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Towards the Development of an Energy-Water-Food Security Nexus based Modelling Framework as a Policy and Planning Tool for South Africa

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Abstract

With the increasing pressure of population on global resources and the imperative of climate change there is a growing interest in the idea of the "Energy-Water-Food Security Nexus", essentially an application of systems thinking to planning that recognises that the resources in the nexus are intimately linked and need to be considered together. This paper describes a project, currently at the funding stage, to develop a modelling framework for South Africa to be used as a tool for policy development and the planning of practical interventions. The need for the modelling framework was identified in the course of a desktop study on the nexus in the context of climate change and this paper explores a portion of this work and the rationale for a modelling framework. This background material examines how water and energy are treated separately or are combined and outlines research needs to realize the opportunities an analysis of the nexus can provide in terms of resource use efficiency and policy coherence.

Traditional energy and water modelling is orientated toward large infrastructure planning and large commercial irrigation projects. This project has as its goal the development of a modelling framework that will tackle the former with a nexus approach but also attempt to provide an effective policy tool for the interlinked water, energy and food security problems of remote and impoverished areas, possibly including climate change as another layer of complexity These areas will usually not be attractive for large scale industrial or agricultural interventions and other means may be necessary to sustainably supply the rural poor with energy, water and sufficient food.

A case study has been developed centred around the municipality of Elundini, located in the North of the Eastern Cape. The area is a catchment for the Umzimvubu River and is characterised by rugged, mountainous terrain. The catchment area has been the subject of many engineering studies because of the abundance of water, one of which observed, *"The Mzimvubu River is the catchment which simultaneously has both the most available water and the greatest poverty in South Africa."*. Typically such studies have however shown that because of the remote and rugged terrain, infrastructure like hydropower plants are at best marginally feasible in economic terms. Similarly commercial scale irrigation schemes have been deemed inappropriate given the terrain and prevailing land tenure practices and skills levels.

The case study will seek to apply a nexus orientated modelling framework to develop practical interventions for not only supplying power and piped water where it is lacking but also improving current agricultural practices by, for instance, providing a framework for evaluating the feasibility of localised gravity fed irrigation schemes. The issue of the type of agricultural products to target with these schemes is central and as has been seen in other countries, needs to be not only high value but supported by institutions that underwrite and emphasise the purity and naturalness of mountain produce as value added. Such produce has been seen to also greatly enhance the tourism potential of such areas. Technology is seldom now the barrier to such initiatives and the sustainability of interventions is more dependent on local skills development and on-going institutional development and support, aspects which will be central to the modelling framework.

1. Introduction

Many parts of Southern Africa face two critical resource constraints on development, namely energy and water. Energy and water are closely linked at different levels and scales. For example, water drives the turbines of hydroelectric power plants. Processing of coal and cooling in thermal and nuclear power plants requires water and energy is required to lift, treat and distribute water. At the same time, coal-based power plants emit large amounts of greenhouse gases (GHGs) into the atmosphere, contributing to climate change and climate variability which then leads to floods and droughts. In times of drought little water flows into hydroelectric dams, affecting electricity generation. In Southern African rural communities, the majority are poor subsistence farmers who depend on rain fed agriculture and will be adversely affected by climate change. The greater frequencies and severity of droughts and floods caused by climate change lead not only to crop failure and subsequent hunger but also interferes with water supply technologies when, for example, the water levels in boreholes rise or fall beyond the specification of the pump.

The complex interconnection of energy and water is called the water-energy nexus. Climate change critically impacts the water-energy nexus. Understanding and analysing the nexus creates opportunities to increase resource use efficiency, secure sustainable access to water and energy and enhance policy coherence (Bonn2011 Conference, 2012). The nexus gained widespread attention at Rio+20 including water, energy, land and food security and generally sustainable development.

Regional climate change projections in Southern Africa indicate that global warming will most likely lead to greater than the global annual mean temperatures for all seasons (Christensen, 2007). Warming will lead to increasing rainfall intensities, decreasing frequencies of low intensity (soft soaking) rainfall and longer dry periods between rainfall events. This will result in more severe droughts, floods and heat waves, which will lead to greater food insecurity.

Universal access to clean and modern energy is a primary goal of many developing countries' energy policies. It is acknowledged that access to energy will improve the livelihoods of people in the region, promote economic growth and help alleviate poverty. Access to modern forms of energy and potable water will continue to be important issues in addressing not only the UN Millennium Development Goals (MDGs), but also the social and environmental impacts of climate change on the most vulnerable sectors of our society.

Southern African countries are expanding industrial development and agricultural production to reduce high levels of unemployment and poverty. Water and energy supply are critically constrained and both sectors will compete for scarce resources in the region. The energy sector is growing and is fuelled by coal-based power plants mainly in South Africa as well as in Zimbabwe and Botswana and hydropower in Zambia and Mozambique. Coal-based electricity generation consumes more water than any other power plant except nuclear (Weissman, 2009).

The use of renewable energy technologies for water services in developing countries is able to address both the need for energy and the need for water services in the most vulnerable areas. Wind and solar photovoltaic energy technologies use hardly any water and are therefore the suitable technologies in water scarce and remote areas which are not connected to the national electricity grid.

Not all areas in Southern Africa are water scarce and in the Elundini area in the Eastern Cape in South Africa there is abundant water but still 79% of the population have no access to piped purified water within 200m of their dwelling and 88% have no access to electricity. Most people in the area are poor depending on subsistence agriculture and government grants for survival and therefore one of the goals of the proposed modelling topic is to address rural poverty by improving the management of water, energy and land resources.

The change in climate will impact the viability and availability of natural resources, but more specifically water resources and consequently food security (GWP and DBSA, 2010). Increased flooding and droughts will threaten water security and national development. Droughts are already significantly reducing electricity supply from hydroelectric power plants in Kenya (Afrepren, 2009). With an ever growing population and rising incomes there will be an increased demand for water for domestic use, sanitation, food production, and biofuels as well as commercial and industrial purposes. Limited or degraded water resources which are further impacted by climate change will affect those most vulnerable in this scenario – the poor, the elderly, women and children. Water transfer from one drainage basin to another is one solution. In Southern Africa and particularly in South Africa there are already a number of water transfer schemes (Figure 2).

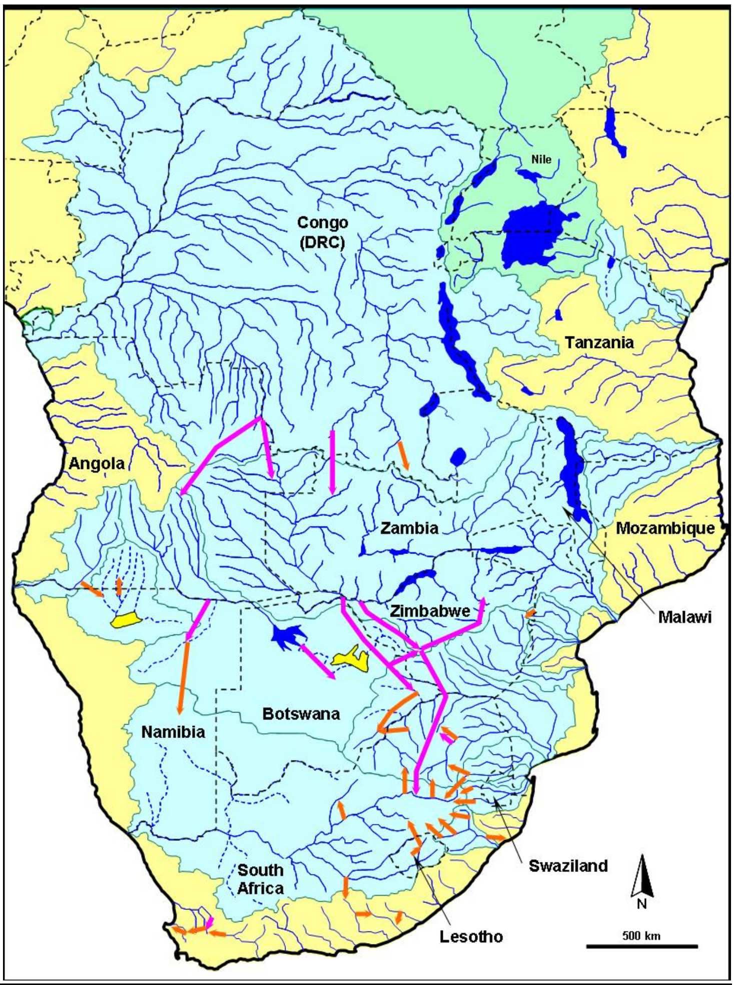

Figure 1: Water transfers in Southern African river basins (Ashton, 2012)

Study on the Water-Energy Nexus in the Context of Climate Change

The need for the modelling framework came out of a desktop study for the International Development Research Centre (IDRC), Ottawa, Canada on the energy-water nexus in the context of climate change in Southern Africa. This involved an assessment of the South African situation that was based on secondary data through a cross-disciplinary desktop study. In addition colleagues and professionals from the energy and water sector have been consulted by email, telephone and in person. A seminar and a workshop have been held to discuss the issues involved in the water-energy nexus in the context of climate change. The findings of this desktop study as regards South Africa and to some degree Southern Africa are summarised below before a general discussion of concepts for the modelling framework and a description of the proposed case study.

Climate change in the Southern African region

Climate change will affect temperatures and rainfall patterns in Southern Africa. Regional climate change projections in Southern Africa, based on GCMs comparing 2080-2099 to 1980-1999, indicate that global warming will most likely lead to greater than the global annual mean temperatures for all seasons, 3.1 degrees for summer warming and 3.4 degrees for winter warming (Christensen, 2007).

Warming in Southern Africa will change rainfall intensities, leading to decreasing frequencies of low intensity (soft soaking) rainfall and longer dry period between rainfall events. Droughts, floods and heat waves will be more severe leading to greater food insecurity. Historically, droughts and floods have already had major impacts on Southern African populations. Around AD1200 to AD1500, droughts led people to abandon settlements in the Kalahari Desert. The Lifaqane wars, starting in about 1815, were characterized by a 25-year period of famine and violent conflict between peoples in Southern Africa.

During the 1991-1992 drought, 20 million people in the region (15% of SADC population) needed food relief (Dejene, 2011).

The impact of climate change will be felt by the majority of the population in Southern Africa who depend on rain fed agriculture. Seasonal climate forecasting will play a major role in climate change adaptation for farmers.

Climate change will add another layer of complexity to the already stressed and high risk water sector and amplify the parameters of the hydrological system (Water Research Commission, 2005). In Southern Africa, climate model-based downscaling tools suggest higher precipitation in the east, a shorter winter season in the southwest and less rainfall in the far west (Hewitson, 2005). Runoff and recharge are sensitive to changes in precipitation and the variability of rainfall amplifies the hydrological response with serious implications for floods and droughts (Schulze, 2005).

Opportunities to address the nexus are not yet taken up

Many countries are developing measures and policies to reduce vulnerability to climate change and this is closely linked to planning for sustainable development. UNFCCC invited National Adaptation Plans of Action (NAPAs) from Least Developed Countries. NAPAs indicate priority activities to respond to urgent and immediate needs to adapt to climate change since further delay would increase vulnerability and/or cost at a later stage. Only two countries in Southern Africa responded. Lesotho submitted 11 projects out of which only one included energy activities. It is to promote wind, solar and biogas energy use as a supplement to hydropower energy. The four projects proposed by Mozambique do not contain any energy component (UNFCCC, 2010). No project includes the need for energy in the water sector and water in the energy sector. Should UNFCCC require an integrated approach?

At a municipal level, climate change and adaptation documents for the City of Cape Town are another example where water and energy were considered as separate sectors but the need for water in the energy sector and vice versa were not documented (City of Cape Town, 2006).

Competing water needs for industrial and agricultural development and potential additional water resources

Competing water needs

The relative use of water in the four major sectors in South Africa shows that by far most water is used in agriculture for irrigation and afforestation (DWAF, 2003). The sector uses 61% of the total available water (Table 1: Water usage in South Africa). Mining and large industries use 8%. If some of the commercial sector which is included in urban and domestic is added to industrial water use approximately 2% could be added to this figure (DWAF, 2003).

Table 1: Water usage in South Africa (DWAF, 2003)

Irrigation and afforestation	61%
Environment	20%
Urban and domestic	11%
Mining and large industry	8%

The water allocated for irrigation in South Africa still reflects the unequal access to water of the apartheid era. White large-scale farmers consume 95% of the irrigation water and mainly black smallholders have access to the remaining 5% (Cullis, 2007).

Additional water and energy resources from water conservation, waste and sewage, water recycling, desalination, inter-basin transfers

This section gives Southern African examples of increasing water and energy supply from existing resources.

Water conservation saves water and energy

Large amounts of water are needed in the production of energy, and a notable amount of energy is used to treat water and transport it to consumers. Savings in energy will translate into water savings, and vice versa. With growing populations and migration to cities comes the need for more power. This in turn requires more water for its generation, hence impacting on water as well as energy resources. This emphasizes the importance of saving water and practising energy-efficiency. Every kilowatt of energy saved also translates into water savings. In Southern Africa, where water is a scarcity and where water is used primarily in agricultural production, and where energy to meet the needs of the future population is in short supply, savings in either or both of these two resources are critical.

In South Africa water is recognized as a key constraint and risk in the Integrated Resource Plan 2010-2030 (DoE, 2011) which is an electricity plan, and water usage is included as one of the criteria in all the scenarios.

Energy from waste and sewage

Extracting energy from waste is a widely applied technology in other parts of the world but it is not yet widely practised in Southern Africa. There is a great need to reduce the amount of waste, particularly in urban areas, where suitable dump sites are filling up fast. The City of Durban captures methane gas, burns it and generates electricity for 6000 homes. The project recovers some of its costs through CDM registration. The University of Cape Town has recently inaugurated a biogas digester in which food waste from a student cafeteria is used to generate gas which is used for cooking the meals in the cafeteria.

Waste water recycling

Recycling waste water is not yet widely practised in Southern Africa and could contribute to the available water supply. Energy is required for recycling. Many municipalities in Southern Africa have plans to recycle because the demand for potable water is continuously increasing. The first private recycling plant in South Africa started operating in Durban in 2001. The plant treats 47.5 million litres of domestic and industrial waste water to a near potable standard. The water is sold to industrial customers for direct use in their processes, saving treated potable water for about 300 000 people. The two largest customers are the Mondi Paper Mills and the Sapref refinery owned by Shell and BP. The industries benefit from a lower tariff as compared to the normal tariff for potable water (Ethekwini Municipality, nd). The use of waste water is included in the water demand scenarios up to 2024 for the City of Cape Town.

Desalination

Desalination is an option for areas near the sea and in regions with saline groundwater. However, the energy requirements for the desalination process are high, making this technology choice viable only if water is very scarce and desalination becomes an economic option. The largest desalination plant using reverse osmosis in South Africa is owned by Albany Coast Water Board, Ndlambe municipality in the Eastern Cape. The original plant has served the Ndlambe municipality for 10 years. It was recently upgraded and has now a throughput of $1800m^3$ per day. The national grid supplies the electricity for the plant. There is also a plant at Saldanha Bay on the South African west coast.

In Namibia groundwater is frequently saline and two desalination plants in the villages of Akutsima and Amarika in the Omusati Region respectively provide 3500 litres and 4500 litres of drinking water daily. Two different solar-powered technologies are used: at Amarika a reverse osmosis membrane system is installed while at Akutsima a multi-effect humidification evaporation process is used. Terra-water provides technical support and training for local people and the project was funded by the German government.

Inter-basin transfer

Inter-basin water transfer takes water from areas of surplus to areas where it is in critically short supply, limiting industrial and other developments. Several Southern African countries already transfer water from one basin to another (Figure 1). The energy demand for pumping the water can be huge.

The largest water transfer scheme in the region, the Lesotho Highland Water Project (LHWP), transfers water from Lesotho to South Africa. Water is transferred from the upper reaches of the Senqu (Orange) River in Lesotho to the Vaal River basin in South Africa where the water is needed for the industrial and urban expansion and development of the Gauteng region. With an expected $70m^3/s$ total water capacity by 2020, this is one of the largest civil engineering projects currently under way. The Lesotho Highland Development Authority and Trans-Caledon Tunnel Authority are the implementing agencies for Lesotho and SA respectively. The Joint Permanent Technical Commission monitors and oversees project implementation on behalf of the two governments. A phased implementation of the project is planned, incorporating phases IA, IB, II, III and IV. Phase IA and IB are completed and the agreement for Phase II was signed in August 2011.

Phase IA of the LHWP is designed for a yield of $18{\cdot}3\ m^3/s$ and also includes a hydroelectric power plant at Katse Dam with a generating capacity of 70MW (LHDA, 2011) . Most of the electricity is sold in Lesotho. Phase 1B increased the project yield by a further $11.7\ m^3/s$. Phase II is expected to increase the project yield to $55\ m^3/s$ (LHWP, 2004). Phase II with a second hydropower station will increase the power capacity by a further 110 MW. Phases III and IV, are yet to be signed and are envisaged to increase the project yield to $64.6m^3/s$ and $70\ m^3/s$ respectively (Nthako, 1997).

Water needs of energy technologies

Thermoelectric power generation uses significant amounts of water. In the USA 41% of all freshwater withdrawals were used for thermoelectric power (Macknick, 2011). In South Africa, only 8% of the available freshwater is allocated to the mining and large industry sector (DWAF, 2003). In electricity generating technologies most water is used for cooling and steam. Renewable energy technologies that require cooling such as concentrated solar power (CSP), trough and CSP Fresnel technologies consume up to 1000 gallon/MWh for plants with wet cooling towers (Macknick, 2011). Wind, photovoltaic and CSP dish Stirling technologies do not need any cooling and require minimal amounts of water for cleaning.

Integrated water and energy planning in the context of climate change

Comparing water and energy data can be challenging due to the difference of spatial planning for energy distribution and water basins. Water planning is carried out at the river-basin level and these basins can be in the same country or they can be in two or more countries, such as the Senqu/Orange River which has its source in the Highlands of Lesotho, crosses South Africa and flows into the Atlantic Ocean on the South African and Namibian border. Energy planning is undertaken at a centralized national level, for example in national power generation companies and then the electricity is distributed to regional and local electricity departments.

Innovative ways of achieving higher efficiencies in the use of energy and water will be the key factors to meeting the future needs of humanity (G-Science Academies, 2012). The G-Science Academies recommend investment in integrated research and innovation and in the development of systems analysis approaches in energy optimization and the sustainable use of water. In USA and Canada there is an on-going active dialogue on water and energy linkages and laws and documents recognize and address the nexus between water and energy. The World Policy Institute (2011) developed an analytical framework to evaluate the water energy relationship. The framework also outlines policies to balance competing resource needs and recommends policy options to address possible trade-offs.

The water needs in all sectors are going to rise as the economy grows, and careful integrated planning of the water and the energy sector is required to use and optimally allocate the water resources so that they do not constrain development and economic growth. Climate change is another possibly constraining variable in this context.

Integrated water and integrated energy plans have been prepared and these plans are updated from time to time. South Africa has long tradition of integrated water resource management including the impact of climate change on water resources (DWAF, 2004) which are regularly updated. The Department of Energy in South Africa published an Integrated Resource Plan on Electricity in 2011 (DoE, 2011) and the use of water for energy is included in the plan projections. But in the region, so far, little attention has been paid to integrated water and energy planning using modelling, although in the water-scarce countries of Southern Africa it is not really possible to separate water and energy planning. These sectors compete for the existing water resources and there are multiple interrelationships of water and energy. More integration will lead to better planning and policy coherence, allocating of resources and optimizing efficient resource use. Integrated and system thinking about water, energy and climate change could enhance resilience and adaptive capacity because the demand and supply assessment could predict shortfalls in the future and outline possible action.

South Africa has the largest and most complex electricity supply infrastructure in Africa and as such the modelling of all aspects of this system and projections of future demand on that system has been practised for some time. Capacity exists within the state utility Eskom, the universities and a number of consultancies. The situation as regards water management is similar with most basins being managed with dams, allocations and sometimes complex transfer networks, the design and management of which is often informed by modelling. There is however one important modelling challenge to integrating these capacities at the outset: water resource planning is often carried out at the regional level of river-basins, even though inter-basin transfers are potentially available policy actions, but energy planning typically needs to be undertaken at a national or even supra-national level.

In August 2011, the Department of Energy in South Africa invited bids for its Renewable Energy Feed-in tariff (REFIT). These renewable energy technologies will add energy resources to the national level planning but will also require additional water resources. Any modelling will need to take such changes into account. The approach would need:

- To identify relevant existing data sources, and collection/collation of data where not readily available, possibly including utilisation of expert judgement;
- To establish critical problem areas, future policy alternatives, regional and national goals and appropriate scenarios for external pressures such as climate change and global economic conditions;
- To construct a general model (or models) to provide an overview of the energy-water system: Sensitivity analysis with such models would serve to identify the most critical policy variables for designing interventions and those model variables needing the most accurate and detailed data Cost benefit analysis or least cost optimisation models of electricity production technologies should include the cost of water and possibly employ a shadow cost for water reflecting the diminishing resource. Certainly the assumption of a constant water cost in long term projections is questionable.
- To develop more detailed models arising out of the general model. These may or may not include some of the following features:
    - Regional modelling for defined regions in Southern Africa - individual countries and regions within countries;
    - Adoption of a systems dynamics approach that would descriptively outline the water energy nexus, for instance with causal loop diagrams and then identify the engineering and scientific tools required to model the system. This might require linking hydrological and energy supply infrastructure planning models.
    - Explicit representation of multiple scenarios; these should, amongst other possibilities, include the main drivers of demand for water and energy which are GDP and population and also the potential effect of climate change on rainfall.
- Modelling of multiple societal goals and objectives as part of the process of developing national strategies for water/energy planning in the context of climate change.

Modelling for the Needs of Poor or Depressed Rural Communities

Can the development of nexus-orientated modelling tools and frameworks be adapted to the needs of poor rural communities? Rural areas are implicitly dependent on the prosperity and equitability of local agriculture. It can be argued that a model that seeks to aid the development and regeneration of rural areas needs to put the smallholder or subsistence farmer at the centre. Systems dynamics models with this approach have been proposed before as shown below (Kassa, et al., 2002).

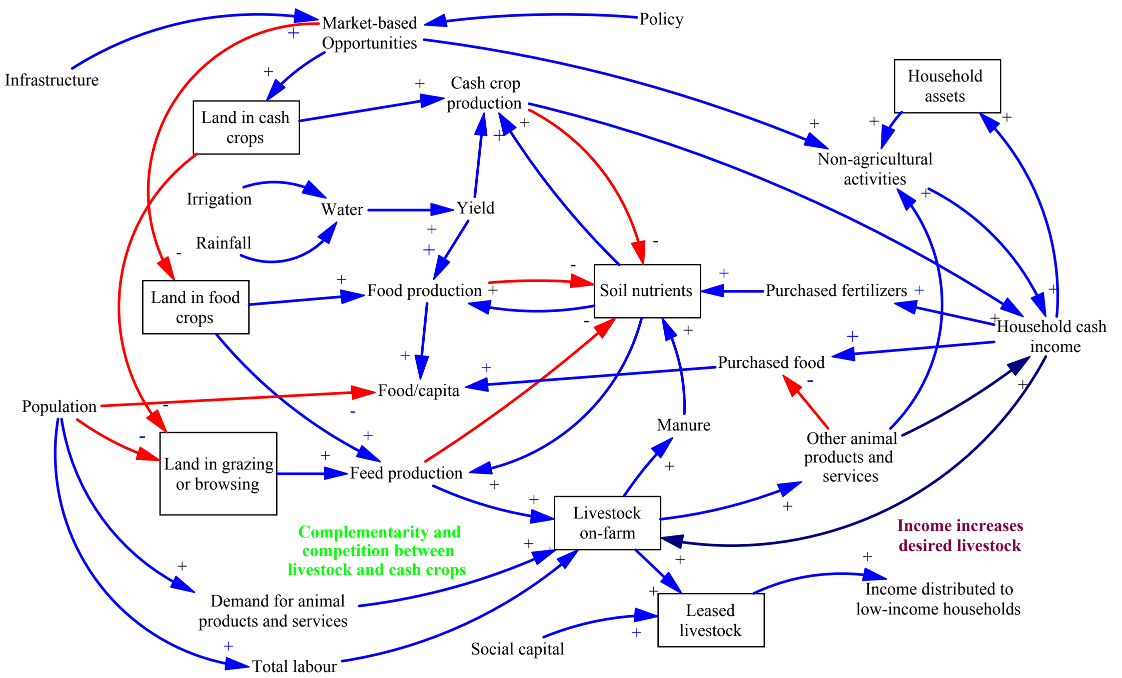

Figure 2: Causal Loop Diagram of the Smallholder Livelihood System (Kassa, et al., 2002)

The proposed approach would seek to expand on the above by inclusion of energy in the system which would be integral to irrigation, possibly processing and transport of agricultural production and the household consumption of the farmer. This would link the infrastructure driver with the irrigation driver. There is potential to expand what is termed the 'Market-based Opportunities' node in this work through examination of the essential inputs to promoting, branding and selling crops that are appropriate to sustainable farming operations outside of large commercial farms. In rural regeneration projects in Europe it has generally been recognised that the crops or products (e.g. speciality cheeses) need to be not only high value but supported by institutions that underwrite and emphasise some attribute of the local environment as value added, say the purity and naturalness of mountain produce (European Commission, 2002) . Such produce has been seen to also greatly enhance the tourism potential of such areas. The rationale for the development of a 'quality mark' in France for produce from remote mountainous areas articulates the commercial imperatives eloquently:

> *"Mountain produce is synonymous with higher prices. These are linked to the cost of harvesting as well as to the provision of services. However, such produce benefits, in the eyes of the consumers, from an intrinsically positive image and quality. Indeed, the very features of these territories which represent difficulties for producers and processors - natural handicaps related to the climate and the nature of the terrain — represent assets for consumers. The impossibility of having a very intensive production process in these areas allows mountain products to benefit from a 'confidence asset' related to an image of purity (naturalness) which will increase its value as long as it is reflected in practice. For this reason, consumers are ready to pay rather more for these products." (European Commission, 2002)*

It is beyond the scope of modellers to delve further into the details of product marketing but the inclusion of the commercial, institutional and external skills inputs into a systems dynamics model is not, particularly at the level of a causal loop diagram, even if the final model is simpler. A key aspect to the quote above is "reflection in practice" which also implies that quality control is also part of the 'Market-based Opportunities' sub-system. The problem of sustainable rural agriculture in remote and impoverished areas is complex and intractable and resulting systems analyses that seek to encompass the nexus of energy, water and food, including its commercial implications, in a modelling framework will tend to be complex and require extensive stakeholder and expert consultation.

Planning Tools, Engineering Standards & Tariffs

Not all effective planning tools need be complex systems or mathematical models. A number of Remote Area Power Supply (RAPS) projects in South Africa have failed simply because there was no planning for customer education, training local technicians and financing on-going maintenance. Two so-called mini-grid systems, Hluleka Nature Reserve and Lucingweni, which connect a number of proximate households in a grid powered by wind or solar photovoltaics were commissioned for demonstration purposes in The Eastern Cape between 2002 and 2004 but by 2006 were defunct because of "social and institutional problems" (Bekker, et al., 2008). Indeed a review found that after 2 years of operation, while monitoring of these pilot projects should have been of "highest priority", no reliable data had been collected and it was difficult to assess exactly when and how the system had degenerated (DME, 2008). It seems that once the installation was commissioned there was little further institutional interest or there was an active withdrawal of technical skills that simply reflects a naïve grasp of problems in engineering development within institutions. Now that the capital cost barrier to renewable technologies is being eroded by economies of scale and technology improvements, these "social and institutional" problems are the chief impediments to rural off-grid power supply that could be used for domestic water supply and even irrigation.

ESKOM themselves had pointed out 10 years before these pilot projects that, "a necessary component of any RAPS programme is customer education and a reliable maintenance and backup service infrastructure". They then advanced the following 3 point strategy for successful RAPS implementations (Ligoff, 1992):

1. The development and implementation of a RAPS tariff to allow customers to pay monthly for a RAPS service, rather than a lump sum capital charge. A feature of the tariff is that payments increase annually as the customer's ability to pay increases.
2. The development and implementation of a marketing procedure to ensure that sufficient information is obtained about customers' energy need, available natural resources and current energy sources. This data is essential to ensure that system designs are fit for purpose and cost effective.
3. The development and implementation of nationwide centres of expertise with regard to technical knowledge, backup service and maintenance facilities, making use of Eskom's existing service infrastructure.

Point 1 is in contention with the later findings in the OR Tambo municipality that the overwhelming majority of potential users preferred a 'pre-payment' option rather than a flat rate, let alone an escalating flat rate (DME, 2008) but of course in 1992, pre-payment was not yet a commercial technology. It's clear that the issue of payment is not simply one of cost recovery and while subsidies also have to be sustainable, it should not be assumed that capital cost recovery will be possible for every project without subsidisation. Like the engineering aspects of the system itself, the commercial aspects need to re-examined and improved until a replicable model is achieved and the resources to do this need to be put in place. In principle though this older proposal by ESKOM of a national RAPS/mini-grid tariff has merit and should be part of a greater effort towards national standardisation.

The enormous national effort in low cost housing has led to industry standards emerging in that sector. The straightforward development of similar minimum standards for RAPS projects could usher in a new era for South Africa's rural population. In addition Experts would need to be consulted to develop an inventory of standard quantities for example the OPEX in Rand/kW installed for each technology, the intervals for maintenance schedules and the stock of spares that must be available to deal with forced outages. The minimum number of local trained technicians per kW installed would also be an essential item. If necessary these standards could be integrated into basic distributed software or even an online tool but even a document would represent a great improvement. Adoption of this by the South African Bureau of Standards and legislation that would prescribe adoption of this minimum standard by any government funded project would be the ultimate goal to ensure quality control of projects.

A Proposed Case Study in Elundini Municipality

Given that a particular goal of the proposed modelling framework is to improve the management of energy and water resources to relieve poverty, the case study dealing with the rural municipality of Elundini has been proposed.

The Elundini Local Municipality, part of the Joe Gqabi (formerly Ukhuhlamba) District Municipality, is located in the North of the Eastern Cape and includes the towns of Maclear, Mount Fletcher and Ugie. The area is a catchment for the Umzimvubu River and is characterised by steep gradients with much of the terrain having slopes steeper than 1:8 as it forms part of the southern Drakensberg range. Aside from organic pollution due to inadequate sewage treatment in and around urban areas, the general water quality is reported to range from excellent to good even downstream near the estuary, with only the phosphate content a treatment concern (DWAF, 2009). Of the towns, Maclear and Ugie are supplied with water by proximate small dams and Mount Fletcher by boreholes. In all cases supply has been assessed as inadequate and expansion projects are proposed or underway (Prasad, Boulle, Boyd, Rahlao, Wlokas, & Yaholnitsky, 2011).The greater population are in general rural and poor with only 21% having access to piped purified water within 200 m of their dwelling and 12% having access to electricity. So a typical research question that a model might be used to answer here is, “What is the energy demand of different technology options to supply piped purified water to the entire population within 200m of their dwelling and what will this cost?”. The challenges to communities in the area is perhaps best captured by a recent Department of Water and Forestry Affairs Report (BKS, 2010)

> *“The Mzimvubu River is the catchment which simultaneously has both the most available water and the greatest poverty in South Africa. Through the ages its abundant water has cut deep, steep valleys into the landscape, creating inaccessibility and remoteness, with major challenges for travel, service provision and most landbased economic activities. Even water, as abundant as it is, is essentially inaccessible.”*

Prasad, Boulle, Boyd, Rahlao, Wlokas, & Yaholnitsky (2011) have proposed that renewable energy technologies have considerable potential to improve the lives of the poor in remote areas not only for domestic heating and lighting but possibly more importantly through the supply of clean drinking water where it is needed. These technologies, their reliability, cost and availability have improved greatly and it can be stated that bringing energy to remote areas for water lifting and other uses is no longer a technological challenge. Investigations of such projects in Southern Africa (Prasad, Boulle, Boyd, Rahlao, Wlokas, & Yaholnitsky, 2011) have however shown that poor or no education and up skilling of the end-user and failure to plan for maintenance of the technologies has often resulted in such projects failing or petering out. As discussed in relation to standards above, the modelling framework will need to place special emphasis on capturing and accounting for the future costs of supporting and maintaining technology interventions and training local personnel. These aspects have to be fully implemented with the installation and commissioning of equipment or public money has almost certainly been wasted.

The area is currently part of a feasibility study of a proposed new dam with associated irrigation, bulk distribution and a hydropower scheme expected to cost R20 billion (Lazenby, 2012). The project forms part of one of the National Government’s 17 priority projects for economic development known as Strategic Integrated Projects or SIPS. SIP 3 titled, “South Eastern node & Corridor Development” undertakes to, amongst other large capital projects that include road, rail and port upgrades and refinery and manganese smelter construction to, “Promote rural development through a new dam at Umzimvubu with irrigation systems” (Presidential Infrastructure Coordinating Commission, 2012). The feasibility study will cover the entire Umzimvubu Catchment which falls within the Mzimvubu to Keiskamma Water Management Area that extends across parts of the Sisonke District Municipality in Kwazulu-Natal Province and in the Eastern Cape Province, the Alfred Nzo, Oliver Tambo and Joe Gqabi District Municipalities, Elundini Local Municipality falling within the latter.

The new feasibility study that started this year is reported to (Blaine, 2012) follow on from an initial study completed by the Department of Water and Forestry (DWAF) in 2005 (Sellick, 2005). This study identified the most promising site for a large scale dam with hydropower potential as being at Ntabaleng on the Tsitsa river. The proposed site is on the border of the Elundini and Mhlontlo Local Municipalities about 20 km east of Maclear (Sellick, 2005). Of the Hydropower sites identified 3 of the most promising were downstream of this dam on the Tsitsa River with another promising site at Mangwaneni on the Tina River about 30 km to the north. The optimum generating capacities were rated at between 16MW and

104MW with probable load factors of between 15 and 30%. Earlier studies apparently identified much higher hydropower potential of 450 MW to 1600 MW but this was based on a large dam at Mbokazi downstream from the confluence of the Tsitsa and Tina tributaries into the Umzimvubu. Concerns about the riverine and estuarine ecology however seem likely to militate against such a project. Hydropower potential in the area has been re-evaluated by a later study for DWAF (BKS, 2010) which had similar findings as regards capacity but drew the following conclusions regarding costs.

> *"Base load power generation is not viable at current electricity tariffs as a single purpose development. Peaking power is only marginal as a single-purpose development. Power generation at a potential dam site may be considered if part of a multipurpose development, and for local power supply."*

These cost analyses did not include transmission lines which are likely to be expensive given the rugged terrain and remoteness of the sites. While this finding seems discouraging, there is a precedent for hydropower developments in the neighbouring catchments with 4 existing stations, Collywobbles on the Mbashe, Mtata Falls 1 and 2 on the Mtata and Ncora on the Tsomo River, totalling a capacity of 61.4 MW (DWAF, 2005).

Pumped storage schemes were also investigated and two locations identified of which one, Ben Avon – Ben Roy, is in Elundini and was estimated to have a capacity of 4400 MW and could be potentially used for transfer of water to the Orange River Basin. Technical problems and the likelihood that other sites would be more economical for transfer purposes, work against the feasibility of this project. DWAF studies have noted that while water supply is more than sufficient for irrigation projects, other factors such as climate extremes including frost, high population densities with small land allocations, land tenure practices, skill levels, remoteness and precipitous terrain present considerable challenges to improving on the current dry-land subsistence / supplemental agriculture (BKS, 2010), (Sellick, 2005). Forestry appears to be a promising, if non-labour intensive, productive land use in certain areas.

While, South Africa is still reported to be a net food exporter (SAIRR, 2012) (FAO, 2011), in spite of alarmist claims to the contrary , the balance has steadily swung in favour of imports over the last 50 years (FAO, 2011). Climate change could cause a step change on top of this shift that would compound our already concerning food security position. There is little doubt that South Africans will need to learn to exact an agricultural surplus from more marginal lands to feed its growing population especially those where there is abundant water like Elundini. The terracing and irrigation of more mountainous farmland and the adoption of modern farming methods in these regions will be a necessity in the future, regardless of the challenges and the start-up costs. One objective of this case study is to employ the proposed modelling framework to assess the appropriate technologies and costs for such an initiative.

It's clear that water/energy projects in the Umzimvubu Basin, part of which is situated in Elundini, are highly topical and the subject of intense study by other parties. It's also clear however that the eventual benefits of future projects are equally likely to benefit municipalities other than Elundini or not occur at all if the cost-benefit ratios of other competing large projects like road, rail, port and refinery construction in SIP3 are more favourable. It is therefore far from certain that the current initiatives offer an economic salvation for the Elundini area specifically. At best then the proposed project could contribute to a way forward in the wake of disappointment while at worst will augment the past and current feasibility studies, focussing on the smaller area of one local municipality. The premise is that policy strategy underpinned by a modelling framework or other scientific approach can tackle the issues of poverty in a more far-reaching way than an unstructured approach. We have therefore attempted to make a modest start in this direction with the research questions below to demonstrate such a framework:

1. A number of studies of the Umzimvubu Basin have noted that while the basin has abundant water resources, the economic case for large scale hydropower or irrigation schemes is poor to marginal. These findings are unsurprising because if the region was easy to develop, it would have already occurred. That being said, just because there are technical and economic challenges, does not mean that the local population should be abandoned and forced to immigrate to the cities to find economic opportunity. This case study presents an ideal opportunity for a CLEW approach to explore the economics of integrated solutions rather than least cost analysis of single projects. This should include but not be limited to:
    - Assessment of integrated local energy supply that includes hydropower, wind, solar and biofuels.

- An assessment of the impact of local biofuel production on the viability of local electricity production and integrated irrigation schemes.
- An assessment of the feasibility of energy-water infrastructure projects on a local scale, for instance micro-hydropower, ram pump or gravity fed irrigation, small scale solar pumping and bio-digester gas production.

2. If withdrawals are made for distribution to residential and irrigation demand in Elundini what are the implications for downstream communities relative to upstream users? Upside implications might include improved water quality because downstream users are vulnerable to contamination of the water by users upstream. Downside implications might include reduced supply as upstream users take up their allocations fully or exceed them once equipped with pumps.
3. What is the most appropriate renewable technology, that can be relatively quickly installed, for bringing piped water to communities that currently lack this amenity and spend long hours carrying water? Energy supply options would include micro-hydropower, solar and wind power. What will the estimated costs be on a unitised basis to provide access to this amenity throughout those areas of the municipality that lack piped supply?

It must be stressed that a modelling approach to problems is best suited to evaluating competing technologies or future scenarios (e.g.: different population growth rates) in terms of cost or utility and presenting the results for each option and scenario such that they can be weighed up against one another. This is the form that the output to these research questions will take rather than a prescriptive solution to the options investigated.

Conclusions

To develop a basis for integrated water and energy planning taking climate change into consideration, modelling tools and scenarios should be developed. The following approach and four actions are proposed:

- Development of a prototype systems-modelling framework for energy/water planning in the context of climate change. Policy options to include national impacts and constraints on local actions (e.g. implementation of community-level renewable energy technologies as a policy).
- Use of the framework in stakeholder and expert workshops to integrate current knowledge and understanding of inter-dependencies.
- Experiment with model to identify key areas of sensitivity or pressure, e.g. potential magnitude of water/energy cross-effects; potential magnitude of climate change effects; where local interventions may have greatest impacts in the broader system; where the greatest data sensitivities are.
- Design of a refined and more extensive model in the light of these experiments. Support of local intervention studies by more detailed models of community-level actions (subject to global constraints)

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This paper derives from a larger research project to assess the water-energy nexus in the context of climate change in Southern Africa. The goal of the project was to analyse the way energy and water services can be combined and improved to enhance the resilience and adaptive capacity of communities to climate variability and change. We are very grateful to the International Development Research Centre (IDRC) to have funded the research.

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