ARTICLES
PUBLISHED ONLINE: 13 JULY 2014 | DOI: 10.1038/NCLIMATE2305

nature climate change

Technology transfer for adaptation

Bonizella Biagini[1], Laura Kuhl[2*], Kelly Sims Gallagher[2] and Claudia Ortiz[3]

Technology alone will not be able to solve adaptation challenges, but it is likely to play an important role. As a result of the role of technology in adaptation and the importance of international collaboration for climate change, technology transfer for adaptation is a critical but understudied issue. Through an analysis of Global Environment Facility-managed adaptation projects, we find there is significantly more technology transfer occurring in adaptation projects than might be expected given the pessimistic rhetoric surrounding technology transfer for adaptation. Most projects focused on demonstration and early deployment/niche formation for existing technologies rather than earlier stages of innovation, which is understandable considering the pilot nature of the projects. Key challenges for the transfer process, including technology selection and appropriateness under climate change, markets and access to technology, and diffusion strategies are discussed in more detail.

Technologies that can reduce vulnerability to climate change and increase adaptive capacity, exist and are being developed throughout the world[1–5]. Technology transfer can link existing 'knowledge to need' and can be defined as the movement of know-how, tacit knowledge, or physical technology from one organizational setting to another[6–8]. The defining aspect of technology transfer is the introduction of a new process or approach in a new socio-political context. The technology does not need to be new to the world; the novelty to adopters is the critical aspect[6,9]. Technology can be understood as both 'hardware' and 'software', that is, the embodied tangible technology as well as tacit knowledge about how to acquire, modify, produce, use and eventually improve on previous technology[6–9].

Although technology transfer for adaptation has gained prominence in the international climate agenda and several reports, including an Intergovernmental Panel on Climate Change Special Report on Technology Transfer, identify and analyse adaptation technologies for different sectors, no systematic analysis of technology transfer in adaptation projects has been conducted so far[3,5,10]. This paper addresses two research questions: How has technology transfer occurred in adaptation projects so far? What are necessary conditions for technology transfer for adaptation? We examine technology transfer for adaptation by analysing projects funded by the Global Environment Facility (GEF), of which two of us, B.B. and C.O., were until recently employees (see Competing financial interests statement). We then use a case study approach to examine technology transfer processes in adaptation projects in Ethiopia, Colombia and Peru.

Evaluating the success of technology transfer ultimately requires looking at the long-term impacts on adaptation, as well as the impacts on the larger systems in which technologies are embedded including markets, political systems, users, and resources[8]. In the cases analysed here, most transfers are too recent for such comprehensive analyses. Instead, an intermediate measure of successful technology transfer, namely technology adoption, is the main measure used and provides a useful indication of potential for broader success.

Many factors influence the adoption process, including the characteristics of the technology, characteristics of intended users, the socio-technical system in which the technology is embedded, and the design of transfer mechanisms[9,11–16]. Unlike models in which technologies are viewed as more or less 'fixed' by the demonstration phase (that is, refs 4,17), incremental but important innovations also occur at later stages owing to feedback processes[18,19]. We present a theoretical model that incorporates factors associated with technology adoption and the stages of innovation in Fig. 1. This model provides a framework for analysing which types of technology are being transferred for adaptation and where these transfers fit into the innovation process.

Results and discussion

Project proposals. Most projects reviewed (74%) referenced technologies or technological practices, suggesting that technology transfer is an important component of adaptation projects, but only 11 proposals (17%) explicitly use the term 'technology transfer.' Historically the term 'technology transfer' has been interpreted narrowly (focusing on 'hard' technologies and north–south transfers), which may explain this discrepancy[5,20–22]. Only 11% of projects approved between 2006 and 2010 explicitly referenced technology transfer, compared with 32% from 2011 onwards. This trend suggests that learning is occurring over time and the increasing prominence of technology transfer in the international climate regime is leading to greater awareness of technology transfer. For the 15 projects that did not contain references to any technology, most focused on either policy or ecosystem-based approaches to adaptation. This outcome suggests that either technology plays a lesser role or it is more difficult to conceptualize the role of technology in such projects. See Table 1 for a summary of the projects' geographic distribution, funding sources, and implementing agencies. Further information can be found in the Supplementary Methods.

The types of technology transferred in projects varied. Some projects included 'hard' technologies such as geo-textiles for reef rehabilitation (India), irrigation technologies (Jordan), water harvesting technologies (Mongolia), and glacial monitoring systems (Bhutan, Ecuador, Peru, Colombia). More projects focused on knowledge transfer and capacity-building, such as introduction of agroforestry techniques (Haiti), climate models (Egypt), training

[1]United Nations Development Programme, New York 10017, USA, [2]Center for International Environment and Resource Policy, The Fletcher School, Tufts University, Massachusetts 02155, USA, [3]United Nations Development Programme, Bangkok 10200, Thailand. *e-mail: laura.kuhl@tufts.edu

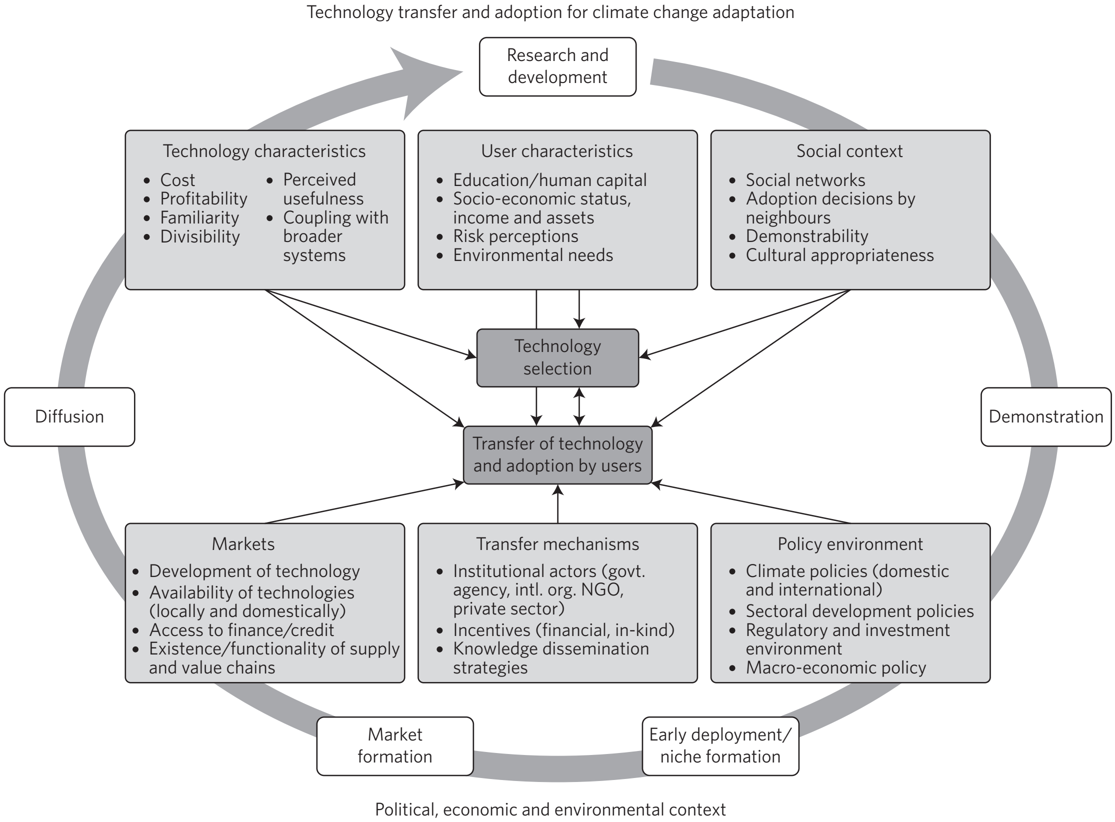

Figure 1 | This model of technology transfer and adoption recognizes that many factors are important for technology selection, transfer and, ultimately, adoption of new technologies by users. The factors included here have been identified, on the basis of the literature, as the most critical for the climate adaptation context, although additional factors may also be influential. This model recognizes that technology transfer and innovation are inherently linked and occur simultaneously, with innovation occurring throughout the transfer process, and feedback loops among all factors. The model is also neutral regarding the source of innovations, both in terms of geographic origin and actors.

Table 1 | Projects in the Global Environment Facility adaptation funds.

Location	Africa: 28
	Asia: 13
	Small island developing states: 10
	Latin America: 7
	Middle East and North Africa: 4
	Europe and Central Asia: 4
Fund	Special Climate Change Fund: 31
	Least Developed Country Fund: 35
Implementing agency	UNDP: 36
	World Bank: 12
	UNEP: 6
	IFAD: 5
	FAO: 3
	ADB: 2
	AfDB: 2
	ERBD: 1
	IABD: 1
	IFAF: 1

Approved projects in the Global Environment Facility adaptation funds (as of December 2011). Note that the number of implementing agencies exceeds the total because some projects have joint implementation.

farmers to use climate forecasts (Sudan), and demonstration tours (Zimbabwe, Ethiopia, Zambia, Mali). This finding challenges us to think more broadly about the types of technology needed to adapt to climate change and recognize that adaptation may require significant behavioural changes as well as a focus on the tacit knowledge aspects of technology transfer[5,22].

When examining the language used in proposals relating to different innovation tasks, most projects focused on demonstration, early deployment and niche formation for existing technologies, with transfers of new or emerging technologies relatively rare (Table 2). One example of a project that did introduce an emerging technology was in Jordan, which promoted a new irrigation technology requiring 30% less water than traditional techniques. The technology was initially poorly suited to the harsh climatic conditions in Jordan and did not work as expected. This experience suggests, consistent with the literature[3,9,21,23–25], that technologies must be demonstrated in new environments and modified before widespread diffusion can be successful and emphasizes the rationale for a strong focus on the demonstration and early deployment processes in the funds. Although early stages of innovation may be critical for 'radical' innovations, incremental innovations in the demonstration and diffusion stages can have at least as profound cumulative impacts on socio-technical regime change[19,26].

Perhaps because of the localized character of agriculture and the dominance of this sector in projects, we found that many projects emphasized domestic diffusion of technologies rather than the north–south transfer of technology that has traditionally been the focus of technology transfer[8,11,23,24,27,28]. In addition to the local nature of agriculture, another factor explaining this trend may be that these practices are already adapted to the specific physical and cultural context[9,16,29]. Concerns about cost-effectiveness

Table 2 | Innovation tasks represented in actions proposed in project documents.

Research and development	Technology selection	Demonstration	Early deployment/ niche formation	Market formation	Diffusion	Unclear
Develop: 14	Identify: 4	Pilot: 25	Implement: 19	Promote: 8	Replicate: 10	Construct: 2
Design: 5	Assess: 3	Demonstrate: 21	Install: 10	Access: 5	Adopt: 8	Integrate: 1
Explore: 2	Select: 2	Introduce: 13	Establish: 8	Scale-up/upscale: 5	Disseminate: 6	Overhaul: 1
Research: 1	Measure: 1	Test: 10	Deploy: 7	Strengthen: 5	Diffuse: 2	Complete: 1
Investigate: 1	Define: 1	Apply: 6	Purchase: 5	Acquire: 2		Repair: 1
	Prioritize: 1		Provide: 3	Deliver: 2		Rehabilitate: 1
	Evaluate: 1		Equip: 3	Expand: 1		Renovate: 1
			Set-up: 2			Maintain: 1
			Launch: 1			Restore: 1
			Produce: 1			Transmit: 1
			Distribute: 1			Upgrade: 1
			Deliver: 1			Use: 1
Total: 23	Total: 13	Total: 75	Total: 61	Total: 28	Total: 26	Total: 13

All actions related to the transfer of technology were identified in project proposal documents and coded on the basis of their relationship to tasks in the innovation cycle. Terms were associated with a task in the innovation cycle on the basis of the literature on innovation as well as the context in which the terms were used in the proposals. Counts represent number of projects using each term. Actions relating to 'Demonstration' and 'Early deployment/niche formation' were the most commonly used, whereas actions relating to 'Research and development,' 'Market formation' and 'Diffusion' were more rare. Although terms relating to 'Technology selection' did not appear frequently in projects, when used, they represented key components of projects. This finding is consistent with the pilot nature of the projects and the focus in most projects on on-the-ground implementation. Several terms could not be clearly mapped to a task in the innovation process, either because the terms were vague, ill-defined, or no context was given.

may also be a factor. Cost-effectiveness is a funding criterion that may have the unintended consequence of biasing projects towards diffusion of locally available, existing technologies rather than new technologies that may be more expensive or riskier. Taking into account the limited resources for adaptation financing, balancing risk-taking and cost-effectiveness is a key challenge.

Case studies. Strong evidence of technology introduction and adoption was found in all cases. All projects were still in the implementation stage or had just completed project activities so it was not possible to observe long-term impacts, but there were many indications that technology use was supporting adaptation. In Ethiopia for example, some chronically food insecure project beneficiaries were self-sufficient and had graduated from the national food safety net program.

Technology selection. Technology selection is critical for adoption, as technology characteristics must match user needs and supporting environments[9,11,12]. Identifying appropriate technologies for adaptation has been a primary focus in the United Nations Framework Convention on Climate Change process, and is a crucial component of adaptation projects[10]. A wide range of technologies were employed, including high-tech equipment such as glacial monitoring equipment, as well as biologically-based technologies such as drought-resistant livestock varieties, each of which presented different transfer challenges. Monitoring and data collection technologies tended to require highly technical knowledge to use and modify the equipment and conduct data analysis. The equipment was highly sensitive, and new data needed to be integrated with existing data collection systems, which was difficult and time-consuming for local staff. That said, not all monitoring equipment was 'high-tech.' The Ethiopian project experimented with farmer-driven data collection, which required education and quality assurance measures. Conservation technologies and techniques typically required significant behavioural change. Biological technologies faced challenges of ensuring quality over time (degradation of seed/livestock quality), supply availability, and distribution issues, as well as user acceptance.

The scope of the project had significant impacts on technology selection. Consistent with resilience theory that emphasizes redundancy as a mechanism for dealing with uncertainty, adaptation projects incorporated many different technologies[30–33]. Although using more technologies can increase robustness, it can also lead to fragmentation[16,34,35]. The Colombian project, for example, attempted to address multiple stresses in various sectors and geographic regions throughout the country, and as a result, resources were spread thinly. In contrast, the Peruvian project had a more coherent set of activities because they were framed around a specific adaptation challenge (glacial retreat and impacts on water supply) and specific geographic location (two watersheds). This project was able to narrow its scope and identify a manageable set of technology choices.

Ensuring that technologies are appropriate for local needs is critical to success, and projects used multiple strategies to ensure appropriateness in their selection process[9,29,36–38]. In Ethiopia, the project team presented committees of local leaders with possible technologies and they determined which met their villages' needs best. In turn, the leaders wanted to ensure that technologies met clearly identified current farmer needs.

In the selection of technologies, adaptation projects face the challenging task of balancing technologies that are beneficial under current climate conditions with those that might be most adaptive under future climate conditions. Technologies for current climate conditions can build resilience to shocks and support adaptation, but they often represent incremental advances, not transformational change[16,19,26,35]. Without sufficient scientific knowledge of future conditions, technologies can be ineffective, or even harmful, if they are not appropriate under a future climate. One example is the promotion of vegetable crops in the Ethiopian project. They receive a better price in the market and can help increase farmer income (which can be used to reduce vulnerability and increase resilience). It was unclear whether all of the crops being promoted are drought-resistant, however. Some of the vegetable crops seemed to have high water needs and were failing under current moderate dry conditions (which may have been due to failure to adopt complementary technologies).

Another question is whether the technologies chosen are optimal. Geomembranes used for harvesting rainwater in Ethiopia helped farmers collect and store rainwater, thus addressing a major constraint under climate change. They are very popular, but they are not covered to prevent evaporation. In the already hot, dry climate, storing water in open ponds with black geomembranes is not an optimal design. There may be ways to modify such technologies to ensure that they do a better job of meeting adaptation goals.

Technology selection consists not only of identifying appropriate technologies but also the most appropriate suppliers of such technologies. The reputation of technology suppliers was an important factor in technology selection. In Ethiopia, there was a choice between two hand-pumps: one produced in India and the other in China. The project selected the Indian model because in the past farmers have had poor experiences with Chinese water pumps. It was argued by project staff that the Indian pumps were worth the additional expense because farmers could trust them and were more likely to adopt them. In Peru and Colombia, existing relationships with equipment suppliers were influential because staff wanted to ensure that data could be integrated into the existing monitoring network. Using the same company helped streamline the repair and maintenance process, as well as the learning curve for technicians. In Colombia, data from high mountain hydrological monitoring stations were easily integrated into the existing network, but new oceanographic monitoring stations required new software that was challenging to learn, particularly because training manuals were not available in Spanish. Stakeholders described the process as one of 'joint learning' for their institute and the supplier, which, although a positive collaboration, required a serious time commitment, and was possible only because of the relatively high level of absorptive capacity of the Colombian government[39–42].

A recurring theme across projects was the challenge of adapting technologies for remote areas, which necessitated improvisation and absorptive capacity. In Colombia, no continuous monitoring devices designed for an ocean environment were available at the time. In both Colombia and Peru, monitoring equipment had to be modified for high mountain ecosystems. Stream-monitoring equipment is typically designed for wide, slow-moving rivers, not the steep watersheds found in the Andes. Fog and clouds are significant sources of precipitation in the upper Andes, but no commercial equipment was available for 'fog harvesting'. Keeping glacial monitoring equipment level in the face of rapidly melting glaciers also required modification. Adaptation practices must constantly evolve as communities face a changing climate and unprecedented challenges.

Market factors. Once technologies were selected, projects faced several market challenges in the promotion and diffusion of technologies. In the Ethiopian and Colombian projects, procurement procedures were viewed as major barriers, limiting the pace of project implementation, causing serious delays to project activities, and increasing the cost of technology transfer. Many of the challenges observed are common across development projects and are not unique to adaptation. A trade-off exists between accountability in the use of funds and the efficiency with which funds can be dispersed.

Some issues with the procurement process may be unique or more extreme for adaptation projects. Adaptation projects often target highly vulnerable communities, which are often remote and the most likely to lack complete markets and face high transaction costs associated with bringing goods to market. In the Colombian case, some project activities were located on a remote island where everything had to be flown in, raising the costs significantly. Requirements for competitive bidding were also a barrier because of remote locations. In Ethiopia, national-level suppliers were not interested in serving the remote project area, particularly given the low volumes the project needed, and project staff had a hard time finding suppliers to complete the bidding process.

The pilot nature of these early adaptation projects meant that they required many small purchases. As adaptation projects may require many technologies, procurement procedures may need to be modified to accommodate these varying needs. When the Ethiopian project sought to procure drought-resistant sheep and goats, project staff needed formal bids from breeders, but rural livestock breeders had never written a receipt, let alone created a bid, leading to serious delays. Delays can have serious implications for technology adoption, particularly in agricultural projects, where seasonal timing is of critical importance. Such procurement requirements can act as a formidable barrier to technology transfer, favouring existing technological options over new technologies.

A related challenge was market formation policies and value chain promotion. Many of the technologies promoted were designed to increase yields, but it was unclear whether local markets could support increased yields and what might be the impact on agricultural prices. An additional challenge was that many of the technologies were not commercially available locally. The widespread adoption of technologies in the Ethiopian case suggests that there was strong demand, and because of their higher productivity, with the right financial mechanisms, farmers could be interested in purchasing the new technologies, but the project had not developed these mechanisms. A focus on both supply and demand is needed to ensure the sustainability of technologies in the long-term[12,37,43].

Technology diffusion. Of the three cases, only the Ethiopian project emphasized technology diffusion. The Colombian case was primarily focused on adoption by government agencies. The Peruvian case did include some diffusion efforts, but explicit strategies were not apparent and this lack of strategy was reflected in the lower rates of technology adoption observed.

Several aspects of the Ethiopian diffusion strategy contributed to its success. One factor was that the project included a specific demonstration phase. By working intensively with 'model farmers', the project demonstrated the effectiveness of the technologies. These demonstrations helped overcome risk-aversion and showed the potential profitability of adoption[9,16,44–47]. Farmer-to-farmer learning was encouraged, and farmers could observe trained 'model' farmers. Another factor was an accountability mechanism for the distribution of drought-resistant livestock and seeds which pre-identified second- (and third-) generation recipients. Second-generation recipients had an incentive to monitor the success of first-generation recipients, ensuring more successful adoption by the first-generation users, and at the same time, facilitating learning by the second-generation recipients.

Building on existing institutional capacity allowed the project to have greater reach and effectiveness. The project design relied on Ethiopia's agricultural extension service, which allowed it to widely distribute information and support farmers. Agricultural extension agents visited model farmers at least once a week to troubleshoot problems. The importance of this consistent institutionalized support could be seen in its absence in the Peruvian and Colombian projects. Although the Peruvian project introduced similar water-saving agricultural technologies, there was little evidence of broad adoption and visible signs of abandoned technologies in the field. Project coordinators explained that only a single training session was conducted and that they did not have the resources for follow-up training or troubleshooting. In Colombia, rainwater collection tanks had been given to vulnerable communities, but when visiting the village, it was evident that most of the tanks were not being used properly. Without a clear diffusion

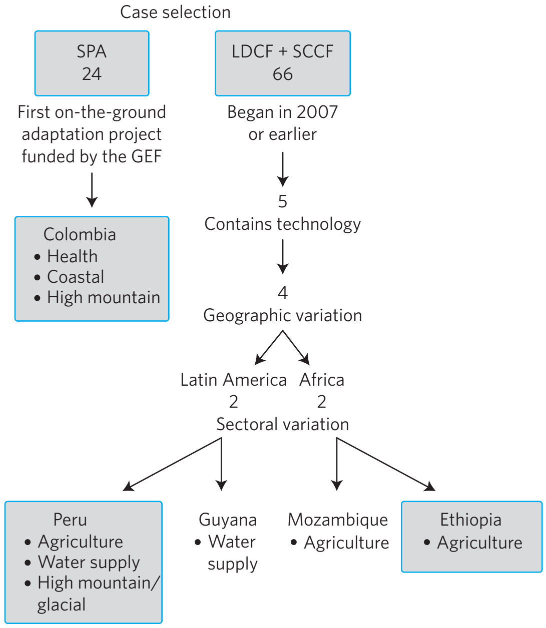

Figure 2 | One case selected from the Strategic Priority on Adaptation fund. As this fund served as a pilot for the development of the Least Developed Country Fund (LDCF) and Special Climate Change Fund (SCCF), lessons learned from these experiences were critical to subsequent projects. Of the 24 projects funded under the Strategic Priority on Adaptation (SPA), the Colombian INAP project was the first that included on-the-ground implementation of adaptation measures, and therefore holds a unique place among adaptation projects, particularly in terms of its demonstration role. From among the 66 projects in the LDCF and SCCF, several criteria were used to select cases. Projects needed to have started in 2007 or earlier and include a technology component. Among the projects that matched these criteria, we aimed for geographic and sectoral diversity. The projects in Ethiopia and Mozambique were both entitled 'Coping with Drought and Climate Change' and were based on a multi-country design. Owing to language barriers, Ethiopia was selected. In Latin America, both Peru and Guyana were possibilities. Peru was selected owing to the greater sectoral diversity covered in the project.

strategy, even useful technologies can fail to be adopted owing to the challenges of changing behavioural practices and overcoming learning barriers[9,11,13,36].

Conclusions

We find that significantly more technology transfer is occurring in adaptation projects than might be expected on the basis of the pessimistic rhetoric regarding technology transfer for adaptation[3,10,20]. However, it is likely that significantly higher levels of technology transfer are still needed to address adaptation priorities, especially as most of the projects reviewed focused on demonstration and early deployment/niche formation activities, and more widespread investments will be necessary to build on these activities to strengthen market formation and diffusion processes. For example, significant challenges remain regarding technology selection, more attention needs to be paid to market conditions, and clear diffusion strategies are essential for widespread adoption. Of course, this focus is consistent with the pilot nature of the GEF funds, and it is possible that other sources of funding and investments are more appropriate for addressing other aspects of the transfer and diffusion process. With limited resources available for adaptation, it is important to ensure that funds are used as effectively as possible, and lessons from existing projects are passed on to new projects. Although adaptation projects will probably face unique challenges for technology transfer, it is important to draw on lessons from past technology transfer attempts in the context of international development. Our analysis of these projects is an early effort to determine the factors that facilitate as well as barriers to successful technology transfer, but additional case studies and empirical analyses are needed to build more robust conclusions.

An interesting domain for further exploration is the difference between technology transfers for adaptation and mitigation. So far, it seems that rather than focusing on emerging or 'radical' technologies, adaptation projects tend to focus on existing technologies. The pattern of transfers also differs. Climate mitigation technology transfer tends to consist of north–south flows of technology (although increasingly there are south–north and south–south transfers), and technology transfer for adaptation in these early projects often consisted of domestic diffusion of existing localized technologies. Absorptive capacity, market formation strategies, and an enabling policy environment are crucial for both mitigation and adaptation. Identifying additional similarities and differences will be helpful for policymaking, especially as many climate technology transfer policies are based on the understanding of mitigation processes, which may or may not be applicable to adaptation technology transfer.

Another area for further research concerns the role of uncertainty in technology adoption. Although technology adoption always involves uncertainty, there are additional sources of uncertainty associated with adaptation that may complicate the adoption process including uncertainty regarding: local climate impacts, suitability of technologies to local circumstances, economic consequences of climate impacts (for example, prices for crops), and lack of correlation between past and future conditions[16,48]. At the same time, many technologies are designed to reduce climate risk and uncertainty, either by reducing the risk of a specific climate impact or by increasing overall resilience to shocks, and may increase incentives for adoption. Balancing these competing sources of uncertainty and risk is of central importance to successful technology transfer for adaptation.

Methods

We conducted a content analysis of funded project proposals and three case studies of adaptation projects under implementation. The content analysis of project proposals allowed us to gain insight into the types of technology being incorporated into projects, as well as the discourse on technology transfer at the time when projects were designed. The three case studies allowed us to study how and why adaptation technologies were transferred.

We analysed projects funded through the Least Developed Countries Fund (LDCF) and Special Climate Change Fund (SCCF) administered by the GEF. Projects funded through the LDCF and SCCF were chosen as the sample for analysis because the funds are global in scope and cover a wide range of sectors, providing representative coverage of global adaptation projects, and because the funds are the only active official funds for adaptation mandated by the Conference of Parties to the United Nations Framework Convention on Climate Change, apart from the Adaptation Fund, which was still too immature for analysis at the time of research. Also, the GEF portfolio is relatively mature and includes some of the earliest on-the-ground adaptation projects globally. Adaptation is being addressed by many actors at different scales, and funding sources for adaptation are quite diverse[34,35,45,49]. This analysis does not purport to be representative of all adaptation efforts globally, but rather to analyse the activities under these prominent funds.

Proposal analysis. For the proposal analysis, a total of 66 projects were analysed, including all projects in the LDCF and SCCF that had been approved by the LDCF/SCCF Council by the end of 2011 and for which project documents were available at the time of analysis. The projects covered a wide range of sectors including agriculture and food security, water management, coastal zone management, disaster risk reduction and early warning systems, health, ecosystem management and climate-resilient infrastructure (see Table 1 and the Supplementary Methods for further details).

We conducted a content analysis of all project proposals and identified references to the following terms and associated concepts in each: technology, technology transfer, adoption, innovation, and demonstration. We also identified all references to specific technologies or technical practices. Content relating to these terms was compiled into a database (Supplementary Methods). We analysed trends across projects in terms of sectors, regions, and implementation dates, and the variables we considered included actions related to innovation tasks (R&D, technology selection, demonstration, early deployment/niche formation, market formation, diffusion), types of technology, and the geography of transfer (local, north–south, south–south). A summary of the analysis of projects in terms of innovation tasks is presented in Table 2.

Case studies. The criteria for selection of the case studies were that they began in 2007 or earlier (owing to the pilot nature of the funds, only the earliest projects had advanced enough in implementation to assess technology adoption), contained a significant technology component, and represented different geographic regions and sectors. Five projects began in 2007 or earlier, one of which included no reference to technology. Of the remaining four, two were located in Latin America and two in Africa (Fig. 2). We selected the 'Coping with Drought and Climate Change' project in Ethiopia, and the 'Design and Implementation of Pilot Climate Change Adaptation Measures in the Andean Region' project in Peru, which was part of a regional project in Peru, Ecuador and Bolivia to maximize our geographic and sectoral variation. In addition, a project in Colombia entitled 'Integrated National Adaptation Plan' was selected because it was the first on-the-ground adaptation project funded by the GEF (this project was funded through the Strategic Priority on Adaptation, which was a window under the GEF General Trust Funds and served as a pilot for the SCCF and LDCF). For a detailed description of the cases, see the Supplementary Methods.

We conducted interviews with key stakeholders, including project staff, government officials at both national and local levels, non-governmental organization (NGO) partners, academic experts, community leaders and project beneficiaries. Participant observation supplemented the information gathered through interviews. A total of 56 interviews were conducted in 2012, which sought to understand the role of technology in the project, the decision-making process, factors leading to success, and barriers from the perspective of all key stakeholders. Specific questions were tailored to the individual cases, and a list of illustrative questions is contained in the Supplementary Methods.

Received 30 September 2013; accepted 17 June 2014; published online 13 July 2014

References

1. Tessa, B. & Kurukulasuriya, P. Technologies for climate change adaptation: Emerging lessons from developing countries supported by UNDP. *J. Int. Aff.* **64,** 17–31 (2010).
2. Lybbert, T. & Sumner, T. Agricultural technologies for climate change in developing countries: Policy options for innovation and technology diffusion. *Food Policy* **37,** 114–123 (2012).
3. IPCC *Special Report of Working Group III of the Intergovernmental Panel on Climate Change* (eds Metz, B., Davidson, O., Martens, J., Van Rooijen, S. & Van Wie Mcgrory, L.) (Cambridge Univ. Press, 2000).
4. Klein, R. J. T. *et al. Application of Environmentally Sound Technologies for Adaptation to Climate Change* (UNFCCC, 2006).
5. Olhoff, A. Adaptation in the context of technology development and transfer. *Clim. Policy* (in the press, 2014).
6. Brooks, H. *Marshalling Technology for Development* 83–96 (National Academies Press, 1995).
7. Grubler, A. *Technology and Global Change* (Cambridge Univ. Press, 1998).
8. Bozeman, B. Technology transfer and public policy: A review of research and theory. *Res. Policy* **29,** 627–655 (2000).
9. Rogers, E. *Diffusion of Innovations* (Free Press, 1995).
10. Sharma, S. & Moehner, A. in *Technologies for Adaptation: Perspectives and Practical Experiences* (eds Christiansen, L., Olhoff, A. & Traerup, S.) 3–17 (UNEP Risoe Centre on Energy, Climate and Sustainable Development, 2011).
11. Hayami, Y. & Ruttan, V. *Agricultural Development: An International Perspective* (John Hopkins Univ. Press, 1985).
12. Feder, G., Just, R. & Zilberman, D. Adoption of agricultural innovations in developing countries: A survey. *Econ. Dev. Cult. Change* **33,** 255–298 (1985).
13. Grubler, A., Nakicenovic, N. & Victor, D. G. Dynamics of energy technologies and global change. *Energy Policy* **27,** 247–280 (1999).
14. Geels, F. Technological transitions as evolutionary reconfiguration processes: A multi-level perspective and a case-study. *Res. Policy* **31,** 1257–1274 (2002).
15. Edquist, C. in *Oxford Handbook on Innovation* (eds Fagerberg, J. *et al.*) 181–208 (Oxford Univ. Press, 2005).
16. Zilberman, D., Zhao, J. & Heiman, A. Adoption versus adaptation, with emphasis on climate change. *Annu. Rev. Res. Econ.* **4,** 27–53 (2012).
17. World Development Report (WDR), *Development and Climate Change* (World Bank, 2010).
18. Freeman, C. The economics of technical change. *Camb. J. Econ.* **18,** 463–514 (1994).
19. Bell, M. in *Low-Carbon Technology Transfer: From Rhetoric to Realticy* (eds Ockwell, D. & Mallett, A.) 45–72 (Routledge, 2012).
20. Brewer, T. Climate change technology transfer: A new paradigm and policy agenda. *Clim. Policy* **8,** 516–526 (2008).
21. Ockwell, D. *et al.* Enhancing developing country access to eco-innovation: The case of technology transfer and climate change in a post-2012 policy framework, OECD Environment Working Papers No. 12. (2010).
22. Markandya, A. & Galarraga, I. in *Technologies for Adaptation. Perspectives and Practical Experiences* (eds Christiansen, L., Olhoff, A. & Traerup, S.) 27–42 (UNEP Risoe Centre on Energy, Climate and Sustainable Development, 2011).
23. Reddy, N. & Zhao, L. International technology transfer: A review. *Res. Policy* **19,** 285–307 (1990).
24. Gallagher, K. Limits to leapfrogging in energy technologies? Evidence from the Chinese automobile industry. *Energy Policy* **34,** 383–394 (2006).
25. Strang, D. & Soule, S. Diffusion in organizations and social movements: From hybrid corn to poison pills. *Annu. Rev. Sociol.* **24,** 265–290 (1998).
26. Freeman, C. *The Economics of Hope: Essays on Technical Change, Economic Growth, and the Environment* (Pinter Publishers, 1992).
27. Lewis, J. Technology acquisition and innovation in the developing world: Wind turbine development in China and India. *Stud. Comp. Int. Dev.* **42,** 208–232 (2007).
28. Lorentzen, J. Learning and innovation: What's different in the (sub)tropics and how do we explain it? A review essay. *Sci. Technol. Soc.* **14,** 177–205 (2009).
29. Ruttan, V. What happened to technology adoption-diffusion research? *Sociol. Ruralis* **36,** 51–73 (1996).
30. Holling, C. Resilience and stability of ecological systems. *Annu. Rev. Ecol. Syst.* **4,** 1–23 (1973).
31. Becker, D. & Ostrom, E. Human ecology and resource sustainability: The importance of institutional diversity. *Annu. Rev. Ecol. Syst.* **26,** 113–133 (1995).
32. Low, B., Ostrom, E., Simon, C. & Wilson, J. in *Navigating Social-Ecological Systems: Building Resilience for Complexity and Change* (eds Berkes, F., Colding, J. & Folke, C.) 83–114 (Cambridge Univ. Press, 2002).
33. Folke, C., Hahn, T., Olsson, P. & Norberg, J. Adaptive governance of social ecological systems. *Annu. Rev. Environ. Res.* **30,** 441–473 (2005).
34. Adger, W., Arnell, N. & Tompkins, E. Successful adaptation to climate change across scales. *Glob. Environ. Change* **15,** 77–86 (2005).
35. Nelson, D., Adger, W. & Brown, K. Adaptation to environmental change: Contributions of a resilience framework. *Annu. Rev. Environ. Res.* **32,** 395–412 (2007).
36. Chambers, R., Pacey, A. & Thrupp, L. *Farmer First: Farmer Innovation and Agricultural Research* (Intermediate Technology Publications, 1989).
37. Snapp, S., Blackie, M. & Donovan, C. Realigning research and extension to focus on farmers' constraints and opportunities. *Food Policy* **28,** 349–363 (2003).
38. Sturdy, J., Jewitt, G. & Lorentz, S. Building an understanding of water use: Innovation adoption processes through farmer-driven experimentation. *Phys. Chem. Earth* **33,** 859–872 (2008).
39. Abramovitz, M. Catching up, forging ahead, and falling behind. *J. Econ. Hist.* **46,** 385–406 (1986).
40. Bell, M. & Pavitt, K. Technological accumulation and industrial growth: Contrasts between developed and developing countries. *Ind. Corp. Change* **2,** 157–210 (1993).
41. Ockwell, D., Haum, R., Mallett, A. & Watson, J. Intellectual property rights and low carbon technology transfer: Conflicting discourses of diffusion and development. *Glob. Environ. Change* **20,** 729–738 (2010).
42. Cohen, W. & Levinthal, D. Absorptive capacity: A new perspective on learning and innovation. *Adm. Sci. Q.* **35,** 128–152 (1990).
43. Tambo, J. & Abdoulaye, T. Climate change and agricultural technology adoption: The case of drought tolerant maize in rural Nigeria. *Mitig. Adapt. Strateg. Global Change* **17,** 277–292 (2012).
44. Foster, A. & Rosenzweig, M. Microeconomics of technology adoption. *Annu. Rev. Econ.* **2,** 395–424 (2010).
45. Smit, B. & Skinner, M. Adaptation options in agriculture to climate change: A typology. *Mitig. Adapt. Strateg. Glob. Change* **7,** 85–114 (2002).

46. Bryan, E., Deressa, T., Gbetibou, G. & Ringler, C. Adaptation to climate change in Ethiopia and South Africa: Options and constraints. *Environ. Sci. Policy* **12,** 413–426 (2009).
47. Deressa, T., Hassan, R., Ringler, C., Alemu, T. & Yesuf, M. Determinants of farmers' choice of adaptation methods to climate change in the Nile Basin of Ethiopia. *Glob. Environ. Change* **19,** 248–255 (2009).
48. Eichberger, J. & Guerdjikova, A. Technology adoption and adaptation to climate change—A case-based approach. *Clim. Change Econom.* **3,** 41 (2012).
49. Tompkins, E. & Eakin, H. Managing private and public adaptation to climate change. *Glob. Environ. Change* **22,** 3–11 (2012).

Acknowledgements
We would like to thank all of the staff at each project site for their generous support of the field research. Funding support was received by a research grant from BP, NSF research grant 0966093 IGERT: Water Diplomacy, and the Fletcher School at Tufts University.

Author contributions
L.K. carried out the proposal analysis, field research for the case studies, and wrote the paper. B.B. and K.S.G. conceptualized the paper and all four authors selected cases. C.O. assisted with access to project documents and coordination of field visits. L.K. performed analysis with contributions from K.S.G. L.K., K.S.G., B.B. and C.O. edited.

Additional information
Supplementary information is available in the online version of the paper. Reprints and permissions information is available online at www.nature.com/reprints. Correspondence and requests for materials should be addressed to L.K.

Competing financial interests
B.B. was formerly employed (during analysis) by Global Environment Facility (GEF) as Head of Climate Change Adaptation Strategy and Operations. C.O. was formerly employed (during analysis) by GEF as Program Associate supporting the adaptation portfolio management, Climate Change Adaptation. Neither stands to gain financially from publication.