Presenting Triple-Wins? Assessing Projects That Deliver Adaptation, Mitigation and Development Co-benefits in Rural Sub-Saharan Africa

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Abstract The concept of climate compatible development (CCD) is increasingly employed by donors and policy makers seeking ‘triple-wins’ for development, adaptation and mitigation. While CCD rhetoric is becoming more widespread, analyses drawing on empirical cases that present triple-wins are sorely lacking. We address this knowledge gap. Drawing on examples in rural sub-Saharan Africa, we provide the first glimpse into how projects that demonstrate triple-win potential are framed and presented within the scientific literature. We identify that development projects are still commonly evaluated in terms of adaptation or mitigation benefits. Few are framed according to their benefits across all three dimensions. Consequently, where triple-wins are occurring, they are likely to be under-reported. This has important implications, which underestimates the co-benefits that projects can deliver. A more robust academic evidence base for the delivery of triple-wins is necessary to encourage continued donor investment in activities offering the potential to deliver CCD.

Keywords Climate change · Sub-Saharan Africa · Triple-wins, adaptation · Mitigation · Development

INTRODUCTION

Climate change is increasingly recognised as a development issue (Reid and Huq 2007; Lemos et al. 2007) and is a key priority in the Least Developed Countries where impacts will be disproportionately felt (Stern 2007). In sub-Saharan Africa (SSA), where over 60 % of people live in rural areas (FAO 2007), climate change presents significant challenges for the day-to-day functioning of many households. Without adequate management, climate change will

exacerbate current vulnerabilities and create new development challenges (Boko et al. 2007). The United Nations Framework Convention on Climate Change (UNFCCC) sets out the international policy framework to manage climate change, focusing on the causes of climate change (mitigation) and coping with its consequences (adaptation). Historically, mitigation and adaptation have been treated separately within both policy and science (de Boer et al. 2010). Due to a ‘timescale mismatch’ whereby mitigation actions will take many decades to have an impact on global climate, it is now accepted that reductions in greenhouse gas (GHG) emissions alone will be insufficient to manage the challenge (Anderson and Bowes 2008). Adaptation therefore becomes inevitable. Consequently, adaptation and mitigation are both core components of any climate change response (Adger et al. 2007).

Realisation that both adaptation and mitigation are necessary for development has resulted in the emergence of the concept of ‘climate compatible development’ (CCD) in the policy arena, as a way of drawing together mitigation and adaptation efforts without compromising development goals. Until recently, this has been an extremely underexplored area (Klein et al. 2005). CCD is defined as ‘development that minimises the harm caused by climate impacts, while maximising the many human development opportunities presented by a low emissions, more resilient future’ (Mitchell and Maxwell 2010). It is argued that by harnessing opportunities for mitigation, adaptation and development, CCD can achieve ‘triple-wins’. However, evidence-based empirical case studies of ‘triple-win’ projects where the ‘wins’ are critically evaluated are extremely rare (Tompkins et al. 2013). More commonly, adaptation and mitigation are examined in the absence of development. For example, the Intergovernmental Panel on Climate Change (IPCC) dedicates a chapter to the linkages

between adaptation and mitigation (Klein et al. 2007). Although development is explored to some extent, the chapter acknowledges a lack of available ‘triple-win’ case-study examples at the regional or sectoral level. A notable exception to this is a study by Ayers and Huq (2009) who use the example of a waste-to-compost project in Bangladesh. In their analysis, the authors demonstrate a reduction in methane emissions (mitigation); soil improvement in drought-prone areas (adaptation); and poverty reduction (development). Furthermore, evidence from Zanzibar, Tanzania suggests that in the absence of specific measures to encourage synergies between adaptation, mitigation and development, autonomous responses to climate change by subsistence communities can create trade-offs between the three strands (Suckall et al. 2014). If continued donor investment in CCD is to be encouraged, a strong academic evidence base for ‘triple-wins’ must be developed. This is recognised by the IPCC who states that ‘learning from the expanding case experience of interrelationships is a priority’ (Klein et al. 2007, p. 770).

This paper takes the first steps towards a regional and sectoral assessment of ‘triple-wins’. We focus our attention on Africa due to the high vulnerability of the continent to climate change. The twentieth century saw warming of approximately 0.7 °C over much of the continent, with Sahelian rainfall decreasing and east Central African rainfall increasing (Boko et al. 2007). Future projections suggest that increased climate variability, as well as floods and droughts will impact on natural resource-dependent populations (Conway 2009). In the absence of case studies that are explicitly framed as offering the potential to deliver ‘triple-wins’, we identify academic case studies of development interventions that incorporate adaptation and mitigation aspects across four climate-sensitive sectors in rural SSA. We focus on the water, agriculture, forest and energy sectors. These sectors face significant threats from the direct and indirect impacts of climate change, which will have consequences for natural resource-dependent communities. At the same time, the four sectors offer enormous potential to contribute to mitigation either through emissions reduction or carbon sequestration or both. Our intention is to provide a qualitative and subjective analysis of ‘triple-wins’ in each sector, rather than to provide a quantitative assessment of adaptation, mitigation and development aspects.

The remainder of the paper is divided into three sections. First, we outline our methodology for identifying ‘triple-win’ projects. Second, for each of the four sectors, we map out the links between adaptation, mitigation and development before presenting an illustrative case study of a development intervention that includes adaptation and mitigation benefits. More specifically, we assess the ways in which the ‘wins’ each project offers for adaptation,

mitigation and development are presented and the extent to which achievement of a ‘triple-win’ is made explicit in the case study. Third, we discuss the implications of our findings for policy.

IDENTIFYING TRIPLE-WINS IN THE LITERATURE

The absence of peer-reviewed case studies on adaptation, mitigation and development across sectors exposes a gap in the literature. We argue that this gap remains because the historical dichotomy between adaptation and mitigation persists. Using this as our point of departure, we identify case studies of projects that deliver development interventions in the water, agriculture, forest and energy sectors. For inclusion in our study, development projects must also incorporate adaptation and mitigation benefits whether this is made explicit or not. Consequently, we specifically set out to only identify projects that have a triple-win element. For each sector, we identify one case study to illustrate what could be achieved.

In selecting our case studies, we make the following definitions. We define a development intervention as a purposeful strategy designed to achieve one or more of the Millennium Development Goals (MDGs). These are to eradicate extreme poverty and hunger; to achieve universal primary education; to promote gender equality and empower women; to reduce child mortality rates; to improve maternal health; to combat HIV/AIDS, malaria, and other diseases; to ensure environmental sustainability; and, to develop a global partnership for development. In line with the IPCC definition of adaptation, we consider an adaptation benefit to be any adjustment that is made in response to ‘expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities’ (IPCC 2001). Finally, we define mitigation as any ‘anthropogenic intervention to reduce the sources or enhance the sinks of greenhouse gases’ (IPCC 2001).

To identify our case studies, we used the ISI Web of Knowledge (ISI WoK) search engine as it covers the main journals relating to climate, science, technology, society, development, risk and ecology. Case studies were identified using a range of search terms from the theoretical literature on triple-wins, for example, ‘conservation agriculture’ and ‘solar power’. For inclusion in this research, cases studies must focus on current or recently completed development-facing projects that infer (or, less frequently, make explicit) additional co-benefits (i.e. adaptation, mitigation or both). All the projects we select have a rural focus and take place at the community or household level.

In the following section, we explore the theoretical linkages between adaptation, mitigation and development

for the water, agricultural, forest and energy sectors. For each sector, we then present details of an illustrative case study of adaptation, mitigation and development. In each case study, we identify the relationship between adaptation, mitigation and development, and assess the ways in which the triple-wins are reported.

ADAPTATION, MITIGATION AND DEVELOPMENT AT THE SECTORAL LEVEL

The Water Sector

With a large part of Africa's population lacking access to clean and safe water and a high dependence on water-intensive sectors (including agriculture), water is key to meeting development challenges. Climate change will exacerbate existing problems of water availability in arid areas and water quality in wetter areas (Bates et al. 2008). Existing water management practices and infrastructures are very likely to be inadequate to overcome the negative impacts of climate change and adaptation of both practices and infrastructure will be necessary (Kundzewicz et al. 2008). In semi-arid areas, access to water for irrigation may not only provide significant adaptation potential, but will also require energy for abatement, pumping and distribution (Halsnæs and Verhagen 2007). Although the emission potential of such practices depends on the mix of fuels and the technologies employed, the potential threat to mitigation is clear (Stillwell et al. 2011). Links between mitigation and adaptation within the sector have been recognised, but complementarity between the two approaches has not been widely addressed in the academic literature even at the theoretical level (Mata and Budhooram 2007). Consequently, a clear dichotomy between adaptation and mitigation remains. Furthermore, Rothausen and Conway (2011) point to a preference for peer-reviewed studies of water and energy that focus on 'water for energy' (e.g. hydroelectric power) as opposed to 'energy for water' (e.g. irrigation).

Despite the overall absence of adaptation and mitigation synergies in the literature, our review highlights a peer-reviewed analysis of the Solar Electric Light Fund (SELF) (a US-based charity) that established a smallholder solar-powered drip irrigation scheme in Benin. More specifically, Burney et al. (2010), Burney and Naylor (2012) examine the scheme's effectiveness for enhancing income generation and food security. Agriculture in Benin is non-existent during the 6-month dry season, and any variation in the rainy season can have severe impacts on food security. This is expected to become severer with climate change. In order to provide year-round agriculture, solar-powered water pumps are used to deliver water directly to plant roots. The aim of this is to ensure household food

security and income generation through an open market garden project, in which high-value fruits and vegetables are grown for commercial sale. Burney et al. (2010), Burney and Naylor (2012) found that solar-powered drip irrigation significantly increased household income and nutritional intake, particularly during the dry season. Households in the project were also less water insecure (more able to meet their daily water needs) than households outside of the scheme, although water access improved for all households over time (Burney and Naylor 2012). There is also evidence to suggest that in the future, farmers plan to use their earnings to send children to school further contributing to development. Whilst the authors do not directly refer to climate mitigation, they highlight that each garden using a solar-powered drip irrigation system saves a minimum of 0.86 tonnes of carbon emissions each year against a liquid fuel (e.g. kerosene) alternative (Burney et al. 2010). Although the project clearly achieves triple-wins (see Table 1) the analysis is framed as adaptation and development, and neither of the terms 'triple-wins' nor 'co-benefits' are used.

The Agricultural Sector

The agricultural sector will be negatively affected by changes to precipitation, increased temperatures and a shorter growing season. For example, in a meta-analysis of regional climate impacts on agriculture, Knox et al. (2012) predict an 8 % decline in overall crop productivity by 2050. This will have significant impacts on food security and human development in general. However, the challenges presented by climate change also create opportunities to develop new agricultural management techniques that incorporate both adaptation and mitigation (Tubiello and van der Velde 2010). This has been recognised at a theoretical level within the literature (Lal 2004; Palm et al. 2010). For example, FAO (2009) describes an overlap between soils that lack carbon ('carbon-gaps') and the geographic incidence of hunger. By increasing the amount of soil carbon, fertility and water retention are improved, thus leading to improved yields (Stringer and Dougill 2012). Lal (2004) estimates that for every 1 ton of carbon that is sequestered into degraded soil, maize yield increases by 10–20 kg ha⁻¹. Against this backdrop, the Climate-Smart Agriculture (CSA) concept was launched by FAO in 2010 (Lipper et al. 2010). The aim of CSA is to increase productivity and resilience (adaptation), reduce/remove GHGs (mitigation), and enhance the achievement of national food security and development goals. Methods for CSA include (amongst others) agro-forestry, where trees are managed together with crops; and conservation agriculture (CA), where land is farmed with minimum soil disturbance. Assessment of both agro-forestry and CA

Table 1 Adaptation, mitigation and development benefits across four sectors

Sector	Example	Adaptation	Mitigation	Development
Water	Solar powered drip irrigation in Benin (Burney et al. 2010; Burney and Naylor 2012)	<ul style="list-style-type: none"> •Year round agriculture •Improved water security 	<ul style="list-style-type: none"> •Lower emission than liquid fuel (kerosene) alternative 	<ul style="list-style-type: none"> •Increased income •Money for education •Improved nutrition
Agriculture	Conservation agriculture (CA) in Karatu District, northern Tanzania (Owenya et al. 2011)	<ul style="list-style-type: none"> •Reduction in labour requirement (more time for income generating activities) 	<ul style="list-style-type: none"> •Soil carbon sequestration* 	<ul style="list-style-type: none"> •Increased yields •Income from surplus •Increased children's education
Forest	Agro-forestry: Modified Taungya System (MTS) in Ghana (Kalame et al. 2011)	<ul style="list-style-type: none"> •Reduces drought and bushfire risk •Buffers against desertification •Timber sales enhance adaptive capacity 	<ul style="list-style-type: none"> •Carbon sequestration in woody biomass 	<ul style="list-style-type: none"> •Financial gain •Increased food security •Empowerment (as land guardians)
Energy	LED lanterns in southern Malawi (Adkins et al. 2010)	<ul style="list-style-type: none"> •Opportunities for livelihood diversification 	<ul style="list-style-type: none"> •Lower emission than liquid fuel (kerosene) alternative 	<ul style="list-style-type: none"> •Decreased fuel spend •Opportunities for evening education

* The benefit is not an explicit output of the project but has been inferred from the literature

projects have been the focus of publications in the grey literature (e.g. FAO 2013), but critical reviews in the academic literature are rare.

Owenya et al. (2011) present an assessment of a CA project in Karatu District, northern Tanzania. The project, facilitated by FAO began as a village-based education programme with the aim to combat persistently low yields. As is common practice in much of rural SSA, farmers in Karatu typically remove all crop residues and intensively till their land after harvest. This provides short-term benefits such as weed control, but over a period of time leaves the soil exposed, leading to erosion, leaching, fertility decline and carbon loss (Lal 1997). CA aims to reverse this by promoting minimal soil disturbance and permanent soil cover (mulch) combined with rotations (Hobbs et al. 2008). In their assessment of the Karatu CA project, Owenya et al. (2011) report a contribution to development and adaptation through increased yields, income generation from surplus crops and a reduction of labour requirements. Water-use efficiency also increased due to better infiltration, holding and uptake within soils. Whilst the authors did not explicitly discuss the impacts for carbon sequestration, it is widely acknowledged that CA is part of climate-smart agriculture and thus can deliver mitigation benefits (see Table 1).

The Forest Sector

Throughout SSA, climate change threatens the sustainability of forests both indirectly, for example, from agricultural expansion as farmers seek more productive lands (Chomitz and Buys 2007) and directly, for example, through forest fires (Cochrane 2003). This has potentially

significant impacts for many SSA communities where forests act as safety nets in that people draw on non-timber goods to meet emergency shortfalls, for example, after a weather-related crop failure (Belcher et al. 2005; Fisher et al. 2010). Therefore, by protecting and increasing forested areas, rural households who live near a forest will be better equipped to adapt to climate variability (Fisher et al. 2010). Furthermore, appropriate management of forests can yield huge mitigation benefits through carbon sequestration (Houghton 2012). As such, synergies between adaptation and mitigation include forest conservation, protected area management, afforestation and reforestation, bioenergy plantations, agro-forestry, sustainable forest management and urban forestry (Ravindranath 2007; Metz 2007). Furthermore, where opportunities for income generation from forest goods exist, triple-wins are created. Arguably, the best-known example of triple-wins for the forest sector exists in the literature surrounding the Reducing Emissions from Deforestation and Forest Degradation (REDD+) scheme (e.g. Somorin et al. 2012). The scheme provides development benefits by making payments for forest services to smallholder farmers, mitigation benefits by increasing carbon storage, and adaption benefits by creating opportunities for livelihood diversification.

As is the case for the water and agricultural sectors, empirical evidence of projects delivering triple-wins in the forest sector are rare, but do exist. Kalame et al. (2011) present a case study of the Modified Taungya System (MTS), an agro-forestry scheme in Ghana. Under the MTS, local farmers are allocated deforested land on which they intercrop food plants with native tree species. Farmers are expected to tend to the trees until a forest canopy is established, at which point crops are shaded out by trees

and farmers move on to a new piece of land to start the process again. The MTS is able to store a significant amount of carbon in its woody biomass thus contributing to mitigation. The same woody biomass contributes to adaptation as trees act as a buffer against droughts, desertification and bush fires. In terms of development, local farmers receive new tools and skills, are in control of the land, and, share in the benefits of forest rehabilitation, such as revenue from timber and increased food security. Although Kalame et al. (2011) present their analysis through an adaptation lens, they are explicit about the mitigation and development benefits of the MTS. In this way, their analysis can be considered an assessment of 'triple-wins' (see Table 1) although the authors do not use this terminology.

The Energy Sector

Low levels of rural electrification are a major barrier to development in SSA. More than 80 % of the rural population depend on biomass (charcoal, fuelwood, dung, and crop residues) to meet domestic energy needs related to lighting, cooking and heating (Kammen and Kirubi 2008). Women and children bear the heaviest burden of biomass use as they often have to travel long distances to collect wood (Calvo 1994) and are disproportionately exposed to combustion pollutants (Bailis et al. 2005). For this reason, rural electrification has the potential to meet gender-equality goals and other development goals through improved access to social and business services, including schools, markets, water pumps and technology for increased agricultural productivity (Kirubi et al. 2009). Where opportunities for livelihood diversification and improved agricultural productivity exist, adaptation goals can also be met. However, becoming reliant on carbon-dependent technologies undermines the principles of CCD. Renewable-energy sources could provide electrification opportunities, but there is a shortage of information on their use on the continent (Szabó et al. 2011). In this light, access to clean-energy sources has been recognised as a key goal of CCD (Mitchell and Maxwell 2010), but empirical studies of the impacts of clean energy are rare.

Adkins et al. (2010) examined the use of LED lanterns in a cluster of rural villages in southern Malawi. The villages were part of the Millennium Village Project (MVP), a development-facing initiative led by the Earth Institute at Columbia University and the United Nations Development Programme. The aim of the MVP is to increase rural productivity and encourage development. In Malawi where fewer than 5 % of the rural population receive electricity from the national grid (IEA 2002), adequate lighting is a priority for better living standards and is essential in achieving the MDGs (Modi et al. 2005). Currently, many

homes and properties are lit using liquid fuel in hurricane lamps. Adkins et al. (2010), in their analysis of the LED project, found that households who adopted the lamps made substantial fuel savings, which were greater than the cost of the lantern over the period of a year. Furthermore, in participating households, use of light lamps in the evenings increased by 63 %. The authors speculated that this would eventually lead to increased livelihood activity in the evenings and more studying for school-age household members. Despite being framed as delivering development, opportunities for mitigation and adaptation can be inferred. In terms of mitigation, the authors note that in the developing world, the consumption of liquid fuel for lighting is the equivalent of using 1.3 million barrels of oil per day and results in around 190 million tons of carbon dioxide emissions per year. In terms of adaptation, there are clear crossovers with development. Lanterns provide opportunities for livelihood diversification, which can be an adaptation strategy (see Table 1); 98.1 % of households felt the lanterns provided opportunities for business, and 10 % of households had begun night-time working. Very preliminary results suggest that some households are using the lanterns for income-generating activities to a greater extent than when they previously used fuel-based lighting.

DISCUSSION

The examples above demonstrate that the theoretical links between adaptation, mitigation and development can exist in practice. They also show that triple-wins can be delivered by a range of different development projects targeting a range of different sectors. However, the case studies do not explicitly report triple-wins, resulting in a weak evidence base to attract continued investment in such projects. This has important implications. Adapting to climate change in SSA is likely to cost thousands of millions of dollars every year. Although estimates are still vague, some sources suggest that the cost of adaptation may touch an amount of US\$30 thousand million by 2030 annually (Watkiss et al. 2010). In addition to this, the UNFCCC's Adaptation Fund comprises money that is additional to Official Development Assistance (ODA). ODA channelled to Africa in 2012 totalled US\$51,261 million (OECD 2013).

To provide a better understanding of the possibility of multiple wins from mainstreaming CCD, researchers need to move beyond a single-impact focus in their analysis of adaptation, mitigation and development projects. Mainstreaming CCD into current policy may save money by making more efficient use of scarce resources (e.g. not building separate institutions and processes to support adaptation and mitigation and avoiding conflicting policies),

although almost no evidence exists to support this. To start to understand the merits and weaknesses of mainstreaming CCD, early reporting is needed. This is currently not taking place.

Through mainstreaming CCD, climate funds (for both adaptation and mitigation) could deliver more sizeable benefits. Lobell et al. (2013, p. 2), in discussing the agricultural sector, point out that ‘investments in agricultural adaptations are viewed exclusively within the realm of adaptation’ and are funded accordingly, i.e. through adaptation (rather than the larger mitigation) funds. This separation is evident in the MTS scheme (see ‘The Forest Sector’ section). The MTS is not recognised by government or policy makers as delivering triple-wins. Instead, as the authors point out, the MTS project is cited as an adaptation intervention in Ghana’s climate change initial communication to the UNFCCC and as a mitigation intervention in Ghana’s REDD+ preparation proposal. Adaptation and mitigation continue to be dealt with separately, and the potential multiple benefits are not being actively recognised.

The challenge of synthesizing adaptation and mitigation into development projects is further complicated by two issues: first, by the gap between scientific knowledge and development practitioners’ needs; and second, by the competing priorities and different knowledge of practitioners who work on distinct areas within development and climate (Lemos et al. 2007; Bizikova et al. 2007). To achieve synergy between adaptation, mitigation and development, interdisciplinary approaches that balance stakeholders’ immediate, local, needs with longer-term global climate issues, is required. Furthermore, synergies will need to take into account temporal and spatial scales, including inter-linkages between sectors, as a gain in one sector may lead to a loss in another. For example, gains in the forest sector (e.g. through reforestation projects such as REDD+) may reduce agricultural land leading to increased food prices (Grieg-Gran 2010). Such schemes may also lead to leakage where deforestation moves to a region with fewer regulations (Murray et al. 2004).

CONCLUSIONS

This paper demonstrates that robust criteria to evaluate triple-wins do not exist. Our four illustrative case studies show that triple-win projects are possible across a range of different sectors. However, without explicit criteria for evaluation, projects that deliver adaptation, mitigation and development are not framed as such. Unless triple-wins are reported as a matter of course, funding and investment opportunities will be missed. As such, there is a need for more clearly defined criteria so that comparable independent evaluations can take place. The development of a robust

academic evidence base for the delivery of triple-wins is needed to encourage continued donor investment in activities offering the potential to deliver CCD. There is a pressing need for this evidence base as mainstreaming CCD requires early reporting of triple-win projects. Monitoring and evaluation therefore needs to integrate adaptation, mitigation and development now to start identifying where triple-wins are occurring, and their relative size, and to locate any trade-offs.

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REFERENCES

- Adger, W.N., S. Agrawala, M.M.Q. Mirza, C. Conde, K. O’Brien, J. Pulhin, R. Pulwarty, B. Smit, et al. 2007. Chapter 17. Assessment of adaptation practices, options, constraints and capacity. In *Climate change 2007: Impacts, adaptation and vulnerability. Contribution of working group II to the fourth assessment report of the intergovernmental panel on climate change*, eds. M.L. Parry, O.F. Canziani, J.P. Palutikof, C.E. Hanson, and P.J. van der Linden, 719–743. Cambridge: Cambridge University Press.
- Adkins, E., S. Eapen, F. Kaluwile, G. Nair, and V. Modi. 2010. Off-grid energy services for the poor: Introducing LED lighting in the Millennium Villages Project in Malawi. *Energy Policy* 38: 1087–1097.
- Anderson, K., and A. Bowes. 2008. Reframing the climate change challenge in light of post-2000 emission trends. *Philosophical Transactions of the Royal Society A* 366: 3863–3882.
- Ayers, J.M., and S. Huq. 2009. The value of linking mitigation and adaptation: A case study of Bangladesh. *Environmental Management* 43: 753–764.
- Bailis, R., M. Ezzati, and D.M. Kammen. 2005. Mortality and greenhouse gas impacts of biomass and petroleum energy futures in Africa. *Science* 308: 98–103.
- Bates, B., Z.W. Kundzewicz, S. Wu, and J. Palutikof. 2008. Climate change and water. Technical Paper of the Intergovernmental Panel on Climate Change, IPCC Secretariat, Geneva.
- Belcher, B., M. Ruíz-Pérez, and R. Achdiawan. 2005. Global patterns and trends in the use and management of commercial NTFPs: Implications for livelihoods and conservation. *World Development* 33: 1435–1452.
- Bizikova, L., J. Robinson, and S. Cohen. 2007. Linking climate change and sustainable development at the local level. *Climate Policy* 7: 271–277.
- Boko, M., I. Niang, A. Nyong, C. Vogel, A. Githeko, M. Medany, B. Osman-Elasha, R. Tabo, et al. 2007. Africa. In *Climate change: Impacts, adaptation and vulnerability. Contribution of working group II to the fourth assessment report of the IPCC*, eds. M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden, and C.E. Hanson. Cambridge: Cambridge University Press.
- Burney, J.A., and R.L. Naylor. 2012. Smallholder irrigation as a poverty alleviation tool in Sub-Saharan Africa. *World Development* 40: 110–123.
- Burney, J., L. Woltering, M. Burke, R. Naylor, and D. Pasternak. 2010. Solar-powered drip irrigation enhances food security in the Sudano-Sahel. *Proceedings of the National Academy of Sciences United States of America* 107: 1848–1853.
- Calvo, C.M. 1994. Case study on the role of women in rural transport: Access of women to domestic facilities, SSATP Working Paper No 11, Washington DC: World Bank Publications.

- Chomitz, K.M., and P. Buys. 2007. *At loggerheads? Agricultural expansion, poverty reduction, and environment in the tropical forests*. Washington DC: World Bank Publications.
- Cochrane, M.A. 2003. Fire science for rainforests. *Nature* 421: 913–919.
- Conway, G. 2009. The science of climate change in Africa: Impacts and adaptation. In *Grantham Institute for Climate Change*. Discussion Paper.
- de Boer, J., J.A. Wardekker, and J.P. van der Sluijs. 2010. Frame-based guide to situated decision-making on climate change. *Global Environmental Change* 20: 502–510.
- FAO. 2007. FAO Statistical databases. Retrieved 20 July, 2013, from <http://faostat.fao.org/>.
- FAO. 2009. Harvesting agriculture's multiple benefits: Mitigation, adaptation, development and food security. Retrieved 20 July, 2013, from <ftp://fao.org/docrep/FAO/012/ak914e/ak914e00.pdf>.
- FAO. 2013. Advancing Agroforestry on the Policy Agenda: A guide for decision-makers. Retrieved 20 July, 2013, from <http://www.fao.org/docrep/017/i3182e/i3182e00.pdf>.
- Fisher, M., M. Chaudhury, and B. McCusker. 2010. Do forests help rural households adapt to climate variability? Evidence from Southern Malawi. *World Development* 38: 1241–1250.
- Grieg-Gran, M. 2010. Beyond forestry: Why agriculture is key to the success of REDD+. In *International Institute for Environment and Development (IIED) Briefing Papers*. Retrieved 18 February, 2014, from <http://pubs.iied.org/pdfs/17086IIED.pdf>.
- Halsnæs, K., and J. Verhagen. 2007. Development based climate change adaptation and mitigation—Conceptual issues and lessons learned in studies in developing countries. *Mitigation and Adaptation Strategies for Global Change* 12: 665–684.
- Hobbs, P.R., K. Sayre, and R. Gupta. 2008. The role of conservation agriculture in sustainable agriculture. *Philosophical Transactions of the Royal Society B* 363: 543–555.
- Houghton, R. 2012. Carbon emissions and the drivers of deforestation and forest degradation in the tropics. *Current Opinion in Environmental Sustainability* 4: 597–603.
- International Energy Agency (IEA). 2002. World Energy Outlook: Retrieved 29 June, 2013, from http://www.worldenergyoutlook.org/media/weowebsite/2008-1994/weo2002_part1.pdf.
- IPCC. 2001. *Climate change 2001: Synthesis report. A contribution of working groups I, II and III to the third assessment report of the intergovernmental panel on climate change*. Cambridge: Cambridge University Press.
- Kalame, F.B., R. Aidoo, J. Nkem, O.C. Ajayie, M. Kanninen, O. Luukkanen, and M. Idinoba. 2011. Modified taungya system in Ghana: A win-win practice for forestry and adaptation to climate change? *Environmental Science & Policy* 14: 519–530.
- Kammen, D.M., and C. Kirubi. 2008. Poverty, energy, and resource use in developing countries. *Annals of the New York Academy of Sciences* 1136: 348–357.
- Kirubi, C., A. Jacobson, D.M. Kammen, and A. Mills. 2009. Community-based electric micro-grids can contribute to rural development: Evidence from Kenya. *World Development* 37: 1208–1221.
- Klein, R.J.T., E.L.F. Schipper, and S. Dessai. 2005. Integrating mitigation and adaptation into climate and development policy: Three research questions. *Environmental Science & Policy* 8: 579–588.
- Klein, R.J., S. Huq, F. Denton, T.E. Downing, R.G. Richels, J.B. Robinson, and F.L. Toth. 2007. Inter-relationships between adaptation and mitigation In *Climate change 2007: Impacts, adaptation and vulnerability. Contribution of working group II to the fourth assessment report of the intergovernmental panel on climate change* eds. M.L. Parry, O.F. Canziani, J.P. Palutik, P. Linden, and C. E. Hanson, 745–777. Cambridge: Cambridge University Press.
- Knox, J., T. Hess, A. Daccache, and T. Wheeler. 2012. Climate change impacts on crop productivity in Africa and South Asia. *Environmental Research Letters* 7: 034032.
- Kundzewicz, Z., L. Mata, N.W. Arnell, P. Döll, B. Jimenez, K. Miller, T. Oki, Z. Şen, et al. 2008. The implications of projected climate change for freshwater resources and their management. *Hydrological Sciences Journal* 53: 3–10.
- Lal, R. 1997. Residue management, conservation tillage and soil restoration for mitigating greenhouse effect by CO₂ enrichment. *Soil and Tillage Research* 43: 81–107.
- Lal, R. 2004. Soil carbon sequestration impacts on global climate change and food security. *Science* 304: 1623–1627.
- Lemos, M.C., E. Boyd, E.L. Tompkins, H. Osbahr, and D. Liverman. 2007. Developing adaptation and adapting development. *Ecology and Society* 12: 26.
- Lipper, L., W. Mann, A. Meybeck, and R. Sessa. 2010. *'Climate-smart' agriculture: Policies, practices and financing for food security, adaptation and mitigation*. Rome: FAO.
- Lobell, D.B., U.L.C. Baldos, and T.W. Hertel. 2013. Climate adaptation as mitigation: The case of agricultural investments. *Environmental Research Letters* 8: 015012.
- Mata, L.J., and J. Budhooram. 2007. Complementarity between mitigation and adaptation: The water sector. *Mitigation and Adaptation Strategies for Global Change* 12: 799–807.
- Metz, B. 2007. *Climate change 2007-mitigation of climate change: Working group III contribution to the fourth assessment report of the IPCC*. Cambridge: Cambridge University Press.
- Mitchell, T., and S. Maxwell. 2010. Defining climate compatible development. Retrieved 19 June, 2013, from <http://www.cdkn.org/wpcontent/uploads/2011/02/CDKN-CCD-DIGI-MASTER-19NOV.pdf>.
- Modi, V., S. McDade, D. Lallement, and J. Saghir. 2005. Energy Services for the Millennium Development Goals. Energy Sector Management Assistance Programme: United Nations Development Programme. Retrieved June 10, 2013, from http://www.unmillenniumproject.org/documents/MP_Energy_Low_Res.pdf.
- Murray, B.C., B.A. McCarl, and H.-C. Lee. 2004. Estimating leakage from forest carbon sequestration programs. *Land Economics* 80: 109–124.
- OECD. 2013. Development aid at a glance: Statistics by region—Africa: Retrieved 1 June, 2013, from <http://www.oecd.org/dac/stats/aidataglancebydonorrecipientandregion.htm>.
- Owenya, M.Z., W.L. Mariki, J. Kienzie, T. Friedrich, and A. Kassam. 2011. Conservation agriculture (CA) in Tanzania: The case of the Mwangaza B CA farmer field school (FFS), Rhotia Village, Karatu District, Arusha. *International Journal of Agricultural Sustainability* 9: 145–152.
- Palm, C.A., S.M. Smukler, C.C. Sullivan, P.K. Mutuo, G.I. Nyadzi, and M.G. Walsh. 2010. Identifying potential synergies and trade-offs for meeting food security and climate change objectives in sub-Saharan Africa. *Proceedings of the National Academy of Sciences* 107: 19661.
- Ravindranath, N. 2007. Mitigation and adaptation synergy in forest sector. *Mitigation and Adaptation Strategies for Global Change* 12: 843–853.
- Reid, H., and S. Huq. 2007. *Community-based adaptation: A vital approach to the threat climate change poses to the poor*. International Institute for Environment and Development (IIED). Briefing Paper. IIED: London.
- Rothausen, S.G., and D. Conway. 2011. Greenhouse-gas emissions from energy use in the water sector. *Nature Climate Change* 1: 210–219.
- Somarin, O.A., H. Brown, I.J. Visseren-Hamakers, D.J. Sonwa, B. Arts, and J. Nkem. 2012. The Congo Basin forests in a changing climate: Policy discourses on adaptation and mitigation (REDD+). *Global Environmental Change* 22: 288–298.

- Stern, N. 2007. *The economics of climate change: The Stern review*. Cambridge: Cambridge University Press.
- Stillwell, A.S., C.W. King, M.E. Webber, and I.J. Duncan. 2011. The energy–water nexus in Texas. *Ecology and Society* Retrieved 10 June, 2013, from <http://www.ecologyandsociety.org/vol16/iss1/art2/>.
- Stringer, L.C., and A.J. Dougill. 2012. Channelling science into policy: Enabling best practices from research on land degradation and sustainable land management in dryland Africa. *Journal of Environmental Management* 114: 328–335.
- Suckall, N., E. Tompkins, and L. Stringer. 2014. Identifying trade-offs between adaptation, mitigation and development in community responses to climate and socio-economic stresses: Evidence from Zanzibar, Tanzania. *Applied Geography* 46: 111–121.
- Szabó, S., K. Bódis, T. Huld, and M. Moner-Girona. 2011. Energy solutions in rural Africa: Mapping electrification costs of distributed solar and diesel generation versus grid extension. *Environmental Research Letters* 6: 034002.
- Tompkins, E.L., A. Mensah, L. King, T.K. Long, E. Lawson, C. Hutton, V. Hoang, C. Gordon, et al. 2013. *An investigation of the evidence of benefits from climate compatible development*. Leeds: Centre for Climate Change Economics and Policy.
- Tubiello, F., and M. van der Velde. 2010. *Land and water use options for climate change adaptation and mitigation in agriculture, SOLAW Background Thematic Report—TR04A*. New York: GET-Carbon.
- Watkins, P., T. Downing, and J. Dyszynski. 2010. *AdaptCost project: Analysis of the economic costs of climate change adaptation in Africa*. Nairobi: UNEP.

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