Exp. 1	<0.0001	1.347	1.235	<0.0001	2.84	0.125	<0.0001
Exp. 2	0.0003	1.794	1.902	0.0005	4.37	0.125	0.0066
Exp. 3	<0.0001	1.603	1.576	<0.0001	3.62	0.125	<0.0001
Exp. 4	0.0721	1.045	1.004	0.0723	2.31	0.125	0.9852
Exp. 5	<0.0001	1.428	1.167	<0.0001	2.68	0.125	<0.0001
Exp. 6	<0.0001	2.016	1.955	<0.0001	4.50	0.125	<0.0001
Exp. 7	0.0005	1.075	1.262	0.0006	2.90	0.125	0.0082
Exp. 8	<0.0001	1.414	1.474	<0.0001	3.39	0.125	<0.0001
Equal	0.8256	0.2123	0.2566	0.2118	0.59		
Item	0.1893	0.9657	1.039	0.1967	2.39		

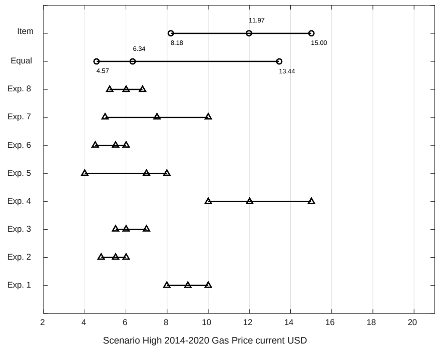
Supplementary Figure 2: **The 5th, 50th and 95th percentiles of expert opinions regarding oil and gas prices in Mexico in 2020 and 2030**

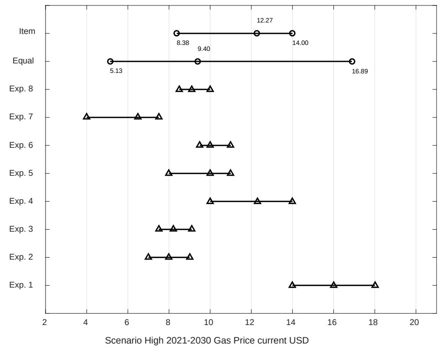


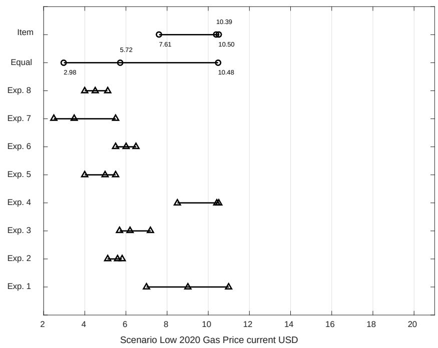


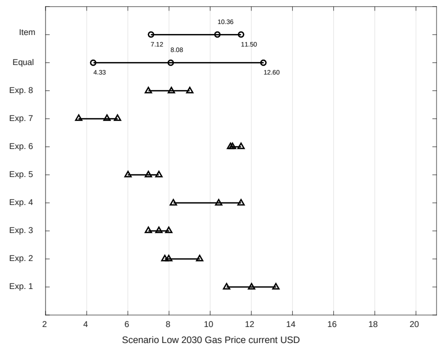

Item
Equal
Exp. 8
Exp. 7
Exp. 6
Exp. 5
Exp. 4
Exp. 3
Exp. 2
Exp. 1
9.49
7.31
12.99
5.59
4.31
11.29
2 4 6 8 10 12 14 16 18 20
Scenario Medium 2014-2020 Gas Price current USD

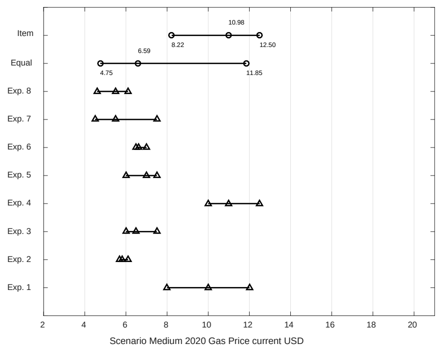

Item
Equal
Exp. 8
Exp. 7
Exp. 6
Exp. 5
Exp. 4
Exp. 3
Exp. 2
Exp. 1
11.16
7.28
12.30
7.87
3.98
14.66
2 4 6 8 10 12 14 16 18 20
Scenario Medium 2021-2030 Gas Price current USD

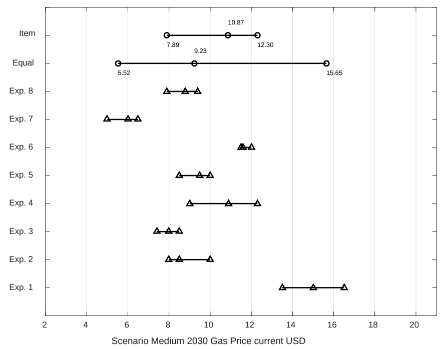

Item
Equal
Exp. 8
Exp. 7
Exp. 6
Exp. 5
Exp. 4
Exp. 3
Exp. 2
Exp. 1
11.97
8.18
15.00
6.34
4.57
13.44
2 4 6 8 10 12 14 16 18 20
Scenario High 2014-2020 Gas Price current USD

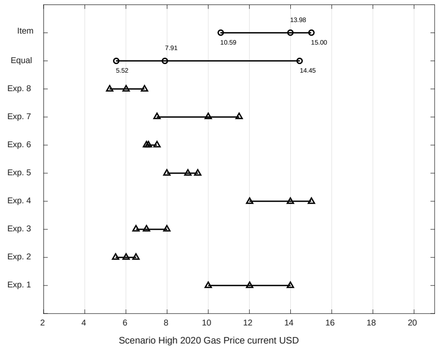

Item
Equal
Exp. 8
Exp. 7
Exp. 6
Exp. 5
Exp. 4
Exp. 3
Exp. 2
Exp. 1
12.27
8.38
14.00
9.40
5.13
16.89
2 4 6 8 10 12 14 16 18 20
Scenario High 2021-2030 Gas Price current USD

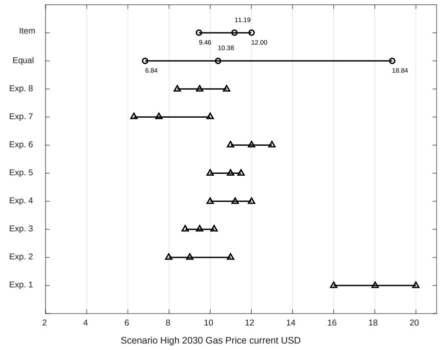

Item
Equal
Exp. 8
Exp. 7
Exp. 6
Exp. 5
Exp. 4
Exp. 3
Exp. 2
Exp. 1
10.39
7.61
10.50
5.72
2.98
10.48
2 4 6 8 10 12 14 16 18 20
Scenario Low 2020 Gas Price current USD

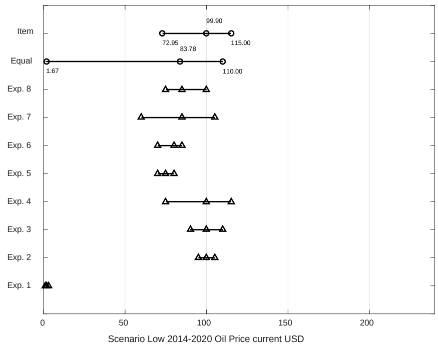

Item
Equal
Exp. 8
Exp. 7
Exp. 6
Exp. 5
Exp. 4
Exp. 3
Exp. 2
Exp. 1
10.36
7.12
11.50
8.08
4.33
12.60
2 4 6 8 10 12 14 16 18 20
Scenario Low 2030 Gas Price current USD

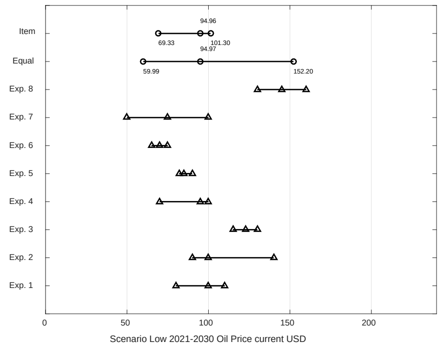

Item
Equal
Exp. 8
Exp. 7
Exp. 6
Exp. 5
Exp. 4
Exp. 3
Exp. 2
Exp. 1
10.98
8.22
12.50
6.59
4.75
11.85
2 4 6 8 10 12 14 16 18 20
Scenario Medium 2020 Gas Price current USD

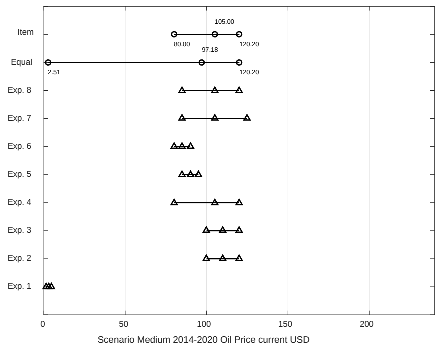

Item
Equal
Exp. 8
Exp. 7
Exp. 6
Exp. 5
Exp. 4
Exp. 3
Exp. 2
Exp. 1
10.87
7.89
12.30
9.23
5.52
15.65
2 4 6 8 10 12 14 16 18 20
Scenario Medium 2030 Gas Price current USD

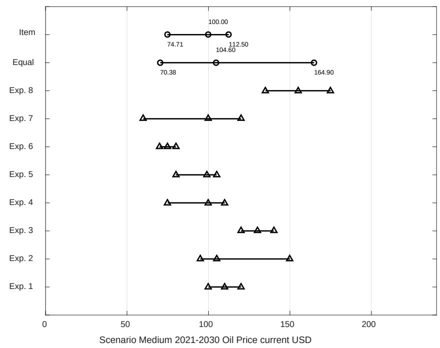

Item
13.98
10.59
15.00
Equal
7.91
5.52
14.45
Exp. 8
Exp. 7
Exp. 6
Exp. 5
Exp. 4
Exp. 3
Exp. 2
Exp. 1
2 4 6 8 10 12 14 16 18 20
Scenario High 2020 Gas Price current USD

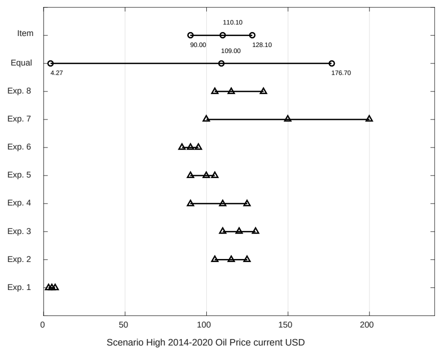

Item
11.19
9.46
12.00
Equal
10.38
6.84
18.84
Exp. 8
Exp. 7
Exp. 6
Exp. 5
Exp. 4
Exp. 3
Exp. 2
Exp. 1
2 4 6 8 10 12 14 16 18 20
Scenario High 2030 Gas Price current USD

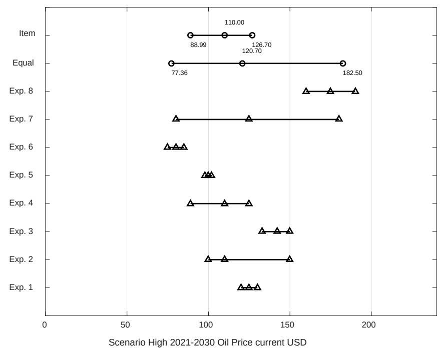

Item
99.90
72.95
115.00
Equal
83.78
1.67
110.00
Exp. 8
Exp. 7
Exp. 6
Exp. 5
Exp. 4
Exp. 3
Exp. 2
Exp. 1
0 50 100 150 200
Scenario Low 2014-2020 Oil Price current USD

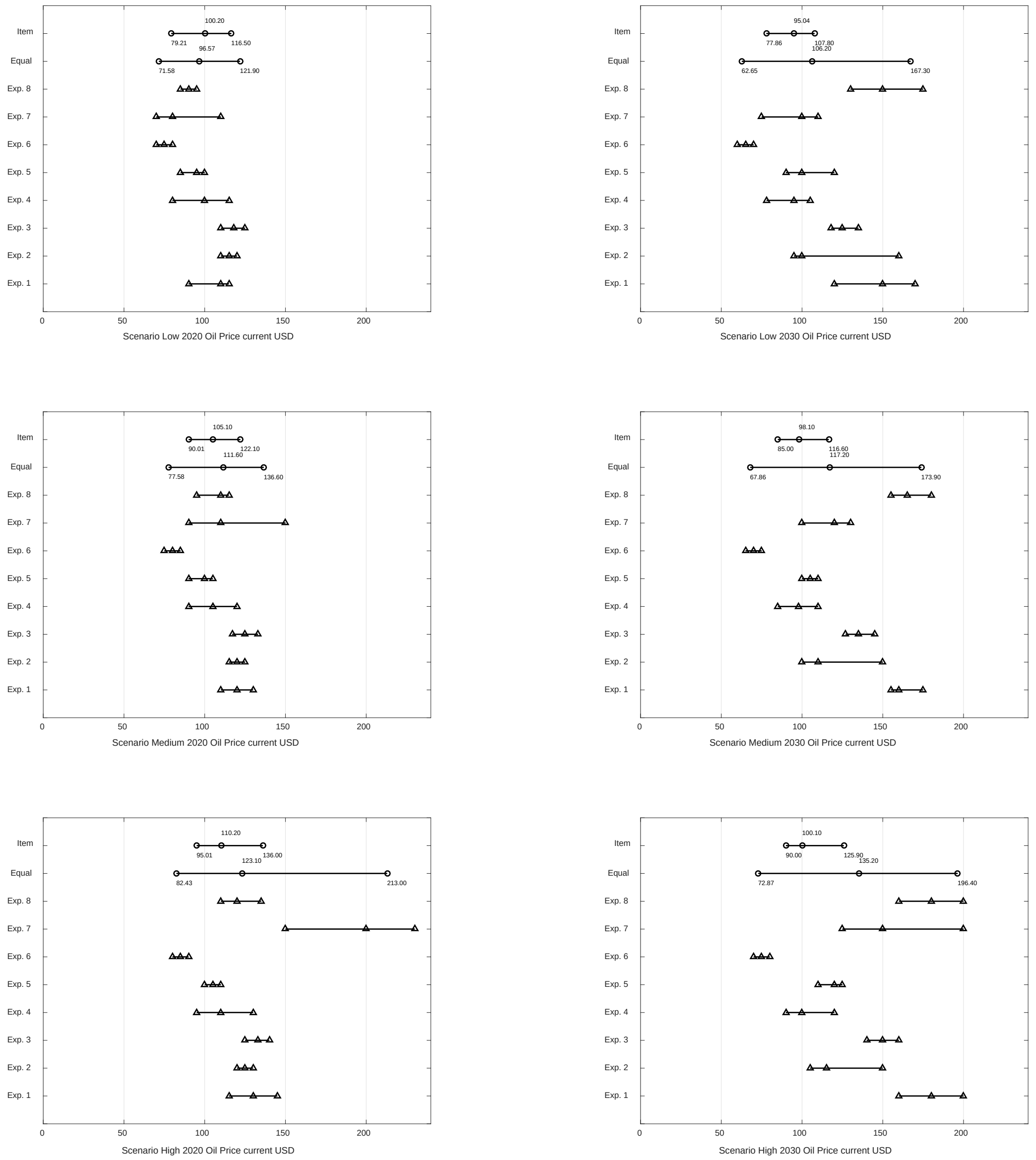

Item
94.96
69.33
101.30
Equal
94.97
59.99
152.20
Exp. 8
Exp. 7
Exp. 6
Exp. 5
Exp. 4
Exp. 3
Exp. 2
Exp. 1
0 50 100 150 200
Scenario Low 2021-2030 Oil Price current USD


Item
105.00
80.00
120.20
Equal
97.18
2.51
120.20
Exp. 8
Exp. 7
Exp. 6
Exp. 5
Exp. 4
Exp. 3
Exp. 2
Exp. 1
0 50 100 150 200
Scenario Medium 2014-2020 Oil Price current USD


Item
100.00
74.71
112.50
Equal
104.60
70.38
164.90
Exp. 8
Exp. 7
Exp. 6
Exp. 5
Exp. 4
Exp. 3
Exp. 2
Exp. 1
0 50 100 150 200
Scenario Medium 2021-2030 Oil Price current USD


Item
110.10
90.00
128.10
Equal
109.00
4.27
176.70
Exp. 8
Exp. 7
Exp. 6
Exp. 5
Exp. 4
Exp. 3
Exp. 2
Exp. 1
0 50 100 150 200
Scenario High 2014-2020 Oil Price current USD


Item
110.00
88.99
126.70
Equal
120.70
77.36
182.50
Exp. 8
Exp. 7
Exp. 6
Exp. 5
Exp. 4
Exp. 3
Exp. 2
Exp. 1
0 50 100 150 200
Scenario High 2021-2030 Oil Price current USD



Sources: own elaboration, based on the results of the expert judgment elicitation.

SI.1.g List of participating experts

Alejandro Villagomez Amezcua (PhD, University of Washington in St. Louis). Dr. Villagomez specialises in savings, pensions and Mexico's monetary policy. He works in Mexico's Centro de Investigación y Docencia Económicas.

Alberto Moritz Cruz Blanco (PhD, University of Manchester). Dr. Moritz specialises in prospective macro-econometric analysis. He works in Mexico's Universidad Nacional Autónoma de México.

Eliseo Díaz González (PhD, Universidad Nacional Autónoma de México). Dr. Díaz specialises in remittances, labour market, fiscal fraud, foreign direct investment flowing to Mexico and economic growth in Mexico. He works in Mexico's Colegio de la Frontera Norte.

Ignacio Perrotini Hernández (PhD, New School for Social Research). Dr. Perrotini specialises in monetary policy, inflation and economic growth in Mexico. He works in Mexico's Universidad Nacional Autónoma de México.

Pablo Ruiz Nápoles (PhD, New School for Social Research). Dr. Ruiz specialises in input-outputs analysis applied to economic growth in Mexico. He works in Mexico's Universidad Nacional Autónoma de México.

Juan Carlos Rivas Valdivia (MSc, Colegio de México). Mr. Rivas specialises in econometric analysis applied to economic growth in Mexico and Central America. He works in BBVA Bancomer, an international bank.

Junior Alfredo Martínez Hernández (MSc, Universidad de Guadalajara). Mr. Martínez specialises in econometric analysis applied to economic growth in Mexico. He works in Mexico's Chamber of Deputies.

Ramón Padilla Perez (PhD, University of Sussex). Dr. Padilla specialises in analyses of exports and competitiveness in Mexico's manufacturing sector. He works in Mexico's delegation of the United Nations Economic Commission for Latin America and the Caribbean.

José Manuel Iraheta Bonilla (MSc, Instituto Tecnológico Autónomo de México). Mr. Iraheta specialises in econometric modelling, inflation and monetary policy. He works in Mexico's delegation of the United Nations Economic Commission for Latin America and the Caribbean.

SI.2 General-equilibrium modelling

Three-ME (Multi-sector Macroeconomic Model for the Evaluation of Environmental and Energy policy) is a model especially designed to evaluate the medium and long term impact of environmental and energy policies at the macroeconomic and sector levels. To do so Three-ME combines two important features. Firstly, it has the main characteristics of neo-Keynesian models by assuming a slow adjustment of effective quantities and prices to their notional level, an endogenous money supply, a Taylor rule and a Philips curve. Compared to standard multi-sector Computable General Equilibrium Model (CGEM), this has the advantage to allow for the existence of under-optimum equilibria such as the presence of involuntary unemployment. Secondly, in an extended version, Three-ME is a hybrid model in the sense that it combines the top-down approach of general equilibrium macroeconomic models with elements of bottom-up models of energy models developed by engineers. As in bottom-up models, the amount of energy consumed is related to their use, that is the number of buildings or cars, and the energy class to which they belong. This hypothesis is more realistic compared to the assumption made in the majority of top-down models where energy consumption is usually directly related to income through a nested structure of utility function (Callonec *et al.* 2013).

Three-ME is a country-generic and open source model developed since 2008 by the ADEME (French Environment and Energy Management Agency), the OFCE (French Economic Observatory) and TNO (Netherlands Organisation for Applied Scientific Research). Initially developed to support the energy/environment/climate debate in France, Three-Me has then been applied to other regional contexts.

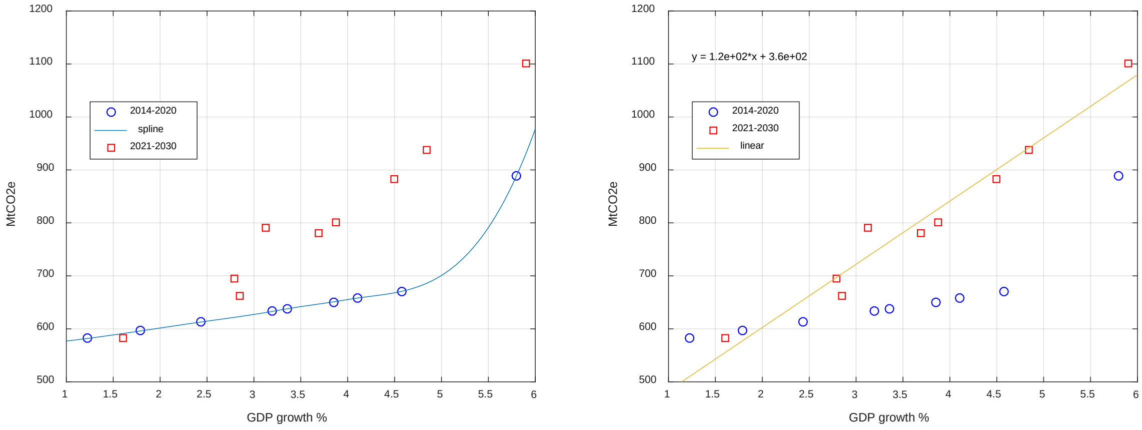
In the period between 2013 and 2015 a team of French and Mexican researchers adapted the ThreeME model for use by government agencies in Mexico. The main objective of the modelling project was to evaluate the impact of climate and energy policies. Through this work, the model was used to produce projections of greenhouse-gas emissions for Mexico for the years 2020, 2030 and 2050. To do this, the model relied on the estimates of growth rates in gross domestic product obtained through the expert judgement elicitation outlined above.

In the ThreeME model gross domestic product is not an exogenous variable that is entered as input to the model runs. Instead, gross domestic product is calculated by the model. For this reason, to produce estimates of greenhouse-gas emissions that are consistent with any one estimate of growth rates in gross domestic product, the model had to be recalibrated each time.

SI.3 Probability distributions of greenhouse-gas emissions for Mexico in 2020 and 2030

We take the estimates from Table 2 and plot the reference scenario forecasts in $MtCO_2e$ as a function of economic growth. For 2014-2020, the relationship is linear up to approximately 4.5 in gross domestic product growth rates, and non-linear thereafter. For this period a spline interpolant would approximate perfectly the relationship between gross domestic product growth rates and emissions of greenhouse gases. In fact, the rank correlation for these nine observations equals 1. This implies a perfect functional relationship between gross domestic product growth rates and emissions of greenhouse gases, when calculated as described in SI.2 for the period of time under consideration. For the period between 2021 and 2030, the relationship is approximately linear throughout the entire period.

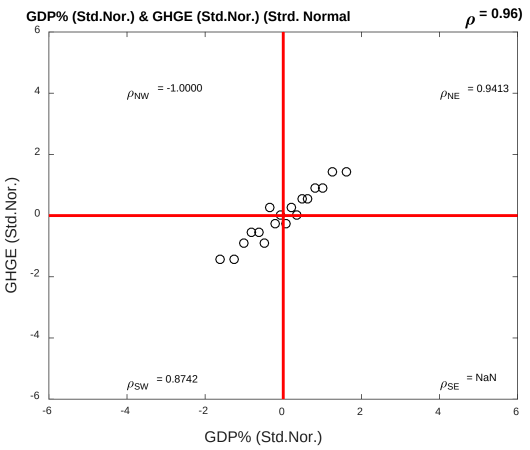
Supplementary Figure 3: Reference scenario forecasts in $MtCO_2e$ as a function of economic growth for Mexico in 2020 and 2030



Sources: own elaboration, based on Table 2.

If the 18 estimates from Table 2 are considered together, and transformed to a standard normal distribution, a product moment correlation of ≈ 0.96 would be observed for the standard normal variates. This is presented in Supplementary Figure 4. Different statistical hypothesis tests (Genest *et al*. 2009, Joe 2014) would indicate that a Gaussian copula is a good approximation for the data.

Supplementary Figure 4: Standard normal transform of data in Supplementary Figure 3



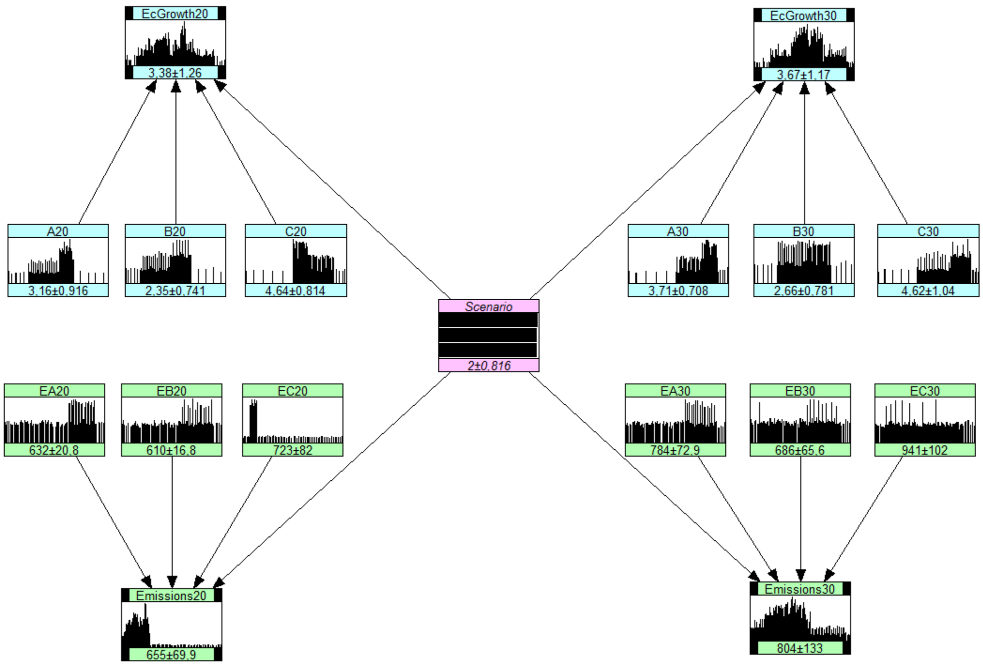
Sources: Own elaboration, based on Table 2.

We assume that the emissions given in Table 2, computed through the Three-ME model as described in SI.2, are indeed the 5th, 50th and 95th percentiles of the uncertainty distribution for each scenario. We determine the probability distribution of greenhouse-gas emissions as a mixture of the individual distributions, where the mixture coefficients are given equal weight in the mixed distribution. Stated differently, we assume equal probability for the three scenarios within each of the periods: until 2020 and until 2030, both for gross domestic product growth rates, and greenhouse-gas emissions. The graphical representation (as a Bayesian Network: see Hanea *et al.* 2015) is shown in Supplementary Figure 5.

The node scenario is a variable representing the equal probability for the three scenarios. Nodes A20, B20 and C20 represent the distribution of gross domestic product growth rates for the period 2014-2020, elicited through expert judgment, and corresponding to the neutral, pessimistic and optimistic scenarios, respectively (Supplementary Information SI.1). Nodes A30, B30 and C30 are the analogous distributions for the period 2021-2030.

Nodes EA20, EB20 and EC20 represent the distributions of emissions for 2020 obtained through the ThreeME model for the different percentiles of gross domestic product growth rates (Table 2 and SI.2.) also assuming neutral, pessimistic and optimistic scenarios. EA30, EB30 and EC30 are analogous to Nodes EA20, EB20 and EC20, but for 2030.

Supplementary Figure 5: Mixture distributions for Mexican gross domestic product growth rates and greenhouse-gas emissions for 2020 and 2030.

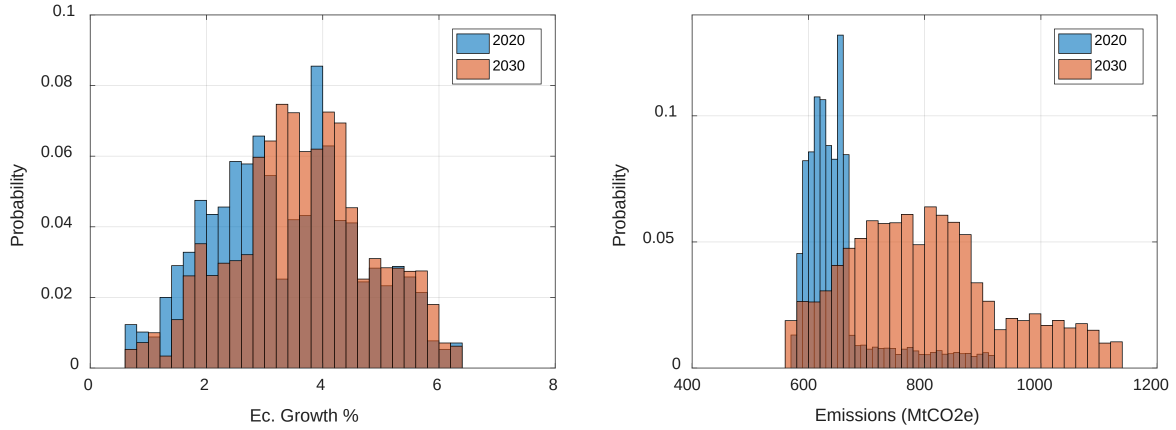


Sources: Own elaboration, based on estimates described in SI.1 and SI.2. The Bayesian Network is presented in UniNet (Hanea *et al.*, 2015)

For comparison, Supplementary Figure 6 shows in the same image the following nodes (from Supplementary Figure 5): EcGrowth20, EcGrowth30, Emissions20, and Emissions30. Figure 6 is constructed such that the height of each bar is equal to the probability of selecting an observation within that bin interval, and the height of all of the bars sums to 1. Notice the larger discrepancies in terms of the distributions of greenhouse-gas emissions, rather than in terms of the distributions of gross domestic product growth rates.

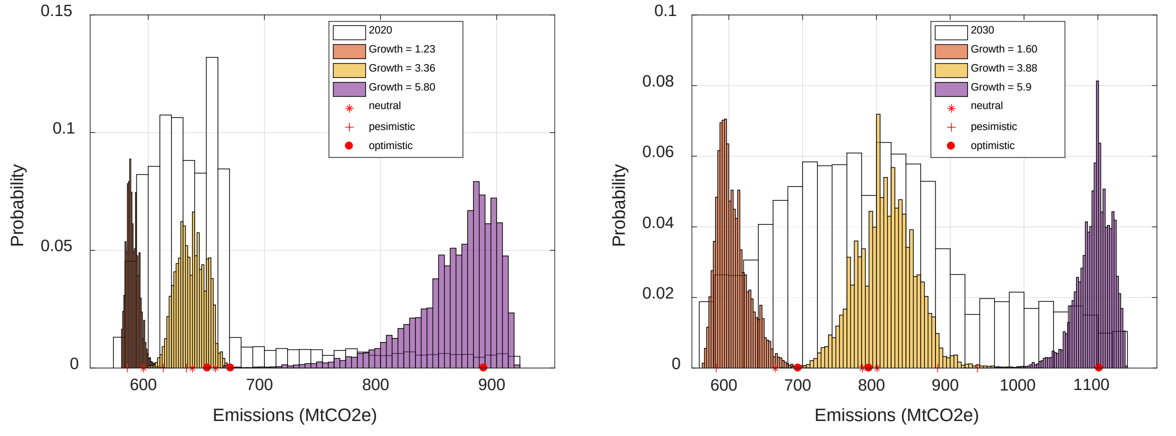
Finally, Supplementary Figure 7 presents the original distributions of greenhouse-gas emissions for Mexico in 2020 and 2030 alongside the conditional distributions given for gross domestic product growth rates = 1.23, 3.36, 5.8 for 2020 and given gross domestic product growth rates = 1.6, 3.88, 5.9 for 2030. The original neutral, pessimistic and optimistic estimates from Table 2 are also presented. All histograms in Figure 7 are constructed similarly as Figure 6 – that is, such that the height of each bar is equal to the probability of selecting an observation within that bin interval, and the height of all of the bars sums to 1,

Supplementary Figure 6: **Comparison of probability distributions of GDP growth and GHGE for Mexico in 2020 and 2030.**



Sources: Own elaboration.

Supplementary Figure 7: **Comparison of probability distributions of GHGE for Mexico in 2020 and 2030.**



Sources: Own elaboration.

Other approaches to estimate the probability distributions could have been used. For example, Oppenheimer and colleagues (2016) propose probabilistic inversion as a suitable alternative. We anticipate that probabilistic inversion would have yielded similar results. The method proposed here, the results of which are summarised in Supplementary Figure 7, is technically more accessible.

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Article 7

de Coninck, H. and Puig, D. (2015). Assessing climate change mitigation technology interventions by international institutions. *Climatic Change 131*(3), pp. 417-433.

https://doi.org/10.1007/s10584-015-1344-z

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Assessing climate change mitigation technology interventions by international institutions

Heleen de Coninck · Daniel Puig

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Abstract Accelerating the international use of climate mitigation technologies is key if efforts to curb climate change are to succeed, especially in developing countries, where weak domestic technological innovation systems constrain the uptake of climate change mitigation technologies. Several intergovernmental agencies have set up specific programmes to support the diffusion of climate mitigation technologies. Using a simplified technological innovation system-based framework, this paper aims to systematically review these programmes, with the dual aim of assessing their collective success in promoting technological innovation, and identifying opportunities for the newly formed UNFCCC Technology Mechanism. We conclude that, while all programmes reviewed have promoted technology transfer, they have given limited attention to innovation capabilities with users, government and universities. Functions that could be further developed include knowledge development, legitimation and market formation. These could be focal areas for the UNFCCC Technology Mechanism. We recommend that, in future programmes, part of the funding is dedicated to programmes doing research and development as well as capability development.

1 Introduction

Since its inception in 1992, parties to the United Nations Framework Convention on Climate Change (UNFCCC) have committed themselves to promote climate technology development and transfer. However, only recently has a so-called Technology Mechanism (TM) been set up. The TM aims to "facilitate the implementation of actions for enhancing technology development and transfer to support mitigation and adaptation activities in developing countries, including research, development, demonstration, deployment, diffusion and transfer of

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technology, and based on nationally determined technology needs" (UNFCCC 2010a). From an innovation system perspective (Lundvall 1992), the TM could be seen as an intervention that aims to form and strengthen national innovation systems for climate technologies in developing countries.

Several related initiatives complement the efforts by the TM – notably, work by UN and other international agencies as well as activities by a range of bilateral agencies and the private sector. Yet no monitoring scheme has been set up to measure progress or impact in the field of technology transfer. Moreover, the literature on technology transfer is often exploratory in nature (e.g., Ockwell and Mallett 2012), limited to case studies (e.g., Ockwell and Mallett 2012; Bhasin et al. 2014), or focussed on a specific category of technology transfer programmes (e.g., Hultman et al. 2012; Ockwell et al. 2014). This makes it challenging to evaluate whether the world as a whole is on track towards well-developed enabling environments for climate change mitigation technologies; a condition for staying below 2 °C global mean temperature rise (IPCC 2014). The absence of monitoring increases the risk of unnecessarily competing and overlapping activities, especially as the scope and modus operandi of the TM is being defined.

This paper reviews selected international efforts in the field of technology transfer for climate change mitigation, to assess the extent to which they contribute to fulfilling functions in technological innovation systems in developing countries. It distinguishes between several 'impact targets' in developing countries, namely actors, the functions each performs in the technological innovation system, and the linkages between them. Where these functions are not or insufficiently fulfilled, there may be scope for the TM to implement activities. The eventual aim of the paper is to identify areas of activities where the TM may be particularly complementary to other initiatives for promoting technology innovation. National and bilateral initiatives are not directly studied, but assessed through earlier review studies.

The paper is structured as follows. Section 2 provides the theoretical framework and explains the approach and its limitations. Section 3 discusses three extensive reviews of technology cooperation that have been done previously, and section 4 adds to that by describing, using the same approach, four specific programmes. Section 5 assesses and synthesises the results, and section 6 concludes.

2 Approach

Following Lundvall (1992) and Freeman (1995), Byrne et al. (2012), in line with Altenburg and Pegels (2012), emphasised the systemic nature of innovation around low-carbon (or climate change mitigation) technologies, also in developing countries. Looking at innovation in general (that is, beyond climate change), Hekkert et al. (2007) and Bergek et al. (2008) developed a Technological Innovation Systems (TIS) framework to categorise the complexity around innovation systems and bring some order into the seemingly anarchic dynamics within innovation systems. The TIS framework is structured around actors and institutions, functions (that the innovation system should fulfil for a particular technology), and connections and networks between actors in the innovation system.

In Blanco et al. (2012), the TIS framework is reorganised into actors and their functions along commonly used technology development phases. The result (including minor modifications) is schematically depicted in Fig. 1. It is based on technological innovation system thinking but also acknowledges that activities around a technology can often still be characterised as what in linear innovation thinking is called different phases of technological

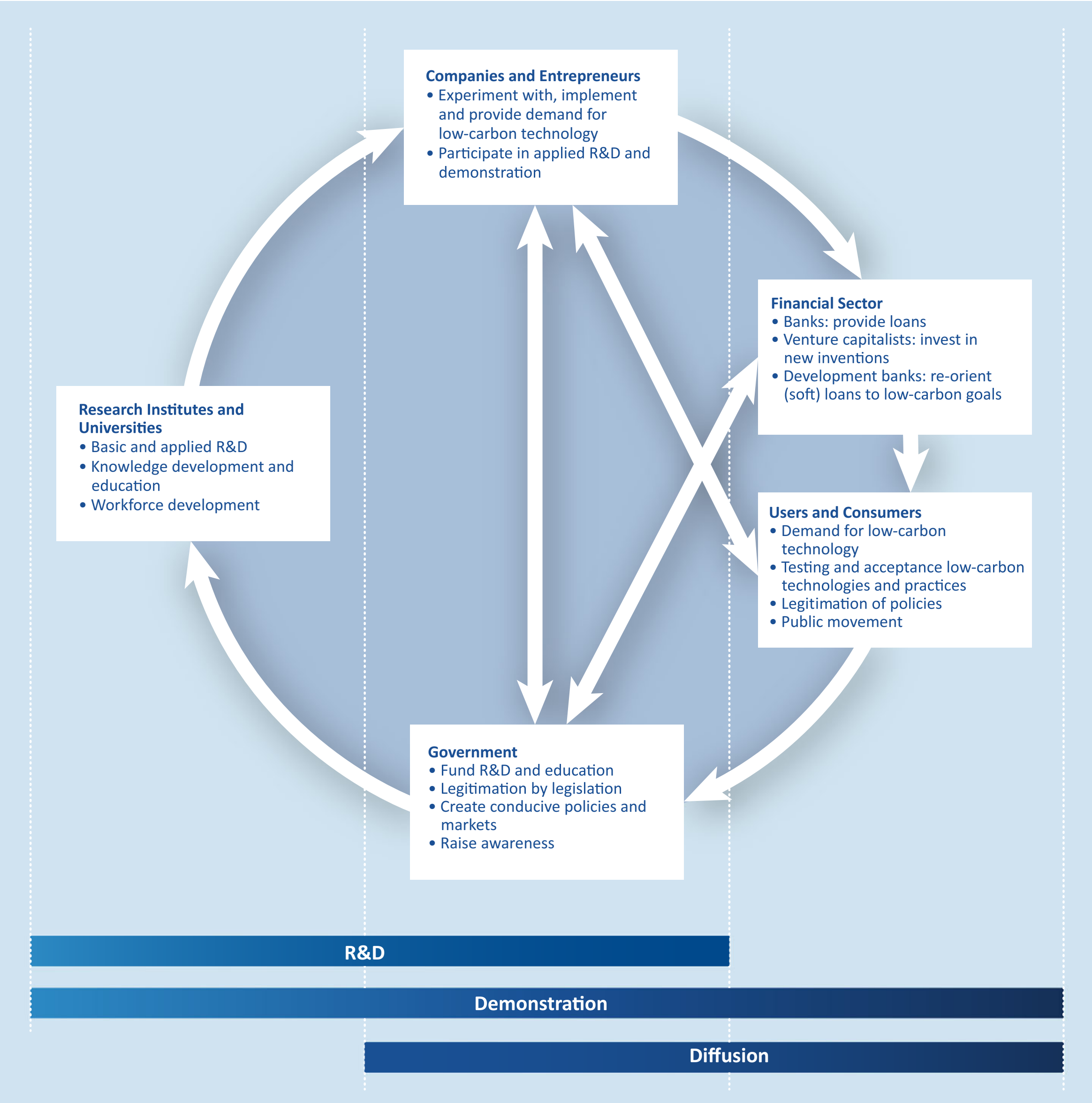

Fig. 1 A representation of functions and linkages between actors in the innovation system and their relation to the technology cycle. In research and development, mainly research institutes, businesses and government are involved. In deployment and diffusion the financial sector and users (including companies and entrepreneurs in many cases) and consumers play important roles, whilst the research sector is less important. When a technology is demonstrated, all actors play a role. The number of actors may encumber technological demonstration (based on Blanco et al. 2012)

maturity. However, Fig. 1 does not aim to suggest a temporal sequence, as the linear model of technological development does.

Figure 1 illustrates that different groups of actors, each performing different functions, play a role in different phases of the 'technology cycle' (Grubb 2004). In research and development, mainly research institutions, government and the private sector contribute to technological development in different roles. When a technology is demonstrated in the real world, financing is required to take it to scale (involving financial institutions) and users need to be able to operate the technology. When a technology diffuses in commercial ways, the role of the research sector is smaller.

Based on the functions in the TIS as identified by Bergek et al. (2008), knowledge development is done in Fig. 1 in the functions under research institutes and universities as well as by companies and entrepreneurs by engaging in applied R&D and demonstration. Market formation is provided by users and consumers, government, and companies and entrepreneurs (in Business to Business context). Legitimation is done by government in legislation and policy and by users and consumers in supporting policies. Resources are mobilised by the financial sector and government (by funding R&D and education, providing (soft) loans). Entrepreneurial experimentation is enabled by companies and entrepreneurs and the financial sector (venture capitalists). The direction of search is influenced by raising awareness through government, creation of policies and by public movement (users and consumers). The function of external economies is not taken into account in this analysis as it is external to the national innovation system.

Figure 1 should be loosely interpreted, as in reality multiple actors can (and perhaps have to) fulfil a single function. While acknowledging imperfections in Fig. 1 we choose to use it as the most practical basis for systematically categorising and assessing key impacts of a selection of international technology interventions. Specifically, we assess whether these programmes have succeeded in:

- increasing the capabilities of relevant actors, which is defined here as their ability to perform their functions in the technological innovation system, as well as their knowledge and skills;
- strengthening and, where relevant, establishing interlinkages between actors according to the linkages shown in Fig. 1.

The description and assessment of the programmes focus on the most representative interventions. The sources of data range from peer-reviewed literature, to technical reports, to personal communications. The assessment of the programmes yields gaps in what the programmes are doing, which could jointly, and where they coincide with the TM mandate, become useful areas to focus for the TM. However, as the approach in this paper is broad but necessarily lacks analytical detail around the initiatives that are discussed here, areas that this paper identifies as gaps may actually be covered anyway, and therefore the conclusions should be treated with appropriate caution.

There are further obvious limitations to how far the 'Technological Innovation Systems' (TIS) framework can be applied to interventions aimed at national innovation systems in general. In this paper, the strengthening of technology-specific, capability- and interlinkages-related functions are assumed to also improve the national innovation system and as such contribute to these, also implicit, aims of the TM.

There are also limitations around applying TIS to mitigating climate change in developing countries. First, least-developed countries suffer a 'brain drain' that is rare in developed countries: qualified individuals tend to seek employment abroad. This element is not reflected in the TIS framework, which is modelled after the realities of developed countries. Second, the market for climate change mitigation technologies depends on a patchy set of (in most cases) struggling markets. Again, this is not the 'standard' case that the TIS framework would describe more aptly: technologies for which there is a regular market – say, for example, micro-chips or biomedical products. Finally, the TIS framework does not reflect properly dynamics or 'discontinuities', such as major governance deficiencies at the national level (if not outright conflict), which impact developing countries more acutely, compared to developed countries, and for reasons mentioned earlier have a disproportional effect on climate change mitigation technologies.

3 Previous reviews of green technology cooperation

This section discusses the results of three reviews of hundreds of international and bilateral interventions relevant to low-carbon technology transfer. Beneficiaries of these interventions in developing countries include governments, research institutions, universities, civil society organisations and (sometimes) companies and entrepreneurs. Activities show a great degree of variety and include information sharing, matchmaking, capacity building and training, finance, R&D and demonstration.

In 2010, the UNFCCC commissioned a search into climate technology R&D cooperation initiatives, which was reported in a SBSTA paper (UNFCCC 2010b) and elsewhere in this special issue (Ockwell et al. 2014). This dataset covered adaptation and mitigation cooperation. In 2012, the International Renewable Energy Agency (IRENA) conducted a survey among its members for initiatives related to renewable energy technology cooperation. This resulted in a so far unpublished database of international and bilateral initiatives in different categories of technology cooperation, as reported by IRENA members (i.e., governments).[1] Hultman et al. (2012) conducted a review of 163 international initiatives "with a stated mission of advancing at least one sector of green growth", categorising them by type of assistance, and identifying lessons. This assessment only includes non-commercial initiatives. Of all initiatives listed, 25 % are IEA Implementing Agreements and almost 10 % are institutes of the Consultative Group on International Agricultural Research (CGIAR).

The UNFCCC database covers both mitigation and adaptation technology, Hultman covers only low-carbon technology and IRENA only initiatives in the field of renewable energy technology cooperation. A considerable overlap in the initiatives covered in the databases can be identified, in particular between UNFCCC (2010b) and Hultman et al. (2012) as the information collection methods were similar. Although the three studies were aiming at the same type of assessment, they used slightly different categories for the functions (or services) the initiatives fulfilled. Figures 2 and 3 give the results of the IRENA survey and the Hultman review, respectively.

The terms used for functions fulfilled or services provided in the studies discussed here differ. As the studies did not use a TIS-based, systemic approach, they mostly also differ from the functions in Fig. 1. For some of the categories in Figs. 2 and 3, the link with functions in Fig. 1 is clear, in particular public awareness, entry- and expert level training, knowledge development, demonstration projects, R&D, industry-level (in IRENA) and technology R&D and implementation, financing, market analysis, technical assistance, training and education and business assistance (Hultman et al. 2012). Testing and quality assurance, public-private partnerships, information sharing, policy advocacy and networking are related to promoting interlinkages and increasing legitimacy for technologies in the context of TIS and Fig. 1. The categories policy analysis and institutional support are harder to classify.

The three studies all arrive at the conclusion that international initiatives choose a focus on a single part of the technological chain, but that many consequentially aim at those elements that are least risky. As a result, demonstration was poorly represented, which could be expected given the "valley of death" hypothesis (Murphy and Edwards 2003), but also direct R&D was usually not performed. There are two remarkable inconsistencies in the conclusions between the studies. First, respondents to the IRENA survey indicated a focus on policy analysis, advocacy and networking, while Hultman et al. (2012) in its survey attributed limited roles for those services.

[1] One of the authors of this paper worked as a consultant for IRENA to collect the data and obtained permission to use them for this paper.

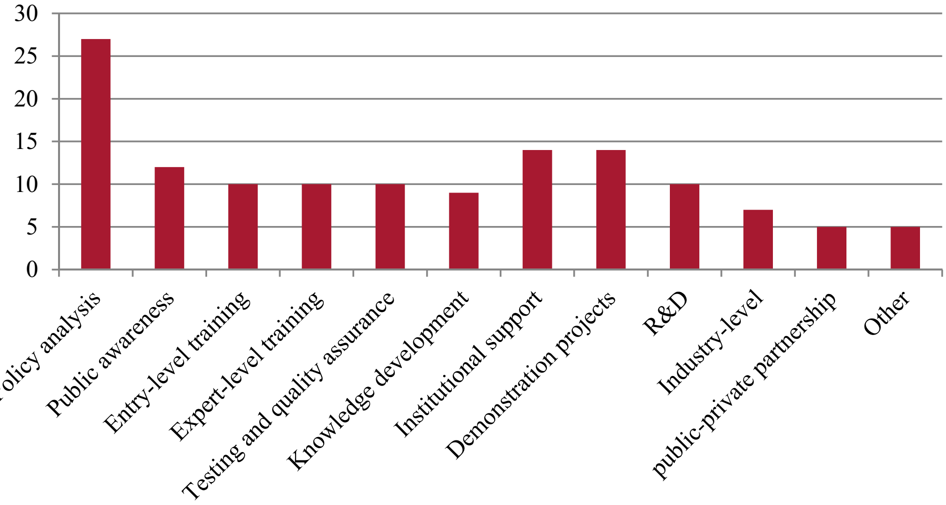

Fig. 2 Overview of amount (counts) of international renewable energy technology collaborations in categories of collaboration resulting from preliminary analysis of the survey responses (IRENA survey results). A single collaboration can add to more than one category

Second, Hultman et al. (2012) indicate that three-quarters of the initiatives are involved in research, while Ockwell et al. (2014) note a dearth of cooperation on actual R&D implementation and point out that much R&D cooperation is actually not funding more than information sharing or matchmaking. It should be noted that a look at the descriptions of the initiatives in Hultman's database reveals that many of the initiatives listed aim to facilitate rather than conduct R&D, supporting Ockwell et al.'s claim.

Both the Hultman and Ockwell studies conclude that RD&D in the field of adapting technologies to local markets and circumstances is underserved in international interventions around climate technology. Hultman et al. (2012) also conclude that gaps exist in the field of technical and business advisory services, linking the knowledge systems in developing countries to the market.

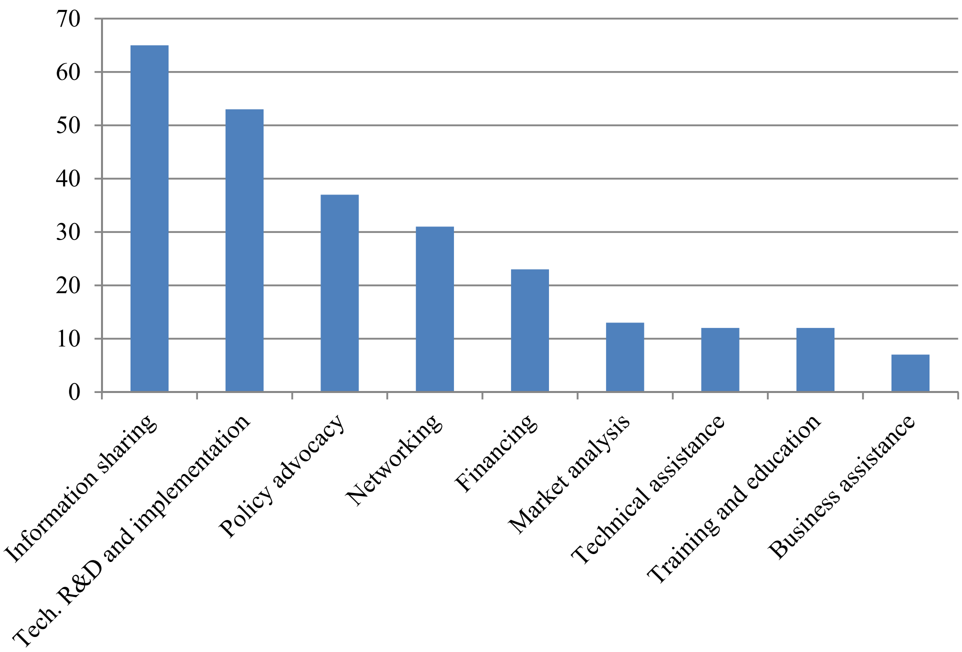

Fig. 3 Percentage of international initiatives indicating that services are provided (from Hultman et al. 2012)

4 Description of the international technology interventions

We further analyse four international programmes. Our selection is based on the programmes' explicit focus on technology development and transfer, including knowledge and institutional capacity. We choose primarily United Nations initiatives because of their geographic breadth, transparency and public availability of information, and stated ambition, compared to any (by necessity) limited sample of equally relevant bilateral or purely national initiatives.

Table 1 gives an overview of the programmes analysed. None of the programmes are directly and exclusively targeting the users of the technologies. Generally, public agencies are either the sole beneficiary, or act as intermediaries between the promoter of the intervention and the end users. Only one programme (the Clean Development Mechanism) is aimed (through its official objective of emission reduction in projects in non-Annex I countries) at direct technology deployment and diffusion, whereas the others all facilitate this in different ways. With the exception of the Clean Development Mechanism, which is concentrated (albeit not by design) on two countries mainly, and the Climate Innovation Centres, which is active in seven countries and one region, all other programmes are broadly spread across world regions.

Table 1 Overview of international technology interventions discussed in this section

Programme and time frames	Beneficiaries in developing countries	Outputs	Geographic focus
Technology Needs Assessment (TNAs) (2010–2013)	National governments	Prioritisation of technologies, assessment of barriers to implementation and suggestions for immediate technology deployment opportunities	Developing countries (33 in total, spread across regions)[a]
Clean Development Mechanism (CDM) (2001-present)	Companies and entrepreneurs	Technology deployment and diffusion	Developing countries (with the vast majority of projects in China and India)
Climate Innovation Centres (CICs) (2012-present)	Companies and entrepreneurs (mainly SMEs), financial sector	Services in the field of business acceleration, market development and access to finance[b]	Kenya, Ethiopia and the Caribbean (with further centres planned Ghana, India, Morocco, Vietnam, and Gauteng (a province of South Africa)).
National Cleaner Production Centres (NCPCs) (1994-present)	Companies and entrepreneurs (mainly SMEs) through national and regional governments	Awareness-raising campaigns, demonstration projects, in-plant assessments and information dissemination activities	Developing countries and Eastern European countries (40 in total, spread across regions)

[a] This refers to the second round of technology needs assessments (referred to at the UNFCCC TT:CLEAR website as Phase I). A third round (Phase II on TT:CLEAR) was launched in 2014, covering an additional 27 countries. Results for this round are not yet available. Therefore this paper discusses the second round only

[b] The goal is that, once established and operational, the centres will help enterprises access finance; will provide them with advice, assistance and educational products of different kinds; will facilitate cooperation between actors; and will give enterprises access to facilities and tools – all of these with the explicit objective of promoting climate technology innovation

4.1 Technology Needs Assessments project

Technology Needs Assessments (TNAs) are a set of country-driven activities to arrive at an official, prioritised list of mitigation and adaptation technology needs at the national level. The first round of TNAs took place from 2004 to 2008 (UNFCCC 2009). Since 2008, TNA development is a key component of the Poznan Strategic Programme on Technology Transfer (under the United Nations Framework Convention on Climate Change), supported by the Global Environment Facility. With this support, the TNA project provided financial and technical assistance to 33 national government agencies charged to prepare the prioritised list of mitigation and adaptation technology needs mentioned above. It is this second round programme that is assessed in Table 2.

Table 2 assesses whether the functions in the technological innovation system as listed in Fig. 1 are performed. Actors that are not mentioned in the table can still be involved in the TNA process in a country. Research institutions, universities, companies and entrepreneurs and civil society were involved in the prioritisation process in all countries, mostly by the invitation to attend meetings. Efforts to build capabilities were not explicitly included in TNA efforts, leading to the conclusion that the ability to fulfil their functions in the technological innovation systems was not significantly enhanced.

4.2 Clean Development Mechanism

The Clean Development Mechanism (CDM), including its recent Programme of Activities, is part of the Kyoto Protocol and aims to reduce the Kyoto compliance costs for developed countries while promoting sustainable development in developing countries. The emission reduction targets of Annex B countries in the Kyoto Protocol form the demand for Certified Emission Reductions (CERs), the unit of emission reduction in the CDM. The European Union is reaching its member states' Kyoto targets partly through a domestic EU Emissions Trading Scheme (ETS), which represents the largest demand for CERs. As of February 2014, 7426 CDM projects had been registered, 31 were in the process of being registered and 1293 were in the process of being validated – that is, a total of 8750 projects (UNEP Risø Centre 2014). With the finalisation of the first commitment period of the Kyoto Protocol, however,

Table 2 Actors, functions and interlinkages in the 2010–2013 Technology Needs Assessment project

Functions (by actor)	*Research institutes and universities*: Sector specialists provided technical advice and developed knowledge (knowledge development). *Government*: National government agencies conducted the assessment (with their own staff or through external experts). *Financial sector*: In some countries lending agencies participated in the prioritisation process and helped identify project opportunities.
Interlinkages	The prioritisation of technologies was carried out using a multi-criteria analysis framework. The prioritisation was generally undertaken through a large multi-stakeholder consultation, which allowed actors to interact. In principle, this allowed the various actors to contribute equally to the desired product (a prioritised list of technologies). In reality, availability, knowledge and experience varied widely across stakeholder groups. Because of this, the influence of the input from civil society groups and, to a lesser extent, research institutions and universities, was reduced. The assessment of barriers and the identification of project opportunities were done by a smaller group, in consultation with other actors only when specific (mostly technical) questions arose.

and the decline in carbon prices in the ETS, the activities in the CDM have decreased in recent years, and the future of the CDM is uncertain.

A distinguishing feature of the CDM is that is has succeeded in involving project developers and companies in the climate change mitigation agenda. By providing a price on greenhouse gas emission reductions, local companies had an incentive to deploy mitigation technologies. In the industrial sector, this has focussed companies on energy efficiency. Host country government involvement was, by design, limited to an approval role on whether the project contributed to sustainable development in the host country, and governance was mainly executed at the international level through the CDM Executive Board and its Panels.

Although technology transfer is not officially part of its remit, many studies have attributed the CDM with positive technology transfer effects, indicating that (self-reported) technology transfer rates stand at about two-fifths of all projects (see Murphy et al. 2013 and studies cited therein). A 2008 assessment showed that 36 % of (at the time) all projects, accounting for 59 % of the annual emission reductions, claimed to involve technology transfer and noted that “technology transfer is more common for larger projects and projects with foreign participants” (Seres 2008). It can be considered a positive sign that the technology transfer rates decline as countries have more projects in their portfolio and capabilities are built (Lema and Lema 2013).

The CDM clearly makes use of capabilities present in developing countries, in particular of research institutions, financial institutions and companies and entrepreneurs. This is one of the explanatory factors of the predominance of large and middle-income host countries in the CDM (Winkelman and Moore 2011). Table 3 only reports on how the CDM enhances the fulfilling of the TIS functions by the actors.

Table 3 Actors, functions and interlinkages in the Clean Development Mechanism

Functions (by actors)	*Government*: Designated National Authorities (DNAs), located within government, screen proposals against national priorities and provide host country approval (i.e., projects that are not in line with the development goals of the government in principle fail to obtain host country approval). In CDM Programmes of Activity (PoAs), local governments can also be project developers. *Companies and entrepreneurs*: Project developers (local and foreign) take the initiative and the risk for developing a CDM project. Sector representatives (or plant representatives, depending on the type of project) define the project with project developers. *Financial sector*: Working with project developers, financial institutions provide capital on commercial terms. Some financial institutions also act as traders of certified emission reductions. *Users, consumers and civil society*: In some instances interest groups or organised civil society (for example, local associations) can act as project recipients, increasingly so in the case of CDM PoAs. Civil society (mainly larger groups) has influenced the legitimation of certain project types.
Interlinkages	Since most projects are site-specific, individual actors rarely come across each other twice, although more permanent collaborations between financiers and entrepreneurs have been set up. Consultants, auditors and accountants (Designated Operational Entities in the CDM) potentially interact with the Designated National Authority on as many occasions as projects, as well as with project developers having several projects in the country. This means some interaction with government is promoted but only with a usually relatively isolated department in government.

4.3 Climate Innovation Centres

Initiated by the World Bank and infoDev, and funded by different donors in different countries, eight Climate Innovation Centres (CICs) have been or are in the process of being set up in various developing regions. Based on a gap and barrier analysis globally (infoDev 2010) and a more detailed process in countries or regions, the operational scope of a CIC is determined. The functions a CIC performs therefore depend on the national assessment. The stated general aim of the CICs is “to build local capacity and address barriers to innovation by offering a tailored suite of financing and services to support domestic ventures” (infoDev 2014).

The way the CICs are currently implemented by the World Bank and infoDev is a significant departure from the original suggestion of CICs by Sagar et al. (2009), who propose to form regional CICs to embark on “a new kind of public–private, North–South, and South–South partnership, intended to advance the development and availability of suitable technologies (i.e., support ‘technology-push’), underpin the creation and development of markets (i.e., support ‘demand-pull’), and carry out other enabling activities to overcome implementation barriers in developing countries”.

The Kenya CIC was started in September 2012, and the Ethiopian and Caribbean CICs in early 2014. Given the short time span of the CICs, none of them have been officially evaluated yet. However, based on business plans and websites, it can be concluded that the CICs almost exclusively focus on services related to business acceleration, market development, access to finance and entrepreneurial incubation. Table 4 summarises the results.

4.4 UNIDO/UNEP National Cleaner Production Centres

Since 1994, the United Nations Environment Programme (UNEP) and the United Nations Industrial Development Organization (UNIDO) have strengthened – and established, in some instances – 40 cleaner technology centres of expertise in developing countries and economies in transition. The goal of the centres is to promote the adoption of cleaner technologies in those countries by facilitating access to resources and international expertise to the centres’ specialist staff. To this end the centres, with support from the United Nations, adapt international ‘good practices’ and make them

Table 4 Actors, functions and interlinkages in the Climate Innovation Centres programme

Functions (by actor)	*Research institutions and universities*: Often serve as host organisations for the CIC (Ethiopia, Caribbean). Also target group for activities around incubation (researchers becoming entrepreneurs in clean technology). *Government*: Only the Ghana business plan mentions policy support, therefore functions by government are generally not enhanced by CICs. *Financial sector*: Except the Caribbean CIC, all mention access to finance as a service. *Companies and entrepreneurs*: The key target group of the CICs and beneficiaries of most of the services provided, such as business acceleration, access to financing, market development (and information), matchmaking, incubation and mentoring/training.
Interlinkages	The interlinkages between companies, entrepreneurs, research institutions, and financiers are planned to be facilitated through matchmaking services. Mentoring and training services aim to strengthen interlinkages between new entrepreneurs (e.g., from universities) and established companies and business. Strengthening contacts between government and other actors is generally not foreseen.

known and available in the respective countries. Supporting innovation is one of the centres' stated objectives (UNEP 2010a).

Each centre was initially set up as a UN-backed technical cooperation project, hosted by a national industry association, technical institute or university. Over time the centres started generating their own revenues from service fees, became financially and administratively independent, and acquired a separate legal entity, generally with buy-in from government, business sector and civil society.

In 2010 the two United Nations sponsors of the centres established a global Resource Efficient and Cleaner Production Network, bringing together National Cleaner Production Centres with providers of similar services. Under this new organisational set-up, with three membership categories, each with its own eligibility requirements, rights and obligations, the centres see their scope of work enlarged. It is too early to tell whether this will come at the detriment of the centres' ability to support technology innovation (UNEP 2010b).

The centres have traditionally struggled to service smaller businesses, because the capacities of such small companies are particularly limited (Luken and Navratil 2004). An evaluation of the longest standing centres found that about three-quarters of the measures implemented with support from the centres entailed relatively minor improvements in investment levels, and seldom involved the adoption of foreign technologies (Luken et al. 2003). Reversing this trend is one of the goals of the global Resource Efficient and Cleaner Production Network.

Table 5 summarises the results.

5 Results

Figure 1 lists a number of functions that groupings of actors in technological innovation systems are generally required to fulfil for a technology to develop and diffuse in a national or regional context. Using the review in section 4, we discuss whether the functions (section 5.1) and the interlinkages (5.2) are strengthened by international initiatives.

Table 5 Actors, functions and interlinkages in the National Cleaner Production Centres (NCPCs)

Functions (by actor)	*Research institutes and universities*: Knowledge is developed by the situation of NCPCs at research institutions (knowledge development). *Government*: Public sector agencies identify relevant sectors and businesses within those sectors, and act as interlocutors between them and the United Nations (raise awareness). *Companies and entrepreneurs*: Technology users (mainly SMEs in the manufacturing sector) are given information and tools to facilitation the adoption of cleaner energy technologies, so they can fulfil the function of experimentation with new technology. *Financial sector*: Local lending institutions provide technical advice for the preparation of financing plans. Financing arrangements are expected to follow (though they sometimes fail) and are rarely part of the service provided by the NCPCs.
Interlinkages	Two features dominate the programme: dissemination of international 'good practices' and the one-off nature of most activities in the programme. The former refers to the efforts of the programme to make tried-and-tested practices available to companies in countries where the programme has facilitated the establishment of a 'cleaner production centre'. The latter refers to the centres' mandate to support different sectors, each with its own stakeholder community, which means that the programme has continuity mainly for the centres' staff, and less so for most other actors. As a result, the programme has strengthened links among domestic actors along sectoral lines. Interaction between the NCPCs has also established an international network among staff from different 'cleaner production centres' (and thus across sectors).

5.1 Strengthening functions

For each of the functions in Fig. 1 above, Table 6 summarises the impact of the programmes on those functions.

Apart from the CICs and several of the Green Technology Cooperation programmes, none of the interventions are designed primarily to foster technology innovation in developing countries. Nonetheless, since the objectives of these programmes are related to innovation, they inadvertedly support some of the functions listed in Fig. 1, albeit mostly indirectly.

Government, companies and entrepreneurs, and research institutions and universities are the actors whose various functions are most commonly supported, whereas the financial sector and users and consumers are least targeted. However, companies and entrepreneurs or research institutes and universities are hardly supported at all when it comes to participating in applied research & development, demonstration and knowledge development.

5.2 Strengthening interlinkages

The literature on innovation systems emphasises that connections between the different actors in (technological) innovation systems are crucial to adequately fulfil the functions (e.g., Hekkert et al. 2007, see also Fig. 1). It is therefore also key to see whether international interventions play a role in connecting the actors in an innovation system, and what role that may be.

The IRENA, Hultman and Ockwell/UNFCCC assessments of green technology cooperation initiatives reported in Section 3 identified a wealth of international interventions that seemed aimed at technological development and transfer, but that in reality gravitated towards strengthening interlinkages between various actors in the targeted country and internationally. It could be argued that in such international initiatives, the interlinkages between actors within a country are supported less than those internationally (perhaps because they are assumed to already exist, or perhaps because finding markets for technologies and companies from donor countries is among the aims of the technology cooperation).

The Technology Needs Assessment project required that all relevant actors, in particular those from government, research institutions and companies, worked together. In many countries, this was done for the first time. Further, the TNA process highlighted both the benefits of cooperation (from increased credibility and legitimacy of the final product, to better understanding of each other's positions) and the challenges associated with it (mainly, varying levels of technical knowledge, time available and understanding of the workings of government). TNAs thus represent a starting point for strengthening the interlinkages between actors, on which future efforts could build. However, it did not create a permanent platform and direct functions cannot be attributed to TNAs. Also, users and consumers and the financial sector were generally less involved than the above-mentioned actors.

Given its international nature, the Clean Development Mechanism has involved a wide range of participants across all actor types outlined in Fig. 1 in many countries. In small countries in particular, successive projects by the same project developer may have helped strengthen the interlinkages between organisations conducting project accounting and verification, specialists developing baselines, the private sector, and government agencies. It also brought together the financial sector and project developers as many banks, in the heyday of the CDM, found it an interesting investment and trade opportunity.

Table 6 Programme impacts by actor and function. The text in the cells answers the question which international technology interventions have contributed to fulfilling the function by the actor, and how this function is fulfilled

Actor	Function	Impact of the programmes analysed
Research institutes and universities	- Basic and applied research and development	Some initiatives reviewed under Green Technology Cooperation promote or fund basic and applied research and development (with a focus on applied R&D). The Climate Innovation Centres are sometimes thought to support R&D but no such intention could be identified in the CIC business plans.
	- Knowledge development and education	NCPCs and numerous initiatives under Green Technology Cooperation are aimed at knowledge development at research institutions and universities. This can include curriculum development for continuity in training. No intervention seemed to aim for general education.
	- Workforce development	Some interventions in the Green Technology Cooperation category contain capacity building, curriculum development and training elements for research institutes and universities that explicitly aim to contribute to workforce development.
Companies and entrepreneurs	- Experiment with, implement and provide demand for low/carbon technology	The CDM has been enormously effective in supporting the implementation of (a relatively reduced number of) mitigation technologies by companies, and in reducing the risk of entrepreneurial experimentation in that field. While experimenting with new technology and implementing it is the ultimate goal of the network of NCPCs, the network lacks a financial mechanism that would allow it to support this goal, beyond the facilitating activities it undertakes. The CICs are expected to support this function, for instance through business intelligence and market analysis insights. The TNA process sought guidance from companies and entrepreneurs with regards to which new technologies could be implemented, though the process' main aim was to reach consensus on a prioritised list of technology needs (see below).
	- Participate in applied R&D and demonstration	No intervention seems to have explicitly promoted the participation of companies and entrepreneurs in applied research development and demonstration. (Interventions for business are usually to market and implement new technology, see former function.)
Government	- Fund research, development and education	A limited amount of interventions reviewed under the Green Technology Cooperation category are government-induced programmes that fund research and development in climate change mitigation technologies.
	- Legitimation by legislation	The prioritisation process around TNAs provided legitimacy for those technologies that appeared in the TNAs. The governmental endorsement of the TNAs is therefore key. Several initiatives in the Green Technology Cooperation category contributed to legitimacy of technologies.

Table 6 (continued)

Actor	Function	Impact of the programmes analysed
	- Create conducive policies and markets	The CDM, in times of high carbon prices, put a price on emission reductions and created a carbon market in developing countries. In some countries, the CDM has also promoted the introduction of policies to ease access to local markets by foreign investors. The network of NCPCs has facilitated the introduction of sector-specific policy incentives for clean energy technologies. Some of the bilateral initiatives in the Green Technology Cooperation category (in particular those assessed by IRENA) have focussed on support for development of conducive policies, mostly for renewable energy.
	- Raise awareness	The network of NCPCs conducts awareness-raising campaigns and develops information products addressed to technical and, in some instances, generalist audiences. The CICs are expected to support this function, in particular by raising awareness among business and governmental actors.
Financial sector	- Provide loans (banks)	The CDM indirectly supports this objective, to the extent that project developers may require loans. Financial institutions are also targeted by CICs for matchmaking with the businesses that CICs hope to help develop. Several instances of the Green Technology Cooperation category also contribute towards providing loans and enabling finance.
	- Invest in new inventions (venture capitalists)	The CICs are expected to facilitate - but not directly support - this function.
	- Reorient (soft) loans to low-carbon goals (development banks)	No technology intervention reviewed in this paper is known to support this.
Users, consumers and civil society	- Demand for low-carbon technology	The CDM has played a role in persuading technology users, consumers and civil society to use low-carbon technologies.
	- Public movement	The NCPCs make a small contribution to this through awareness-raising, but the scope is limited.
	- Testing and acceptance low carbon technologies and practices	The CDM has played a role in persuading technology users, consumers and civil society to try out new low-carbon technologies.
	- Legitimation of further policy	Through its educational tools and awareness-raising campaigns, the NCPCs have indirectly supported policy changes in some countries.

As mentioned above, only one of the various Climate Innovation Centres is operational long enough to give an impression of how it is operating (in Kenya since 2012). The rest are still being or were very recently set up

The network of National Cleaner Production Centres exists to serve local businesses in developing countries and countries with economies in transition. It focuses on SMEs, as they have limited or no access to other forms of support, especially compared to multinational companies. Because of this, the network has strengthened the interlinkages between government and companies and entrepreneurs in particular. However, more important have been the interlinkages between centre staff in different countries.

Finally, the CICs also aim to connect business actors (companies and entrepreneurs) and will provide a network function between the CICs internationally.

6 Discussion and conclusion

Many activities are being undertaken to strengthen the global innovation system for climate change mitigation technologies. A full review is out of the scope of this paper, and comparable and reliable data are hard and labour-intensive to obtain. Those data that are available are generally of a secondary and generic nature.

Nonetheless, it is clear that current activities have neglected many countries, technologies and 'innovation system functions' as discussed in Fig. 1. Because of this, there is scope for the UNFCCC Technology Mechanism to fill a range of 'technology innovation' gaps. Below are some preliminary recommendations of broad areas on which the Technology Mechanism (in particular the Climate Technology Centre and Network (CTCN) as its 'implementation arm') could focus its activities.

A wealth of initiatives focuses on inter-linkages, including activities such as networking, advocacy and information sharing, possibly because this is a relatively cost-effective intervention area (it is often considered the 'low-hanging fruit' in technology cooperation). Funding actual R&D, sustained institutional capacity, or innovation capabilities is costly and risky compared to funding a one-off training, facilitating the development of a stakeholder dialogue platform, or organising a matchmaking event. Funding for R&D constitutes a gap that the TM could help fill. In addition, it seems that many initiatives seem more set on increasing linkages between foreign and domestic actors, rather than the actors within a country. The network part of the CTCN could perhaps be developed to support national networks around low-carbon technologies as well as international ones.

Although not for technology transfer in its official aims, the CDM has played a key role in scaled market formation, where other initiatives lacked the required funding levels for making such a difference. It follows that, with regards to innovation (and notwithstanding other equally valid reasons), the prevailing low carbon prices and waning market formation within the CDM hinder the diffusion of low-carbon technology, including incremental innovations to adapt technology to local circumstances. Market formation functions – there are many ways to fulfil those other than through a carbon market – could also be considered by the TM.

In general, studies and documentation do not mention the user community – in particular households and consumers – as an actor that needs to be involved in technological innovation. Yet, the innovation literature is increasingly recognisant of the role that users and consumers can play in shaping and guiding the direction of innovation, and improving processes of incremental innovation. Increased emphasis on user communities would arguably be an asset in future interventions aimed at promoting technology innovation.

So what are the gaps that the Technology Mechanism can fill? The first obvious gap is in the field of research and development, which is often facilitated, but rarely directly supported, through the existing programmes. Research institutions and universities can be assisted in fulfilling their function of knowledge and workforce development by there being earmarked R&D funding for targeted research as well as networking with research institutions abroad. This point has been made by earlier assessments (Ockwell et al. 2014).

Governments can be supported in developing policies for improving technological innovation systems in their locality. Based on the experience from, for example, the Latin American Energy Organization, a regional centre of excellence, exchange of practices, possibly through regional fora, could arguably go a long way toward supporting more robust technology innovation systems and policies. Connected with the point in the previous paragraph, governments could also be supported in making funding available for actual research and development activities beyond facilitation, and for market formation.

In this review we also found that, while international linkages are often supported, national systems and connections may be weak. It is therefore recommended that the CTCN collaborates with CICs in those countries where they are being set up, to connect business opportunities in climate technology with users, government policy and legislation, and research institutions within countries.

Not least, we recommend that the Technology Mechanism explores how the innovation capabilities of relevant actors have been promoted in the past. This might be easier in sectors were technology providers are few in number and technology recipients are concentrated. Analysing this and drawing lessons that could be applied to the energy sector is arguably a relevant task for the Technology Mechanism– and could also constitute a relevant research agenda for international low-carbon technology transfer.

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Article 8

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SPECIAL ISSUE

Advancing methodological thinking and practice for development-compatible climate policy planning

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Abstract There are growing calls for identifying climate mitigation and adaptation policy packages that would also support human development objectives at the national and regional levels. The literature on climate policy analysis and impact assessment continues to be driven by standard economics with its body of competitive general equilibrium optimization models and cost-benefit analysis techniques of aggregation and monetization. However, its recommendations for climate action are often based on highly restrictive underlying assumptions, which have been increasingly criticized for being too prescriptive, not adequately capturing salient observed socioeconomic realities, and not acknowledging pluralism in values. The main aim of this paper is to put forward a new methodological approach that seeks to address these deficiencies. A generic but comprehensive framework eliciting mitigation-adaptation-development interactions, accounting for institutional barriers, and drawing on a combination of an emerging body of new climate economics and multi-criteria decision analysis is suggested. We purport that, by using this framework, multi-dimensional impacts and multi-stakeholder interests could be better represented when planning climate policy actions. We also argue that analytical tools drawing on economic thinking which embraces interdisciplinary

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analysis and deep uncertainty and avoids the fallacy of unique optimal solutions, may deliver more effective strategies for pushing economies onto the transformational pathways required.

Keywords Climate policy · Development · Impact assessment · Planning · Climate economics · Multi-criteria decision analysis

1 Setting the context

A critical challenge today is that, if man-made emissions of greenhouse gases are not urgently and drastically reduced, human societies across the globe may be confronted with dangerous tipping points in the climate system. Uncertainties in the precise amplitude of long-term changes in the global climate and their exact potential impacts at the regional and local scales continue to persist. However, there is strong consensus amongst climate scientists that our planet's climate is shifting rapidly and that recorded climatic changes, particularly since mid-nineteenth century, are very likely to be human-induced through the accelerated release of greenhouse gas (GHG) emissions in the atmosphere (AAAS 2009; IPCC 2013). More extreme weather events such as floods and droughts are already being observed and there is growing evidence and confidence that these are linked to anthropogenic increases in GHG atmospheric concentrations (Panton et al. 2008; IPCC 2012, 2013).

Strong and rapid climate change mitigation and adaptation actions are warranted worldwide. However, international and national policy responses on this front have hitherto been poor, to say the least. Current worldwide climate policy pledges are far from sufficient or able to make a significant dent in curbing the relentless rise in global greenhouse gas emissions and meet climate change targets, such as the 2 °C global warming target by end of 2100. Even if one takes an optimistic view and assumes that all current country pledges to reduce emissions are to be implemented in practice, a significant gap between emission levels consistent with a 2 °C limit and those resulting from the pledges would still be expected in 2020 (UNEP 2013). Furthermore, this gap has been increasing over recent years, meaning that the world would have to rely on more difficult and costlier means after 2020, in order to keep the rise in global average temperature below 2 °C by end of this century (UNEP 2010, 2012, 2013).

Reasons why climate pledges and actions are far from sufficient may be at least partly attributed to intertwining political and epistemological factors. On one hand, there has been a lack of political will and poor international institutional and resource mobilization to this end. On the other hand, a large body of standard climate economics literature has mostly emphasized the burden of structurally changing energy and economic systems towards climate resilient low-carbon development pathways. Mitigation-induced economic welfare losses or the costs of compliance as percentage of national income relative to a baseline are frequently highlighted (e.g. Nordhaus 2010; Edenhofer et al. 2010), whilst important issues of risks and ethics (Dietz and Stern 2008) and the potential benefits (including avoided damages) that might endogenously emerge from such transformational shifts are often side-lined. In other words, the climate policy planning process is complicated by the sheer complexity of the linkages in terms of synergies and trade-offs between climate change-related policy goals and broader developmental policy objectives.

Despite the absence of a global climate deal, both developed and developing countries are nonetheless increasingly taking action at the national and sub-national levels, for a variety of reasons, such as energy security, energy dependency, and local pollution (Climate Policy Initiative 2013). There is also heightened demand for practical assistance to governments, particularly in developing countries, in preparing their climate change mitigation and adaptation strategies and accessing international climate finance. Some developing countries are still at an early stage of developing formal climate change policy plans and identifying specific nationally appropriate mitigation actions (NAMAs) and national adaptation plans and actions (NAPAs).

The aim of this paper is to put forward a novel methodological framework that takes the above challenges into due consideration and offers an alternative practical approach to the formulation of climate policy plans, particularly at the country level. The methodology, which we label MCA4climate (Multi-Criteria Analysis for climate change), draws on a combination of new economics of climate change and a multi-criteria decision analysis approach to identifying, assessing, and prioritizing climate policy options that support national development goals and account for the relevant ethical values at play.

2 A brief review of methodological approaches to climate policy planning

Reducing man-made emissions is conventionally associated with burden sharing and sharing the pain, instead of sharing the benefits and allowing all parties to gain from universal access to clean energy services (Moomaw and Papa 2012). The possibility of policy-induced green economic growth occurring at greater rates than those of business-as-usual or brown growth is typically ruled out by default in standard economics. This typically draws on representative-agent utilitarianism, perfectly rational and self-interested behaviour, competitive general equilibrium theory, and optimization techniques, whilst neglecting strong kinds of uncertainty, such as fundamental uncertainty (Dequech 2008). According to traditional economic theory, the economy has an equilibrium point to which it naturally progresses, which has raised major concerns as to its ability to meaningfully represent socioeconomic realities (Beinhocker 2007).

There are certainly, particularly upfront, investment costs or expenditures involved when shifting efforts and resources away from current practices towards more sustainable societies. However, any investment bears a return, and there are strong reasons to believe that these may substantially outweigh the costs, particularly when costs are defined in a broader social sense. Furthermore, even when costs are defined in strict economic terms, stringent climate stabilization efforts may still result in macroeconomic benefits and increased economic output. This may occur via technological innovation dynamics, improved competitiveness, shifting the tax burden from employment and income to environmental pollution, and market diffusion and spill over effects induced by global trade and technological transfer (Jochem and Madlener 2003; Barker et al. 2012; Bosquet 2000). System-wide effects need to be also considered, as an intervention in a particular sector may reverberate across the entire economy. For example, increasing active travel (walking and cycling) instead of using private cars has been shown to reduce costs to the healthcare services (and improve fiscal sustainability prospects) by reducing prevalence of some chronic diseases (Jarrett et al. 2012). Investment therefore in transport infrastructure to promote active travel and reduce emissions can lead to cost savings and benefits elsewhere, such as the health sector.

No-regret options can also offer substantial incentives for climate action, although these are largely regarded as incompatible with traditional economics since it is assumed that if such options were possible they would have already occurred under optimal equilibrium (Maréchal 2007). Having said this, there are some recent developments in the CGE (Computable General Equilibrium) traditional economics literature that accommodate the suboptimal behaviour of economic systems, such as the DSGE (Dynamic Stochastic General Equilibrium) models. These allow for suboptimal macroeconomic behaviour, such as the existence of involuntary unemployment (Kemfert 2003). Nonetheless, few have been applied to climate policy analysis, and, furthermore, they still assume that economies revert to market equilibrium conditions in the long run, which may not necessarily be the case. Some examples include the QUEST (QUarterly European Simulation Tool) III new-Keynesian DSGE model used by the European

Commission (Conte et al. 2010), a DSGE model for the Polish economy (Bukowski and Kowal 2010), and a DSGE model for China (Schenker 2011). In addition, optimal growth and equilibrium models function on the descriptive representative-agent assumption, which has been shown to cause an intrinsic (regressive) distributional bias in favour of the rich and produce questionable optimal emissions recommendations (Skott and Davis 2013). This constitutes a serious issue for social wellbeing should climate action follow in the footsteps of such recommendations.

The stern insistence on the traditional economic (static and inter-temporal) optimization and equilibrium theory has resulted in the dominance of a particular methodology for framing thinking and decision-making in a large range of economic, social and environmental problems, including that of climate change, i.e. the cost-benefit analysis (CBA) approach. CBA provides a strong theoretical framework for the maximization of resource allocation efficiency, with the particular standard variant of market or price-centred valuation being the most commonly used (Sen 2000). This takes a utilitarian perspective by providing monetary valuations to all impacts involved. It compares the marginal costs of a mitigation or adaptation policy with the marginal benefits associated with the climate change that is avoided (including ancillary benefits), in order to identify the most beneficial (economically efficient) policy response (Dessler and Parson 2006). Marginal in this context refers to the additional cost that will be incurred by the current emission to the atmosphere of one unit of greenhouse gas. CBA may be well suited for the pure financial feasibility of investment projects or efficient financial allocation decision-making, where future financial flows may be readily identified and predicted, monetary aggregation justifiable, and price setting clear-cut. Nonetheless, the standard CBA approach has major limitations when applied to the long-term, multi-dimensional, challenging problem of climate change. This is in part because of "the incredible magnitude of the deep structural uncertainties that are involved in the climate change analysis" (Weitzman 2009: 18).

Within the context of dealing with climate change with highly complex features, such as future time, doubt, and irreversibility, standard CBA falters and implementing it is no longer a technical task because many subjective choices are due (Verbruggen 2013). Several non-market impacts, or externalities, are difficult, and we would argue even unethical, to price, and as a result do not figure in the evaluation of costs and benefits. There are also fundamental concerns about intergenerational equity (Broome 2008) and, therefore, the appropriate discount rate to use in CBA analysis. CBA studies are highly sensitive to the choice of discount rates (Egenhofer et al. 2006; Wright and Erickson 2003; Ackerman 2008), reducing the robustness and reliability of their findings and estimations.

Despite the dominance of the CBA method, particularly in its traditional format which does not incorporate issues of deep uncertainty and stakeholder participation (Chambwera et al. 2012), alternative economic approaches and models are nonetheless being developed and increasingly used in the analysis of and decision-support for climate action. Such alternatives include cost-effectiveness analysis (CEA), robust decision-making approaches (RDMA) and multi-criteria decision-analysis (MCDA), which are briefly summarized and compared in Table 1.

CEA is a technique that can be used to identify least-cost options to meet a certain, pre-defined or fixed target or policy objective, for example, in the case of mitigation, the reduction in GHG emissions to particular levels at different periods in time (Haines et al. 2009). As policy intervention costs constitute the key variable of consideration and as it is subjected to finding cost-minimal solutions, CEA does not necessarily require the quantification of benefits, which can be fixed beforehand, such as reducing disaster fatalities and losses. A critical question, however, remains the identification of a threshold (e.g. permissible increase in global average temperature or the willingness to pay per unit gain), which may also be the subject of heavy debate.

Table 1 A summary of different decision-support techniques, their pros and cons, and their suitability for being applied to climate change policy planning

Decision support technique	Decision criterion	Advantages	Challenges	Application	References
CBA[a]	Optimality: maximize the money value of social welfare	Rigorous framework based on aggregating costs and benefits to a single number; readily compares and prioritizes options based on net monetized benefits	All costs and benefits must be monetized and aggregated; difficulty in representing plural values; takes no account of uncertainty; assumes 'marginal' changes	Well-specified interventions with tangible price-centered benefits and costs	Pearce et al. (2006); Boardman et al. (2010); Dietz and Hepburn (2013)
CEA	Least cost: minimize costs	Ambition level fixed, and only costs to be compared. Intangible benefits (e.g. avoided loss of life) do not need be monetized	Produces only a single solution, ambition level needs to be agreed upon; usually takes no account of uncertainty	Well-specified interventions with important non-monetary targets	Haines et al. (2009); UNFCCC (2011)
RDMA	Satisfy objectives coupled with explicit characterization of uncertainty	Explicitly addresses uncertainty and robustness	Computationally very demanding	Interventions with large uncertainties and long timeframes using a scenario approach	Weaver et al. (2013); Hall et al. (2012); Walker et al. (2013)
MCDA	Balance multiple objectives	Facilitates stakeholder participation; allows for multiple solutions; impact assessments retain close links to natural units; integrates objective measurement with subjective values	Effective elicitation of subjective judgments may be difficult to realize in practice; possibility of multiple solutions may make consensus difficult to achieve; facilitation needed for comprehensive stakeholder engagement	Multiple and systemic interventions involving plural values embedded in a process and participatory-based approach	Figueira et al. (2005); Belton and Stewart (2002); Gregory et al. (2012); De Bruin et al. (2009); Bell et al. (2003)

Uncertainty within the table above refers to events with unknown probabilities, also known as 'Knightian uncertainty' in economics (Knight 1921). *CBA* Cost-benefit analysis; *CEA* Cost-effectiveness analysis; *RDMA* Robust decision-making approaches; *MCDA* multi-criteria decision analysis

[a] The characterization of CBA is made primarily with reference to the standard version most commonly used in the literature, which draws on price-centred valuations and optimisation, equilibrium and representative agent economics, and does not account for 'deep' uncertainty or stakeholder participation

RDMA methods have seen limited use in the area of climate change to date, though they are receiving increasing attention. RDMA essentially provides an analytical decision-support framework for situations characterized by high uncertainty. Within this context, uncertainty refers to the lack of agreement among interested parties, lack of analytical approaches to analyze the issue at hand, lack of knowledge about the state and trends of the parameters affecting that issue, or any combination of these. Rather than attempting to make decisions on the basis of predictions of future states in variables of interest, RDMA attempts to identify the full range of plausible future states and, on that basis, make decisions that are robust across as wide a range as possible of those future states. A key aspect is the notion of iteration and repeated analysis with modified assumptions and scenarios. Two main families of RDMA approaches can be distinguished, static and dynamic. The latter take better account of cost-effectiveness considerations, but are much more demanding in terms of human capital and data collection capacities. A recent effort to prepare a water management plan for the city of Ho Chi Minh in Vietnam illustrates the trade-offs between these two approaches (World Bank 2013). Quantitatively, it may mean running many simulations for tracing out uncertainty across key variables. Methods are nevertheless rather complex and often require the use of advanced statistical and mathematical methods (Lempert and Collins 2007; Lempert 2012; Ranger et al. 2010).

In the area of climate change, MCDA studies constitute a relatively narrow body of analysis in comparison to more established evaluation methods when applied to climate change policy analysis. Indeed, despite MCDA being recognized for some time as a valid tool with an important role to play in evaluating trade-offs between climate policy alternatives over multiple, disparate and often conflicting criteria (Bell et al. 2001, 2003), its use in this area remains limited. MCDA has been nonetheless applied extensively to environmental management choices (e.g. Gregory et al. 2012; Khalili and Duecker 2013; Hämäläinen et al. 2010; Kiker et al. 2005; Huang et al. 2011). We would argue though that both the nature of the climate change policy decision problem and the societal responses to this differ significantly from those associated with most environmental issues. Firstly, from a scale perspective, climate change is affecting our entire planet, both human societies and ecological systems, whereas environmental problems occur at a smaller scale, and are typically dealt with locally. Secondly, solutions to climate change entail systemic shifts or deep transformations in our energy and economy, whereas environmental problems can often be remedied without necessarily requiring the fundamental restructuring of our production systems (e.g. end-of-pipe technologies dealing with local pollution versus widespread replacement of oil refineries with low-carbon technologies mitigating GHG emissions).

Having said this, some potential benefits of using MCDA have been demonstrated recently in: the assessment of emissions control options (Solomon and Hughey 2007); carbon capture and storage measures (Gough and Shackley 2006); mitigation policy instruments (Konidari and Mavrakis 2006, 2007; Grafakos et al. 2010); sustainable energy options (Wang et al. 2009; Ehrgott et al. 2010b); and prioritization of water management schemes (Yang et al. 2012; Yilmaz and Harmancioglu 2010). However scarce they may still be, these studies have made some headway in demonstrating the value of using MCDA tools to climate decision-making.

Notwithstanding, the use of alternative frameworks such as RDMA and MCDA continues to be in severe minority in the area of climate change. In addition, the economic thinking underpinning assessments that are used in both CBA and non-CBA studies is seldom questioned, particularly in terms of departing from the traditional optimization equilibrium economics advocating monetization of all impacts and imposing representative and fully rationalistic behaviour on all agents of change, For example, a recent survey of the literature (Scrieciu et al. 2013a) revealed that, out of 30 climate-economy models considered in seven widely-cited model comparison studies in the area of climate mitigation economics, including those used in the reporting of the United Nations Intergovernmental Panel on Climate Change (IPCC), only one model (the E3MG model as in e.g. Barker et al. 2012) adopted a non-optimization and non-equilibrium simulation approach to the issue. Finally, the wider development implications of climate interventions, such as the scope for poverty alleviating mitigation action at the national or local level continue to be insufficiently understood, although important efforts have been made in this respect. For example, the Climate and Development Knowledge Network (CDKN), the Mitigation Action Plans and Scenarios (MAPS) programme, and the Low Emissions Development Strategies Global Partnership (LEDS GP), to name but a few, represent important institutional and research-support efforts in this respect. As is gradually being recognized, benefits essentially cut across many sectors and actors, and strongly interact with non-climate policies, one of the implications being that the standard CBA approach with its narrow focus on monetary outcomes becomes severely challenged (Mechler 2013).

3 Conceptualizing the MCA4climate framework

The MCA4climate methodological framework that this paper advocates is chiefly based on three crucial components, which are captured in Fig. 1. In their totality, these aim to support a systematic assessment and strategic planning of development-compatible climate actions. The proposed framework is chiefly concerned with issues actively operating at the interface between climate policy and wider development issues, and also incorporating, where feasible, mitigation-adaptation interactions. It seeks to help identify which climate policy actions have the most potential in influencing contextualized human development and environmental sustainability outcomes, whilst meeting their primary climate objectives.

First, there is a set of guiding principles or good practice evaluation standards that is argued to be critical for a meaningful and robust formulation of pro-development climate policies. Second, there is a comprehensive and systematic criteria tree, which provides a generic and structured development impact assessment and climate policy evaluation template, spanning financial, economic, social, environmental, climate and institutional dimensions. Alongside this generic criteria tree, for each of the key areas of adaptation and mitigation, a detailed folio of expert advice could support the interpretation and customization of the generic criteria tree to a specific area of climate policy intervention. And third, there is the process of developing and using MCDA models to support the transparent identification and prioritization of development-compatible climate policy options. This process necessarily involves and thereby facilitates the active engagement of stakeholders over the entire duration of the policy design, evaluation, planning, and implementation phases, through a series of well-defined steps that operationalize the conceptual approach. The first two components are further described in this section, whereas the MCDA process is addressed in the following section.

The MCA4climate framework has been primarily developed with a view to *ex ante* applications, i.e. to evaluate policies before they are adopted. It is equally valid though to apply the approach to *ex post* evaluations. In this case, monitoring, reporting and verification issues and ensuring flexibility in policy design play an important role (e.g. focusing on the feedback loop between the third and first components of the MCA4climate framework as illustrated by the dashed arrow line in the right side of Fig. 1).

As such, the added value of our proposed approach to the existing literature on climate policy impact assessment and decision analysis is fourfold. First, as its name suggests, it focuses on the application of multi-criteria decision analysis to the climate problem and its

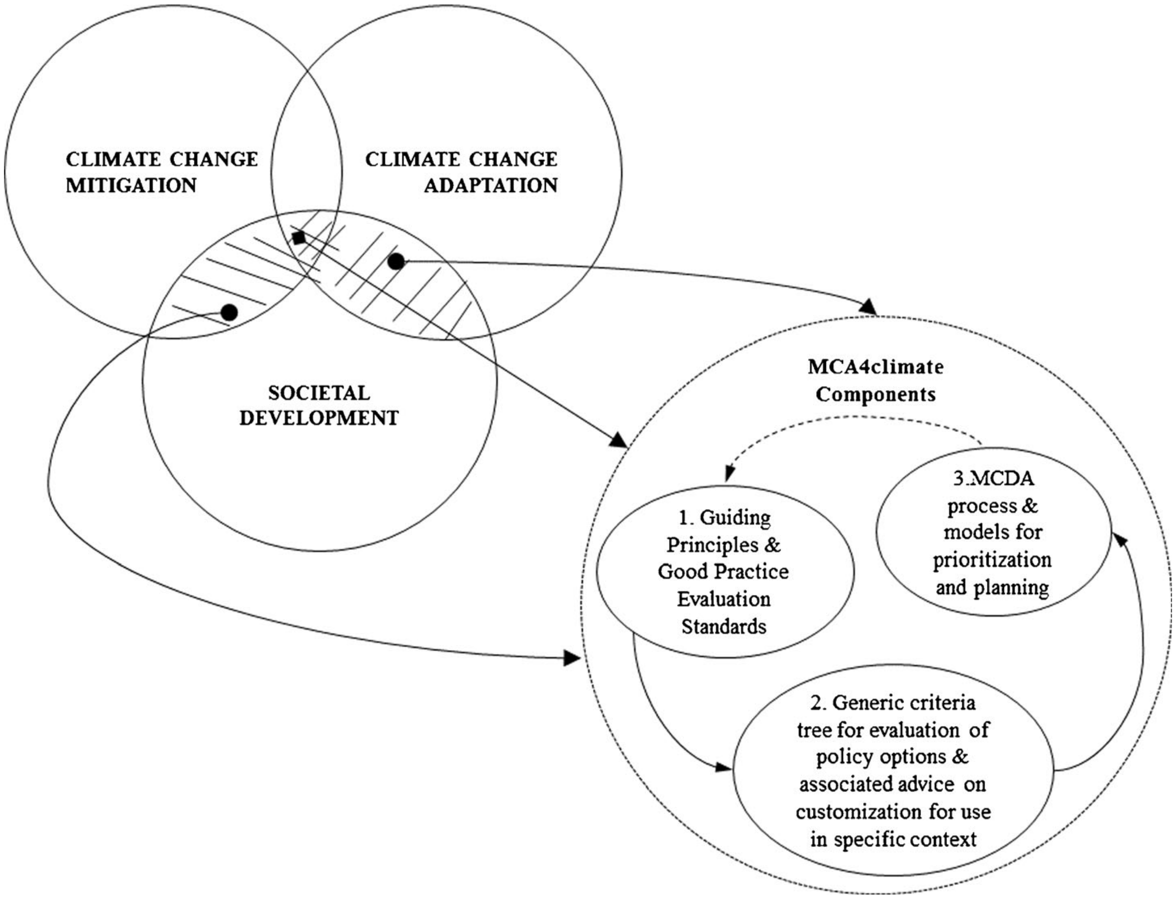

Fig. 1 The general structure and main components of the MCA4climate methodological framework approach. The top left circles illustrate the scope of the MCA4climate methodological approach, which is to identify, assess, and prioritize climate policy options that take account of the interactions between mitigation, adaptation, and development. The bottom right hand panel of circles portrays the three main components that form the basis of the methodological framework explained and presented in this paper

policy responses (discussed in more detail in Section 4), which as outlined above has been less prevalent in the climate policy literature so far. Second, MCA4climate offers a generic framework that may be applied across a wide range of mitigation and adaptation topics and policy options. It is generic, since its fundamental approach and structure can be translated into context-specific variants tailored to a wide array of national or local circumstances. In other words, the framework being advanced in this paper is arguably both widely applicable and flexible enough to cater for the diverse circumstances in which climate decision-making is typically embedded. This is particularly valid within the context of developing countries, for which institutional barriers to climate action are prevalent and for which the climate problem may not figure high on national or regional policy agendas, unless they are explicitly coupled to development objectives. For instance, a major component of our framework is its institutional or governance dimension, against which any climate policy measures need to be evaluated in order to render meaningful situational descriptions. This supports both the universal applicability and contextualization of the approach, and lends a more practical dimension to planning and prioritization of actions.

Third, the economic principles underpinning the MCA4climate approach depart significantly from traditional economic theory, particularly in its neoclassical utilitarian form and its associated value-neutral equilibrium and optimization modelling apparatus. In other words, a different kind of economics (relative to CBA economics) is called for, which embraces an interdisciplinary perspective, pluralism, and combines objective assessments with value judgements. Furthermore, evaluating future socioeconomic impacts, and the benefits and costs of mitigation and adaptation policies, typically involves the use of detailed empirical research and modelling. This inevitably rests upon a number of choices about the methodological approach and underlying assumptions, which have important consequences for socioeconomic projections and, therefore, the ultimate selection of policies to be implemented (Scrieciu et al. 2013b). Chief among these choices are baseline macroeconomic assumptions; technological innovation, learning, dynamics and feedbacks; no-regrets options for mitigation and adaptation; monetary valuation and non-marketed impacts; discounting future costs and impacts; time horizon of the analysis; and risk and uncertainty. Traditional economic approaches to these issues are arguably ill suited to offer good practice evaluation standards in this respect. This is partly because human preferences, ecological properties, and technological possibilities cannot be valuated solely through utilitarian lenses and standard welfare economic theory (Söderholm and Sundqvist 2003), but would require instead a conceptual pluralism approach to the concepts of value, value systems, and valuation (Farber et al. 2002). It is also partly because standard economics techniques tend to neglect important ethical questions (Booth 1994) and overlook the variability in value judgements across population and across time (the so-called value heterogeneity and value endogeneity as defined in Sen 1988). Put differently, the MCA4climate approach being proposed goes beyond the mere application of decision analysis to climate policy making, and attempts to reshape economic thinking underpinning climate policy analysis and the evaluation of related development impacts.

Fourth, the MCA4climate perspective aligns well with recent thinking prevalent in climate science and economics regarding notions of low-regrets, uncertainty, iteration and process focus. As one example, the recent United Nations Intergovernmental Panel on Climate Change (IPCC) report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation (IPCC 2012) demonstrates that climate change is shaping risks from climate extremes and there is the need for bolstering resilience to climate impacts. At the same time, it shows that, at least in the short to medium term, many non-climatic factors are fundamentally driving risk (Rogelj et al. 2013). As well, uncertainties about future projections of risk are numerous and unlikely to go away soon. The IPCC suggests that an approach grounded in a low regrets strategy may usefully provide for more robust mitigation and adaptation strategies. Such an approach has high potential for reducing long-term risk and at the same time provide for short-term benefits in terms of, for example, reducing vulnerabilities today in the case of adaptation. As one consequence, the above-mentioned IPCC report suggests to focus more strongly on iteration, process focus, learning and innovative thinking, which are attributes that can be closely aligned with a multi-criteria approach (IPCC 2012).

In short, we argue that the combination of these four factors summarizes the contribution of our MCA4climate approach to the literature situated at the intersection between climate policy analysis, climate economics, development impact assessment, and decision analysis strands. Moreover, the proposed methodological framework rests at the border between research and practice, and, as such, it aims to render methodological thinking in this area practical and with immediate application to real-life climate change related decision problems.

3.1 Guiding principles and good practices for climate policy evaluation

New thinking on the economics of climate change and analytical tools for decision support are emerging in response to the limitations of traditional economic approaches, and their assumptions on economic behaviour, ecological properties, and socio-technical responses. It may be argued that new economics brings under one umbrella a series of common elements spanning disparate schools of economic thought and can draw on both mainstream and heterodox thinking. As argued in Barker (2008), the term new economics may be understood through the prism of Boulding's work (1992) to include systems thinking, complexity, evolutionary and Post Keynesian theory with an emphasis on institutions, non-linear dynamics, and deep uncertainty. In other words, the new economics literature puts forward analysis that overall departs from the standard practice in contemporary economics of combining optimization, equilibrium, and the aggregation of heterogeneous actors as per the representative agent assumption. With application to climate change, a new economics approach would explicitly account for systemic effects, risk and uncertainty, technological change, multidimensional impacts across space and time, ethical perspectives of multiple stakeholders, and the institutional constraints and drivers for climate policy implementation (Barker 2008; Dietz and Stern 2008; Heal 2009; Stern 2007). As such, an adequate all-embracing framework would need to offer alternative approaches to understanding and incorporating underlying value judgments, and consider the multi-dimensional interactions between the economy, environment and society, which often do not lend themselves to monetization and aggregation. It would also need to recognize the importance of catastrophic risks and irreducible uncertainty, warranting a precautionary approach to climate policy. Finally, a solid understanding of the economics of climate change policies would call upon increased empiricism in understanding socioeconomic behaviour and relations, incorporate policy-induced technological change, and explicitly address the role of institutional drivers and barriers to policy planning, implementation, monitoring and verification (Scrieciu et al. 2013b).

The MCA4climate conceptual framework draws on this growing body of new (climate) economics literature. In this respect, we argue that a meaningful, effective and comprehensive assessment and planning of climate policies should rest on three main principles. The first is that climate change policy has multi-dimensional implications for human societies and the environment, affecting multiple interests and calling for the consideration of a wide range of values and priorities. The second principle asserts that policy responses to climate change may contribute, if adequately formulated, towards meeting country-specific development objectives, and that there may not necessarily be trade-offs between climate action and the economic performance or poverty alleviation targets of a given country. The third principle states that non-monetary values, uncertainty and the long-term dynamics of environmental, socioeconomic, and technological systems should be inherent to the formulation of any responses to the climate change problem.

Projecting future impacts, and calculating and exploring likely benefits and costs for society as a result of climate intervention inevitably involve a number of choices on the methodological approach deployed and its underlying epistemological assumptions. As a result, we also identify and propose a set of good practice evaluation standards with an emphasis on the social economic dimension that could better guide future assessments in the area of climate policy analysis and planning. These constitute the first component of our overall MCA4climate methodological framework approach and are outlined in Table 2. They are to be taken as a wish list, as in practice, actors may lack the capacity to implement these, though they should be regarded as potential aspects to be considered. Preferably and where relevant, both mitigation and adaptation options should be included in the evaluation and planning of development-compatible climate action.

3.2 Evaluation criteria tree linking climate policy with development

At the core of the MCA4climate framework, we propose a systematically structured and comprehensive hierarchical criteria tree. This contains a set of generic criteria, against which climate policy planners can evaluate proposed climate-policy actions with regard to their

Table 2 Proposed critical issues and good practice evaluation standards to be considered in the performance of robust climate policy analysis and impact assessment

Critical issue to consider for climate policy evaluation	General suggestions on good practice evaluation standards for the socioeconomic analysis of climate action
Baseline formulation	Consider issues of transparency (such as stating definitions and purpose of the baseline, or providing information on emission factors and technology learning rates used for example) as well as uncertainty considerations (notably the methods used to calculate GDP projections and whether or not sensitivity analyses have been carried out).
Macroeconomic assumptions	Incorporate and, where possible, endogenously account for assumptions on anticipated growth rates or changes in population numbers, GDP, investment, trade, income and demographic distribution, health status, sectoral employment, government budgets and policies, energy prices, and competing technologies. Climate variability, GHG emissions and climate impacts need to be explicitly included in baselines.
Technological innovation	Account for policy-induced and endogenous technological change (e.g. as in 'learning curve' or 'learning by doing' analyses) and include at least a small number of crucial feedback and system dynamic effects of policy choices.
No- and low-regrets options and co-benefits	Use the best available, disaggregated information on no- or low-regrets options and co-benefits. These will normally be the first priorities in any climate policy proposal, as they reduce the overall costs of a comprehensive climate-policy.
Monetary valuation and non-marketed impacts	Consider interactions between the economy, environment and society in their multi-dimensional, often non-monetized integrity. Apply only the most established and least controversial valuations of non-market benefits, and in addition, report these in their natural units (including qualitative appraisals).
Discounting future costs and impacts	Explicitly state the value judgements underlying the (economic) analyses, particularly judgements about the importance of current versus future generations, with implications for discounting.
Risk and uncertainty	Cover the entire spectrum of uncertainty, including catastrophic risks and irreducible uncertainty, for example, by the development and use of scenario analysis and the consideration of adaptability.
Institutional constraints and enablers	Identify context-specific institutional factors that might constrain or support climate policy implementation. Account for the market and non-market barriers, or the transaction and transition costs of policy implementation, as well as the contribution of the civic sector and social collective action.
Fiscal sustainability[a]	Explicitly account for climate policy impacts on fiscal sustainability and the short to long run implications for fiscal systems.

Based on Stanton and Ackerman (2011), Ackerman et al. (2011), UNEP (2011), Scrieciu et al. (2013b) and Puig et al. (2013)

[a] Fiscal sustainability is discussed at length in Ekins and Speck of this special issue

potential contribution to a broad range of climate, environmental and socio-economic development objectives (Fig. 2). An important characteristic of the criteria tree and a requirement of the MCDA approach that we are advocating is that the selected criteria are judgementally independent of each other. That is, the assessment of preference with regard to the consequences of policy options against any one criterion is independent of preference with regard to any other criterion. This ensures that options can be scored on one criterion without knowing what the scores are on any other. However, preference with regard to the policy options

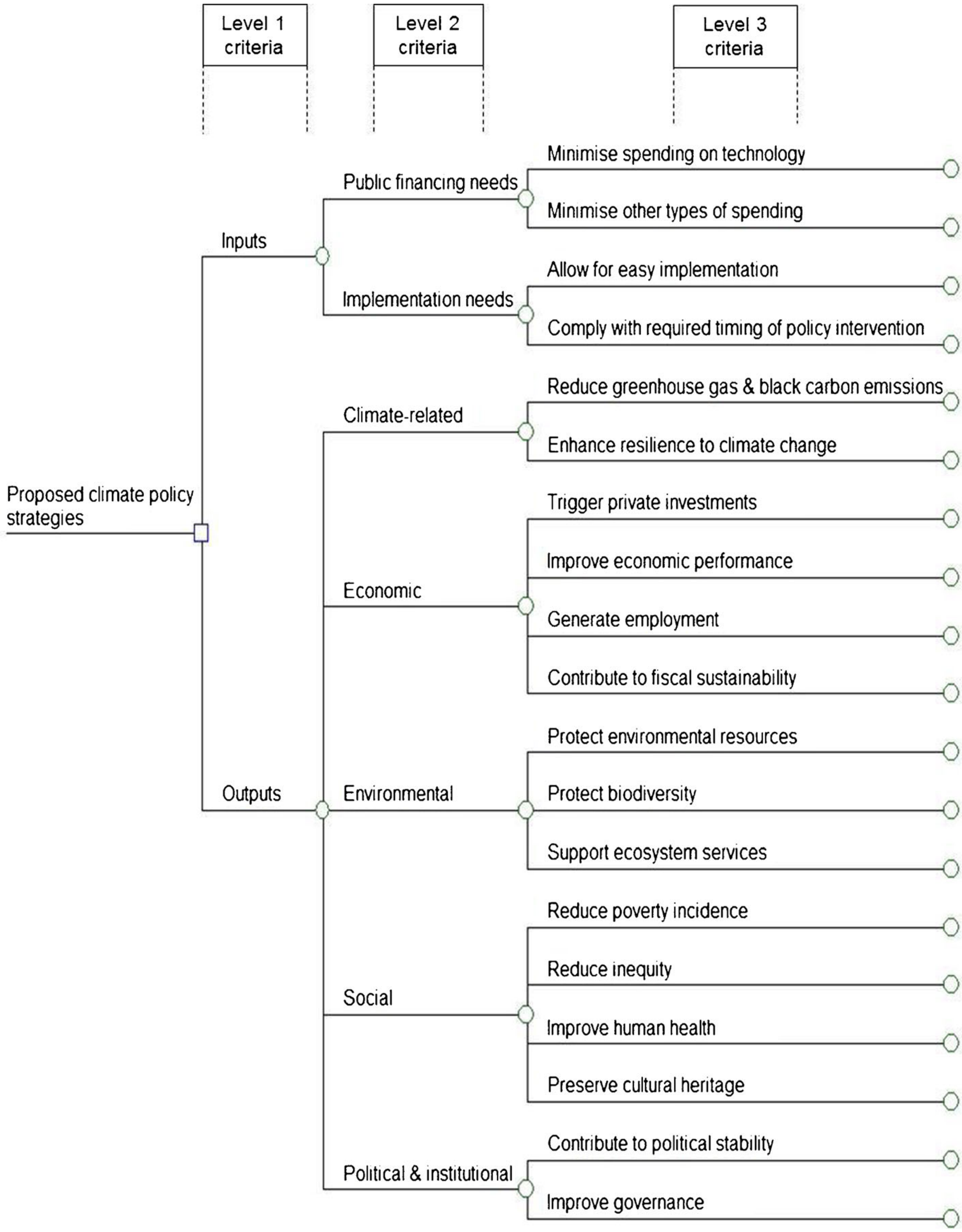

Fig. 2 The generic criteria tree used for evaluating development-compatible climate policy action according to the MCA4climate methodological framework approach. The generic criteria tree of the MCA4climate methodological framework is structured in three layers. The first level consists of inputs (investments and efforts required) versus outputs (impacts) criteria against which climate policy options are evaluated. The second level comprises seven criteria groups, two on the input side and five on the output side, whereas the third-level criteria refer to nineteen criteria, four associated with inputs and fifteen linked to outputs

themselves may not be independent in the sense that it is important to be aware of potential synergies or negative interactions between options. In other words, preferences for portfolios combining two or more options may not be simply derived from (summing up) preferences defined for the options individually.

In public decision-making, it is important to ensure that the set of criteria on which an analysis is based is both value-focused and complete, capturing all relevant concerns; that is, the criteria do not reflect a restricted or partisan perspective on the issue, which might lead to a biased evaluation. In this respect, the generic criteria tree displayed in Fig. 2 has been shaped by extensive, multifarious and systematic consultations amongst leading experts in climate change mitigation and adaptation, and other relevant stakeholders spanning academia, multilateral organizations, and governmental bodies. Put differently, the evaluation template provided by the criteria tree in Fig. 2 was formed through an iterative process of group brainstorming and thought exercises involving around 25 experts, who have participated in the 2-year inception phase of the MCA4climate initiative developed at the United Nations Environment Programme (UNEP 2011). The criteria identified were thought to be important due to their prevalence in both the literature and practical work related to development impact assessment, likely climate change damages, and climate policy planning processes. In addition, the criteria are sufficiently generalized to allow for important flexibility in terms of indicator identification and formulation as a function of the needs and priorities of the country or region under consideration.

The aim of developing the evaluation criteria tree has been to alert decision makers and raise awareness of the complexity and multidimensionality aspects of assessing, planning and implementing climate action in a clear and transparent fashion. As shown in Fig. 2, the generic evaluation criteria tree contains three levels or layers for evaluating development impacts of climate action. On the first level, there are two criteria groups: inputs to (or efforts required for) and outputs (or possible impacts) of proposed policy options. On the second level, inputs and outputs are further split into seven sub-groups of criteria. Two of these relate to the inputs or investment efforts necessary to implement climate actions, i.e. public financing needs and implementation needs, whereas five sub-groups relate to the likely impacts or outputs of climate policy implementation, i.e. the climate-related, economic (including fiscal), environmental, social, and political and institutional dimensions of development. Criteria on the output side can capture either positive or negative impacts. Finally, on the third level of the generic criteria tree, there are a total of 19 generic criteria. Four of these are linked to the input side, which include monetary and non-monetary costs that need to be met for effectively carrying out climate policy interventions, and 15 criteria connect to the output side, which relate to specific impacts on society, the economy and the environment.

Based on these third-level criteria, sets of more specific indicators tailored to the issue under investigation could be identified. The bottom-level generic criteria with examples of quantitative and qualitative indicators are summarized in Table 3. More in-depth practical examples on the interpretation and customization of the generic criteria tree to a specific area of climate policy intervention are provided in another three papers that are also part of this special journal issue: Chalabi and Kovats on health and adaptation, Miller and Belton on water resource management, and de Bremond and Engle on the adaptation of terrestrial ecosystems. These represent complementary theme-specific detailed studies that we argue enhance the contribution of the MCA4climate methodological framework being put forward in this paper.

4 Operationalizing the framework: the use of MCDA in practice

The MCDA term is generic and refers to a collection of formal approaches that take explicit account of multiple criteria in helping individuals or groups explore decisions that matter (Belton and Stewart 2002). Approaches differ in terms of their underpinning philosophy and associated preference model, the nature of the underlying aggregation procedure, processes of value elicitation, and the type of the problems to which they are applicable (see Figueira et al.

Table 3 Description of the 19 third-level generic criteria considered in the MCA4climate framework, with examples of possible indicators

Criterion	Description	Examples of indicators
1. Minimize spending on technology	Financing needs required from the public purse in order to support a particular mix of technologies.	• Differences between market prices and guaranteed electricity prices linked to renewable feed-in tariffs. • Capital and operating expenditures relating to the rendering climate-resilient infra-structure.
2. Minimize other types of spending	Financing needs required from the public purse in order to support a climate-policy measure other than the technology itself.	• The cost of implementing, enforcing and monitoring a policy, such as energy-efficiency standards
3. Allow for easy implementation	The suitability of existing regulatory frameworks and changes in institutional arrangements, including ownership and empowerment, required for pursuing effective and socially-inclusive climate action.	• Required changes in laws and ordinances. • Clearly defined land property rights. • Social acceptability or stakeholder engagement.
4. Comply with required timing of policy intervention	The time necessary for a proposed policy option to become effective and how well that fits in with the need to respond to climate threats.	• Time required for designing energy efficiency policies and time taken by policies to be effective.
5. Reduce GHG and black carbon emissions	The extent to which a climate action reduces the amount of man-made emissions with global warming potential released in the atmosphere.	• Changes in the annual rate or cumulative emissions of GHGs and black carbon emissions.
6. Enhance resilience to climate change	How a policy builds the ability of social-economic and ecological systems to persist in the face of climate change, as well as to transform them into new and more desirable configurations when required.	• Increase in the number and quality of health-related measures (number and qualitative description).
7. Trigger private investments	The potential of a policy to leverage investments from the private sector. This may be determined at the macroeconomic, industry or sectoral level	• The difference between investment costs and energy savings over time for an energy- efficiency policy).
8. Improve economic performance	Economic output, competitiveness and technological change effects arising from climate policy. This may refer to a specific industry or region, as well as to the economy as a whole.	• Price competitiveness (e.g. changes in productivity. • Non-price competitiveness (e.g. trade flow changes).
9. Generate employment	Direct job creation effects of a policy on a specific industry or region plus indirect knock-on effects throughout the rest of the economy, including distributional employment impacts across population cohorts.	• Net amount of jobs created as a consequence of encouraging carbon capture and storage.
10. Contribute to fiscal sustainability	Climate-policy effects on public revenues and expenditures over the business cycle (or on changes between present value of future primary surpluses and current debt levels), measured against those associated with inaction; also see Ekins and Speck paper in this special issue.	• Development of public investment over time, including projected (and realised) public spending on energy-efficiency policies, and changes in government revenue from energy taxes.
11. Protect environmental resources	Policy-induced impacts on water, land and air quality and the corresponding natural resource stocks, where applicable.	• Indoor air quality indicators such as the use of appropriate fuels, pollution control and exposure reduction.

Table 3 (continued)

Criterion	Description	Examples of indicators
12. Protect biodiversity	Supporting the variety of living organisms, the genetic differences among them and the diversity of ecosystems that they inhabit.	• Changes in number of species. • Location of CCS storage potential in nature reserves.
13. Support ecosystem services	Climate-policy impacts on the services of natural ecosystems that humans benefit from, as per the Millennium Assessment (2003) definition of provisioning, regulatory, supporting and cultural services.	• Projected leakage rate into groundwater resources for human consumption under CCS legislative scenarios.
14. Reduce poverty incidence	Impacts of a climate policy on the incidence of income poverty, access poverty and empowerment or social fabric issues.	• Basic energy needs covered (e.g. % of households with access to electricity). • % of household income spent on fuel & electricity.
15. Reduce inequity	Climate policy-induced changes in the systematic disparities between groups of population (intra- generational) or generations (inter-generational) in terms of income and access to resources or services (in addition to the employment and health distributional impacts included in the other criteria).	• Household energy use across income groups. • Inclusion of appropriate stakeholder engagement guidelines for realising empowerment. • Increase in household access to healthcare services and spending by age, sex and socio-economic group.
16. Improve human health	Human-health aspects directly or indirectly affected by climate policy concerning nutrition, vector-borne diseases, water and air-related risks and diseases, and the overall health of populations, including distributional health impacts across population cohorts.	• Reduced mortality and morbidity rates attributable to climate change (number). • Environmental conditions of the housing properties.
17. Preserve cultural heritage	Climate policy-induced impacts on the cultural assets of a country or region, which may refer UNESCO's definition of tangible and intangible cultural heritage. In the case of adaptation, cultural assets at risk due to climate change can be protected, though mal-adaptation may increase these risks. In the case of mitigation, cultural assets may be either endangered or may be further preserved.	• The effect of building a wind farm on culturally-valuable sites. • Avoided deforestation in forests associated with important spiritual or cultural values.
18. Contribute to political stability	Climate policy impacts on changes in conflict and violence risks related to water-stress, food security and migration, as well as on energy security. These risks may be avoided but also multiplied depending on how climate-change impacts are addressed	• Changes in energy security risks due to changes in the vulnerability of a country's energy supply to external factors beyond its control, such as wild fluctuations in oil prices, politically unstable oil import sources, increases in frequency & intensity of extreme events
19. Improve governance	Policy impacts on national or local governance structures, including institutional setups and regulatory frameworks.	• Actions organised at the community-level to help manage and adapt to climate change can improve overall local governance.

2005 and Ehrgott et al. 2010a, for comprehensive overviews of the field). The specific approach embedded in the MCA4climate methodological framework is multi-attribute value analysis (MAVA), which is a well-established method used in the practice of MCDA (Belton and Stewart 2002).

The process of applying MCA4climate involves seven main steps that are aligned with the three key methodological phases of MCDA, namely, problem structuring, model building, and use of the model to inform and challenge thinking about preferred solutions. These steps are summarized in Table 4.

Table 4 Main steps pursued in implementing the MCA4climate methodological framework approach to development-compatible climate policy planning

1. Establish the context
Clarify climate policy goals for mitigation and/or adaptation.
Identify the decision makers and main stakeholders.
Consider the main national socio-economic, political, institutional and environmental circumstances.
2. Identify the options to be evaluated
Draw up a set of mitigation and/or adaptation policy options. These can be a collection of independent policy actions formulated at appropriate levels of detail for the context, or a collection of portfolio options defined by different combinations of one or more individually defined policy options.
3. Agree on criteria and indicators
Consider at what level of criteria the criteria tree analysis should occur,, if it is necessary to modify the generic criteria tree to suit the specific context and determine contextually appropriate theme-specific criteria and indicators.
4. Agree on scenarios, timeline of analysis and methods of assessment
Establish the climate and socio-economic scenarios for the future that are to be considered in the analysis.
Agree on key feedback loops, time-dependent relationships between variables, and time frames for the analysis.
Agree on the methods of assessment that are most suitable for the type of analysis considered.
5. Score the different options
Assess the performance of each policy option against all of the criteria (which may be based on quantitative or qualitative indicators).
Based on this assessment, score the options against the criteria (in each scenario if different scenarios are explicitly modelled).
Examine the performance/score profiles of the options across all criteria to confirm inputs and give an initial indicator of dominating or dominated options.
6. Weight the different criteria and calculate an overall input and output values for each policy option
Assign weights to each criterion to reflect the relative value attributed to improving performance against the different criteria. In some circumstances it may be appropriate to enable different stakeholder groups to assign weights that reflect their specific priorities.
Calculate aggregate weighted scores for each option at each level in the hierarchy (keeping the input group separated from the output groups).
Calculate overall weighted scores on the input side and on the output side.
7. Examine and test the results
Examine the results, comparing the performance profiles of options at each level of the criteria tree to identify options which are strong or weak overall in particular those that are dominating or dominated, options with particular strengths or weaknesses, and options which are good ‘all-rounders’.
Compare pairs of options to identify dominating and dominated options or particular subsets if relevant.
Carry out sensitivity analysis by exploring the impact of altering weights and/or scores on the relative rankings of policy options
Compare the performance of options across different scenarios if explicitly modelled or compare the performance of options according to different stakeholder priorities if elicited.
In light of the results, consider new policy options.

Once the context has been established, including clarifying climate-related and other development policy objectives, the key steps are to: identify policy options or policy portfolios to be evaluated; agree, amongst concerned stakeholders, on the criteria and indicators (starting, we would argue, with those already suggested under this framework); agree on scenarios, the timeline of the analysis and methods of assessment (drawing on the guiding principles and good practice evaluation standards described above); score the different options against the agreed criteria; weight the criteria to reflect different stakeholder perspectives and priorities and use these values, together with the scores, to derive a measure of aggregate performance for each option at higher levels of the criteria tree; and, finally, explore these initial results through appropriate analyses including sensitivity analyses. It needs to be stressed that the process should seek to engage all relevant stakeholders, support a shared understanding of the issues, and identify a commonly-agreed way forward. This would ensure that expertise and values are surfaced and appropriately captured, and that all stakeholders have the opportunity to learn from each other and from the process.

The application of the framework up to the fifth step can provide useful insights into how each policy option performs and may be sufficient to inform decision-making, without attempting to prioritize those options in an explicit way. However, proceeding beyond this step calls for judgment in determining the weights to be assigned to each criterion, reflecting the prioritization of development impacts and the values that concerned stakeholders may attach to the corresponding criteria (step 6). This underpins the calculation of aggregate scores at higher levels of the criteria tree in order to come up with a definitive comparative evaluation of all of the options and enable the exploration of the outcomes through sensitivity analysis (step 7). The analysis up to and including step 5 can be done manually, although an overview of the performance of options is facilitated by formal visual presentations of the scores. The calculation of aggregate scores and associated sensitivity analyses can be done using a spreadsheet, but is greatly assisted by the use of customized decision support tools.

4.1 The use of multi-criteria decision-support methods for consistent scoring and weighting

Unlike CBA, multi-criteria decision analysis has not benefitted from the same political mandate and consequently has been less well known and, to date, less widely applied in support of public policy decision-making. Standard CBA has been, for example, the recognized and required approach to policy appraisal and evaluation in the USA and in the UK for a long time (Shapiro and Morrall 2012; Pearce 1998) and more recently across Europe (e.g. since 2000 for the formulation of the European Commission's Cohesion Policy; European Commission 2008). However, as observed by Gamper and Turcanu (2007), MCDA is gaining momentum relative to the more established analytical methods of cost-benefit and cost-effectiveness analyses in policy evaluation. Others (e.g. Dietz and Morton 2011) have recognized the potentially complementary nature of CBA and MCDA. In particular, the past decade has seen a significant growth in the use of multi-criteria methods across all areas of environmental decision-making (Huang et al. 2011).

The MCDA approach represents a well-defined technique for identifying multiple impacts and aiding decision-making. It facilitates stakeholder engagement and ensures that the different dimensions of climate policies, including those that cannot be easily measured in monetary terms are taken into consideration. Other non-monetary issues (be they quantitative or qualitative), such as morbidity and mortality, equity, environmental damage, avoiding catastrophic risks, and uncertainty can also be taken into consideration, resulting in a more comprehensive analysis of monetary and non-monetary costs, risks and impacts. An attractive feature of some MCDA methods is that the impacts of policies with regard to these different dimensions are assessed by reference to relevant metrics, which are progressively aggregated to provide an overall evaluation if required, but enable options to be compared at the most appropriate level of (dis)aggregation. Thus, the impact of climate policies is broken down into separate elements, for which data can be compiled and assessments made. These independent assessments provide valuable insights into overall costs and benefits, highlighting the strengths and weaknesses of different policies and enabling the identification of dominating and dominated options (Belton and Stewart 2002; Smith and Hitz 2003). In summary, MCDA does not rely solely on the use of market prices and does not impose limits on the forms of criteria or pre-ordain objectives, allowing for consideration of social objectives and other forms of equity rather than focusing only on resource efficiency (Munasinghe 2007).

The first four steps in the MCA4climate conceptual framework (as outlined in Table 4) can be collectively referred to as problem structuring. The importance of effective problem structuring as a participative process was recognized in the field of OR/MS (Operational Research/Management Science) over 25 years ago (Rosenhead 1989) and was soon acknowledged by MCDA researchers and practitioners (Belton 1990; Bouyssou et al. 1993). Belton and Stewart (2010) provide an overview of current thinking and practice with regard to problem structuring for MCDA. The MCA4climate framework was developed through a process which engaged experts across the spectrum of climate-change impacts and in itself provides substantial support for the process of problem structuring in a specific context, including the identification of options to be evaluated and the set of criteria and associated indicators against which to evaluate these. However, as already noted, it is important that this process is an inclusive one that seeks to involve all relevant stakeholders.

The key components of MCDA are: the set of options/alternatives to be evaluated; the criteria against which these are to be evaluated; the scores which define the performance of the options with respect to the criteria; and the weights which reflect the relative importance that decision makers attribute to the criteria. In the multi-attribute value analysis (MAVA) approach to MCDA that underpins the MCA4climate framework, these weights are clearly defined as the trade-offs decision makers would be willing to accept between levels of performance on different criteria, i.e. the increase in performance on criterion A that would compensate for a unit decrease in performance on criterion B. A discussion of the interpretation and assessment of importance weights in different MCDA methods is discussed for instance in Belton and Stewart (2002). In other words, the MCDA component of the MCA4climate framework is chiefly concerned with how to score, weight and prioritize a multitude of climate policy options against a range of development impacts and investment efforts, when several actors are involved in the evaluation and planning processes of development-compatible climate strategies.

The process of scoring options against a specified criterion aims to capture the added value relative to a defined reference point. There are many different ways of scoring options that vary according to the amount of work involved and the extent to which the outcomes are justifiable to a public audience, explainable and replicable. The MCA4climate approach does not impose any particular method for scoring. As an example, the illustrative case studies, which have been undertaken during the initial development phase of MCA4climate approach while hosted at UNEP, primarily adopted a well-specified approach, widely used in MAVA, of direct rating on a 0 to 100 locally defined preference scale (UNEP 2011). Local preference scales are simply scales anchored at their ends by the most and least preferred options on a specific criterion. For example, the preferred option is assigned a preference score of 100, and the least attractive is given a score of zero. Scores are assigned to the remaining options to reflect their performance relative to the two reference points. The underlying scale is an interval scale, which means that strength of preference is represented by relative differences in the allocated scores. Whilst the process of scoring is one that is easy to use in practice, it is important to remember that it should be underpinned by data, to the extent that this is possible, and informed by sound contextual knowledge. The task is a substantial and challenging one that should not be underestimated and would require high level of commitment from the problem-owner. Furthermore, Belton and Stewart (2002) discuss other approaches to scoring that are appropriate in the context of MAVA, for example modelling could be used for some criteria to construct a partial value function that converts the impacts of climate policy options into scores that are comparable.

As with scoring there are many different approaches to weighting criteria and it is important to ensure that the process used is transparent and robust. However, in some circumstances (e.g. the number of criteria is small, or the evaluation reveals a clear pattern of dominating/ dominated options), it may be possible for a decision to be made directly from the scoring information obtained, without the requirement for formal weighting of criteria and the aggregation of values. Where this is not the case, the criteria will need, nonetheless, to be weighted. As mentioned above, in a MAVA, criteria weights reflect the relative worth of value added on different criteria. The meaning of the weights and the associated elicitation process must be well understood by those whose judgments the weights reflect, who should be able to explain and justify the outcomes. As with scoring, this can be achieved by a sound, facilitated, multi-stage elicitation process, involving a number of individuals representing the same stakeholder perspective and forming the basis for discussion that seeks to illuminate and reconcile differences.

Weighting has a significant impact on the aggregated scores for each option. Again using the example of weighting used for the stylized cases contributing to the development of the MCA4climate approach (succinctly summarized below), a sound and commonly used method is swing weighting (Belton and Stewart 2002). Swing weighting is based on comparisons of differences in the same way as for scoring using relative preference scales, and is used to determine the weights across the bottom level of the criteria tree. When all weights have been determined the values are normalized to sum to 1 (simply as a mechanism to keep the aggregate scores at all levels of the tree within the range 0–100). Also, depending on the extent to which involved parties can be expected to have similar priorities, a sharing or comparing approach to determining weights may be more appropriate (Belton and Pictet 1997). A sharing approach seeks to attain an agreed set of weights, possibly starting with the assessment of individual values then seeking to reconcile differences through a process of discussion. A comparing approach accepts that different individuals, or sub-groups of stakeholders, will have different priorities and only seeks agreement on weights within the sub-group, going on to compare the resulting overall evaluations across sub-groups and, if appropriate, to go on to use this as a basis for discussion and negotiation.

The weighting stage of the analysis is necessarily subjective in that there is no value-free or absolute statement of the relative significance of impacts as diverse as those captured in the MCA4climate criteria tree. It is to be expected that different stakeholder groups would prioritize outcomes differently and one of the strengths of MCDA is to enable the exploration of the consequences of those differences. However, it should be recognized that all aspects of decision making and associated methods for support are inherently subjective not only in the importance afforded to different criteria, but also in the selection of what factors should be taken into account and in the measurement of impacts. Even in cases where these are measurable, the value added is not necessarily linearly related to the impact measure. If properly supported, this should be seen as a strength rather than a weakness of MCDA approaches, as discussed below.

The final step in the MCDA process is to explore the performances of policy options at different levels of the value tree through progressive aggregation of the scores and weights, culminating in a comparison of aggregate scores for each of the two main branches of the criteria tree (Fig. 2). A simple plot of each option's aggregate score for outputs versus its aggregate score for inputs enables the visual identification of those options which provide the highest output at a given level of input, the so called efficient options (it should be noted that the ratio of these values is meaningless, as the level of measurement in use is an interval scale). The aggregation model underlying MAVA is a simple weighted sum as potential interactions between criteria are considered in the building of the value tree and nonlinearities in preference are taken into account in scoring the options. The consideration of aggregate values should be accompanied by sensitivity analyses to gain an understanding of the extent to which the results depend on the specified weights and scores. In particular, such analyses can also be used to explore different stakeholder perspectives.

In many cases, the outcomes are relatively insensitive to changes in the scoring and weighting, which gives confidence that the priorities that have been established are robust. In some cases the outcomes may challenge the intuitive expectations of participants in the process, a situation that might surface factors relevant to the decision which have not been included in the analysis or which may cause some participants to review their priorities. If this happens, the model can be used to reconcile the differences.

The process of comparing options can also be used to encourage creative thinking, potentially leading to the identification of new or slightly modified options, which yield greater benefits in relation to costs. For example, it may be possible to address a weakness of an otherwise strong alternative without significant increase in costs. Or it may also be possible to define a climate policy option, which offers many of the benefits of the strongest option, but at lower cost by reducing the benefits, and thus the cost, on criteria that do not carry much weight. Reducing the cost in this way may more than compensate for the loss of benefit, giving an option that is quite beneficial without being too costly. If new options are generated in this way, they should be added to the set of options and evaluated along with the others in a second run. Several iterations of the scoring and weighting procedures may be necessary to arrive at a final decision. The overall process is one that should both support and challenge thinking, with a view to arriving at a decision that is well founded, transparent and justifiable.

4.2 Methodological challenges to the standard MCDA approach

It is recognized that, as with any analytic approach, there are challenges and limitations that need to be understood when using MCDA. Four key challenges are outlined below: subjectivity, dynamics across time, uncertainty, and extreme events.

MCDA has been criticized because of the subjectivity of the inputs. This criticism applies not only to the scores and criteria weights but also the structure of the criteria tree. However, its proponents recognize that there is subjectivity inherent in all decision making. They claim that a particular strength of MCDA is that it provides a framework in which the nature and degree of that subjectivity is made explicit, in order that it can be appropriately and transparently managed, seeking to minimize it where appropriate and explore its impact when relevant to do so. The effort to accommodate subjectivity should not be taken to imply a lack of rigor. On the contrary, it underpins a sound methodology that provides meaningful and reliable outputs. A rigorous approach to the management of subjectivity will seek to adopt a five-pronged approach. First, an experienced facilitator leads the process, who supports and challenges those responsible for providing inputs and recommending decisions. Second, the processes of eliciting inputs to an analysis are well founded and well documented, seeking to incorporate the knowledge and views of relevant stakeholders and appropriate experts with regard to both content (e.g. health impacts) and local context. Third, all elements of an analysis are explainable and justifiable, with reference to objectively measured impacts where appropriate. Fourth, the consequences of differing views of stakeholder groups can be explored through sensitivity analysis, with a view to finding options that perform well from the perspective of all groups, facilitating compromise if it proves difficult to reach consensus. Finally, fifth, the whole process is subject to a broad critique from a diversity of perspectives. Moreover, in addition to providing an effective framework for the management of subjectivity, effective facilitation by a skilled multi-criteria practitioner should seek to guard against recognized potential weighting biases (Hämäläinen and Alaja 2008; Pöyhönen and Hämäläinen 1998).

MCDA methods have not been explicitly developed to model impacts over time and most applications take static rather than inter-temporal or dynamic perspectives of the evaluation of policy alternatives. However, in assessing climate policy alternatives, addressing the time dimension is important because of the relevance of the temporal distribution of intergenerational impacts and the long-term nature of climate change processes. Although it can be argued that one way of dealing with time is via discount rates, there is strong debate in the literature on what rate to use (Weitzman 1998; Ackerman et al. 2009) to discount future impact and furthermore there could be ethical concerns with discounting some of the impacts such as the health impacts. It is possible to incorporate temporal consideration in a multi-criteria analysis in a number of ways, either by the specification of criteria relevant to different time horizons (which could then be weighted to reflect the relative priorities accorded to these) or by the definition of individual criteria that evaluate the performance of options over a specified time horizon.

Intertwined with the time issue is uncertainty. On the one hand, there is deep uncertainty about what the future will bring, but also, the further in the future the impacts of the climate policy alternatives are compared, the greater the uncertainty about the extent of those impacts in absolute and relative terms. Although there are many ways of dealing with uncertainty in MCDA (Durbach and Stewart 2012; Stewart et al. 2013), the tangled relationship between the time horizon of assessment and uncertainty presents major challenges, whatever methodology is used. Furthermore, the mix of types and levels of uncertainties in the different criteria under consideration (fiscal, economic, environmental, social, and health) also makes a uniform treatment of uncertainty across all criteria challenging.

Fourthly, there is the issue of handling extreme and catastrophic events in the evaluation of climate policies. Historically, multi-criteria approaches that explicitly model uncertainty are based on the classical Von Neumann-Morgentsern axioms of decision-making under uncertainty and were designed to deal with steady-state risk scenarios and not with extreme or catastrophic risks. By their nature, these axioms are insensitive to dealing with low probability high impact events. New axioms of decision-making are required to handle extreme and catastrophic risks under uncertainty (Chichilnisky 2000, 2009). These axioms lead to decision criteria, which are themselves multi-criteria in nature and therefore well aligned with MCDA.

The MCA4climate conceptual framework explicitly acknowledges these challenges that are incorporated into its best practice climate evaluation standards as described in Table 2. However, there is considerable scope for future research in these areas, particularly in terms of improving MCDA techniques to account for and respond to advances in the energy-environment-economy literature in modeling dynamics, uncertainty and extreme events.

Further to the above challenges, which relate specifically to considerations relevant to the formulation of climate policies, we feel that it is important to acknowledge the concern that the use of different MCDA methods, with different underpinning principles, could lead to alternative rankings of policy alternatives (Bell et al. 2001). If used naively, without proper appreciation of the underlying preference model and interpretation of its parameters, then different models may appear to generate conflicting recommendations. If used in an informed and thoughtful manner, the outcomes of different models can potentially enrich understanding but the resource and cognitive burdens of doing so would be excessive for any complex issue. This paper and the rest of this special issue aim to ensure that the MCA4climate approach and its accompanying MCDA methods are methodologically sound.

4.3 Application considerations

It is important to note that the analytical framework being put forward in this paper has not yet been applied widely. For this reason, its impact on actual policy change (to advance pro-development climate policy) remains to be proven. Notwithstanding, three thought experiments have been conducted, which allowed us to draw lessons on the potential value and practicality of the framework. These related to three expert group exercises and scenarios that were developed in order to test the value of the methodological framework as a practical aid to decision-making (UNEP 2011). They included: infrastructure resilience and climate change adaptation in Mumbai, India; water resource management and climate adaptation in the Sana'a Basin, Yemen; and climate mitigation and change in the fuel mix for the electricity sector in South Africa. These exercises drew on existing large-scale studies and incorporated face-to face and virtual workshops involving key stakeholders. Each looked at different types of policy options: single policies in Mumbai, broadly defined energy scenarios in South Africa, and single policies that were combined to form portfolios of options in the Sana'a Basin in Yemen. The latter case is discussed in more detail in the Miller and Belton paper, which is also part of this special issue.

Furthermore, the MCA4climate framework has been recently used, albeit rather schematically, in two developing countries, Mexico and Peru, for aiding decision making in the area of development-compatible climate policy planning. In addition, the approach also inspired the preparation of a comprehensive review of national methodologies exploring baseline scenario calculations in ten major developing country economies (Puig et al. 2013). The Mexican Ministry of Environment applied the framework in its process of prioritizing the country's policy for adaptation to climate change in the area of irrigation agriculture. To this end, the generic criteria for the agriculture sector were adapted to the Mexican reality and indicators were developed for each criterion. Methods of assessment for the various indicators were developed, distinguishing between the different irrigation districts (crops, climates and climate risks vary markedly from one district to another), types of policy measures (e.g. some focused on building infrastructure, whereas others sought to train farmers, thus requiring different approaches) and types of crops. While the adaptation process retained the main elements of the generic MCA4climate criteria tree, the criteria were changed substantially, to tailor them to the realities of the country. Two sets of stakeholder groups were convened to adapt the generic MCA4climate framework: a policy stakeholders group who identified broad priorities for these areas, and a technical stakeholders group who took further and refined the assessment criteria, whereas an inter-ministerial committee assigned weights. The model was then calibrated by using the scores obtained for a range of pre-existing policy measures that had been developed through an extensive consultative process, with a view to eliminate potential biases. At the time of writing, this work is meant to inform the forthcoming adaptation strategy for the country and the revision of the Mexican special plan for climate change.

In Peru, the MCA4climate approach was experimented in the case of prioritizing climate change adaptation investment projects targeting agriculture. Following discussions at national level, which incorporated agreement on customization of the criteria tree to the specific context, the framework was used (via stakeholder workshops) to support representatives from the Piura region in prioritizing planned agricultural adaptation projects (Rivera et al. 2013). The results produced contributed towards the development and implementation of Peru's national plan for risk management and adaptation to climate change in the agricultural sector (PLANGRACC) for the period 2012–2021.

Even though these thought experiments and applications are far from representing fully-fledged case studies, several lessons were nonetheless drawn with regard to the potential applicability of the MCA4climate framework and its role in aiding decision-making. First, there may be interactions among different types of mitigation and adaptation options that have important implications for how well the individual options will work in practice. Consequently, policy assessments should consider alternative portfolios of options as well as efficient sequencing of options within a portfolio. Second, it is preferable to identify and agree on criteria and carry out initial scoring of policy options before undertaking detailed analytical modelling in a climate-policy planning process to ensure that the outputs of the modelling are useful in applying the MCA4climate framework or any other multi-criteria decision analysis tool. Third, the methodology could provide a powerful means of enabling a wide range of stakeholders to engage in the complex climate-policy decision-making process. However, for this to occur, there is the need for a supporting environment that would enable and foster stakeholder participation and democratic forms of decision-making. Fourth, the weighting of different criteria can have a profound effect on the relative value of different policy options. This emphasizes the importance of good facilitation to ensure that values are elicited in a sound manner. It also stresses the importance of ensuring that all stakeholder views are represented and appropriate weights are given to different criteria, including those concerned with social and economic development.

5 Conclusions

Any meaningful evaluation and effective implementation of climate policy options would need to account for the multiple values, interests, trade-offs and synergies between climate policy goals, their likely consequences, and the development objectives of the country wishing to put into practice its climate policy plans. Moreover, due to the complexity and multidimensionality of the climate change problem, decision-making in this area would have to involve a range of relevant stakeholders. There is also an urgent need to take stock and reflect on the type of information being used in climate policy evaluation and planning, how the respective knowledge has been generated, what the main assumptions underpinning it are, and how funders and users of climate policy analyses could ensure pluralism in methods and approaches. Identifying and discussing pro-development climate policy options grounded in space and time and which have the potential of being robust across a range of plausible future outcomes, may deliver better suited responses, rather than searching for unique optimal or first-best solutions.

Further efforts are required in order to gather the diverse information available within the research community, so that a range of scientific approaches (particularly involving the economics discipline) is represented. Most importantly, innovative and guiding conceptual frameworks are demanded to foster the mobilization and uptake of interdisciplinary knowledge and catalyse action on the climate policy front. It is hoped that the MCA4climate approach proposed in this paper takes a step forward in this direction and helps catalyse new thinking, debate, and practice in the area. However, an important caveat remains. Any inclusive and effective climate action would require a certain level of organization and co-ordination amongst the private sector, civil society, local governments and other stakeholders at the national or regional level. Where the decision-making process is highly hierarchical or where climate-policy action is the domain of a particular executive power, multiple stakeholder participation may not be possible. Nonetheless, the results of applying the MCA4climate framework can still be of value, especially where they are made available for public consultation.

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ANNEX 2

Annex 2: related documents

In addition to the articles listed in Chapter 1, I have authored or co-authored a number of peer-reviewed journal articles (Table A2-1), and peer-reviewed documents (Table A2-2) in areas that are related to the thesis. I have also edited several peer-reviewed documents (Table A2-3) in these areas. While none of these publications are among those selected to underpin the thesis, most are referenced in the text. All of them are relevant to the thesis' topic.

Table A2-1: Additional peer-reviewed journal articles and book chapters

Article	Reference	Status
1	Calliari, E., Vanhala, L., Nordlander, L., **Puig, D.**, Bakhtiari, F., Hossain, F, Rahman, F. and Huq, S. (2020). Loss and damage. In Reins, S. and van Calster, G. (Eds.) *Commentary on the Paris Agreement* (pp. n.a.). Cheltenham: Edward Elgar Publishing.	In press
2	Moner-Girona, M., **Puig, D.**, Mulugetta, Y., Kougias, I., Abdulrahman, J. and Szabó, S. (2018). Next generation interactive tool as a backbone for universal access to electricity. *Wiley Interdisciplinary Reviews: Energy and Environment 7*(6), e305.	Published
3	**Puig, D.**, Farrell, T.C. and Moner-Girona, M. (2018). A quantum leap in energy efficiency to put the Sustainable Development Goals in closer reach. *Global Policy 9*(3), 429-431.	Published
4	Henrysson, M., Lütken, S. and **Puig, D.** (2018). Could baseline establishment be counterproductive for emissions reduction? Insights from Vietnam's building sector. *Climate Policy 18*(4), 459-470.	Published
5	Haselip, J., Hansen, U., **Puig, D.**, Trærup, S. and Dhar, S. (2015). Governance, enabling frameworks and policies for the transfer and diffusion of low carbon and climate adaptation technologies in developing countries. *Climatic Change, 131*(3), 363-370.	Published

Table A2-2: Peer-reviewed documents (authored or co-authored)

Report	Reference	Status
1	Levin, K., **Puig, D.**, Bakhtiari, F., Desgain, D., Rich, D., Northrop, E. Elliott, C., Dinshaw, A., Hinostroza, M.L., Riva, M., Hodes, G., Comstock, M., Huyer, S., Mogelgaard, K. and Chao, V. (2020). *Implementing Nationally Determined Contributions (NDCs)*. Copenhagen: UNEP DTU Partnership.	Published
2	**Puig, D.**, Calliari, E., Hossain, M.F., Bakhtiari, F. and Huq, S. (2019). *Loss and damage in the Paris Agreement's transparency framework*. Copenhagen, London and Dhaka: Technical University of Denmark, University College London, and Independent University Bangladesh.	Published
3	Bakhtiari, F., Hinostroza, M.L. and **Puig, D.** (2018). *Institutional capacities for NDC implementation: a guidance document*. Copenhagen: UNEP DTU Partnership.	Published
4	**Puig, D.** and Bakhtiari, F. (2017). *The impact of debiasing on uncertainty communication: an application to multi-criteria decision analysis in the area of climate change*. Copenhagen: UNEP DTU Partnership.	Published
5	Höhne, N., Drost, P., Bakhtiari, F., Chan, S., Gardiner, A., Hale, T., Hsu, A., Kuramoch, T., **Puig, D.**, Roelfsema, M. and Sterl, S. (2016). Bridging the gap – the role of non-state action. In Olhoff, A. and Christensen, J. (Eds.) *The emission gap report 2016: a UNEP synthesis report* (pp. 23-30). Nairobi: United Nations Environment Programme.	Published
6	**Puig, D.**, and Aparcana Robles, S.R. (2016). *Decision-support tools for climate change mitigation planning*. Copenhagen: UNEP DTU Partnership.	Published
7	**Puig, D.** and Farrell, T.C. (2015). *The multiple benefits of measures to improve energy efficiency: a summary report*. Copenhagen: UNEP DTU Partnership.	Published
8	**Puig, D.** (2015). *Uncertainty in greenhouse-gas emission scenario projections: experiences from Mexico and South Africa*. Copenhagen: UNEP DTU Partnership.	Published
9	Olhoff, A., Bee, S. and **Puig, D.** (2015). *The adaptation finance gap update - with insights from the INDCs*. Copenhagen and Nairobi: UNEP DTU Partnership and United Nations Environment Programme.	Published
10	**Puig, D.**, Krog Søbygaard, J., Larsen, P., Rygner Holm, S., Blatt Bendtsen, U. and Prag, A. (2013). *National greenhouse gas emissions baseline scenarios: learning from experiences in developing countries*. Copenhagen and Paris: UNEP Risø Centre, Danish Energy Agency, and Organisation for Economic Co-operation and Development.	Published
11	**Puig, D.** and Malyshev, T. (2007). *Analysing our energy future: some pointers for policy makers*. Nairobi and Paris: United Nations Environment Programme and International Energy Agency.	Published

Table A2-3: Peer-reviewed documents (edited)

Report	Reference	Status
1	**Puig, D.** (ed.), Olhoff, A. (ed.), Bee, S. (ed.), Dickson, B. and Alverson, K. (2016). *The adaptation finance gap report*. Nairobi: United Nations Environment Programme.	Published
2	Olhoff, A. (ed.), Alverson, K., **Puig, D.** (ed.), Olhoff, A., Noble, I., Watkiss, P., Baarsch, F., Trabacchi, C., Caravani, A., Trærup, S., Chatterjee, M. and Kontorov, A. (2014). *The adaptation gap report: a preliminary assessment*. Nairobi: United Nations Environment Programme.	Published
3	Alcamo, J. (ed.), **Puig, D.** (ed.), Metz, B. (ed.), Demkine, V. (ed.) and Farrell, T.C. (2014). *The emissions gap report 2014: a UNEP synthesis report*. Nairobi: United Nations Environment Programme.	Published
4	Alcamo, J. (ed.), **Puig, D.** (ed.), Olhoff, A. (ed.), Demkine, V. (ed.) and Metz, B. (ed.) (2013). *The emissions gap report 2013: a UNEP synthesis report*. Nairobi: United Nations Environment Programme.	Published
5	**Puig, D.** (ed.) and Morgan, T. (ed.) (2013). *Assessing the effectiveness of policies to support renewable energy*. Nairobi: United Nations Environment Programme.	Published
6	**Puig, D.** (ed.), McIntosh, J. (ed.), Moner-Girona, M., Fluri, T.P., Gariseb, G., Meyer, A.J., Palmer, D., Van Niekerk, J.L., Bueno Pereira, E., Martins, F.R., Pereira, S.V., Sayuri Yamashita, C., Zhongying, W. and Jingli, S. (2011). *Enhancing information for renewable energy technology deployment in Brazil, China and South Africa*. Nairobi: United Nations Energy Programme.	Published
7	Morgan, T., Scrieciu, S.Ş. (ed.), Bristow, S. (ed.) and **Puig, D.** (ed.) (2011). *MCA4climate: a practical framework for pro-development climate policy*. Nairobi: United Nations Environment Programme.	Published

ANNEX 3

Annex 3: editorial choices

“Climate” and “climate change” are not synonymous (IPCC, 2014). Yet, they are often used interchangeably (as adjectives, complementing nouns such as “policy” or “action”). This usage responds to convenience, rather than ignorance: simply, “climate” is used as a shorthand for “climate change”. Nonetheless, for the sake of accuracy, I avoid doing this: I use “climate change” throughout, as I do not refer to “climate” in the thesis.

Similarly, “climate change” is often used to refer to mitigation of (or adaptation to) climate change. Stated differently, the noun is understood and, therefore, omitted. In the interest of clarity, I avoid doing this: I write “climate change mitigation” (or “climate change adaptation”). When both mitigation and adaptation are concerned, I write “climate change management”.

Often, “programme”, “policy” and “measure” are used interchangeably, to refer to any kind of action taken to manage (in this case) climate change. Consistent with practice (Vedung, 2017), I use “programme” to refer to a set of policies, “policy” to refer to a set of measures, and “measure” to refer to the set of changes (inducements, information, or funding, for example,) introduced with the intention to alter the status quo. These precisions are indispensable in some of the paragraphs in the thesis.

I use double angle quotation marks (« ») for direct citations. I use regular quotations marks (“ ”) to highlight a particular word or phrase, or a specific usage of that word or phrase, to distinguish it from other, usually more common usages.

In a human development context, most uses of the phrase “developing country” refer to countries with low per-capita income levels. Indirectly, this use of the adjective “developing” equates development with generation of financial wealth. Yet, “development” is a broader concept, encompassing notably cultural and humanistic aspects.[1] For this reason, to refer to countries with low per-capita income levels, I avoid the phrase “developing countries” and use “low-income countries” instead. Similarly, I used “high-income countries” instead of “developed countries”.

To improve the readability of the text, I insert citations at the end of the sentence. Exceptions to this are sentences in which clarity is increased by situating the citation next to the most relevant word. For example, I do so in sentences containing referenced lists, or in sentences requiring two unrelated citations. The same considerations apply to endnotes.

To improve the readability of the text, I avoid acronyms. Thus, I write phrases in full, unless doing so makes the text unclear. Text may become unclear because the phrase in question is long, or because it is used more than once in the same sentence. In these cases, I use short-hands, such as “the Convention”, instead of “the United Nations Framework Convention on Climate Change”.

I use British English spelling. The only exceptions to this are direct quotations of text originally written in American English.

I use the Oxford comma, as it helps avoid misunderstandings and, therefore, it helps increase the clarity of the arguments made. I use capital letters sparsely, mainly to write the names of institutions.

References

IPCC (2014) Annex II: Glossary [Mach, K.J., S. Planton and C. von Stechow (eds.)]. In: *Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, pp. 117-130.

Sen, A. (2001). *Development as freedom*. Oxford: Oxford University Press.

Vedung, E. (2017). *Public policy and program evaluation*. London: Routledge.

Endontes

[1] For an overview of the shortcomings of measures of development based purely in gross national income, and the importance of including issues such as health, life expectancy, education and freedom, among others, the reader is referred to Sen (2001).