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The energy-water nexus in the context of climate change in developing countries:

Experiences from Latin America, East and Southern Africa

Synthesis Report

by

Inna Platonova and Michele Leone
Climate Change and Water Program
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EXECUTIVE SUMMARY

Access to energy and water resources are interconnected and both issues are central for building adaptive capacity to climate change. Despite growing research on the relation between climate change and water resources on the one hand, and the relationship between water availability and renewable energy for development on the other, not enough has been done to integrate research on climate change, water and energy at the local level in the context of developing countries. The International Development Research Centre launched in 2010 a project “Clean Energy and Water: An Assessment of Services for Local Adaptation to Climate Change” to assess the drivers and barriers to the use of decentralized renewable energy technologies for water services to help communities better adapt to climate variability and change and to enable equitable access and robustness of those services under growing conditions of uncertainty. Four research teams became involved in this project: Fundacion Bariloche, (Argentina), the Clean Energy Incubator of the University of Texas at Austin (USA), the Energy Research Centre of the University of Cape Town (South Africa), the Energy, Environment and Development Network for Africa (AFREPREN/FWD) (Kenya), which produced in-depth assessment reports in Latin America, Southern Africa and East Africa.

You can access to the full studies and related documents here:

South Africa Report

Barriers to the integration of the water-energy nexus in policy and practice in Southern Africa and future research opportunities

Water-energy nexus in the context of climate change in the Southern African region

Water-energy nexus and climate change in Southern Africa : towards a modelling framework as a policy and planning tool

Mexico Report

Argentina Report

East Africa Report

All research teams focused on the analysis and synthesis of the existing qualitative and quantitative data on the topic and included primarily the review of scientific literature and policy documents. In addition, the research teams conducted consultations with experts in water and energy. The South Africa team also organized a seminar and a workshop focused on energy-water nexus in the context of climate change. While guided by the same set of research objectives, the teams adopted a variety of conceptual and analytical frameworks reflecting the multidisciplinary nature of the conducted research, complexity of the studied phenomenon and lack of established common frameworks to tackle the raised issues. All research teams had to struggle with the scarcity of specific data and lack of documented experience in the region.

While diverse in terms of their geography, climate, natural resources, demography, social, economic and political aspects, the regions under investigation face similar challenges related to energy-water-climate change nexus and are generally characterized by water scarcity, lack of access to clean energy and high vulnerability to climate change. The case studies show that when renewable energy technologies are successfully adopted for water services, positive impacts can be observed. Developing energy sources at both a local and national but decentralized scale promises to free up financial resources for local development and to enhance national energy security. Decentralized renewable energy technologies can also help address community vulnerability, food security, health, education and business opportunities and thus mitigate rural-urban migration and prevent resettlement to areas at climatic risk. A decentralized energy production network is more resilient to local nodes/links failures due to a climate change dramatic event. There are indications that the water cycle involved in local energy production is likely to be less disrupted.

A number of barriers exist that prevent the uptake of the renewable energy technologies for water supply. The case studies emphasize the importance of ensuring the quality and reliability of the technology and taking into account technical limitations, in particular, related to increasing water scarcity. Technologies need to be affordable and socially and culturally appropriate to the users. Adopting the affordable financing schemes, e.g., via micro-credit, in particular, for poor rural users, that need the studied technologies most, is critical. The uptake of the technologies is fully dependent on building adequate maintenance and servicing capacity, improving basic infrastructure in rural areas, involving community members in the projects, and responding to the local needs and preferences. Broad institutional support for the dissemination of the technologies through policy, inter-institutional and sectorial coordination is necessary. In addition to providing specific technologies, a climate adaptation strategy should include diversification of water supply sources, increase of water storage facilities and measures to rationalize the water use.

The reports emphasize that the more fundamental research in the realm of energy-water-climate change nexus in developing countries is needed. Modeling and planning in the energy-water nexus is one of such areas of research where integration of fragmented geological, geophysical and hydrological information as well as further development and application of system models is necessary. It is recommended to develop an analytical framework that brings together the fragmented knowledge on factors limiting or promoting renewable energy options for water services in regions under climatic stress. It is also important to examine how these options promote inclusive development and decrease vulnerability. The question on the optimal balance between mitigation and adaptation in the context of sustainable development remains open. More research is needed on innovative ways to combine and jointly implement water and energy policies that can reduce vulnerability to varying climatic conditions, to implement regulatory frameworks and rules in an efficient way, to establish effective coordination between relevant institutions that currently operate in silos, and develop appropriate budgeting, implementation and evaluation processes in the area of water, energy and climate change. A problem-oriented, inter- and multidisciplinary, both primary and secondary research is recommended to deal with the complexity of the issues in the studied domain. For research to be effective, differences in the language between researchers and policy makers need to be reconciled, and better and continuous communication needs to be established between them. A possible way forward could be the institution of centres of excellence on knowledge transfer directly in the countries under stress, and the promotion of cross communication between single large initiatives on enhanced energy access, water access and adaptation at the donor and governmental levels.

Key Words: water-energy nexus, adaptation to climate change, renewable energy technologies, developing countries

INTRODUCTION

Energy and water resources are closely intertwined (Scott et al., 2011). Energy is needed to extract, treat and purify, distribute, heat and cool water, and to collect and treat the wastewater (Olsson, 2011). Water is required to produce electricity, extract fossil fuels, and store potential energy that can be used to run hydroelectric power plants, cool turbines, grow and treat maize, sugar cane and other biomass in order to cope with the increasing demand of biofuels (Searchinger et al., 2008; Voinov & Cardwell, 2009). Access to both water and energy are central elements of sustainable development and poverty alleviation and should not be addressed in isolation (Olsson, 2011). As the world is facing challenges of climate change, rising demand for water and energy in the context of increasing energy insecurity and water scarcity, the intertwined dimensions of the water-energy nexus are drawing attention through new research, policy and public debate (Siddiqi & Anadon, 2011). While the research on climate change and water (Bohannon, 2010; Mulitza et al., 2010; O'Reilly et al., 2003; Verburg et al., 2003), and the relationship between water availability and renewable energy for development (Practical Action, 2012; UNDP/WHO, 2009; World Energy Council, 2010) has been growing, not enough has been done to integrate research on climate change, water and energy at the local level, in particular, by researchers in developing country institutions.

To promote research in this urgent, yet up to recently neglected topic, the International Development Research Centre (IDRC) launched in 2010 a call for studies on the theme of "Clean Energy and Water: An Assessment of Services for Local Adaptation to Climate Change". The studies aimed to assess the potential of and barriers to the use of decentralized renewable energy technologies for water services to enhance resilience and adaptive capacity of local communities to climate variability and change, and to enable equitable access and robustness of those services under growing conditions of uncertainty. The premise of this project is that access to energy and water resources are interconnected and both issues are central for building adaptive capacity to climate change. The need to understand the socio-economic feasibility of a transition from carbon dependent energy sources towards low-carbon and climate resilient decentralized renewable energy technologies is widely recognized. Equally important is to explore how users can be encouraged to become technology owners, energy producers and distributors, in a decentralized but networked world. Furthermore, it is critical to examine how energy and water service, regulations, investments and policy can support such a transition. The payoff could lead to more reliable services that would maintain a more stable equilibrium with the environment, and gain that resilience and robustness to external change that characterizes healthy systems. However, the way this transition will take place both at the policy and at the cultural level will be crucial, otherwise a wider access to energy, driven by a combination of economic opportunities, equitable development and climate change mitigation necessities, can have the unintended consequences of an increased pressure on ecosystems services, biodiversity and water resources; and of an increasing number of conflicting players having access to those resources.

To address these pressing issues, four research teams became involved in this project and produced in-depth assessment reports based on available literature and case studies in Latin America, Southern Africa and East Africa:

- **Fundacion Bariloche**, in Argentina, focused on an assessment of alternative energy options for agriculture in regions of increasing water scarcity in northern Patagonia, with case studies from Catamarca, Neuquen and La Rioja.
- **The Clean Energy Incubator of the University of Texas at Austin**, USA, provided an assessment of water and energy services in Mexico, with case studies from Mexico City, Southern Mexico (Oaxaca and Chiapas Regions) and the Rio Sonora Watershed in Baja California, Northern Mexico.
- **The Energy Research Centre of the University of Cape Town**, South Africa, assessed policy and institutional issues driving success or failure in the uptake of clean energy technologies for enhanced water supply in Southern Africa based on case studies from Botswana, Namibia, South Africa, Lesotho and Mozambique.
- **The Energy, Environment and Development Network for Africa (AFREPREN/FWD)** based in Nairobi, Kenya, researched the use of renewable energy technologies for agricultural and domestic water pumping, and of the role of policies to increase water security at the community level in the Greater Horn of Africa with focus on Kenya and Tanzania.

Based on the four studies (AFREPREN/FWD, 2012; Bravo et al, 2011; King et al., 2011; Prasad et al., 2012); this article aims to highlight commonalities and differences in the ways clean energy and water services are being combined in different regions in the developing world.

The synthesis report starts with a brief outline of the methods used by the authors of the reports, followed by a short description of the context of the studied regions and the rationale for choosing the specific cases, focusing on physical factors, socio-economic aspects, technological choices and policy responses. It then presents the analysis of opportunities and challenges in the diffusion of relevant technologies and application of the policy instruments highlighted in the studies. Finally, it discusses implications and priorities for future research and policy response.

METHODOLOGICAL ASPECTS[1]

All research teams focused on the analysis and synthesis of the existing qualitative and quantitative data on the topic and included primarily the review of scientific literature and policy documents. In addition, the research team from South Africa conducted a consultation with 22 experts in water and energy and also organized a seminar and a workshop focused on energy-water nexus in the context of climate change. The list of experts consulted during the preparation of the full report can be found in Appendix 1. Written consultations with experts from policy making were present in all studies.

In Argentina, the following institutes were contacted and responded: the National Institute of Statistics and Census, the National Water Institute, the Environment and Sustainable Development Secretariat, the National Meteorological Service, the Argentine Institute for Arid Zones Research, the Argentine Institute of Snow, Glaciology and Environmental Sciences and the Argentine Institute of Hydro Resources.

[1] Based on AFREPREN/FWD (2012), Bravo et al. (2011), King et al. (2011), and Prasad et al. (2012).

In Mexico, consultations were done with: the National Association for Solar Energy, the National Energy Board (for efficiency, use and regulation), the National Water Commission, the National commission for Environment, the Secretaria de Agricultura, Ganaderia, Desarrollo Rural, Pesca y Alimentacion

Finally, the East-Africa team received feedback from the Energy Regulation Board (Kenya), the Energy Regulation Commission (Tanzania), the Energy and Water Utilities Regulatory Authority (Uganda), the Kenya Rural Electrification Authority and the Kenya Water Services Regulatory Board

While guided by the same set of research objectives, the teams adopted a variety of conceptual and analytical frameworks reflecting the multidisciplinary nature of the conducted research, complexity of the studied phenomenon and lack of established common frameworks to tackle the raised issues.

Thus, the Argentina study adopted a "niche" concept based on Nadal et al. (2006) to assess the relevant technologies in terms of the required needs, the available resources, the local situation, and other factors. Researchers conducted an analysis of barriers to the use of renewable energy for water supply in arid and semi-arid areas classifying the problems under the following categories: economic-financial, socio-cultural, technological, institutional, regulatory/legal, environmental and cross-cutting. Each problem was then discussed in terms of problem definition, problem manifestation, causes, stakeholders involved and objective. The Southern Africa research applied Painuly (2001) framework to analyze barriers to the dissemination of renewable energy technologies using the following categories: market failure, market distortions, economic and financial, institutional, technical, social, cultural and behavioural, and other. The Kenya team adopted a policy oriented framework focusing mainly on the comparison of nation-wide policies across the east Africa countries. The Mexico team took a case-study based approach that summarized itself in a matrix where – for each renewable energy technology option - policy interventions in financing, right pricing of water and energy services, mandates and regulations, subsidies and facilitation of community engagement were evaluated against their effectiveness in reaching specific objectives as: carbon management, water quality, energy security and water security.

All research teams had to struggle with the scarcity of specific data and lack of documented experience in the region. For example, the East Africa study notes that limited data is available on the impact of dissemination of renewable energy technologies for water services in the region, in particular, in the context of climate change. The information available is based on anecdotal evidence from few pilot projects. The Argentina research team was also constrained by the lack of data on typical costs, implementation efforts, and barriers as well as difficulty to access specific data, e.g., GIS information. The Southern Africa team emphasized as a methodological issue a lack of analytical framework to systematize findings of the case studies.

Implicit in the reports is the importance of keeping both a statistical and historic perspective on the landscape of past and current renewable energy and water projects. The statistical perspective would allow assessing recurrences in the conditions during the success or failure of a large number of single projects, while the historic one would allow assessing how these conditions have come to be established and how they could or could not presently re-occur.

ENERGY-WATER NEXUS IN THE CONTEXT OF CLIMATE CHANGE IN LATIN AMERICA, EAST AND SOUTHERN AFRICA

Background

While diverse in terms of their geography, climate, natural resources, demography, social, economic and political aspects, the regions under investigation share similar challenges related to energy-water-climate change nexus and can be generally characterized by water scarcity, lack of access to clean energy and high vulnerability to climate change.

For example, in the case of Mexico, over 11 million people (roughly 10% of population) lack access to water supplies, and 22 million (around 20%) have no access to sanitation. Water reservoirs are becoming increasingly depleted and contaminated by leaching processes and dilution of minerals and chemicals in decreasing water volumes. While being the 7th largest producer of oil, the country has 3 million people who are not connected to the electric grid (King et al., 2011). In East Africa, close to 50% of the rural population have no access to improved water services. In Tanzania, for instance, only 7.4% of the population is served by piped water. The electrification levels in the region are low as well. For example, in Uganda only 9% of the population has access to electricity (AFREPREN/FWD, 2012). In Southern Africa, the energy sector is growing fuelled by coal-based power plants located mainly in South Africa, Zimbabwe and Botswana. Yet, 45% of people in Botswana are without access to electricity. Other studied countries face even more dire situation with both water and energy supplies. Thus, in Mozambique, 42% of people have access to an improved water source and only 12% of the population have access to the electric grid (Prasad et al., 2012).

These regions are increasingly under stress due to climate change (overall temperature increase and projected decline of rainfall, excluding some parts of Mexico and East Africa), coupled with the anthropogenic factors (e.g., land use changes, growing population pressure). Within Argentina, the studied provinces have large extensions of dry areas and will be particularly affected by a reduction in snow precipitation in the Andes, increased evapotranspiration and increased water requirements for hydroelectric generation and large scale agriculture and livestock activities. Sporadic drought events are likely to transform into recurrent ones (Bravo et al., 2011). Physical water scarcity affects nearly the entire country in Mexico. The ongoing drought is considered the most severe in the climate record of the country. As a result of climate change, East and Southern Africa countries are expected to experience rising temperatures and increased variability of rainfall leading to more severe droughts, floods and heat waves. As the economies of this region are dependent on rainfed agriculture, the climate change will invariably impact food security. These effects have already been felt in East Africa, where frequent droughts have led to food shortages and devastating episodes of famine (AFREPREN/FWD, 2012). In 2011, the worst droughts since 1995 have caused a severe food crisis across Somalia, Djibouti, Ethiopia and Kenya (OCHA, 2011).

Opportunities and Challenges

In the context of increased climate variability, renewable energy technologies can be useful in improving water services, in particular via solar water heating, small scale pumping and water purification and treatment in off-grid areas.

Moving from such premises, the research teams examined among others the cases of the use of renewable energy in accessing water in the communities under climatic risk or water stress in various regions in Latin America and East and Southern Africa (Table 1). The researchers focused on identifying drivers and challenges to the promotion of these technologies, associated socio-economic and environmental impacts and the role of policy in supporting the uptake of these solutions.

Table 1: List of Case Studies on Renewable Energy Technologies for Water Services in Latin America, East and Southern Africa

<table>
<tr><th>Country</th><th>Studied Cases</th><th>Key Findings</th></tr>
<tr><td rowspan="3">Argentina</td><td>• photovoltaic (PV) pumping from deep wells in Catamarca</td><td rowspan="3">• The dry regions in the studies are particularly vulnerable to the climate variability, which will exacerbate existing water availability problems.
• Renewable energy-based water pumping systems can be a cheaper and more reliable alternative to conventional systems. However, some renewable energy systems (e.g. PV pumping) could also show limitations due to decreased availability of underground water due to salinization, pollution or water level depression related or not to climate change. Furthermore, isolated renewable energy based pumping systems seem to require more long term technical support and capacity development of local communities than diesel systems.
• Both renewable and conventional systems are burdened by increased costs and technical challenges to solve water availability problems. Renewable energy pumping systems, in particular PV technology, have high investment cost.
• When respective resources are available, preferred choice of the renewable energy options in the studies is hydro, wind, solar. Hydro is usually excluded in dry areas. PV pumping can be more suitable for very small rural productive units, while hybrid or diesel systems are better options for medium and large scale productive units.
• Institutional framework for water supply and management is very fragmented with weak coordination across institutions and sectors.
• An adequate adaptation strategy to climate change will require diversification of water supply sources, increase in water storage facilities, implementation of efficient and rational water use.
• Information availability; community organization and commitment; capacity development for new technologies, and support of land use planning are key to an adequate implementation of adaptation strategies.</td></tr>
<tr><td>• pumping with low power wind turbines in Neuquen</td></tr>
<tr><td>• grid connected high-power turbines for irrigation in La Rioja</td></tr>
<tr><td colspan="3"></td></tr>
<tr><td>Mexico</td><td>• solar water heating in Mexico City</td><td>• When appropriately implemented, distributed rain water collection and solar water heating are effective technologies relevant to the energy-water nexus that reduce the use of fuel based resources.
• Technical reliability, readily available technical support, awareness, public education, and subsidization of upfront costs improve penetration rates for the technology.</td></tr>
</table>

	• distributed rainwater harvesting in Mexico City • solar-powered desalination in Sonora and Baja California	• Affordable financing, such as provision of loans with affordable interest rates, is essential for technology adoption. • Policy instruments such as mandates and right-pricing of water and energy can support sustainable operation of water and energy systems. • Cultural acceptance and understanding a customer's ability and willingness to pay are important factors in technology deployment. • Information communication technology (ICT) can be an effective means of education and enables collection and distribution of important data on natural resources.
Kenya/ Tanzania	• treadle pumps • wind pumps • ramp pumps	• Renewable energy technologies can play an important role in addressing challenges for water services in the region. Used for irrigation these technologies can be useful in improving food security among the poor. • Compared to other water pumping renewable energy technologies, treadle pumps are most disseminated. This is mostly because of the low cost of treadle pumps, where low income users can purchase the systems from savings or retirement benefits. However, the lifetime use of the treadle pumps is six years, while ram pumps – 40 years and wind pumps - 20 years. • There is limited support by governments to promote the dissemination of treadle pumps, wind pumps and ram pumps. • There is no clear-cut policy support for the dissemination of renewable energy technologies for water services as an adaptation strategy to climate change. Existing national policies and strategies target mainly large-scale technologies and national electrification projects.
Namibia	• off-grid solar systems for groundwater extraction • solar water heaters and solar water pumping • solar diesel hybrid energy supply system in Gobabeb and Tsumkwe	• The region faces critical resource constraint in water and energy. Renewable energy technologies for water services can address these constraints in the most vulnerable areas. • The introduction of these technologies faces numerous barriers, such as high capital cost and lack of access to affordable financing. Dependency of external donors creates dependency and therefore affects sustainability of the initiatives. • Technical barriers include lack of skilled personnel and a lack of renewable energy entrepreneurs. • Uncertain government policy, lack of policy support for the renewable energy

		technologies, lack of institutional capacity and lack of faith in the technologies by the government hamper diffusion of these technologies. • Lack of infrastructure, such as roads, grid connection, communications, become a particular problem in the remote areas. • Active community participation and leadership of local government are central to successful deployment of the technologies. Other success factors include good planning, management and education.
Botswana	• solar energy for ground water extraction in Ngamiland	
Mozambique	• solar water pumps in Nampula and Zambezia	
	• solar water pumps in Maputo and Guro	
South Africa	• water and energy policy and planning	• The water-energy nexus is not sufficiently recognized in policies, laws and regulations. • Mining companies, Eskom and banks are promoting the nexus to the government. • Integration of solar water pumps or solar water heaters can potentially benefit municipal service delivery in terms of providing GHG mitigation opportunities, poverty alleviation contribution and expenditure savings.
Lesotho	• climate adaptation strategy	• The country experienced extraordinary success of large-scale water supply initiatives; however, the benefits were unevenly distributed. The issue of land use and land rights remains problematic. • The following measures are recommended to increase resilience to water related stress: intensive landscaping for storm water retention; technology for water supply and sanitation; general adoption of renewable energy technology; and environmental education.

Source: AFREPREN/FWD, 2012; Bravo et al., 2011; King et al., 2011; Prasad et al., 2012

The case studies to a certain extent show that when renewable energy technologies are successfully adopted for water services, positive impacts can be observed:

- Energy is produced locally, where it is consumed, and users become at the same time producers and owners of the technology. This has the potential to increase energy equity and security of a community, and to facilitate diffusion via an enhanced sense of ownership. Dependence on imported energy is a huge economic burden on developing countries with implications on their economic and political stability, and an equal burden has become that of production of out-flowing energy that benefits growing neighboring economies. Developing energy sources at both a local and national but decentralized scale promises to free up financial resources for local development and to enhance national energy security.
- Addressing community vulnerability, food security, health, education and business opportunities decentralized renewable energy technologies can help mitigate rural-urban migration and prevent resettlement to areas at climatic risk.
- A decentralized energy production network is more resilient to local nodes/links failures due to a climate change dramatic event.
- There are indications that the water cycle involved in local energy production is likely to be less disrupted.
- The increased awareness of marginalized communities of their rights on the production assets can guide policy reforms.
- Decentralized technologies can be managed by the same social networks on which communities rely in their adaptation effort to climatic variability and change.

Thus, the case studies from East Africa demonstrate increased food security and improved livelihoods among poor rural farmers using treadle pumps (AFREPREN/FWD, 2012). In Southern Africa, the case study of PV water pumps in the Maputo province in Mozambique shows improved security of water supply and increased resilience to climate change among beneficiaries (Prasad et al., 2012). The Argentina study reports that since the 80s the experience with using renewable energy systems for water access has been limited with variable results. Nevertheless, the access to water services in the related projects has generally improved (Bravo et al., 2011). The Mexico report indicates that combining renewable energy and water systems can be appropriate in both urban and rural environments, for example, with a series of strategies ensuring co-benefits such as reducing energy tariffs via solar water heating and, at the same time, enhancing water availability and reducing flooding risks via a diffused rainwater harvest system connected to the solar heaters in urban areas (King et al., 2011).

Yet, a number of barriers exist that prevent technological uptake. Researchers participating in the four studies raise similar issues related to the deployment of the renewable energy technologies for water supply, while highlighting factors specific to their context (Table 2). While different analytical frameworks are used in each report, the identified factors can be grouped into the following categories:

- Technical issues;
- Physical factors;

- Maintenance and servicing capacity;
- Financial aspects;
- Community involvement;
- Social and cultural aspects;
- Institutional environment;
- Other factors.

The table reveals that there is not a clear hierarchy of importance in the highlighted factors. However, financial barriers and lack of policy supports are overwhelmingly present as they influence other factors in the causality chain.

Interestingly enough, the East Africa study does not place cultural and social constraints among the important factors, and gives only a medium weight to the lack of community involvement, in partial contradiction with anecdotic evidence coming from a large number of development projects in the region. This is partially due to the fact that when technology development programs are supported by policies favoring knowledge dissemination and financial contribution towards affordability of the technology, and support partnerships between public and non-state actors on capacity building, cultural barriers can be overcome with the showcase of successful pilot examples.

In this respect, cultural barriers are often not to be seen as the root causes of the lack of technology dissemination, but to reactions to badly designed programs, lack of information or financial constraints.

Table 2. Key Technological Diffusion Issues in the Studied Regions

Key issues identified	Mexico	Argentina			East Africa			Southern Africa		
		Nequen	Catamarca	La Rioja	Kenya	Tanzania	Uganda	Namibia	Botswana	Mozambique
Poor quality and inadequate installations	++	+	++	–	+	++	+	++	+	+++
Limitations due to physical factors	+	+++	+++	+++	++	+	+	+	n/a	++
Lack of capacity for maintenance and repairs	+++	+	+++	–	++	++	+++	+++	+++	+++
Financial barriers	+++	++	++	+++	++	+++	+++	+++	+++	+++
Lack of community involvement	+++	+	+++	–	+	++	++	+++	+++	+++
Cultural and social constraints	+++	++	+++	+	+	+	+	+++	+	++
Lack of policy support	+++	++	+++	+	+++	++	+++	+++	+++	+

+++ High importance
++ Medium importance
+ Low importance
– Not important
n/a Not available (not mentioned)

Source: Based on consultations with the research teams

Technical issues

Poor quality of the systems and inadequate installations can significantly hinder the adoption of the studied technologies. All four research teams emphasize this as a barrier to a widespread adoption of the pertinent technologies. The case study of solar water heaters in Mexico City is one such example (King et al., 2011). The initial deployment of the solar hot water heaters was unsuccessful mainly due to lack of operational standards and lack of technical expertise, which resulted in faulty installations and no fixing services (Mallett, 2007). Only since the Mexican Energy Commission launched in 2007 its Programme to Promote Solar Water Heating (PROCALSOL), which ensured high quality installations through training and certification programs and strict quality standards, the uptake level has significantly improved. This example shows how appropriate policies and public programs can overcome technological and knowledge barriers in some cases (King et al., 2011). The case study on small wind turbines in Neuquen, Argentina points out that the quality of the turbines from different brands is not even and post-sales technical support is limited (Bravo et al., 2011). The studies from Southern Africa also emphasize poor quality of systems, lack of quality control and inadequate standards as pressing technical barriers (Prasad et al., 2012). Similarly, the East Africa report indicates that due to lack of standards, the quality is not always consistent among similar systems (AFREPREN/FWD, 2012).

Physical factors

Renewable energy systems can show some limitations due to physical factors related to climate variability. For example, the researchers in the Argentina study point out that PV pumping systems are not suitable for high hydraulic loads and for variable water demands (Bravo et al., 2011). Linked or not to climate change, salinization, pollution or underground water level drop are likely to affect the water availability for both renewable and non-renewable water supply systems. Technological choices are often dictated by what a limited number of commercial providers can offer, irrespective of the study of local physical factors (Bravo et al., 2011). Even when a wide range of options is available, the choice comes with a high degree of uncertainty due to the lack of knowledge on the local hydrological cycle and on the extent, depth and nature of underground water resources. In the case of current commercially available treadle pumps in East Africa, the technology works best in the areas with shallow groundwater levels, as it only reaches water within a depth of seven meters. Prolonged droughts can lead to the drop in the underground water tables, which directly affect performance of this technology. Maintenance and substitution costs can therefore be significantly higher than originally estimated. Researchers emphasize that, while renewable energy technologies for water services are important adaptation option, the technologies' design will need to account for increased frequency and duration of droughts (AFREPREN/FWD, 2012). Based on the review of the reports and broader literature on the topic, while consistent efforts have been made to understand the economic and financial sustainability of the adoption of single technological solutions, studies on the robustness of those solutions to varying environmental conditions have been circumscribed to technical papers and have not made their way into practical development and adaptation interventions yet.

Maintenance and servicing capacity

To improve the uptake of the renewable energy systems for water supply, capacity needs to be built for operation, maintenance and servicing of these technologies. As noted in the Southern Africa study, rural communities lack skilled personnel to maintain and repair systems and have to rely on technicians traveling from the distant urban areas, which delays servicing and increases costs (Prasad et al., 2012). One way to remedy it is to build technological capacity in the community so that the community takes care of maintenance and repairs as shown in the case study of PV-powered water pumps in Maputo, Mozambique. Creation and training of the artisan associations in the project in the Guro district, Mozambique is a good example of ensuring the development of local skills necessary for maintenance and repairs (UNICEF, 2010). The East Africa study also emphasizes that in comparison to urban centres, rural communities significantly lack installation and maintenance skills. Maintenance of dispersed small scale systems, e.g., wind pumps, is particularly problematic and clustering of installations is recommended for improving maintenance services. Similarly, the cases from Argentina point to the lack of capacities at the user and installer levels. The problem is aggravated by low density of population and low payment capacities. Researchers indicate that more local knowledge is available on maintenance of conventional systems and compared to these technologies the maintenance time for renewable energy systems is longer. They further note that in the long run the isolated renewable energy-based water pumping systems require more technical support and community level capacity building than diesel systems (Bravo et al., 2011). In the case of solar water heaters in Mexico City the promotion of training programs was critical in improving the rates of diffusion of the technology (King et al., 2011).

Financial aspects

Financial barriers related to the high initial costs of the renewable energy systems and the lack of financing for the rural poor users, who need this technology most, continue to persist. In the cases of PV pumping and small scale wind pumping in Argentina, the affordability of the technology ranges from very low to medium. It is particularly low for PV water pumping and smallholder farmers often cannot pay for the systems. A financing institution or a donor needs to be involved in these projects (Bravo et al., 2011). In East Africa, one of the reasons for wider dissemination of treadle pumps compared to renewable energy-based pumping systems is their relatively low cost (AFREPREN/FWD, 2012). Farmers can purchase pumps with personal savings and retirement benefits. The researchers also note a growing reliance on local banks and micro-finance institutions. The East Africa study notes that due to decentralization efforts, in particular in Kenya, local governments may contribute to the financing of the renewable energy-based water technologies. In the case of Southern Africa, the government funding is limited for the renewable energy-based water projects and the external donors provide key funding, which can lead to dependency and lack of sustainability in the long run. As a way to recover the costs, some projects started to adopt a system where community is providing financial contributions towards maintenance (Prasad et al., 2012).

Community involvement

Community involvement is another factor in the technology deployment emphasized by some research teams. For example, the Southern Africa research shows that successful projects are those where community is actively involved in their design and that show a clear economic advantage that can be reached via investments affordable at the community level (Prasad et al., 2012). According to the East Africa report many renewable energy-based water pumping projects in developing countries continue to fail because the needs and preferences of the target communities are not taken into consideration. In the case of the technology that benefits the entire community, e.g., wind pumping systems, a community-based organization will need to be created to ensure the management of the system according to the community needs (AFREPREN/FWD, 2012). The Argentina study indicates the exclusion of the rural poor from the decision process as one of key barriers to the use of renewable energies for water supply in arid and semi-arid areas (Bravo et al., 2011).

Social and cultural aspects

Cultural and social acceptance of the technologies under study is of great importance. Among other factors, adequate information and education about the benefits of the technology are important measures to enhance the acceptance levels by the users. The case study of solar water heaters in Mexico City is a good example (Mallett, 2007). The local people generally did not embrace the environmental benefits and were lacking reliable information about the technology. They were buying cheaper systems of inferior quality, which resulted in the spread of a bad reputation of the technology independently of the quality of single installations. Public awareness campaigns emphasizing a wide range of benefits of the systems coupled with other measures discussed earlier allowed to increase the utilization levels of the technology (King et al., 2011). Examples from Southern Africa, e.g., the project in Maputo, Mozambique, show how lack of awareness and acceptance presents itself as a significant obstacle to the technology adoption (Action Group for Renewable Energies and Sustainable Development, 2007).

Institutional environment

Researchers focusing on the East and the Southern Africa regions conclude that, though there are some signs of change, there is no clear policy support for the deployment of the renewable energy technologies for water services (AFREPREN/FWD, 2012, Prasad et al., 2012). Existing policies generally target large scale conventional energy technologies. The Southern Africa cases from Botswana, Namibia and Mozambique also emphasize the lack of policy and government support and lack of government capacity as a barrier. The case studies highlight the importance of having leadership from local governments in the projects. In Argentina, the institutional framework for water supply and management is very fragmented with weak inter-institutional and sectorial coordination (Bravo et al., 2011). It is burdened by the provincial nature of water governance where multiple provincial stakeholders have conflicting responsibilities in water issues. The example of solar water heaters from Mexico City shows how PROCALSOL program by providing among other measures the necessary policy support, for example, through subsidization of the up-front purchase costs, created favourable conditions for the diffusion of the technology (King et al., 2011).

Other factors

In addition to the above listed issues, there are other factors that are brought forward in some reports. The research from East Africa emphasizes the role of women in the diffusion of the studied technologies. For example in the case of treadle pumps, about 70% of the technology users are women

(Karekezi et al., 2005). It is also noted that most often it is women who benefit from the technologies for water services. Researchers recommend that training needs to target women to develop necessary maintenance and servicing skills (AFREPREN/FWD, 2012). Another aspect brought forward by the East Africa study is the growing cost for fossil fuels and decreasing cost of renewable energy technologies for water supply. Both trends are likely to have a positive impact on the promotion of the latter technologies. Lack of basic infrastructure, such as roads and communications, is noted in the Southern Africa report as a significant barrier, particularly, in remote areas (Prasad et al., 2012).

In sum, the reports underscore the opportunities associated with the use of the renewable energy technologies for water services in the context of adaptation to climate change provided the quality and reliability of the technology is ensured and technical limitations, in particular, related to increasing water scarcity linked or not to climate change, are taken properly into account. This factor is particularly important as the performance of renewable energy technologies such as wind, hydro and solar is usually tested and assessed under the hypothesis of static climatic conditions and without taking into consideration proper water availability and hydrogeological studies in each implementation site.

Technologies need to be affordable and socially and culturally appropriate to the users. Adopting the affordable financing schemes, e.g., via micro-credit, in particular, for poor rural users, that need the studied technologies most, is critical. However, financing mechanisms can have unintended consequences if superficially designed. For instance, they can increase debt if not supported by capacity building programs for users intending to generate revenue from the newly adopted services. Moreover, they may be interpreted by users as incentives to increase the use of water – seen as a public good – unsustainably, through the diffusion of a direct degree of control on the resource at household level. Finally, in Africa in particular, micro-finance institutions are in many cases replacing banks in their role of financial promoters of economic growth. This is positive in some cases, as poorer population sees increased access to financing schemes, but in the case of the promotion of renewable energy technologies it has favoured a situation were financed activities do not go beyond the pilot, NGO or donor-backed schemes.

The uptake of the technologies is fully dependent on building adequate maintenance and servicing capacity, improving basic infrastructure in rural areas, involving community members in the projects, and responding to the local needs and preferences. Broad institutional support for the dissemination of the technologies through policy, inter-institutional and sectorial coordination is necessary. In addition to providing specific technologies, a climate adaptation strategy should include diversification of water supply sources, increase of water storage facilities and measures to rationalize the water use.

FORMULATING RESEARCH AGENDA

The reports (AFREPREN/FWD, 2012; Bravo et al., 2011; King et al., 2011; Prasad et al., 2012) reformulated in a more circumstantiated way the research questions contained in the initial IDRC proposal, prioritizing a sub-set of them in each region. One can conclude that those questions are still open and as highlighted in the reports more fundamental research in the realm of energy-water-climate change nexus in developing countries is needed in the following areas:

- ***Modeling and planning in the energy-water nexus.*** Given the scarcity of data in this area, the integration of fragmented geological, geophysical and hydrological information is necessary. The knowledge on underground water resources, water requirements and use needs to be improved. It is also recommended to further develop and apply in a systematic way models able to quantify energy-water fluxes and footprints, matching human economic activities and ecosystems flows in particular in agriculture, and how those fluxes can be altered due to changing climatic conditions. In order for the use of those models to be widespread, institutional capacity building efforts at a country-scale level must be undertaken. Common tools used for energy system analysis include, for example, the MESSAGE, MARKAL and LEAP models. A commonly used model for water system planning is the Water Evaluation and Planning system (WEAP), and for water scarcity and food security planning, the Global Policy Dialogue Model (PODIUM) model is well established. However, these and other models, lack the data and methodological components required to conduct an integrated policy assessment especially where these may be needed in a developing country policy context. Generally, they focus on one resource and ignore the interconnections with other resources; have overly simplified spatial representations; are not short term applied decision support models, or analyse scenarios which are impractically long term. Finally, they do not allow adjusting their parameters so as to study the impact of climate change on the performance of energy technologies for water services.
- ***Developing a framework to analyze numerous but disjoint case studies.*** As indicated earlier, the documentation on the projects in renewable energy for water services is incomplete and/or limited. It is recommended to develop an analytical framework that brings together the fragmented knowledge available on the subject. The framework should include the analysis and ranking of factors limiting or promoting renewable energy options for water services in regions under climatic stress. It is also important to examine how these options promote inclusive development and decrease vulnerability. Willingness to pay for water and wastewater services, the role of social and cultural factors, economics of integrating renewable energy with water services, technical complexity, and the role of micro-financing are among the factors that need to be further explored. How to scale-up the projects in this area and ensure their sustainability remains an open question and an important avenue for future research.
- ***Relationship between mitigation and adaptation for sustainable development.*** The question on the optimal balance between mitigation and adaptation in the context of sustainable development, in particular, when natural and environmental resources are used in a competing way, or may involve competing behavioral shifts and socio-economic decisions, remains open. Programs looking at addressing energy poverty rarely contain climate change adaptation considerations, and target energy policies only. Similar situation is with the enhanced water access programs targeting water related policies only. Adaptation actions consider energy technologies as a static tool and not as a part of the adaptation process itself. Further research is needed to explore the implications and manage the impacts of enhanced energy access on the sustainable use of water; and impact of uncertain water availability on energy production.

- ***Harmonization between water and energy policies.*** More research is needed on innovative ways to combine and jointly implement water and energy policies that can reduce vulnerability to varying climatic conditions, to implement regulatory frameworks and rules in an efficient way, to establish effective coordination between relevant institutions that currently operate in silos, and develop appropriate budgeting, implementation and evaluation processes in the area of water, energy and climate change. It is important to identify present and/or potential conflicts between water and energy policy and regulations, and ways to mitigate these.
- ***Water and energy footprint.*** The literature nearly agrees that global food production system generates considerable environmental footprints and the situation would likely get worrisome, as global population grows by 50% by 2050. Investments are needed today to buffer the negative impacts of food production on the environment. Investments to boost water productivity and improve energy use efficiency in crop production are two pathways to reduce the environmental. However, initiatives promoting diffusion of renewable energy often fail to monitor how enhanced access to energy redistributes water allocation and has an impact use patterns, and fail to complement access to energy with interventions encouraging water savings and conservation of ecosystem services. In this way, they risk reproducing at the individual and community level the lack of harmonization seen at the policy level, as people with enhanced local access to water via decentralized energy systems often give up water savings and management recommendations, increasing the water footprint of their economic and food production activities. In this context, it is still unclear whether many projects focusing on energy poverty reduction – when successful – have the potential to provide good or bad adaptation solutions in the long run, mainly due to the increased water footprint of the wider technological uptake.

What emerges from the studies is the need to work in parallel at a series of nested scales, including a longer time scale revealing how the learning of adaptation and poverty reduction strategies co-evolve, and how individual and collective behaviors change. This approach would allow revisiting previous choices on a regular basis and adjust them without the presumption that enhanced access to energy – even when renewable – is a general adaptation strategy *per se.* Overall, a problem-oriented, inter- and multidisciplinary, both primary and secondary research is recommended to deal with the complexity of the issues in the studied domain. For research to be effective, differences in the language between researchers and policy makers need to be reconciled, and better and continuous communication needs to be established between them. A possible way forward could be the institution of centres of excellence on knowledge transfer directly in the countries under stress, and the promotion of cross communication between single large initiatives on enhanced energy access, water access and adaptation at the donor and governmental levels.

POLICY IMPLICATIONS[2]

Many countries are developing measures to reduce vulnerability to climate change, to promote energy access and the use of renewable energy technologies, and improve water services. In the least developed countries, strategy papers on poverty reduction include considerations on energy and water, but

[2] Based on AFREPREN/FWD (2012), Bravo et al. (2011), King et al. (2011), and Prasad et al. (2012).

they are usually not prepared by the same people working on adaptation strategies such as the National Adaptation Programs of Action or the National Adaptation Plans.

As indicated in all reports, water and energy policies are too often not formulated in an integrated way and not at a proper scale. Current institutional structures in many developing countries are set up in a way that makes the necessary coordination, integration and horizontal communication very difficult. For example, in the case of Argentina, the institutional framework of water management and supply involves multiple actors at various levels whose responsibilities and functions overlap or are not clearly defined. This presents a source of conflict between different jurisdictions and also between competitive users, e.g., irrigation and hydroelectricity generation. Researchers note that there are no mechanisms in place to mitigate these disagreements. In South Africa, the analysis of national planning in the country shows that integration of water and energy planning is missing on all government levels. In the case of East Africa, researchers characterize the policy architecture in the studied countries as “impervious silos”, where coordination and communication between ministries in charge of water and those in charge of energy is very limited.

The following aspects emerge as critical when formulating water-energy policies, in particular in the context of agriculture:

- Subsidizing the costs of energy for water provision is a backfiring strategy in many cases, as farmers have few incentives to limit pumping. New policies must be accompanied by awareness raising on their potential consequences, and must touch all terms of the energy-water use system: instead of being allowed to use more energy, farmers should be enabled to use less water to achieve equivalent of better yield results. This can be done decreasing irrigation dependency on groundwater resources via better communication and use of weather information and with policies encouraging efficient agricultural techniques. Some of these techniques (climate smart irrigation, conservation agriculture, monitoring of plant health, monitoring of soil moisture and nutrients levels) can be enhanced by the use of very small scale decentralized energy systems and therefore this is an area where subsidies may be critical, instead of that of mere water pumping.
- Subsidizing decentralized renewable energy technologies for water pumping may have water footprint impacts similar to the ones observed in the case of subsidies given for on-grid electricity usage. It could even in principle promote a complete deregulation of water consumption. On the other hand, policies accompanying technology diffusion with water saving and efficiency measures could promote a sense of ownership through which communities could autonomously regulate the use of resources.
- Policies should be designed with social equity in mind. This seems a trivial consideration, but highly relevant to this report as the linkages between power pricing and energy and groundwater footprints and social equity are complex and highly debated. On the one hand pro rata electricity tariff with built in positive marginal cost of pumping could lessen environmental footprint by promoting efficient use of groundwater. On the other, levels of tariffs to influence demand could reduce net social welfare as a result of: reduction in demand for electricity and groundwater; lower net surpluses individual farmers could generate from cropping; and upward pressure on food prices, impacting the livelihood and food security of millions of people.

- Promotion of decentralized renewable energy technologies should not be sought as a strategy *per se*, but always in conjunction with plans promoting a more efficient use of water resources and the decrease of water footprint of food production

In all these cases, the reports emphasize that governments need to become more aware of the issues related to the energy-water-climate change nexus and research will play an important role in this regard. Political will and enabling framework will be necessary to develop required policies and strategies, ensure commitment of participating institutions and the collaborative effort necessary to design, implement and provide long-term follow-up of appropriate strategies and regulations. It will be useful to discuss in-depth the roles and responsibilities to be taken by different actors in promoting pertinent interventions. As well, it is important to explore the types of partnerships being promoted in the energy-water-climate change domain and which ones and why appear to be more effective in promoting policy formulation and implementation in this area. Research is also lacking on integrating large poverty reduction programs and adaptation measures and how the results of adaptation research can influence the choice of these programs and related investments.

CONCLUSIONS

In the context of growing water scarcity, lack of access to clean energy and vulnerability to climate change prevalent in developing countries, the in-depth assessment reports and case studies prepared by the interdisciplinary research teams in Latin America, Southern Africa and East Africa provide an important building block in advancing research for policy influence in the emerging area of energy-water-climate change nexus in developing countries by 1) assessing the opportunities, impacts and challenges to the use of decentralized renewable energy technologies for water services to help communities adapt to the climate variability and change; 2) understanding the role of policy and regulatory environment in promoting these solutions; 3) identifying areas and key questions for future research; and 4) discussing policy implications.

Further research is needed to better understand the factors of diffusion of decentralized renewable energy technologies for water services in the context of climate change and the relationship among these factors. More needs to be done in terms of evaluating the impacts of these solutions on communities, in particular, in terms of enhancing communities' resilience and adaptive capacity to climate variability and change. Further development of methodologies is needed through formulation of common analytical frameworks and elaboration of conceptual underpinnings. Research also needs to tackle the role of specific actors and partnerships in promoting policy changes in this area. A problem-oriented, inter- and multidisciplinary, longitudinal research is encouraged in this field.

APPENDIX 1

List of experts consulted by the Energy Research Centre, University of Cape Town, during the preparation of the report

Arthur, Fatima	Electricidade De Mocambique E.P., Mozambique
Cuamba, Boaventura	Energy Physics Group, Eduardo Mondlane University, Mozambique
Hughes, Alison	Energy Research Centre, University of Cape Town, South Africa
Ngceba, Thembelani	Water Superintendant, Elundini Municipality, Eastern Cape, South Africa
Gashi, Khaya	Municipal Manager, Elundini Municipality, Eastern Cape, South Africa
Ginster, Martin	SASOL, South Africa
Klintenberg, Patrik	Desert Research Foundation, Windhoek, Namibia
Letete, Thapelo	Energy Research Centre, University of Cape Town, South Africa
Moseki, Chris	Water Research Commission, South Africa
Paulo, Julieta Felicidade	Rural Water Department, Mozambique
Reinecke, Josh	Master Student, Energy Research Centre, University of Cape Town
Rozani, Luyanda	Electricity Superintendant, Elundini Municipality, Eastern Cape, South Africa
Schulze, Roland	University of KwaZulu-Natal, Pietermaritzburg Campus, South Africa
Schultz, Robert	Tsumkwe Energy Project Coordinator for Desert Research Foundation Namibia
Scott, Kirsten	University of Cape Town, Environmental Evaluation Unit
Sparks, Debbie	Energy Research Centre, University of Cape Town, South Africa
Stewart, Theo	Department of Statistics, University of Cape Town, South Africa
Swatuk, Larry	School of Environment Enterprise and Development, University of Waterloo
Trollip, Hilton	City of Cape Town, South Africa
van der Merwe, Steyn	former Nelson Mandela Bay Municipal Renewable Energy Project Manager
Ward, Sarah	City of Cape Town, South Africa
Winkler, Harald	Energy Research Centre, University of Cape Town, South Africa

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