Climatic Change (2015) 131:417–433
DOI 10.1007/s10584-015-1344-z

Assessing climate change mitigation technology interventions by international institutions

Heleen de Coninck · Daniel Puig

Received: 28 May 2014 / Accepted: 29 January 2015 / Published online: 5 March 2015

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

This article is part of a Special Issue on "Governance, policy, and enabling frameworks for the transfer and diffusion of low carbon and climate resilient technologies in developing countries" edited by Subash Dhar, Ulrich Hansen, James Haselip, Daniel Puig, and Sara Trærup.

H. de Coninck (✉)
Institute for Science, Innovation and Society, Faculty of Science, Radboud University, P.O. Box 9010, Mailbox 77, 6500 GL Nijmegen, The Netherlands
e-mail: h.deconinck@science.ru.nl

D. Puig
UNEP DTU Partnership, Marmorvej 51, 2100 Copenhagen Ø, Denmark
e-mail: dapu@dtu.dk

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

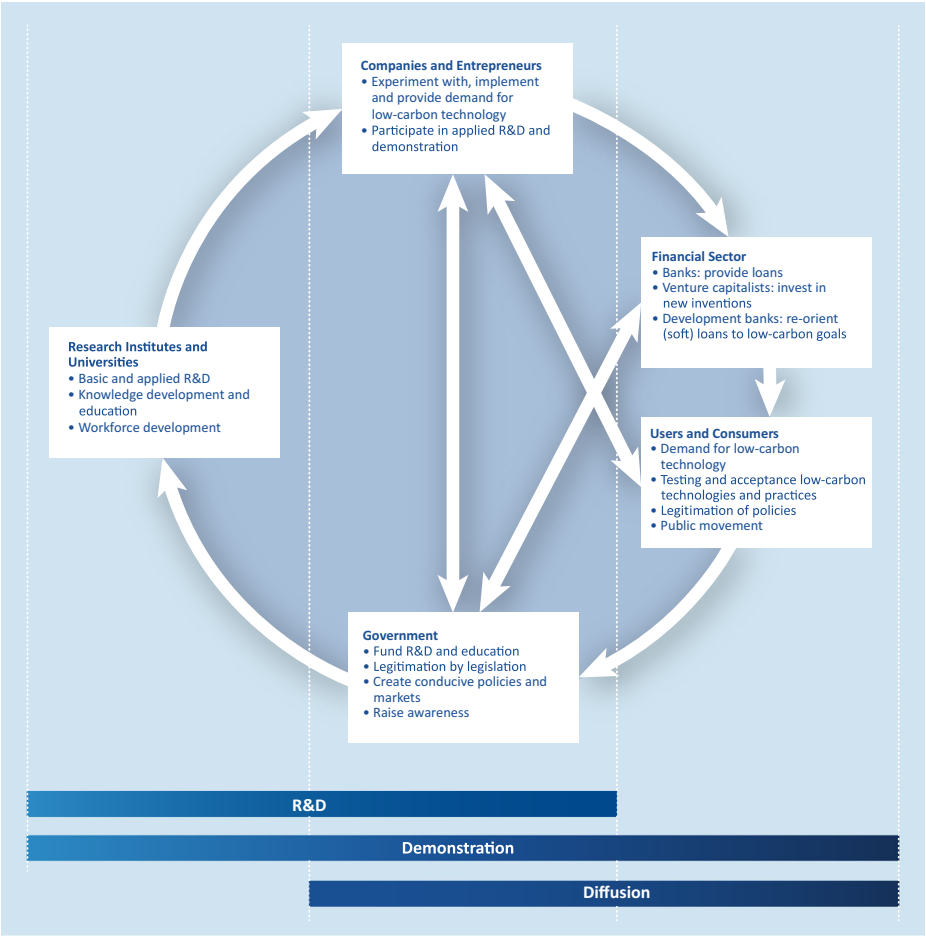

Fig. 1 A representation of functions and linkages between actors in the innovation system and their relation to the technology cycle. In research and development, mainly research institutes, businesses and government are involved. In deployment and diffusion the financial sector and users (including 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.

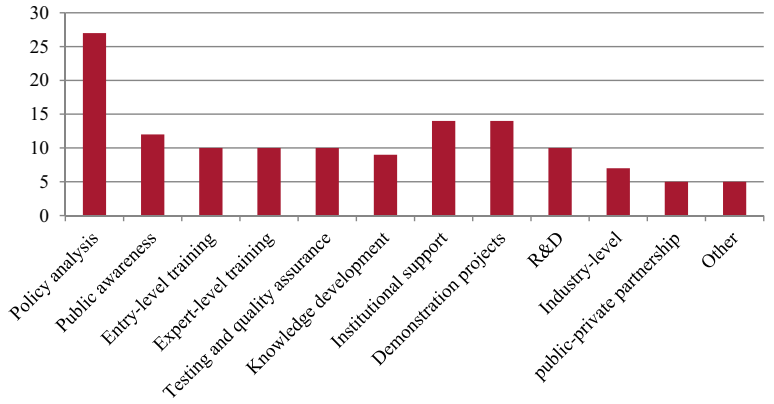

Fig. 2 Overview of amount (counts) of international renewable energy technology collaborations in categories of collaboration resulting from preliminary analysis of the survey responses (IRENA survey results). A single collaboration can add to more than one category

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.

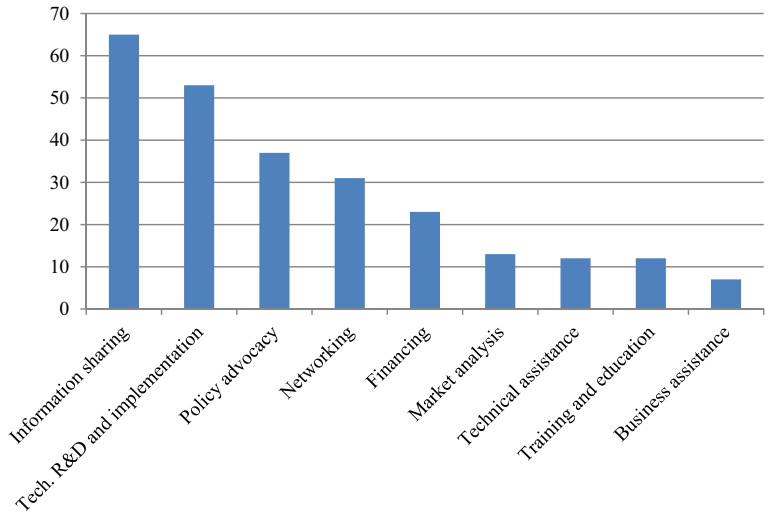

Fig. 3 Percentage of international initiatives indicating that services are provided (from Hultman et al. 2012)

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.

References

Altenburg T, Pegels A (2012) Sustainability-oriented innovation systems – managing the green transformation. Innov Dev 2(1):5–22

Bergek A, Jacobsson S, Carlsson B, Lindmark S, Rickne A (2008) Analyzing the functional dynamics of technological innovation systems: a scheme of analysis. Res Policy 37(3):407–429

Bhasin S, Blanco G, Bristow S, Byrne R, Cameron L, Coninck H de, Fang Z, Gallagher KS, Ionita R, Mikunda T, Sagar A, Wuertenberger L (2014) Climate technology in context: synthesis report on climate technology and development. April 2014: ECN: Petten, Netherlands. Available via climatestrategies.org

Blanco G, Coninck H de, Wuertenberger L (2012) The technology mechanism under the UNFCCC: ways forward. Climate Strategies Policy Brief in Climate Technology and Development project. Available via www.climatestrategies.org

Byrne R, Schoots K, Watson J, Ockwell D, Coninck H de, Gallagher KS, Sagar A (2012) Innovation systems in developing countries. Climate Strategies Policy Brief in Climate Technology and Development project. Available via www.climatestrategies.org

Freeman C (1995) The "National System of Innovation" in Historical Perspective. Camb J Econ 19(1):5–24

Grubb M (2004) Technology innovation and climate change policy: an overview of issues and options. Keio Econ Stud 41(2):103–132

Hekkert MP, Suurs RAA, Negro SO, Smits REHM, Kuhlmann S (2007) Functions of innovation systems: a new approach for analyzing technological change. Technol Forecast Soc Chang 74:413–432

Hultman N, Sierra K, Eis J, Shapiro A (2012) Green growth innovation: new pathways for international cooperation. GGGI and the Brookings Institution - Global Economy and Development

infoDev (2010) Climate Innovation Centres: a new way to foster climate technologies in the developing world? An infoDev publication in collaboration with UNIDO and DFID prepared by Ambuj Sagar and Bloomberg New Energy Finance, October 2010. Available at: www.infodev.org

infoDev (2014) Annual report: pages 26–27. Available at: www.infodev.org

IPCC (2014) Climate change mitigation. Contribution of IPCC Working Group III to the IPCC Fifth Assessment Report. Cambridge University Press, Cambridge

Lema A, Lema R (2013) Technology transfer in the clean development mechanism: insights from wind power. Glob Environ Chang 23:301–313

Luken RA, Navratil J (2004) A programmatic review of UNIDO/UNEP national cleaner production centres. J Clean Prod 12(2004):195–205

Luken RA, Navratil J, Hogsted N (2003) Technology transfer and the UNIDO/UNEP national cleaner production centres programme. Int J Environ Technol Manag 3(2):107–117

Lundvall B (1992) National systems of innovation: towards a theory of innovation and interactive learning. Pinter, London

Murphy LM, Edwards PL (2003) Bridging the valley of death: transitioning from public to private finance, NREL NREL/MP-720-34036: Golden, CO

Murphy K, Kirkman GA, Seres S, Haites E (2013) Technology transfer in the CDM: an updated analysis. Clim Pol. doi:10.1080/14693062.2013.812719

Ockwell DG, Mallett A (2012) Low-carbon technology transfer: from rhetoric to reality. Routledge, Oxon and New York

Ockwell D, Sagar A, Coninck H de (2014) Collaborative research and development (R&D) for climate technology transfer and uptake in developing countries: towards a needs driven approach. Clim Chang. doi:10.1007/s10584-014-1123-2

Sagar A, Bremner C, Grubb M (2009) Climate innovation centres: a partnership approach to meeting energy and climate challenges. Nat Res Forum 33:274–284

Seres S (2008) Analysis of technology transfer in CDM projects—a report to the UNFCCC's registration and issuance unit. Available via: http://cdm.unfccc.int/Reference/Reports/TTreport/TTrep08.pdf

UNEP (2010a) Taking stock and moving forward the UNIDO–UNEP National Cleaner Production Centres (http://www.unep.fr/scp/cp/pdf/Taking%20Stock%20of%20NCPC%20Programme.pdf). Accessed on 26th Feb 2014

UNEP (2010b) Joint UNIDO-UNEP programme on resource efficient and cleaner production in developing and transition countries (http://www.unep.fr/scp/cp/pdf/RECP%20Programme%20Flyer%20April%202010.pdf) Accessed on 26th Feb 2014

UNEP Risø Centre (2014) CDM/JI pipeline analysis and database (http://www.cdmpipeline.org/). Accessed on 26th Feb 2014

UNFCCC (2009) Second synthesis report on technology needs identified by Parties not included in Annex I to the Convention. Note by the secretariat: FCCC/SBSTA/2009/INF.1: 29 May 2009

UNFCCC (2010a) The Cancun agreements: outcome of the work of the Ad Hoc Working Group on Long-term Cooperative Action under the Convention, FCCC/ CP/2010/7/Add.1 Decision 1/CP.16

UNFCCC (2010b) Report on options to facilitate collaborative technology research and development. Note by the Chair of the Expert Group on Technology Transfer. Document code: FCCC/SBSTA/2010/INF.11, available on www.unfccc.int

Winkelman AG, Moore MR (2011) Explaining the differential distribution of clean development mechanism projects across host countries. Energ Policy 39(3):1132–1143