Collaborative research and development (R&D) for climate technology transfer and uptake in developing countries: Towards a needs driven approach

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Collaborative research and development (R&D) for climate technology transfer and uptake in developing countries: Towards a needs driven approach

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Abstract

While international cooperation to facilitate the transfer and uptake of climate technologies in developing countries is an ongoing part of climate policy conversations, international collaborative R&D has received comparatively little attention. Collaborative R&D, however, could be a potentially important contributor to facilitating the transfer and uptake of climate technologies in developing countries. But the complexities of international collaborative R&D options and their distributional consequences have been given little attention to date. This paper develops a systematic approach to informing future empirical research and policy analysis on this topic. Building on insights from relevant literature and analysis of empirical data based on a sample of existing international climate technology R&D initiatives, three contributions are made. First, the paper analyses the coverage of existing collaborative R&D efforts in relation to climate technologies, highlighting some important concerns, such as a lack of coverage of lower-income countries or adaptation technologies. Second, it provides a starting point for further systematic research and policy thinking via the development of a taxonomic approach for analysing collaborative designs. Finally, it matches characteristics of R&D collaborations against developing countries' climate technology needs to provide policymakers with guidance on how to configure R&D collaborations to meet these needs.

Key words: climate change; technology transfer; collaborative research and development; R&D; UNFCCC; Technology Mechanism

1. Introduction

The transfer of climate technologies (technologies of relevance to climate change mitigation and adaptation) to developing countries is one of four pillars identified as necessary for a new climate deal[1]. It is seen as central to assisting countries' development along low-carbon, climate-resilient pathways whilst fulfilling international climate change mitigation objectives (Bazilian et al., 2008; Ockwell et al., 2010; 2008). The IPCC (2000) defines climate technology transfer (TT) as "… the broad set of processes that cover the flows of knowledge, experience, and equipment for mitigating and adapting to climate change among different stakeholders. These include governments, international organisations, private sector entities, financial institutions, NGOs and research and/or education institutions. It comprises the process of learning to understand, utilise, and replicate the technology, including the capacity to choose it, adapt it to local conditions, and integrate it with indigenous technologies".

One approach to assist flows of climate technologies to developing countries under the UNFCCC is the facilitation of international collaborative research and development (R&D): collaborations in technological innovation between institutions (private or public) in different countries. The innovation process can be conceptualised as progressing along a continuum of stages, from early stage R&D, through demonstration, to revision and supported commercial deployment, all the way through to mature market technologies being produced and used at scale. There are limits to what early stage R&D efforts in developing countries can achieve, as they may primarily be relevant to countries with higher existing levels of technological capacities (Bell, 2009) and less so to lower-income countries. As Gagnon-Lebrun (2004, p.26) stresses, "collaboration cannot work without capacity, but it can build capacity". Moreover, R&D activities themselves will not make a contribution to adaptation or mitigation directly. Nevertheless, collaborative R&D (as part of a broader suit of collaborative efforts in the innovation process) is considered a necessary condition for achieving climate objectives and does raise opportunities for developing country institutions, including firms, to build capacities by learning through interaction with more technologically advanced institutions, and to adapt technologies for operation in local contexts via incremental changes and improvements (Ockwell and Mallett, 2012), which in turn can enable action on climate change adaptation and mitigation.

Collaborative R&D represents an existing commitment under the UNFCCC[2] and has received some attention in policy discussions[3]. These discussions include the facilitation of collaborative

[1] This is asserted in the "Bali Road Map" – the outcome of the 13th Convention of the Parties (COP) to the UNFCCC which aimed to provide a route to agree a post Kyoto climate deal.
[2] Collaborative R&D is mentioned under Article 4 of the UNFCCC. It is also covered by Decision 1/CP.13 of the Bali Action Plan and is part of the UNFCCC's TT Framework (Decision 4/CP.7).
[3] At the request of the UNFCCC Subsidiary Body for Scientific and Technological Advice (SBSTA) the Expert Group on TT (EGTT) prepared a report on options to facilitate collaborative R&D relevant to technology development and transfer. The resulting report was adopted by the SBSTA at its COP16/CMP6 meeting in Cancun, December 2010.

R&D as part of the "Technology Mechanism" – a building block of the current UNFCCC regime – the operational modalities of which are emerging with the agreement on the Climate Technology Centre & Network (CTC&N) and the first work programme of the Technology Executive Committee (TEC). At present, however, reference to R&D within these policy fora has not been accompanied by any attempt to unpack the multiple potential configurations that R&D collaborations might take and their different distributional implications in terms of who gains and who loses from different policy approaches. Despite its policy salience, the field is therefore characterised by a distinct lack of empirical or theoretical work dealing with the specific context of climate technologies and in particular collaborations involving developing countries. Instead there is a danger that collaborative R&D might be treated in the same "one-policy-fits-all" way that has hampered the realisation of low-carbon TT under international climate policy to date (Ockwell et al. 2010).

The majority of existing research on collaborative R&D focuses on collaborations between private firms, and predominantly in areas of obvious commercial interest to these firms, with an emphasis on understanding what firms stand to gain from collaboration (see Hagedoorn et al., 2000 for an overview). However, these firm-centred, commercial-gain-oriented analyses have not engaged with policy-based facilitation of developed-developing country collaborations for the purposes of delivering a public good (i.e., climate change mitigation or adaptation), or specific considerations relating to climate technology R&D. For example, collaborative climate technology R&D needs to involve a range of private, public and not-for-profit actors, but can require involvement of developing country actors that have limited innovation capacities and are therefore of little strategic interest to international technology leading firms. A central question therefore is: why would public and private actors engage in R&D collaboration? And under what circumstances could collaborative R&D meet needs of developing countries at the same time as being attractive to firms? The aim of this paper is to begin to address these questions by providing a point of departure for systematic policy thinking and research in this currently un-researched area. It makes three contributions:

1) It analyses of a sample of existing collaborative R&D efforts in relation to climate technologies, representing a first effort towards understanding areas that might require particular policy attention.
2) It provides the basis for further systematic research and policy negotiations by developing a taxonomy for analysing collaborative initiatives.

3) Building on Sagar (2009), it develops a systematic approach to facilitating needs-driven policy analysis on collaborative R&D in the specific context of climate TT to developing countries. This is achieved by developing a matrix to guide policymakers in matching options for collaborative R&D with developing country climate technology needs.

It should be emphasised from the outset that this paper does not claim to represent a final, comprehensive view. Rather, in response to the policy salience of the issue, it attempts to provide the basis for researchers and policymakers to move more systematically towards needs-based policy.

The paper proceeds as follows. Section 2 outlines three broad categories of climate technology needs against which collaborative R&D might deliver. Section 3 assesses the existing coverage of a sample of existing collaborative mechanisms. In Section 4, a taxonomy of key characteristics of collaborative R&D mechanisms is developed. Finally, in Section 5 a matrix-based approach is suggested which might aid policy analysts in matching collaborative R&D options against developing countries' climate technology needs.

2. Designing R&D collaboration to meet developing countries' needs

Most analysis of technological change is pursued either on the basis of stages of innovation, from R&D, through demonstration to deployment (see, for example, Grubler et al. 1999) on a sectoral basis (e.g. IEA 2012a and the IEA Technology or Sectoral Roadmaps), or based on a combination of innovation stages and sector. While these approaches are helpful in identifying patterns and gaps in broad innovation processes (e.g. in the energy sector) or in specific sectors, we are particularly interested in trying to better understand how to advance technologies for the public good (i.e. climate change mitigation and adaptation in developing countries), where markets often don't work well and where countries often lack the indigenous capabilities to develop technologies. It is the lack of such markets and capabilities in many developing countries, combined with the urgent need to enhance the availability of climate technologies in these countries, which provides the core rationale for cooperation in climate technology development and transfer.

Therefore, in this paper we take a different perspective, which begins from the point of view of availability of technologies to meet the climate needs of developing countries. For this, we adopt and further develop a needs-based approach that draws on Sagar (2009), which broadly classified climate technologies on the basis of, first, those that already exist, either through market incentives or through application of public policy in industrialised countries, second, those that don't exist yet, due to the absence of market incentives or appropriate public policy, and, third, those types of technologies that might be needed in the future. In that sense, it is a classification of technologies along a different dimension that the two classifications mentioned above, but is useful in terms of identifying the kinds of policy interventions that might be needed to meet different developing countries' technology needs, especially for R&D.

Sagar (2009) articulates three categories of developing country climate technology needs where R&D might play a role:

1. Adaptation and modification of existing commercial or emerging technologies to suit local needs and conditions for benefits in the near future.
2. Development of technologies and products that have climate and development gains for the poor in developing countries, but that are mostly unaddressed by global technology markets.
3. R&D for the development of technologies that would be relevant in the medium-to-long term.

Consideration of these needs is fundamental to the design of collaborative R&D initiatives if climate policy is to deliver any "development dividends" (Forsyth, 2007), in addition to meeting climate mitigation or adaptation goals.

2.1. Adaptation/modification of existing commercial or emerging technologies to suit local needs and conditions

In most cases, some (or significant) adaptation, modification, or redesign of commercial technologies or products is needed to make these useable in local contexts. If a technology does not meet the needs of local consumers or is not optimized for local operating conditions, it will have limited uptake. This goal of R&D collaboration mostly involves middle-stage innovation around existing technologies close to market deployment. Examples include boilers that could be tailored to local coal characteristics and/or ambient conditions (Ockwell et al., 2008); 'green' or 'climate-proof' building designs that take into account local climatic conditions as well as occupants' use patterns; components in electrical equipment such as air-conditioners or refrigerators that may need changes in order to perform suitably in local conditions (such as high ambient temperatures or voltage/frequency fluctuations in local power supplies), or crops that need to be modified for local soil and rainfall patterns.

Because it provides access to a new market for products, such modifications may be carried out by the original supplier or manufacturer – e.g. a firm that manufactures air conditioners may change the compressor design or the working fluid to extend the range of ambient temperatures the device can operate in efficiently. These changes may also be carried out in conjunction with the local supplier of compressors. Improvements may also be made by third parties, although eventually they will need to be incorporated into the product design.

Advances in this area could benefit multiple developing countries simultaneously by enhancing the availability and uptake of climate-relevant technologies in the short term, as in many cases, technologies are generalizable across a number of developing countries. Developing countries with a relatively weak science and technology base would particularly benefit since they often do not have capabilities to engage in these kinds of activities on their own and are risky and unattractive markets for foreign firms.

2.2. Development of technologies for meeting local unaddressed needs

A large fraction of the world's population is living in poverty. An estimated 1.3 billion people do not have access to electricity (IEA, 2012b). The development of suitable clean and high-efficiency technologies can play a key role in meeting the needs of poor people and contributing to climate change mitigation, e.g. cleaner cooking through fuel efficient cookstoves which reduce emissions and reduce reliance on fuel wood whilst simultaneously yield health benefits and potentially free up time for other productive activities. However, such technologies are often not seen as market opportunities and could therefore be ignored by R&D funders and actors. For example, the inefficient and dirty combustion of biomass in traditional household stoves leads to indoor air pollution and deleterious health effects (between 2.7 and 4.5 million excess mortalities worldwide annually - mainly women and children. Biomass combustion is the fourth-largest risk factor globally in terms of disability-adjusted life years (Lim et al., 2012)) while also requiring enormous time for collection of biomass. Products of incomplete combustion have also been shown to be significant contributors to climate change. A replacement technology which provides more efficient and clean energy services can lead to both climate and development gains (Venkataraman et al., 2010). Furthermore, a positive contribution to the human development of this group should enhance their resilience to climate impacts, thereby contributing to climate change adaptation.

A range of technologies and products can help developing countries meet their particular energy needs. Examples include biomass-burning devices (such as cook stoves and industrial ovens), small-scale biomass conversion technologies (such as gasifiers for power and thermal applications and biogas digesters), advanced kerosene and solar lanterns, agricultural technologies to improve the resilience of cropping systems to climate change, and water conservation technologies. These opportunities are recognised by policy initiatives, but these initiatives generally assume that the technology is already available on the shelf. R&D opportunities, often requiring collaboration, are generally unaddressed, remain outside the mainstream global energy innovation system and often outside established commercial markets in developing countries. Developing countries also have unaddressed needs in, for example, the waste management, transportation and agriculture sectors, where climate technologies can have significant development co-benefits.

Although programmes for implementation are being started, technology R&D activities in this area remain small and fragmented and are generally sidestepped by global markets. Markets are not conducive for companies to develop products for poorer citizens of developing countries since markets are difficult to access and risky (Schmidt et al., 2013), and their purchasing power is not valued, even though it may cumulatively present a significant business opportunity (Prahalad, 2004). Focusing on these opportunities will simultaneously advance climate and development goals with additional gains from the feedback between development and climate resilience. This could be particularly important for smaller and poorer developing countries that do not have the resources to develop such technologies.

2.3. Research & development of technologies for medium-to-long term needs

There is a concurrent need to work towards developing mitigation and adaptation technologies for the medium-to-long term. This could include, for example, advanced renewables such as third-generation biofuels or solar thermal and photovoltaic technologies, advanced nuclear generation technologies and cycles, and super-efficient end-use technologies. It could also involve the development of advanced agricultural technologies (both crops and production technologies) and practices that could serve both mitigation and adaptation in this sector. Adaptation technologies include building technologies for coastal areas, technologies to protect against sea-level rise, and disaster management practices. Basic and applied R&D in this category could help with the development of new and improved technologies, tools, and processes and practices.

3. Current patterns of R&D collaboration around climate technologies

Consideration therefore needs to be given to what model of collaboration might best deliver against these different needs. A diverse range of models and practices currently exist around different aspects of the innovation chain for climate and other technologies. In order to begin to systematically analyse models and practices of collaborative R&D a sample of existing collaborations was collated into the table presented in the online Annex and analysed in order to: a) assess existing patterns of coverage; b) identify any innovative new collaborative R&D models in other sectors which might be relevant to climate technologies and developing countries, and c) develop a taxonomy of variables around which collaborations might usefully be differentiated.

This taxonomy was developed via the collation of secondary data on a sample of existing collaborative R&D initiatives that either involve, or can potentially involve, developing countries (collated between 1st and 31st August 2010). Initial data related to whether collaborations were bilateral, regional or international, the key actors (including countries) involved, the technological focus and an indication of the organisation and main activities of the collaboration. Data collection consisted of a literature review of existing published and grey literature, a search of online resources and invited responses from nine climate technology experts in relevant governmental and non-governmental organisations (two via face to face interviews, seven via in-depth written questionnaires) who were asked to identify and explain examples of collaborative climate technology initiatives that they or colleagues were aware of.

The study identified a sample of 44 existing climate technology and other potentially relevant initiatives (see online Annex). A number of caveats and explanations apply:

- The list does not claim to be exhaustive. In particular, analysis of collaborative R&D within the private sector is inherently difficult. The informal, often commercially sensitive nature of private sector collaborations makes them difficult to identify or research. The list presented should therefore primarily be seen as a non-exhaustive overview of public-sector or charity-funded initiatives.
- The sample is heterogeneous, i.e. includes one-off R&D collaborations (e.g. FutureGen), funding programmes for collaborations (e.g. the EU 7th Framework Programme, which funds hundreds of international R&D collaborations), and national science and technology programmes initiated by one country (e.g. CYTEC from Spain), which often fund many technologies.

- A number of regions and topical areas where bilateral collaborations are believed to be underway were identified (e.g. a Brazil-Venezuela collaboration on biofuels), but there was insufficient further information to include them in the sample.
- The initial sample included a large number of collaborations *about* technology that did not involve R&D. Examples include the Methane2Markets, the Global CCS Institute and the International Platform for the Hydrogen Economy. Often, such international collaborations focus on knowledge sharing and coordination rather than on R&D (Coninck et al., 2008). These collaborations were therefore excluded.
- When an international collaboration indicated that it would, alongside technology-enabling activities, also undertake or fund technology modification and adaptation to local circumstances, it was included, even when that would only be a small share of its overall activities (e.g. the Renewable Energy and Energy Efficiency Programme, REEEP).

These caveats emphasise the need to consider analysis in this paper as a starting point, as opposed to a comprehensive view on understanding the coverage and component variables of alternative configurations of climate technology collaborative R&D.

Notwithstanding these caveats, observations can be made regarding the coverage of the sample. R&D collaborations seem to be biased towards mitigation as opposed to adaptation technologies. As the world's poorest countries and communities are also most vulnerable to the impacts of climate change this implies a policy imperative to scale up the level of collaborative R&D around adaptation. Initiatives focussing on mitigation emphasise energy over other relevant sectors, e.g. forestry and agriculture. A similar bias towards energy technologies was observed in the UNFCCC Expert Group on TT's assessment of financing available for climate TT to developing countries (EGTT, 2009). However, these biases do not imply there is no gap in R&D funding for mitigation or energy technologies. Various studies indicate R&D spending on energy needs to increase multi-fold for long-term climate targets.

There is a strong bias towards involvement of large, emerging developing economies, such as Brazil, China and India. Notwithstanding the important differences between these three countries, their disproportionate representation is perhaps not surprising given low levels of technological capabilities in LDCs and the relatively (to other developing countries) high levels in emerging economies, as well as their size. As highlighted above, a certain level of technological capability is definitive of firms' and countries' ability to engage in R&D collaborations. China, India and Brazil are also characterised by strong national innovation strategies, which again may serve to drive their involvement in collaborative R&D.

The dominance of the emerging economies, together with the relative lack of emphasis on adaptation needs, has distributional implications. It suggests richer developing countries benefit most from existing collaborative R&D efforts, whereas the needs of poorer countries, particularly LDCs, and the more adaptation-oriented needs of poor and marginalised people within all developing countries, receive less attention. This suggests a need for more explicit policy focus on engaging with lower-income, smaller developing countries. It may be, however, that technological capacity development in lower income countries is best served by collaboration later in the innovation chain or around training and information sharing-based activities (Bell, 2009).

Another policy-relevant observation seems to be that public-private or public-private-charity partnerships can lever private investment. Private sector involvement is widely viewed as a condition for successful deployment of technology at later innovation stages (Hladik, 2002), but it is declining as a result of the more short-term focus of firms in the international, shareholder-driven market place (Wang et al., 2012).

The lack of emphasis on permanent initiatives within the sample raises questions as to whether it is possible to distinguish between the temporal characteristics of collaborations and their relative ability to deliver against developing countries' climate technology needs. E.g. it could be posited that more permanent initiatives, such as the Collaborative Group on International Agricultural Research (CGIAR), have more potential than one-off projects to build capabilities in developing countries and to contribute to more sustained, needs-based R&D. Indeed, the CGIAR is often referred to as a successful initiative, delivering capacity building benefits as well as achieving significant penetration of the technologies produced (Gagnon-Lebrun, 2004). Distinguishing between the relative benefits of permanent and medium-term collaborations, on the other hand, is more difficult.

4. A taxonomy of R&D collaboration

The analysis above identifies a number of distinguishing characteristics within the sample of R&D collaborations. To assist future analysis and policy design and guide further categorisation and inventory, below we disaggregate these characteristics into an initial taxonomy.

Six main taxonomic variables can be distinguished from the analysis above:

1. Type of actors involved
2. Temporal scope
3. Technical focus
4. Organisational configuration
5. Funding sources
6. Geographic coverage of actors involved

Each of these is described below. Note that any R&D collaboration is classifiable according to all variables, e.g. a collaboration with long term temporal scope might have a sectoral focus, a network-based organisational structure, funding from public sources, a global coverage and only research university actors involved.

4.1 Type of actors involved

Collaborations can include multiple combinations of actors, including:

1. Universities.
2. (Partly) publicly-funded research laboratories.
3. Private sector actors – for-profit organisations or firms e.g. equipment manufacturers, component suppliers.
4. NGOs – not-for-profit organisations – NGOs have played an increasingly important role in identifying the needs base for climate technologies in developing countries and conducting R&D.
5. Coordinating organisations – private, public or NGO actors who play a role in coordinating collaborations e.g. an organisation taking a lead role in coordinating a research consortium or network.

Widely varying numbers of actors might collaborate, from very large (e.g. 30-100 partners) to small (2-3 partners).

4.2 Temporal scope

1. *One-off projects* including opportunistic projects commissioned in response to immediate needs and short-term collaborative projects commissioned as part of a broader strategy, e.g. individual projects commissioned under the EU's Framework Programme or by the UK's Energy Technology Institute (ETI)[4].

2. *Medium term collaborations* including collaborations formed around more strategic goals beyond a one-off project, e.g. the UK Engineering and Physical Sciences Research Council's (EPSRC) UK-China Ecoregion research networks[5], projects under the Asia-Pacific Partnership on Clean Development and Climate[6], and the India-EU Strategic Partnership on clean technology, CDM and adaptation.

3. *More permanent, long term collaborations,* e.g. a new centre or network e.g. the CGIAR or a strategic, long-term MIT & Masdar Institute Cooperative Program.

4.3 Technical focus

1. *Adaptation or mitigation.* Focus on technologies for either climate change adaptation or mitigation or serving both purposes.

2. *Sectoral.* Broad sectoral focus such as agriculture, health, renewable energy, cement industry etc., e.g. CGIAR in agriculture, the African Network for Drugs and Diagnostics Innovation (ANDI)[7] in health.

3. *Technology/product based.* Focus at the level of individual technologies, e.g. the Indian National Hybrid Propulsion Platform on hybrid vehicles and the UK-China Near Zero Emissions Coal (NZEC) initiative[8] on CCS.

4. *Open issue.* Collaborations without a pre-defined focus. These often consist of national innovation funds which aim to broker collaborations between firms and research organisations and others overseas, e.g. MATIMOP Israel[9], and the International Science and Technology Partnerships Program (ISTPP), Canada[10].

[4] http://www.energytechnologies.co.uk/Home.aspx
[5] http://www.dongtanepsrc.org/ or http://www.energy.soton.ac.uk/buildings/Ecoregion-Leaflet.pdf
[6] http://www.asiapacificpartnership.org
[7] http://apps.who.int/tdr/news-events/news/pdf/ANDI-rd-landscape-abstracts.pdf
[8] http://www.nzec.info/en/
[9] http://www.matimop.org.il/Content.aspx?code=18
[10] http://www.tradecommissioner.gc.ca/eng/science/istpp.jsp

4.4 Organisational set up

Perhaps the most complex variable:

1. *Induced self-assembly.* Collaborations formed in response to a particular incentive. This could be a call for proposals through a mechanism like the EU Framework Programme or UK Energy Technology Institute (ETI)[11], or could be incentivised by an innovation prize for innovations in certain specified technological areas, e.g. the U.S. Department of Energy's Advanced Research Projects Agency-Energy[12] (ARPA-E) programme, which advances high-potential, high-impact energy technologies that are too early for private-sector investment (for a discussion, see Mazzucato, 2011).

2. *Strategic self-assembly.* Consortia or alliances where actors voluntarily broker relationships to respond to strategic objectives e.g. technological objectives, promoting national or regional competitive advantages, or delivering global public goods, e.g. the Asia Pacific Partnership, the European Energy Research Alliance[13], and the African Network for Drugs and Diagnostics Innovation (ANDI)[14].

3. *Internally Competitive Consortia.* Competitive consortia where members bid amongst themselves for individual projects, e.g. the Metals Affordability Initiative. This is different from a consortium where all members participate jointly in activities.

4. *Product Development Partnerships (PDPs).* A relatively new way of structuring collaborative R&D, developed in the health sector. A PDP is a non-profit organisation that builds partnerships between the private, public, academic and philanthropic sectors to drive development of new products for underserved markets. PDPs are created for the public good and resulting products made affordable to all who need them. Examples focus on development of medicines, vaccines or products for treating or preventing diseases such as the Medicines for Malaria Venture (MMV), the International AIDS Vaccine Initiative (IAVI) and the Global Alliance for Vaccines and Immunization (GAVI).

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11 http://www.energytechnologies.co.uk/Home.aspx
12 http://arpa-e.energy.gov/?q=arpa-e-site-page/about
13 http://www.eera.eu
14 http://apps.who.int/tdr/news-events/news/pdf/ANDI-rd-landscape-abstracts.pdf

5. *Network model.* Networks of research centres across different countries focussing on R&D around a range of priority issues within a certain sector. Networks can be used to target funding on priority areas of research whilst facilitating partnerships, information sharing and capacity building, and ensuring initiatives respond to the needs of different regions and localities. This model can be used to target R&D activities across a range of levels of research, from early stages to adaptive R&D and the targeting of previously neglected areas, according to the nature of technologies in question and geographically specific needs. The classic example of an international sector-based network is the CGIAR. The African Network for Drugs and Diagnostics Innovation (ANDI)[15] provides an example from the health sector. They can range from lighter, relatively loose networks in which institutes participate alongside other activities (e.g. IEA Cost-Sharing Implementing Agreements), to much tighter networks where, as in the CGIAR, existing institutes develop into centres that are exclusive to that network. Tighter networks have several advantages over looser. Their long term nature enables them to build and sustain capacity, to develop institutional memory (e.g. building and maintaining learning of successful approaches, available knowledge sources and relationships with partners) and to develop more efficient and effective approaches to interacting across the network over time, thus significantly reducing transaction costs.

6. *Open Innovation.* Open-innovation R&D is a relatively novel approach to research that lets scientists collaborate freely across organisations, disciplines and borders to solve problems where they share an interest. It uses social networking as a mechanism to enable open innovation. This prevents a single firm, including international companies, from monopolising knowledge, and responds to increasing levels of technological specialisation which make it difficult for firms to find solutions to all problems in-house. The term "open source" denotes only the type of licence under which a product is made available. The distribution terms of open source must comply with specific criteria, including free redistribution, providing access to source code and the right to modify it, and distributing it further under the same terms as the original software license. A number of licenses convey such rights, e.g. the GNU General Public License, the MIT License, and Apache.[16] Specific research is required to explore to what extent open-source can be applied successfully to climate technologies which differ significantly from IT as well as differing significantly from one another.

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[15] http://apps.who.int/tdr/news-events/news/pdf/ANDI-rd-landscape-abstracts.pdf
[16] See http://www.opensource.org/

7. *Nationally based innovation centres*. These consist of nationally based, often not-for-profit centres which aim to identify relevant opportunities for collaboration with international partners geared towards specific innovation interests or needs (see Sagar, 2010). An example is Fundacion Chile[17] which works to identify relevant areas of innovation that might be beneficial nationally then brokers relationships with international technology leaders in this area and works to collaborate on R&D to make these applicable within Chile. The World Bank is also setting up Climate Innovation Centres in various developing countries[18].

4.5 Funding sources

1. *Public sector*: Through governments' R&D programmes, bi- or multilateral funding flows. In addition, public funding can be provided through international public organisations, such as the CGIAR.

2. *Private sector*: Provided in-kind, in a collaboration where industry is a partner, contract research (e.g. the development, improvement or testing of an innovation) or via collaborations with universities, e.g. ExxonMobil funding a large CCS programme at Stanford University.

3. *Philanthropic sources or NGOs'* own funding initiatives, e.g. funding for research on malaria.

4. *Public-private partnerships* – where public funding is used to incentivise collaborations that lever additional funds from private sector collaborators. This is beneficial in maximising funding leverage and securing private sector engagement, directing R&D efforts towards areas with market applications and increasing the potential for product development as a result of R&D.

4.6 Geographic coverage of actors

Collaborations range from national to bilateral to multilateral. They could be country or region specific, or globally distributed, including south-north, south-south or north-north collaborations. A distinction can also be made in the level of development of countries involved e.g. differences between middle-, and lower income countries.

5. Targeting collaborations at specific technology needs

The discussion above illustrates both the varied coverage of existing collaborative R&D efforts and the myriad of different characteristics that different collaborations might exhibit. As

[17] http://ww2.fundacionchile.cl/portal/web/guest/home
[18] http://www.infodev.org/en/Topic.19.html

emphasised from the outset of this paper, more empirical research is required to develop a more detailed understanding of how alternative configurations might best serve different countries and different climate technology needs. To assist such future research and to provide a guide to the accelerating international policy discussions on this topic, we conclude this paper with a matrix (Table 1) that begins to tease out the characteristics of collaborations that might be best suited to meeting different technology needs.

Each block of rows in Table 1 represents options relating to the three types of developing country climate technology needs outlined in Section 2 (listed as goals in the first column). The columns then operationalise key attributes of the taxonomy detailed above. The second column lists the stage of innovation that forms the focus of the technical work. The third column represents potential actors. Potential sources of funding are listed in the fourth column. The fifth and final column lists the likely geographic focus of collaborations.

Temporal scope and technical focus are not mentioned, despite their analytical relevance, as they are not connected to specific goals or innovation stages. Of course, long-term R&D requires a longer temporal scope, but this does not necessarily mean it is the result of a long-term collaboration (as opposed to being pursued by single actors). This does not mean, however, that temporal scope and technical focus should not be considered once appropriate collaborative configurations have been decided upon relative to specific needs-driven goals.

It is also important to note that the role of different actors in the field of climate technology is continually changing. The increased emphasis given to climate change in policy agendas and the activities of NGOs might well lead to a greater role for public and NGO actors across all three of the goals that define Table 1. In addition, institutional changes as a result of changing political preferences may shift responsibilities from government to private and non-governmental organisations. Such developments, and the actions of these actors resulting from them, could also incentivise greater private sector involvement across all three goals e.g. through publicising carefully targeted research on nascent markets for currently ignored needs.

Table 1. R&D collaborative options tailored to developing-country needs.

Goals	Innovation stage	Actors	Organisational model for collaboration	Funding	Geographical coverage
Adaptation and modification of existing technologies	Middle-stage, market-oriented	Industry, dedicated laboratories, research universities and institutes	Industry-industry	Public/private	Country/region specific
			Industry-laboratories/universities	Public/private	
			CGIAR-type networks	Public	Globally distributed
New technologies and products for “unaddressed” needs	Middle- or early-stage, end user-oriented	Industry, dedicated laboratories, research universities and institutes, NGOs	Product-Development Partnerships	Public	Global or region-specific
			CGIAR-type networks	Public	Globally distributed
			Innovation prize-induced collaborations	Public/philanthropic	
			Industry-laboratories/universities	Public/private	Country/region specific
Long-term R&D	Early stage	Research universities and institutes, industry, dedicated laboratories	University-university	Public (e.g., climate financing, bilateral, multilateral, philanthropy)	Country/region specific
			University-industry		
			Industry-industry		
			CGIAR-type networks		Globally distributed
			Global facility		Single-location

6. Conclusion

As international policy interest in the transfer and uptake of climate technologies in developing countries accelerates, international collaborative R&D is also expected to increase. The UNFCCC, through its Technology Mechanism, has already indicated that collaborative R&D is part of its remit (TEC, 2013). This paper offers a tentative starting point for empirically grounded, systematic thinking on the issue. Analysis of a sample of collaborative R&D efforts identified through this initial research highlighted a number of policy relevant considerations, such as the relative absence of activities in low-income countries, the relative lack of R&D on adaptation technologies and the importance of attending to technology needs that are unaddressed in the open market.

It must be emphasised that further research is required to develop a more extensive empirical base than the sample of initiatives assessed in the paper. Further analysis could examine the way in which, and the extent to which, public-private and public-private-charity collaborations have levered private investment to inform design of policy incentives, as well as lessons for designing and coordinating collaborations around climate technology R&D.

Other areas future research might usefully focus on include unpacking the relationship between relative technological capabilities of different developing countries, and firms and industries therein, and the related implications for countries' ability to engage in R&D collaborations as a meaningful way of facilitating climate TT. Work is also required to assess which collaborative initiatives have been successful to date - which collaborative designs have worked, which haven't, how and for whom. Identifying good practices, success stories and failures to learn from is not straightforward as circumstances vary tremendously, leading to different things working in different places, and failures are often not reported making it difficult to draw lessons.

The leaning towards sectoral collaborations also raises interesting questions. Are there, for example, benefits in pursuing a broad, sectoral focus, again characterised by the much referenced CGIAR, or is it more appropriate to keep collaborations tightly focussed around a single technology or product? Does the latter risk precluding alternative technological options and fall into the trap of "picking winners" rather than letting the market decide on the most cost-effective option? Or is, as Watson (2008) suggests, and Mazzucato (2011) further emphaises, the mantra of "avoiding picking winners" a flawed idea in itself? Should governments accept that all policy favours certain technologies over others and be willing to take risks in favouring the development of certain technologies over others, whilst being able to review this support and change tack if and when necessary?

A related question is whether an emphasis on a broader subject (e.g. malaria prevention or rural electricity access) might provide a more productive approach to meeting developing country needs. This could perhaps be combined with innovative approaches to incentivise R&D collaborations, such as the use of innovation prizes for technologies developed to serve these needs – prize-based collaborative models having been absent from the sample. To encourage the development and uptake of climate technologies, however, prizes need to be focussed on procurement competitions for specific applications – not on early stage technological breakthroughs (Mowery et al., 2010). The latter type of competition requires precise output or performance targets to be specified, and the ability of entries in any competition to meet these targets must be readily verifiable. Whilst such targets could be feasible for some climate technologies, the huge diversity of relevant technologies and context-specific considerations renders ex ante specification of such targets difficult if not impossible. The lack of representation of other new approaches to R&D collaboration, such as open source or internally competitive consortia, raises further questions relating to a seemingly limited cross-fertilisation from non-climate collaborative R&D models. Further research unpacking the potential and relative benefits of these models within the area of climate technologies would therefore be of value.

Another interesting and potentially important area for further research is to explore the drivers that have led to the establishment of existing collaborations and what lessons might be learnt for establishing future initiatives. What are the politics behind the way in which different collaborations have formed? Who instigates them, why are some actors involved and others not? What role does policy play in defining this? For example, why is there a CGIAR? Could there be a similar organisation for international climate technology research? Do the current Climate Innovation Centre and CTC&N initiatives have the level of political and financial backing that the CGIAR did? If not, why not? What were the specific political and contextual factors that allowed a collaboration like the CGIAR to form and what has sustained it over the decades? How does this learning translate across to climate technology research, transfer and uptake? Are there particular lessons to be learned with regard to delivering against the needs of poor people through climate TT?

Whilst this paper is only a first step into empirical research on this issue, combining the taxonomy with a needs-based approach to climate technology R&D, as demonstrated in the analysis and matrix above, provides a starting point for policy thinking. This needs-based approach stands in stark contrast to more generic "one-policy-fits-all" approaches which continue to characterise negotiations around technology and development, such as the bland reference to "cooperative R&D" in existing UNFCCC policy documents (UNFCCC, 2011) with little attempt to unpack the multiple potential configurations and their distributional implications. It is hoped that this paper will contribute towards such needs-based, empirically driven policy analysis, and will prove useful for climate policy negotiations more generally by focussing attention on different needs bases that are served by different policy configurations.