The Energy–Water–Food Nexus at Decentralized Scales

Synergies, trade-offs, and how to manage them

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This paper uses Practical Action's experiences with micro-hydro schemes to connect global nexus debates to the experiences of and solutions for remote off-grid communities and smallholder farmers. Through examples in Peru, Nepal, and Zimbabwe we exemplify the need for an integrated approach to energy, water, and food security. We show that decentralized energy provision has a huge potential to deliver the services that communities need and have a right to, while balancing the constraints of an increasingly resource-scarce environment.

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Executive summary

A notable feature of almost all the discussions surrounding the energy–water–food nexus to date is that they have focused on national or supra-national scales. Most key background documents lack discussion of smaller, more localized scales. This is despite the fact that the majority of the food in developing countries is provided locally by smallholder farmers (IFAD and UNEP, 2013), fishers or herders; and the International Energy Agency's calculation that 55 per cent of all new electricity supply will need to be from decentralized systems if we are to reach the goal of universal energy access by 2030 (IEA, 2010).

This paper uses Practical Action's experiences with micro-hydro schemes to illustrate some of the nexus conflicts and synergies that arise for remote communities and smallholder farmers. We recognize that electricity provision through micro-hydro schemes is not the only example of nexus issues connecting water, energy, and food for poor communities. However, using examples from Peru, Nepal, and Zimbabwe we exemplify the potential added value of an integrated approach to energy, water, and food security.

Opportunities can be missed where energy provision is not linked with mainstream agricultural practices

Taking a 'Total Energy Access' perspective, we demonstrate the huge potential for decentralized energy provision to deliver for poverty reduction. However, opportunities can be missed and inequalities arise where energy provision is not linked with mainstream agricultural practices. Stand-alone energy schemes have reasonably good levels of sustainability, but they may perform below their optimum and fail to account for the full needs of the community without sufficient focus on nexus issues – which are well understood by communities themselves – as well as ensuring that the right kinds of institutions are in place to handle trade-offs as they arise.

Nexus debates are still relatively new; the practical lessons of adopting a nexus approach still need to be explored. There is an urgent need for capacity building at different levels within both donors and governments to bring better cross-sectoral working and a greater focus on decentralized scales and the needs of smallholder farmers. A focus on 'productive uses' should not over-emphasize off-farm enterprises, but build on what people are already doing. Initiatives such as the SE4ALL High Impact Opportunity on nexus issues which brings key players in the sector together must support this drive, and ensure that the emphasis lies not only on large-scale national and supra-national issues, but also on the needs of poor people.

Introduction

We live in a world of growing resource scarcity. Demands on water, food, and energy in particular will only increase as populations rise. It is now widely recognized that these resources are deeply interlinked. If we are to respond to the challenge in any one of these areas we must consider each resource as part of an interconnected system – an approach now commonly referred to as 'nexus thinking'. Some of the connections are illustrated in Figure 1.

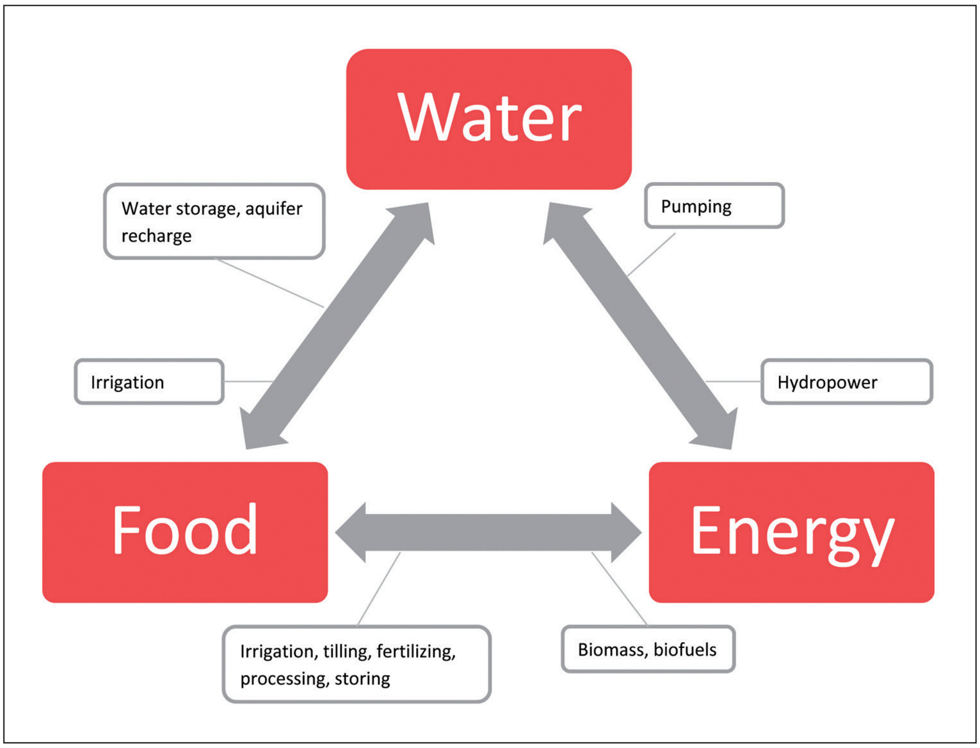


Figure 1 Connections between water, energy, and food

This nexus is complex. The competing uses of water, energy, and food can be controversial; in the energy sector, modern fossil fuel energy consumption is directly linked to climate change, and the replacement of traditional food crops with fuel on a large scale is a challenging option when fertile land is increasingly sought after and food security is at risk.

Making the connections between different elements of the nexus relates to 'Total Energy Access'

Nexus thinking is also not a wholly new approach. For Practical Action, making the connections between different elements of the nexus relates to our 'Total Energy Access' approach (Practical Action, 2014). This highlights how poor people need access to a range of energy supplies and services in households, productive uses, and community services to support human, social, and economic development. Smallholder farmers are acutely aware of the importance of an integrated approach at home and in the fields. They use various resources to ensure food security every day. Animal waste for example can provide a free, sustainable source of power all year round in the form of biogas, and biomass is a useful form of fertilizer to grow healthy crops.

We have many decades of experience of bottom-up, community-based planning to design energy systems with and for poor people whose needs, due to location, weak institutions or lack of political or economic influence are not normally factored into national energy plans. In this paper we consider what relevance current literature and the global debate have to a poor person's experience of energy access and resource scarcity.

We draw on our practical experience of micro-hydro systems in Nepal, Peru, and Zimbabwe. This is not because micro-hydro is the only appropriate option to meet resource challenges, or the only example of the nexus at these scales, but because our experience of competing demands on water and energy for household and productive uses offers us some useful lessons about the benefits and trade-offs that arise.

In some cases, nexus thinking was not an explicit goal at the start of a project. Where this is the case we retrospectively apply a nexus lens to see the extent to which trade-offs were present and the potential for synergies missed. Finally we analyse some of Practical Action's current work in Zimbabwe which makes a more deliberate attempt to tackle nexus issues. We review the potential of these schemes to maximize benefits from the energy infrastructure in terms of increased incomes and improved resilience.

The global debate on nexus issues

In recent years, the importance of the connections (or 'nexus') between the key resources of water, energy, and food has been increasingly recognized. The concept gained momentum at events such as the German government-sponsored 2011 conference in Bonn titled 'The Water, Energy and Food Security Nexus – Solutions for the Green Economy' and the resulting web platform it launched.[1] It has been further promoted by international agencies, donors, governments, and NGOs in the name of achieving sustainable development. It has been adopted by technical experts in these fields and the private sector, especially multinationals searching for ways to ensure resource security within value chains. There are also examples of different stakeholders coming together to discuss shared risks, such as the report published by WWF and the brewers Saab Miller on *The Water–Food–Energy Nexus: Insights into Resilient Development* (WWF and SAAB Miller, 2014).

Perhaps the most helpful definition of this approach is that it is one in which the 'solution for any one problem, like energy, must give equal consideration to others in the nexus, finding interconnected solutions that maximise synergies and manage trade-offs' (Best, 2014).

Literature on the topic, despite coming from diverse sources, identifies common concerns and incentives for a nexus approach, namely: expanding populations in need of more of all three resources, changes in consumption patterns (often linked to urbanization and a growing middle class), increasing water scarcity, and climate change effects from current and future energy use.

Most thermal sources of electricity generation are heavily dependent on water for cooling

At a global level these challenges and competing pressures on resources remain unresolved. In many areas of the world such as China, India, and the Middle East and Northern Africa, demand for fresh water exceeds supply and an estimated 1.2 billion live in areas of water scarcity (Hoff, 2011). At the same time, most thermal sources of electricity generation are heavily dependent on water for cooling. For example, thermo-electric power plants account for 39 per cent of annual freshwater withdrawal in the United States and 43 per cent in Europe (Rodriguez et al., 2013).

These water-intensive systems not only provide the energy we need at work and in the home, but often the energy they produce is vital for the production of food. The food production and supply chain already accounts for an estimated 30 per cent of total global energy consumption and agriculture is also the largest user of water, accounting for 70 per cent of total global water withdrawals (WWAP, 2014). To feed the 9 billion people expected to populate the world in 2050, it is estimated that agricultural productivity must increase by 70 per cent (FAO, 2009). This will require more energy[2] and improved access to it at each stage of the agro-food production chain (Practical Action, 2012, 2014).

The response by a number of studies to these well-publicized pressures on resources has been to treat the water–energy nexus primarily as a technical issue. Considerable attention is given to calculating the life cycle water use of electricity generating technologies (Meldrum et al., 2013), along with projecting future water needs based on historical patterns (World Energy Council, 2010). These calculations are often based on the assumption that large-scale and centralized energy systems will provide the energy of the future. However, the literature fails to connect these big picture technology questions with the reality of who currently lacks access to energy, who is likely to produce the food for a growing population, and what energy systems are most likely to meet their needs. There is rarely more than a passing reference to the decentralized, small-scale energy solutions recognized as required to solve the global energy poverty crisis.

The literature fails to connect big picture technology questions with who lacks access to energy

For smallholder farmers, who produce the majority of the food in developing countries (IFAD and UNEP, 2013), this lack of energy access is acutely felt. In sub-Saharan Africa 65 per cent of farm power relies on human effort, 25 per cent on animals, and only 10 per cent on engines (Best, 2014; FAO and UNIDO, 2008). A two-pronged approach is needed to both improve energy access and support improvements in productivity based on low-external input agriculture which can make the most efficient use of locally available resources. This is particularly true for women farmers who make up the majority of the agricultural workforce in sub-Saharan Africa (World Bank et al., 2009) and currently have the least access to technological inputs and energy services (Gill et al., 2012).

Best (2014) makes an important contribution to refocusing the discussion by advocating for a greater understanding of delivery models relevant to improving the food security of smallholder farmers. Practical Action has previously, through our flagship series *Poor People's Energy Outlook*, explored the range of energy needs for farmers across the agricultural value chain. We have advocated for a Total Energy Access approach which seeks to encourage a move away from business-as-usual energy supply by recognizing the range of energy supplies and services that poor people need in households, at work, and in the community to support human, social, and economic development.

In the following sections we add depth to this work by analysing a decentralized energy solution (micro-hydro power) through an energy–water–food-nexus lens. We fill gaps in the existing nexus literature and contribute to the current debate by connecting to the needs and experiences of the millions of smallholder farmers and off-grid communities.

Learning from the past: nexus synergies and trade-offs

Practical Action has long-standing and internationally recognized field experience in decentralized energy provision of all kinds. In particular, we have worked on micro-hydro systems[3] for decades in Nepal, Peru, and Zimbabwe.

In this section, we draw on studies looking back at micro-hydro schemes that have been running for at least five years. These studies were initially commissioned to review the technical, social, and economic sustainability of the schemes. However, we now review their findings in the light of what they reveal about the energy–water–food nexus.

Peru

In 1992, Practical Action began a programme of scaling up the installation of micro-hydro schemes in Peru. In 2005 we commissioned a study to evaluate the sustainability of these schemes, taking a sample of 9 out of the 29 that had been completed at that time (Calderón Cockburn, 2005). Table 1 gives some basic information about a selection of them. In all the communities, agriculture was the backbone of livelihoods; 65 per cent of families had farm land, and among the 35 per cent that did not, most worked as agricultural labourers. People also made some money from value-addition activities such as knitting and weaving.

Table 1 Micro-hydro schemes evaluated in Peru for the looking back study, 2005

Location: District/ Province/ Department	Started operating in	Power (kW)	Households connected: Original/ 2005/2014	Comments
Conchán Chota Cajamarca	1995	80	114 368 450	A milk cooling plant was added. By 2014 power had been increased to 150 kW to cater for additional users
Chetilla Cajamarca Cajamarca	2001	80	89 89 250	Very isolated area. Expansion of the scheme required installation of a power booster
Huarango San Ignacio Cajamarca	2000	50	150 150 150	Service is affected when there is a prolonged dry spell – or when rains have been too heavy
'Yumahual' scheme, Magdalena Cajamarca Cajamarca	1997	25	5	A scheme which only serves a small private enterprise rearing chickens. Still functioning in 2014
Incahuasi Ferreñafe Lambayeque	1999	50	150 150 Mkt only	Very isolated area. There is less power during the dry season so street lights are switched off, but power for households is maintained. By 2014 serving only the market as households are connected to the national grid
'Chalan' scheme, M. Iglesias Celendín Cajamarca	1994	25	87 87 –	This scheme faced operational and management problems. Only about 50% of households were connected, and power levels insufficient. No longer in use by 2014 due to arrival of the national grid

From a technical perspective, the sustainability of the schemes has been very good. By 2014 they were all still functioning, except two which had been overtaken by the arrival of the national grid. Four had a power booster or additional installed capacity to reach additional users. The 2005 study found that impacts from the schemes included:

- increased access to energy services (lighting, food processing, cooling, and ICTs especially TV);
- spending on energy reduced significantly (by 2–3 times);
- significant impacts on the quality of education (materials, teaching, homework) and health care provision;
- 60 per cent said that family incomes had improved (small businesses – restaurants, bars, carpentry, bakeries).

However, the report found that electrification had no direct impact on the mainstream agricultural practices of cultivation or livestock rearing. In the design phase of the micro-hydros, no particular consideration was paid to how energy (or water) could support these practices,

Power house of the Conchán micro-hydro, Cajamarca, Peru

and any benefit to agriculture-related activities of knitting and weaving were incidental. The systems were designed on the basis of the availability of water and hence total potential energy that could be generated, and on payment capacity, rather than on eventual productive uses for increasing incomes. The project focus was on electricity alone, and did not consider any other types of energy which could have had a closer connection to agricultural livelihoods such as biogas production.

In general there was enough water to operate the micro-hydros and supply sufficient drinking water (especially as the water is returned to the river once it has passed through the turbine). However, some trade-offs were reported. In Chalan, the river level was affected by farmers in the higher lands building irrigation canals, disrupting electricity supply in the summer months. In the case of Yumahual, where the micro-hydro was used solely by a private chicken-breeding company, it was decided that some of the water source used by the system needed to be diverted for drinking water for the nearby town of Choropampa above the level of the micro-hydro, thus reducing the electricity generation capacity.

A more deliberate attempt to examine energy needs in smallholder agriculture is needed

Overall, the report concluded that although many households benefited economically, the benefits were greater in the larger and better developed areas where there was more scope for non-agricultural livelihoods and small businesses. For other areas, the report indicated a more deliberate attempt to examine energy needs in smallholder agriculture would bring further benefits.

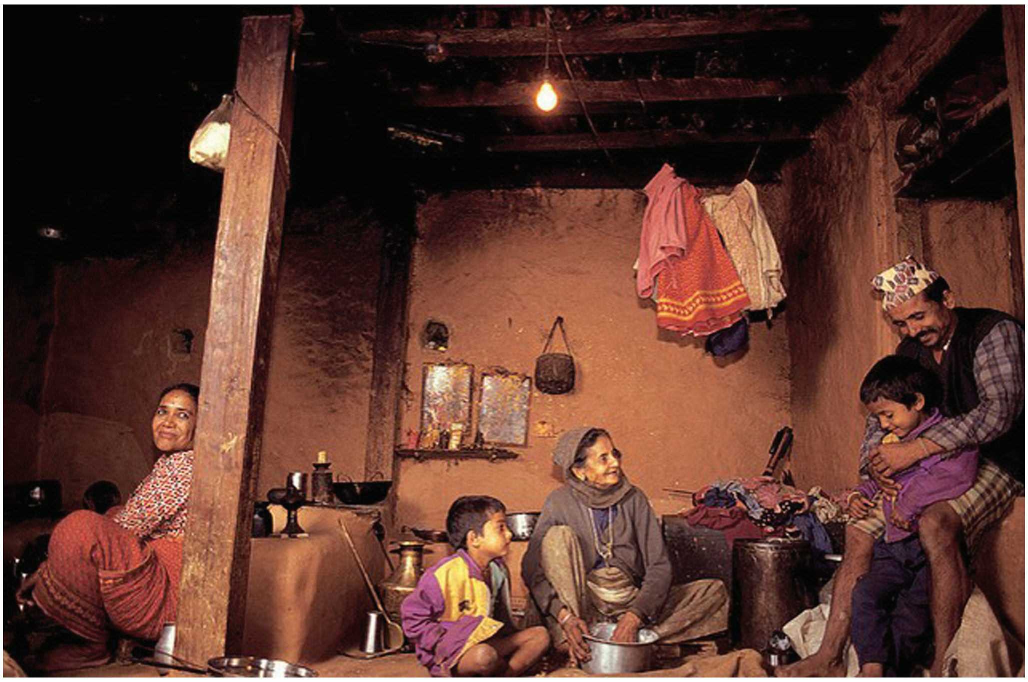
Nepal

Practical Action was very active in the early stages of the micro-hydro sector in Nepal. The first Pelton turbine was installed in Nepal in 1975,[4] and from 1979 Practical Action played an important role by providing training on manufacturing, project design, and other aspects. Over the years, the scaling up of these schemes has mainly occurred when private companies have been involved in the manufacturing of parts and installation of the systems. Government support through various subsidy policies and, since 1996, the AEPC (Alternative Energy Promotion Centre) has also been crucial. By 2013, a total of 2,778 pico- and micro-hydro sites had been installed in Nepal, with a total generating capacity of 26,535 kW (AEPC, 2014).

Practical Action has carried out two studies to review the performance of a selection of these micro-hydros. One study in 2002 (IPRAD, 2002) looked at six systems across four districts, and a second study in 2006 surveyed ten systems (Bhattarai et al., 2006). In both studies, it was found that almost all of the micro-hydros were operating at levels far below their design capacity. The 2002 study found that five out of the six schemes had a load factor[5] of 0.33 or below, while generally a load factor of at least 0.4 is needed to make the systems financially viable. The 2006 study found that eight out of the ten schemes surveyed were temporarily closed or generating power at minimum levels 'due to various technical and management reasons'.

The presence of a micro-hydro plant in a village does not guarantee that every household will be connected

The 2002 study also reminded us that the presence of a micro-hydro plant in a village does not guarantee that every household will be connected (as also found by Khennas and Barnett (2000)). The study looked at the impact of micro-hydro for different socio-economic groups. It found that the poorest households[6] were less likely to be connected to electricity, and if they were, were less likely to use it for productive purposes. The productive end use of electricity was also far higher in the more 'advanced' villages. This was largely because these were almost always in off-farm enterprises and required additional investment (such as buying a fridge or other appliance) which poorer households could not afford. Similarly, a 2011 study found that only 3.4 per cent of households with electricity started a new income-generating activity (UNDP, 2011). As in Peru, the schemes were not well integrated with the mainstream agricultural practices of the communities. The exception to this, perhaps, is the widespread use of either the electricity or the water-power itself for milling in Nepal.



A family at home with electricity, Patla Village, Nepal

Despite these conclusions, we should not down play the importance of micro-hydro in reducing the hardships of rural life. For example, the provision of clean lighting and better access to information (via television, radio, and phones) can support improved agricultural practices indirectly not least through a better connection to markets. The UNDP study (2011) found that in communities with electricity, households spent 60 per cent less on power for lighting and batteries and they dramatically reduced time spent on agro-processing (grinding grains, hulling rice, and pressing oils), saving an estimated 155 hours a year for women and 85 for men through the use of electrical mills. There was also evidence of improved education, better sanitation and health services, and decreased pollution (UNDP, 2011; Fulford et al., 1999).

In Nepal, therefore, one result of not being effectively linked with mainstream agricultural livelihoods is that the schemes are making a smaller contribution to broad-based development than they might otherwise. This ultimately affects their long-term sustainability.

Planning for the nexus: examples from Zimbabwe

Due to their topography, the Eastern Highlands of Zimbabwe are particularly suited to micro-hydro power, offering a viable option for some of the 87 per cent of rural households unserved by centralized energy infrastructure (SE4ALL, 2012). Practical Action has been the main implementer of such schemes in the country and has constructed five key micro-hydros in this area over the last 14 years.

As with many other installations around the world, the initial projects were focused almost exclusively on energy supply: demonstrating that the technology could work in this

Irrigation scheme linked to the micro-hydro plant, Himalaya, Zimbabwe context, and gaining acceptance for it. Apart from one early scheme in Nyamarimbira, there were few deliberate attempts pre-implementation to make connections between the use of water for energy and for irrigation. This was despite the central importance of agriculture in this region. In more recent projects, such as the Himalaya micro-hydro (where construction began in 2013), a more deliberate attempt to connect the energy scheme with agricultural livelihoods has been undertaken.

Contested objectives of stakeholders

Although micro-hydro schemes have great potential in Zimbabwe, the variable climate and recurrent periods of drought mean that access to water can be a source of contention. Competing community needs and trade-offs around water use have been evident at some stage in the development or use of all of the micro-hydro schemes in the area (illustrated in Figure 2). There is less conflict and fewer trade-offs over the use of the available electricity – where the challenge is more about how to make the most of the productive potential of the power, as well as using it to provide energy services for households and community facilities.

Trade-offs around water use have been evident in all the micro-hydro schemes

The Himalaya community micro-hydro, although in its infancy, is proving to be the most synergistic. The community was inspired by, and learned from, the experiences of a neighbouring scheme at Chipendeke. They wanted a system that would not only supply community services and households but would connect with the agricultural livelihoods crucial to the survival of the community. As a result, an irrigation component was included as part of the project design. The electricity is being used to pump water for the irrigation scheme, and a cold-storage facility is being set up to help keep produce fresh before it is sold.

This type of approach was made possible by a sophisticated and organized community structure. With initial capacity building and technical support from Practical Action, the community has been able to learn from other micro-hydros and take ownership of their scheme. Trained members of the community are responsible for all future maintenance of the plant and delivery of energy. The community has developed two additional co-operatives: one takes advantage of the plentiful supply of wood in the area to make fencing and electricity

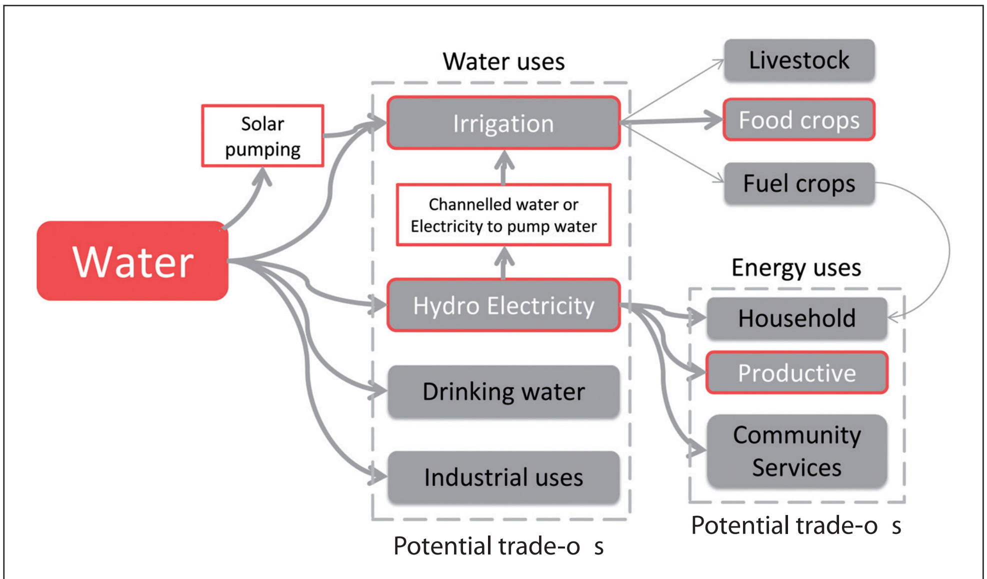


Figure 2 Water–energy–food connections at small scales

poles (for the plant itself and for sale at a significant profit to other electricity suppliers and projects) and the other is implementing the irrigation scheme.

This dual irrigation and community services approach is a conscious improvement on the Chipendeke scheme, which though benefiting farmers through the provision of such services as power for grinding mills and workshops for fixing tools, failed in the early stages to recognize the needs, and crucially, the current water usage of some farmers. As is usual for a micro-hydro scheme, in Chipendeke river water is diverted to the plant before being returned to the river. While this has little impact on downstream farmers, the water needs of the farmers close to the plant were not accounted for. These farmers needed the water to irrigate their land and this supply was now at risk – particularly during the dry season.

There were clear incentives to resolve the tension caused by the water needs of the new plant: all community members stood to benefit from improved community services and electricity to houses. As a result of community discussions, it was decided that the micro-hydro should be switched off for short periods during months when the river level is low. While a nexus approach which had fully integrated existing water and energy needs might have avoided or at least foreseen this initial conflict, it was possible to deal with the unpredicted trade-offs because the community owned and ran the plant. Had the energy supply been divorced from the community, the farmers would have struggled to recover from its unintended impacts.

Similarly, tensions have existed in another scheme 'Ngarura' between the immediate needs of the farmers and the longer term potential of the scheme. While the micro-hydro received widespread community support in its initial design phase, delays in construction undermined the confidence of some farmers who lost faith in the ability of the plant to deliver livelihood outcomes. As a result they returned to practices which damaged the plant such as cultivating the steep river banks. When heavy rains did come (2013–14), these farming practices on the river banks caused significant siltation of the system, and

Clearing silt from the weir at Ngarura, Zimbabwe urgent work was required to clear it from the weir. But this farming practice remains a problem in 'normal' weather conditions as silt can severely damage the plant turbines.

While it is possible to incentivize farmers not to participate in destructive practices (e.g. through penalties and the influence of local leaders), the success of the project is dependent on the community having a high degree of continued trust in the scheme and understanding of the nexus benefits it can deliver. In this context, the farmers (who were not a discrete group in this heavily agricultural rural area) were eventually convinced of the importance of protecting the scheme through continued community negotiations and further participatory planning. This highlights both the importance of understanding the competing needs and trade-offs when implementing a scheme and the fundamental importance of community buy-in throughout each stage of design and implementation.

External influences

There are, of course, many additional factors which have an impact on the water–food–energy nexus and the success of new energy initiatives. In particular the political economy in a given context is important. In Ruti, for example, Oxfam worked with the government and Practical Action to install a 60-hectare irrigation scheme using solar-powered pumps. The project was initially very successful with farmers receiving 0.25 hectares of irrigated land along with start-up support in the form of seeds, tools, fertilizers, pesticides, and training. Household incomes were said to have increased by 286 per cent for the very poor and 173 per cent for the poor (Magrath, 2014).

However, the scheme was dependent on a national resource (the Gutu reservoir) that the community had little control over. When the water levels behind the dam dropped below expected levels there was an immediate crisis. The government decided that the nearby sugar plantation should be prioritized for the limited water supply and so the irrigation project was sacrificed at a time when the drought was already severely affecting crops in the region. The challenges facing the scheme continued; during the course of the two year-long drought, water levels dropped even further than predicted and when the water finally did return, it caused damage to the irrigation pipes.

While climate change and variability was at the heart of the problems faced by the community during this period, unlike the Ngarura micro-hydro which also had to contend with adverse weather conditions, the community in Ruti had little power to adapt and become resilient to those changes. While new rains and technical solutions (such as sourcing water from deeper wells) offer hope for farmers in this area, a successful and continued dependence on a resource of national importance such as the dam will require further capacity building to enable improved local institutions that can connect with and garner support from government and with vested interests outside of the community.

> It was only the strength of community institutions which meant trade-offs could be effectively dealt with

Overall our experience in Zimbabwe further illustrates that where there are no clear links made between the energy supply (or water usage) and mainstream agricultural livelihoods, important opportunities for development are missed, and the performance and sustainability of the energy scheme is put at risk. At the same time, undesirable trade-offs may well emerge. We found that it was only the strength of community institutions, built up through the approach taken to planning and constructing the scheme, together with the ownership and management structures put in place, which meant these trade-offs could be effectively dealt with.

Conclusion

Practical Action's experiences with micro-hydro schemes echo global nexus debates by exemplifying the need for an integrated approach to energy, water, and food security. This chimes with Practical Action's calls for a 'Total Energy Access' approach by bringing a closer focus on the productive uses of decentralized energy alongside household and community services uses.

Decentralized energy provision has a huge potential to deliver for poverty reduction. Stand-alone energy schemes have good levels of sustainability, but our examples show that they may perform below their optimum and fail to account for the full needs of the community without sufficient focus on the nexus issues, which are well understood by communities themselves. This means making a more deliberate attempt to connect energy and water uses with mainstream agricultural livelihoods. It also means using the kinds of bottom-up approaches which ensure the right kinds of local institutions are in place to handle trade-offs as they arise.

Given the impacts of climate change, and growing resource scarcity even at local levels, there is a need to make the most efficient use of the resources available to produce the best development outcomes. A combination of improved energy access with low external input, agro-ecological approaches offers the best hope to deliver this sustainably. To maximize the benefits in terms of poverty impacts will also require connecting successfully with local market systems for the crops produced.

There are a number of barriers which need to be overcome to make this approach a reality. Major donors currently emphasizing the importance of the 'nexus' must do more to build the needs of rural communities and smallholder farmers into their programming. This will require new kinds of cross-sector dialogue and working internally which in turn will require high-level commitment and encouragement.

Major donors emphasizing 'nexus' issues must build the needs of smallholder farmers into their programming

Similarly at national levels, a change of emphasis and approach is needed, to redress the balance and put sufficient emphasis on the potential of decentralized energy systems and the needs of smallholder farmers. This will require new ways of working between ministries of agriculture, water, and energy, who may have competing objectives. Piloting this with cross-departmental teams at local levels, working in partnership with NGOs experienced with the community engagement necessary to avoid the pitfalls illustrated above, will also be required. The SE4ALL High Impact Opportunity on nexus issues must also champion these issues, and the need for capacity building within donor agencies and ministries at national and local levels as key objectives.

Notes

1. GIZ (no date) *NEXUS: the water, energy, food security resource platform*, <www.water-energy-food.org/> [accessed 3 February 2015], Eschborn, Germany, GIZ.
2. This assumes trends in consumption remain the same. How much more energy will be required, however, will depend fundamentally on the choice of production system. It is possible to significantly and sustainably increase agricultural productivity based on agro-ecological principles that might require some energy inputs, but far less than, for example, mechanized, intensive monoculture agricultural systems.
3. Micro-hydro systems are defined here as those with a generation capacity of 5–100 kW. Most are run-of-the-river schemes which do not require water storage. For more information see <http://answers.practicalaction.org/our-resources/item/micro-hydro-power> [accessed 3 February 2015].
4. The very first micro-hydro power plant was installed in 1962 by a private company. It used a propeller turbine to generate 5 kW of power. The introduction of Pelton turbines was critical to the scaling-up of micro-hydro in the country because these turbines are designed to work with low discharge, high head streams which are common across much of the country.
5. Load factor is the average load divided by the maximum load in a given time period. It is always >0 and <1. A low load factor shows the system operates with occasional high demand. In these cases, it implies peaks of electricity use (e.g. for lighting in the evening) and little use at other times of the day.
6. 'Poorest households' were classified as 'deprived' on the basis of only producing enough of their own food for half the year or less, and accounted for 49 per cent of all households.

References

AEPC (Alternative Energy Promotion Centre) (2014) 'Growth trend of MH Electrification Scheme' [online] <www.aepc.gov.np/?option=statistics&page=substatistics&mid=6&sub_id=50&id=1> [accessed 21 January 2015].

Best, S. (2014) *Growing Power: Exploring Energy Needs in Smallholder Agriculture* [pdf], IIED Discussion Paper, London: IIED <http://pubs.iied.org/16562IIED> [accessed 27 January 2015].

Bhattarai, H.P., Chitrakar, P. and Sharma, B.P. (2006) *Status of Governance in Community Managed Micro-Hydropower Plants in Nepal*, Nepal: Practical Action.

Calderón Cockburn, J. (2005) *Social Impact Evaluation Project: Fund for the Promotion of Micro-hydro Power Stations (MHSP)* [pdf], Lima: ITDG <http://practicalaction.org/docs/energy/cockburn_social_impact_evaluation_of_fund_for_mhsp.pdf> [accessed 27 January 2015].

FAO (2009) *How to Feed the World in 2050*, *Background Paper for the High-Level Forum on How to Feed the World in 2050*, FAO: Rome.

FAO and UNIDO (2008) *Agricultural Mechanization in Africa…Time for Action: Planning Investment for Enhanced Agricultural Productivity*, *Report of an Expert Group Meeting, January 2008, Vienna, Austria* [pdf] <www.unido.org/fileadmin/user_media/Publications/Pub_free/agricultural_mechanization_in_Africa.pdf> [accessed 27 January 2015].

Fulford, D., Gill, A. and Mosely, P. (1999) *Micro hydro Generation as Instrument of Poverty Reduction: Asian Achievement and African Potential*, report for DFID-UK, Reading, UK: University of Reading.

Gill, K., Patel, P., Kantor, P., and McGonagal, A. (2012) *Invisible Market: Energy and Agricultural Technologies for Women's Economic Advancement*, Washington, DC: International Center for Research on Women (ICRW).

Hoff, H. (2011) *Understanding the Nexus. Background Paper for the Bonn 2011 Conference: The Water, Energy and Food Security Nexus*, Stockholm: Stockholm Environment Institute.

IEA (International Energy Agency) (2010) *World Energy Outlook*, Paris: OECD.

IFAD (International Fund for Agricultural Development) and UNEP (United Nations Environment Programme) (2013) *Smallholders, Food Security and the Environment* [pdf], IFAD <www.ifad.org/climate/resources/smallholders_report.pdf> [accessed 27 January 2015].

IPRAD (Institute for Policy Research and Development) (2002) *Evaluation of Impact of Renewable Energy Programme on the Poor People*, Report commissioned by Practical Action, Nepal.

Khennas, S. and Barnett, A. (2000) *Best Practices for Sustainable Development of Micro-Hydro Power in Developing Countries*, report produced for DFID-UK and the World Bank, Rugby: Practical Action Publishing.

Magrath, J. (2014) 'Adapting to a hotter, hungrier world in Zimbabwe' [blog], Oxfam <http://policy-practice.oxfam.org.uk/blog/2014/03/adapting-to-a-hotter-hungrier-world-in-zimbabwe> [accessed 27 January 2015].

Meldrum, J., Nettles-Anderson, S., Heath, G., and Macknick, J. (2013) 'Life cycle water use for electricity generation: a review and harmonization of literature estimates', *Environmental Research Letters* 8: 1 <http://dx.doi.org/10.1088/1748-9326/8/1/015031>.

Practical Action (2012) *Poor People's Energy Outlook 2012*, Rugby: Practical Action Publishing.

Practical Action (2014) *Poor People's Energy Outlook 2014*, Rugby: Practical Action Publishing.

Rodriguez, D.J., Delgado, A., DeLaquil, P., and Sohns, A. (2013) 'Thirsty energy' [online], Water Papers, Washington, DC: World Bank <http://documents.worldbank.org/curated/en/2013/01/17932041/thirsty-energy> [accessed 29 January 2015].

Sustainable Energy For ALL (SE4ALL) (2012) *Zimbabwe: Rapid Assessment and Gap Analysis* [pdf] <www.se4all.org/wp-content/uploads/2014/01/Zimbabwe_Rapid-Assessment_Gap-Analysis-draft-final-14-June-2012.pdf> [accessed 27 January 2015].

UNDP (2011) *Decentralized Energy Access and the Millennium Development Goals: An Analysis of the Development Benefits of Micro-Hydropower in Rural Nepal* [pdf] <www.undp.org/content/dam/undp/library/Environment%20and%20Energy/Sustainable%20Energy/UNDP-Decentralized-Energy-Access-and-MDGs-book.pdf> [accessed 27 January 2015].

World Bank, FAO, IFAD (2009) *Gender in Agriculture Sourcebook*, Washington, DC: World Bank.

World Energy Council (2010) *Water for Energy*, London: World Energy Council.

WWAP (United Nations World Water Assessment Programme) (2014) *The United Nations World Water Development Report 2014: Water and Energy*, Paris: UNESCO.

WWF and SAAB Miller (2014) *The Water-Food-Energy Nexus: Insights into Resilient Development* [pdf] <http://assets.wwf.org.uk/downloads/sab03_01_sab_wwf_project_nexus_final.pdf> [accessed 27 January 2015].

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Front page photo: Weir of Tungu-Kabiri micro-hydro power scheme, Kenya ©Practical Action

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