Off-grid energy provision in rural areas: a review of the academic literature

SUMMARY

This review overviews the academic literature on off-grid energy provision in rural areas. The geographic scope of the review is broad, covering 47 countries in seven regions. The review complements the scoping report and the report on existing rural village development projects and provides useful background information for the Smart Villages Initiative. Studies focusing primarily on techno-economic feasibility have been omitted.

Dr Terry van Gevelt
Research Associate
Cambridge Trusts and Centre of Development Studies
University of Cambridge

TABLE OF CONTENTS

EAST ASIA AND PACIFIC

China

There is a relatively significant body of literature on off-grid energy provision in rural China. This is as the provision of energy to remote villages has been made a priority of the Chinese government due primarily to concerns over the negative impact of increased regional and urban-rural inequality in the Western regions (primarily the Inner Mongolia Autonomous Region, Qinghai Province and Xinjiang Uygur Autonomous Region).

Studies tend to fall into two main streams: studies that evaluate various government initiatives and studies that examine the potential impact of off-grid energy on rural livelihoods. Sovacool (2011) presented an incredibly detailed study and evaluation of China's national improved cook stove programme (1983 – 1998). The programme is widely considered to have been immensely successful in achieving its objectives of preventing fuel shortages, reducing forest degradation and stimulating economic growth through job creation and saving approximately four million working days per year that were previously spent collecting fuel. Over its lifespan, the project saw approximately 185 million improved cook stoves installed. The success of the project is arguably due to the "self-building, self-managing, self-using" approach which emphasized the importance of the rural population playing a key role in inventing, distributing and maintaining cook stoves, as well as the bypassing of many administrative levels of the Chinese government.

Sovacool (2012; 2012c) also evaluated the more recent Renewable Energy Development Project (REDP) where approximately 400,000 solar home systems were installed in north-western China between 2002 to 2007. The REDP, which was supported by the World Bank, has been touted by donors and energy analysts as a best practice case study for the deployment of solar home systems. Rural households benefited in a number of ways, notably increased: workable hours, access to information, reduced fuel consumption due to a significant decline in the use of candles and kerosene, increased usage of basic household appliances, and income. Regarding income, a post-project evaluation noted that the solar home systems had improved the incomes of 53% of surveyed households. Benefits also accrued to solar home system retailers and Chinese PV producing companies, who were able to reduce costs and improve the quality of their product - this allowed some companies to enter export markets. Some notable aspects of the programme which are likely to have contributed to its success include the use of a technology that matched the scale and scope of its target area, demonstration of technologies in rural areas (road shows) and community-level education regarding energy usage and practical suggestions in how energy can help generate income. An important consideration revealed from the evaluation, however, is that many rural customers saw the solar home systems as a temporary stop-gap on the way to on-grid electricity.

Perreira etal. (2011) and Chian (2010) review the government's 1996-1999 Brightness Programme and the 2002 Township Electrification programme, respectively. The driving force behind both programmes is postulated by the authors to be the government's concern about the impact of rural-urban and east-west inequality on socio-political stability. The Brightness Programme aimed to provide 23 million people with solar and wind power (average capacity of 100W per capita and an additional installed capacity of 2,300MW) in the Western regions of

Xinjiang, Inner Mongolia, Gansu, Qinghai and Tibet. This effort was coordinated by the State development Planning Commission and involved complementary investment in other infrastructure. Using a similarly designed experiment, Perrira et al. (2011) found improvements in the quality of life, attributable mainly to the increase in leisure time as a result of using basic electronic household appliances. Additionally, there was a reduction of indoor pollution due to a decline in the use of candles and kerosene and a decrease in environmental damage due to battery disposal.

Chian (2010), in an examination of two townships, found that the provision of off-grid electricity generated through solar, wind, hydro and hybrid systems to rural households had a negligible impact on a variety of household socio-economic indicators, the overall township economy and the environment. Additionally, Chian (2010) found that the electricity provided from off-grid sources was not sufficient to meet household needs resulting in the continued use of traditional energy sources. This is largely attributed to the top-down approach adopted in policy formation, as well as insufficient considerations of financial, technical and capacity considerations during implementation. Pauchauri and Jiang (2008), in their study of the energy consumption behavior of households, suggest that another potential reason for the continued use of traditional energy sources is that rural households prefer to use their relatively abundant labour time collecting biomass or coal, rather than their relatively limited financial resources on paying for energy from off-grid sources. Liu et al. (2008), in their study of rural energy consumption in Tibet, also suggest that cultural tradition may be a reason for the continued use of traditional energy sources.

Zhou and Bryne (2002) and Byrne et al. (2007) assessed the potential of stand-alone, small-scale renewable energy technologies to improve the economic and livelihood situations of rural households in Western China. This was achieved through simulating 20 photovoltaic, wind and hybrid configurations using the Rural Renewable energy Analysis and Design (RREAD) model. Additionally, data from 531 households across three regions in Western China were collected and a logistic regression run to discern the technical, economic and social factors that determine household choice regarding renewable energy technology. GIS mapping was also used to spatially estimate supply and demand of energy across the regions. Simulation suggests that off-grid renewable energy can be a cost-effective and reliable method to providing the energy required by rural households. Another interesting finding is that the majority of households surveyed preferred decentralized off-grid energy systems to the extension of the grid. Similarly, Liu et al. (2008) surveyed the current energy use of households in the Tibetan autonomous region and suggest that off-grid renewable energy sources, particularly photovoltaic and hydro, can significantly benefit households and the natural ecosystem. Notably, the Liu et al. (2008) also stressed their belief that cultural traditions may prove a barrier to the uptake of renewable energy sources.

Despite the apparent success of off-grid energy provision in rural china, Cherni and Kentish (2007), Liming (2009) and Martinot (2010) noted that China continues to face numerous regulatory challenges related to technology development, financing, and policy. Additionally, Gan and Yu (2008) and Zhang and Kumar (2011) stress the need for policies to be designed with the village at the centre. Lastly, Zhang and Kumar (2011) also note the need to take a dynamic approach to off-grid energy policies due to the observation that household electricity requirements often dramatically increase due to the use of household appliances.

East Timor

The government of East Timor sees solar home systems (SHS) as a major component of economic development. Based on the overall development environment of East Timor and an awareness of a number of small-scale donor-funded solar PV efforts, Bond et al. (2007) examined solutions for creating a successful SHS delivery infrastructure. Bond et al. (2007) suggested that a market-driven approach (including microfinance) will be unsuccessful as the commercial sector is weak and rural household incomes are prohibitively low. Instead, the authors concluded that the subsidization of capital costs, using either a fee-for-service or donation model, would have the best chance of success. In order for the operational costs of SHS to be affordable for rural households, the authors stressed that smaller systems with relatively low recurrent costs are required. In addition, supporting capacity must be improved. This includes: government capacity to plan and implement SHS policy; the creation of a pool of trained technicians who can install and maintain SHS; and a robust fee collection and maintenance system.

Fiji

Urmee et al. (2009) provided an evaluation of the Japanese and Fijian funded Vunivau solar home systems programme (2002 – 2005). The objective was to implement “commercially viable energy services for sustainable development” and during the course of the programme 250 SHS were sold. All SHS were the same size (100Wp) and included one power point and five lights. The distribution mechanism was fee-for-service with the government owning the SHS and a Rural Electricity Service Company (RESCO) employed to cover installation, maintenance, monitoring and tariff collection. The Department of Energy was responsible for the overall project and monitored the RESCO. The monthly tariff for SHS was USD14 per month. This took the form of a card that was topped up monthly at Post Offices. USD13.5 was used to cover operational and maintenance expenses and USD 0.5 was paid to the Post Office as a commission. The initial capital costs were covered entirely by the government. In terms of regulation, the imposition of an import duty on SHS parts by the government is suggested to have deterred private investment. Regarding the impact of the programme, two surveys paint two very different pictures. The first survey reported by Urmee et al. (2005) was conducted by the Department of Energy one year after the commencement of the project. Results suggested that 85% of respondents reported a positive social and economic return as a result of the programme. In addition, results showed that the fee-for-service model worked well and that RESCO provided excellent operational and maintenance services. A second survey, carried out at the end of the programme by academics from Murdoch University, found that about 80% of the SHS were not working due to component failure (in part, potentially caused by households overusing their batteries). In addition, monitoring and maintenance services were unavailable and there were no spare parts available. Additional key findings included: that the Department of Energy did not sufficiently monitor RESCO and that communities were not consulted prior to the installation of SHS and no use and maintenance training was provided to users (Gonelevu 2006).

Indonesia

The Indonesian literature presents a number of case studies of solar PV systems. Outhred et al. (2004) summarized the first pilot PV village (Sukatani in West Java) programme in 1988 where 102 PV lighting systems were installed. Sukatani was monitored and audited periodically, from both technical and social aspects. According to the authors, the villagers continued to speak positively of the PV lighting systems 15 years after their initial installation. Furthermore, villagers retained their PV systems as a backup after the village was connected to the grid in 2001. Anecdotal evidence from two other cases suggested less positive outcomes. In one particular case, a change of management led to difficulties in continuing to provide operational and maintenance support for solar PV systems. This led to non-payment by users. In another case, users reported that the PV lamps were too bright for sleeping and that the lights also attracted thieves. As a result, many users used traditional kerosene lamps after 10pm. Some users, replaced the standard bulbs with motorcycle bulbs to reduce brightness. This exhausted the stored PV energy very quickly which surprised users and showed the importance of providing important technical information to users.

Retnanestri et al. (2003) identified key success factors for the implementation of SHS programmes from three case studies in Indonesia. The first case study was an organic market for new and used SHS. The second case study was the World Bank/GEF Project (1997 – 2003). The third case study was the PLD Village Electricity Management Model. The key success factors included: the integrity of local institutions; the quality of project design and the use of safe exists as a contingency; the enabling environment and robustness to adverse changes; prior studies that understand existing energy sources and uses, and enhance existing community resources; training of local agents; and including target users at an appropriate stage of project design.

Japan

The literature on off-grid energy in rural Japan is sparse. Rural Japan is connected to the grid, although the cost per kWh for many rural areas is relatively expensive. As such, off-grid energy sources are considered for rural areas as a means to reduce costs and to reduce dependence on fossil fuel imports. According to Nakata et al. (2005), the vision or rural Japan is for rural areas to primarily use local renewable resources. Electricity from the grid would then be used only to mitigate the intermittency of the renewable energy. Nakata et al. (2005) calibrated the METANet economic modelling system to evaluate the potential of a hybid energy source for the village of Kuzumaki in Iwate prefecture, northern Japan. Results suggest that a hybrid energy source consisting of wind, geothermal heat pumps, petroleum and grid electricity would be most economically efficient. Morozumi (2007) briefly overviews several projects related to connecting distributed energy to microgrids. The Kyoto eco-energy (Kyotango) project seems to provide some rural coverage and connects biogas plants, wind turbines, and solar PVs to a microgrid.

Laos

Arriaga (2010) evaluates the technical and economic feasibility of the Pump as Turbine concept in Lao PDR. Results suggest that this can electrify isolated communities of between 40-500 people by hydro power alone. In addition, Arriaga (2010) highlight the complexity inherent in implementing projects. In particular, Arriaga (2010) stresses that appropriate time must be spent in setting up a social/payment structure in villages even if time constraints are pressing. This is as the system is likely to fail, be misused or lead to tension within the village if not given adequate time. Bambawale et al. (2011) examined the Lao government and World Bank's Rural Electrification Project Phase 1, which led to the electrification of approximately 40,000 rural households in four years through both expanding the grid and off-grid renewable technologies. The authors concluded several general lessons from the project: geographic and socio-economic data must be collected prior to final planning of and implementation of electrification programmes; programs should explicitly focus on making sure electricity suppliers are commercially viable; fee-for-service models may be an optimal distribution strategy; and outsourcing can lead to improved efficiency and efficacy.

Pode (2010) used the case study of Vientiane, Lao PDR to suggest some positive elements of boosting the use of solar-powered lighting. In particular, rental prices were lower than the price of kerosene. A well-trained and carefully selected network of franchises was recruited for installation and maintenance. Franchises trained technicians resident within villages to handle day-to-day maintenance. The solar-powered lighting equipment is rented directly by each villages village energy committee and the village energy committee is selected by villagers and leases the equipment to individual households.

Mustonen (2010) used the LEAP model to simulate electricity demand in a rural village after electrification. This was achieved by collecting baseline data before electrification of the village. A notable finding was that concurrently electrifying public sector services in the village may lead to a more equitable development outcome.

Lastly, Smits and Bush (2010) shed light on the politics of rural electrification in Laos. In particular, Smits and Bush (2010) asked why pico-hydropower – which is extensively used in Laos – was neglected in state and non-state actor-led energy policy. Smits and Bush (2010) found that the widespread use of pico-hydropower had developed without any intervention. Instead, pico-hydropower expanded from neighbouring China and Vietnam. Smits and Bush (2010) found that the main reasons for pico-hydropower being neglected were: a lack of information for policy makers; a government preference for large scale investments (from foreign sources) resulting in large hydropower dams; the universal applicability of solar home systems; and the centralized nature of the government.

Malaysia

Although 99% of Malaysia's population has access to the electricity grid, 150,000 to 200,000 homes in rural areas rely on diesel generations or do not have access to modern energy services (Sovacool and Drupady 2011). Extension of the grid is difficult and not economically viable in many of these areas, and diesel generators are often expensive to run due to transportation costs and increasing fuel costs (Lau et al. 2010; Mekhilef et al. 2012). The government of Malaysia acknowledges the uneven development that has resulted and is therefore keen to harness the potential of renewable energy sources to provide energy to off-grid households (Ajan et al. 2003).

Ajan et al. (2003) provided the first techno-economic feasibility study of a hybrid diesel-solar PV for use in Sarawak state. The authors argued that replacing current diesel generators with a PV system is not feasible due to the need for large batteries during the evening or in periods of low insolation. Lau et al. (2010) also suggest that a hybrid diesel-solar PV system has much promise for deployment in remote areas. This is based on simulation using HOMER and an acknowledgement of the successful implementation of a hybrid diesel-solar PV system for the Langkawi Cable Car Resort Facilities Project and a rural communication technologies telecentre (Abdullah et al. 2009). Mekhlief et al. (2012) also acknowledge the feasibility of hybrid systems but stress the need to take into account resource availability, socio-economic factors, demand for electricity, the environmental impact, and the willingness to pay of end users, among other factors.

Wong and Chai (2012) discuss a fascinating case study where a stand-alone AC Bus configuration solar system was implemented in Long Berurang village in Sarawak. Long Berurang is extremely remote and does not have a connection to the grid. Only a handful of households had diesel generators. Under the Stimulus Rural Electrification Project (2009 – 2010), the Public Works Department of Sarawak installed a 54kWP PV system in the village. The project was a community-based project meaning that villagers participated in aspects of construction and system installation. The costs of construction and installation were covered by the government. Training to villagers concerning operation and maintenance were also provided so as to increase the autonomy of villagers. The project successfully provides electricity to 54 households with each household having an average of three lighting points. Another impact was that the number of electric appliances used in the village has increased. For example, the number of washing machines in the village has increased from two to 12. The Public Work Department has also announced plans to set up an information centre in the village to allow villagers to use computers and access the internet.

Sovacool and Drupady (2011) present a fascinating study on Malaysia's Small Renewable Energy Power (SREP) Programme (2001 – 2010). A flagship programme, SREP had four main goals which included providing off-grid energy access to rural villages through hydro and solar power. In addition, it was thought that SREP would help develop appropriate off-grid and micro-grid technologies for this purpose. The programme, however, can be classified as a failure as the goal was to install 500MW of renewable energy facilities by the end of 2005. At the end of 2005, only 12MW of capacity were installed. The 2010 target was lowered to 350MW, however only 11 projects were completed and 61.7MW were installed by 2010. Sovacool and Drupady (2011) suggest that the project was derailed by capacity issues, red-tape, poor monitoring, the exclusion of stakeholders, and a lack of pre-feasibility studies.

Mongolia

Sovacool (2011) examined Mongolia's highly successful Renewable Energy and Rural Electricity Access Project (REAP). The total cost of REAP was USD23 million and was funded primarily by the Chinese and Japanese governments. The project had three main components: to establish a rural retail network of private solar home systems (SHS) and small-scale wind turbine systems (WTS) aimed at nomadic herders; to develop institutional and technical capacity among rural electricity suppliers' and to develop a national regulatory framework. Key stakeholders were the National Renewable Energy Centre, the Mongolian Ministry of Fuel and Energy and a steering committee. As of 2011, REAP distributed approximately 40,000 SHS and small-scale WTS to nomadic herders. Benefits from the programme include: increased access to energy; improved SHS quality; more affordable energy services; and a reduction in greenhouse gas emissions. Despite the success of REAP, Sovacool (2011) notes five remaining challenges: the relatively expensive capital costs of renewable energy systems; dependence on China for materials and technology; a continued lack of institutional capacity; poor consumer awareness; and a political commitment to centralized energy systems. Key lessons from the project are: that the private sector should participate in rural energy programs and that feedback should be collected from end users and that, in the short term at least, rural electrification may not be profitable.

Papua New Guinea

Sovacool et al. (2011) analyses technical, economic, political and social barriers to the uptake of Solar Home Systems (SHS) in Papua New Guinea. Technical barriers refer to poor-quality equipment and logistical issues. Economic barriers are a high rate of poverty, a lack of financing and a partial understanding of the market economy. Political barriers are poor institutional capacity and the government's commitment to grid electrification using fossil fuels. Social barriers refer to unrealistic expectations concerning the ability of a SHS, jealousy, vandalism and theft, and not being familiar with solar technology. A key point stressed in this study is that, in Papua New Guinea, attempts to distribute SHS have failed partially due to excluding the role of culture.

Philippines

Hong and Abe (2012) performed a sustainability assessment of the Pangan-an Island Solar Electrification Project. Pangan-an Island is a small rural island offshore of Cebu Island in the Philippines. The only prominent industry is fishing. In 1999, a centralized solar plant was installed through funding from the Belgian government. Before the solar plant, households used diesel generators or and kerosene lamps for electricity. In order to operate and maintain the plant, a community cooperative was developed. The cooperative collected user fees to cover the costs of replacing batteries. The cooperative, however, was dependent on external technical support and was not able to recoup the cost of maintenance through user fees. Additionally, it was found that the quality of PV panels was low meaning a relative fast decline in the system's efficiency.

As the rural community was characterized by low income and education and the village economy's main economic activity was fishing, electricity did not increase incomes and was a barrier to household's ability to pay for electricity. Therefore, although the cost of electricity from the solar plant was lower than energy from a diesel generator or kerosene, many households were unable to commit to the monthly cost of electricity from the plant. This led to a relatively low number of user connections and higher electricity prices. Despite this, users were broadly satisfied with the project and their welfare was judged to have improved due to better lighting – which benefitted education – and the use of television and radio. Overtime, however, a decline in the efficiency of the plant has largely reversed these gains by forcing users to revert to diesel generators and kerosene.

In addition, Hong and Abe (2012) used multiple correspondence analysis to understand user factors that affect the uptake and sustainability of an off-grid rural electrification project. Results suggested that individuals with higher income levels, whose primary income source was not fishing, and with a better education, were more likely to be users. This suggests that an important element of an off-grid electrification project may be to support different income-generating activities and education.

Pode (2010) provided a brief overview of USAID's ongoing development of off-grid renewable energy systems in the autonomous region in Mindanao. The project aims to install systems in 160 remote rural villages. Preliminary results suggest that the systems have reduced the cost of lighting by 70% for villagers who used to use kerosene. This has also been touted to have increased working hours for artisanal activities, study and household work. As a main component of the project, USAID are deploying significant resources to tackle several key barriers: a lack of awareness; fossil fuel policy bias; the inability of end-users to pay for electricity; and ensuring that energy catalyses activity in agriculture, health, education and information and communication technologies.

South Korea

Starting in 2010, Korea Electric Power Corporation, LS Industrial, Sanion and Inha University have been developing and field testing a standalone microgrid in Gasa island, which is a small island situated off the Southern cost of the peninsula. The microgrid configuration is PV 200kW, wind power 300kW and diesel 200kW. Off-grid microgrids are scheduled to be deployed both domestically in islands and rural areas, and to be commercialized and sold to developing countries in the near future (Hwang 2013).

Thailand

The government in Thailand has financed and continues to finance the development and implementation of renewable energy sources to provide energy to remote areas, particularly to villages in the North (Chenvidhya et al. 2003). Green (2004) provides an evaluation of the government subsidized solar battery charging programme. The programme was rolled out over a period of 15 years at the cost of approximately USD 11 million. At the village-level, the objective was to help provide access to new income-generating activities and improve the living standards for off-grid villages. An evaluation of the project, however, found that the programme did not succeed in providing access to new income-generating activities as the 12V DC electricity supply from the batteries was insufficient to run necessary appliances. Improvements in the standard of living mainly took the form of improved light quality. A lack of training regarding operation and maintenance quickly eroded benefits for the majority of households with a reported 60% of systems being inoperative at the time of the survey. Green (2004) highlights the role that social factors played, with language and gender barriers between the installers of the systems and the end-users resulting in misunderstandings regarding battery and system use. Lastly, some secondary effects are catalogued. In particular, access to television caused tension between the younger and older generations in ethnic minority villages.

Yangket and Tezuka (2013) evaluated a 2004 government initiative to electrify off-grid areas. Rather than providing solar battery charging systems, solar home systems were distributed to approximately 200,000 households in rural Thailand over the course of two years. Installation and the dissemination of operational and maintenance information was contracted to private companies. The main benefit of the systems was found to be a reduction in kerosene use. Phuangpornpitak and Kumar (2007), in their study of a PV-disel hybrid system at Kohjig village in Chantaburivilla, find that training villagers in routine maintenance and repair works allowed for the majority of issues to be solved locally.

Tonga

Outhred et al. (2004) reviewed the environmental, economic, technical and institutional sustainability of a 1996 EU funded solar photovoltaic lighting project covering ten remote islands off the main island of Vava'u. Regarding the environmental sustainability of the project, Survey results found that kerosene consumption had decreased by 70%. PV equipment, however, has also led to an increase in solid waste materials which are disposed improperly due to a lack of recycling facilities. Regarding economic sustainability, the budget was found to allocate insignificant resources to project software (2%) with the vast majority of resources allocated to project hardware (98%). Project software covers areas such as installation, operation and maintenance training, as well as service delivery and institutional support. Furthermore, only 35% of surveyed users paid monthly user fees to the government. This was attributed with users perceiving the payment process to be unfair and with the inability of the government to enforce relevant By-laws. Lastly, PV lighting systems were only able to improve the productivity of handicraft artisans (by extending working hours). The other main livelihood strategies (agriculture and fishing) did not benefit directly from the PV lighting systems meaning that the impact on income was negligible.

From a technical standpoint, Outhred et al. (2004) found that maintenance was sometimes ignored altogether and that spare parts were difficult to procure due to insufficient funding, and poor communications and transportation infrastructure. Additionally, further technical problems were attributable to low quality equipment, a lack of testing facilities, inadequate regulatory codes for installation and maintenance, and not understanding the social and cultural characteristics of the island communities. Regarding institutional sustainability, a major issue was the unavailability of local technicians who often moved to the main island. This was a major constraint to installing, operating and maintaining the PV systems.

Vietnam

Nguyen (2007) used an innovative GIS-based approach to estimate the technical potential of wind energy in Vietnam - a country where 75% of the population lives in rural areas and 20% of the population lacks electricity. Results suggested that wind energy can result in ecological and socio-economic benefits. Nguyen (2007), however, noted political barriers to harnessing the potential of wind energy.

EUROPE

Denmark

In Denmark, small-scale combined-heat and power (CHP) power plants have been established since the 1970s energy crisis in small cities to supply local heating systems (Hammons 2008; Sovacool 2011). Chen et al. (2007) provide a brief overview of Ærø Island – winners of the “Danish solar city 2000” prize. Wind and solar power generate the majority of electricity. Regarding solar energy, there are an unprecedented 3.7m^2 per inhabitant of panels installed. The Island committed to a ten year plan (1998 – 2008) whereby the goal was for renewable energy sources to cover 80 to 100% of electricity demand.

France

Dumbs and Juqois (2003) briefly overviewed aspects of the French rural electrification programme. The programme was funded by the French Environment and Energy Agency and Electricité de France and installed off-grid energy systems, mainly standalone PV systems. Over the last ten years, systems have been installed in more than 5,000 isolated areas in France and the French overseas departments. The authors suggested that the programme could benefit from teaching users how to efficiently use the systems through initiation training courses.

Germany

As of 2012, Germany has approximately 50 “bioenergy villages.” A bioenergy village is a village where residents have planned, funded and implemented a conversion of their village’s energy supply from fossil fuels to locally available energy sources, primarily biomass (Wuste and Schmuck 2012). The concept of a bioenergy village was developed in 1998 by an interdisciplinary team based at the Universities of Gottingen, Berlin and Kassel. The initial motivation behind the concept was threefold: to achieve the targets of the Kyoto Protocol; to stimulate research on sustainable development; and to find a practical way of putting sustainable development into practice. Specifically, the central goals of the bioenergy village concepts were: to switch a village’s entire energy supply from fossil fuels to biomass that are sustainably produced; to create employment opportunities in local trade, agriculture and forestry; to promote the rural identity; and to create a transferable concept (Karpenstein-Machan and Schmuck 2007).

Prior to piloting the bioenergy village concept, the researchers considered both technical and social barriers. On the technical side, the technical solutions have been well-known for many years and state-of-the-art techniques were chosen. Specifically, electricity and heat are produced by burning biogas in a combined heat and power station. The electric power is fed into the public grid while the heat is distributed to households via a hot water grid. During winter, peak heat demand is satisfied by a wood chip heating plant (Wuste and Schmuck 2012). On the social side, the research team analysed "social success factors" in similar projects. Among these factors, the following were considered important: good contact with the local media; a neutral moderator; personal contact with villagers and the spread of verbal information; visiting model sites; engagement for something, not against; festivities and the use of humour; and well-established advocates. The typical barriers were also assessed through a literature review and found the following: uninterested village leaders and residents; intra-village dynamics; negative experiences with renewable energy; an image of wood energy as regressive and ecologically damaging; concern regarding the economic efficiency and smell of bioenergy; and envy concerning "already wealthy" farmers becoming more wealthy. The approach taken by the research team was to apply the success factors to the barriers.

The project was piloted in the Gottingen area. Firstly, an intensive publicity campaign was launched using the local press and through screening films. This was followed up with presenting the bioenergy village concept to 17 interested villages. In each of the 17 villages, a public meeting was held where the concept was discussed. All residents were invited and members of the research team were present. 4 villages were selected based on the level of interest garnered during the public meeting. The research team proceeded to analyse the suitability of each of the villages through household survey questionnaires and a review of technical aspects, such as the density of houses and biomass availability. The village of Juhnde was selected, largely due to the fact that many residents expressed a willingness and intention to support the bioenergy village project and the village had eight agricultural enterprises willing to join the project.

Planning began in 2001 and continued until 2003. Planning was done by a group of 30 residents from the village who worked in specialized groups focusing on a particular aspect of the project (e.g. the biogas plant, the central heating plant, the cooperative society, the housing technique, public relations, energy crop cultivation). Groups met several times per month and meetings were partially moderated by the research team. A central planning group was also set up. Together, this resulted in a transparent participatory process that fostered an environment of trust among the community and in the project.

In 2004, village residents established a cooperative society that is the official operator of the energy plants. One year on, the villagers and research team found that there were no significant problems with village-based production of renewable energy and that the project was successful. As a follow up, the research team launched a longitudinal study to understand changes in the village's structure and culture, and on the well-being of participants. Preliminary results suggest that the project has seen an increase in the general well-being of villagers, ecological awareness, a stronger sense of rural identity and a growth in the social support networks of the village. In addition, the research team expects the following positive ecological, economic and social effects. Ecological: a significant reduction in carbon dioxide and sulfur dioxide; increased agrobiodiversity and ecosystem service benefits. Economic: increases in income derived from agriculture; employment creation. Social effects: improved community relationships; improved individual and social well-being; a feeling of security regarding energy production and prices (Karpenstein-Machan and Schmuck 2007).

The success of Juhnde, and its replication in a number of five villages in Lower Saxony, led to federal funding for “Bioenergy Regions” from the Federal Ministry of Food, Agriculture and Consumer Protection (Wilkens and Schmuck 2012). In addition, there has been international interest in the bioenergy village concept from, among other countries, Japan, Indonesia, China and Taiwan (Karpenstein-Machan and Schmuck 2007).

Greece

Chen et al. (2005) briefly review renewable energy production in the Greek Islands. As of 2004, there were: 50 wind parks generating 120MW in total; 300KWp of PV systems; one small hydroelectric system (300KW) and one biogas-burning system (166KW). The authors suggest that investment in energy storage and management are needed in the Islands.

Portugal

Chen et al. (2005) also review the renewable energy production situation in the Madeira Islands and the Azores Archipelago. For Madeira, wind and hydro energy provided 33% of total electricity production in 1996 and 16% of total electricity production in 2000. The nine islands of the Azores Archipelago are rich in biodiversity. As a result, there is significant pressure to protect their natural environments meaning that renewable energy is relatively well developed. In 2002, 43% of energy was generated through renewable energy sources.

Spain

Calero and Carta (2004) provide an overview of the Action Plan for the Development of Wind Energy in the Canarian Archipelago. The Plan was formulated by the Mechanical Engineering Department of Las Palmas de Gran Canaria University and financially and institutionally supported by the Board of Industry and Energy of the Canary Island Autonomous government. The objectives were: to guarantee energy supply; to reduce vulnerability on the existing energy supply and on imported energy sources; to promote efficient use of energy sources; to minimize energy costs; and to protect the environment. During the Plan’s implementation, more than 80 researchers and technicians from a wide variety of disciplines contributed. The plan is considered to have been successful.

Munda and Russi (2008) applied social multicriteria evaluation retrospectively to a case study in Catalonia, where 1,063 households lack electricity. The case study is Tagamanent village located in Montseny Natural Park. The Park has been designated a UNESCO Biosphere Reserve since 1978. The population of the village is approximately 1,000, with the majority of settlements being farmhouses. Recently, there has been an increase in restaurants and pensions. In 1994, the Park administration launched a plan to electrify settlements through PV systems. Between 1995 and 2000, thirty-two farm systems benefited from solar energy. However, village residents disagreed with the decision to electrify the village using solar energy and wanted to be connected to the grid. Through the retrospective application of social multicriteria evaluation, Munda and Russi (2008) found that the decision to use solar energy was efficient due to environmental and social criteria, and indifferent preferences of end-users concerning solar energy and grid-extension options. The real issue was that, due to budget constraints, too few PV systems were installed and the energy demand for many end users exceeded supply. Some general observations concerning the suitability of solar energy for rural electrification are mentioned. These include: the ability for public incentives (e.g. subsidies) to modify user preferences; the importance of end user temporal horizons; and the importance of end user electricity demand.

Switzerland

Trutnevyte et al. (2011) and Trutnevyte and Stauffacher (2012) used a case study of a small Swiss village, Urnäsch, to show that visions of the future energy system play an important role in undertaking energy-related action. The studies also showed that when villagers were introduced to analytical and technical information they took into account the new information and revised their preferences.

UK

Hain et al. (2005) and Walker et al. (2007) detail the concept of community renewable-energy projects in the UK, which have recently become increasingly popular as a means to help reduce greenhouse gas emissions and alleviate energy security concerns. Yadoo et al. (2011) detailed the case study of the Isle of Eigg in Scotland – an island with 37 households and 5 commercial properties that is not connected to the main grid. Residents bought the island in 1997 and are shareholders in the Isle of Eigg Heritage Trust. When the Trust was formed, the shareholders made a 10-year development plan and decided that the island required a 24 hour supply of electricity in order to better develop its main economic activities (selling of crafts and tourism).

It was estimated that connecting to the grid would cost £4-5 million. The design and implementation of an off-grid renewable energy system, however, cost only £1.66 million. This funding was secured from a number of sources and took the form of a 10kW solar photovoltaic array, a 100kW run-of-river hydro plant, two existing 6kW hydro plants, four 6kW wind turbines, a 212kW battery system that can provide 24h of stored energy and two 80kW diesel generators to be used as back-up power. There was a 100% uptake of the system which proved to be an improvement on the previous system whereby households owned their own diesel generators which were found to be noisy and unreliable. Furthermore, the high cost of diesel meant that generators were only used in the evenings. The hybrid system is owned by Eigg Electric Limited, which is a subsidiary of the Heritage Trust. Four residents are employed as a maintenance team. Measures are also taken to maintain a balanced system. These include: a 5kW cap per household; the use of smart meters; and a traffic light system indicating when renewable sources are running low. The operation and maintenance of the system is self-sufficient with funding coming from the Renewables Obligation Certificate scheme and an electricity tariff of 20p per unit paid by households.

NORTH AMERICA

United States of America

The academic literature on rural electrification in the USA has focused on the rural electric cooperative model that has been broadly successful and is increasingly encouraged in developing countries, particularly by USAID. In the USA, rural electric cooperatives required fewer subsidies than municipality-owned or private investor-owned utilities despite having fewer customers per kilometre on their distribution line. Additionally, rural electric cooperatives were found to be more efficient and effective in serving local consumers and were able to extend the national grid at a faster rate than centralized utilities. Operation and maintenance costs, as well as distribution losses were all found to be lower in areas where cooperatives have taken over management from public utilities. Lastly, cooperatives are argued to be democratic and self-regulating (Wilson et al. 2008; Yadoo and Cruickshank 2010).

LATIN AMERICA AND CARRIBEAN

Argentina

Alazraki and Haselip (2007) detail the 1999 Renewable Energy Project for the Rural Electricity Market (PERMER). The aim of the project was to contribute to providing off-grid electricity (PV systems) to the rural population and to rural public services. The cost of PERMER was USD120.5 million and was part funded by the World Bank among other donors and the Argentine Government's Electricity Investment Development Fund. The financing system of the project is novel as a competitive bidding process was used to select concessionaires who would lease, manage, maintain and finance the project in a particular region. In exchange, the concessionaire obtained a monopoly in the specified region. The specific concessionaire contracts were tailored according to region and tariffs were renegotiated every two years. The average return on investment for the concessionaire was approximately 14% making it a relatively attractive investment. This innovative financing method allowed for the programme to engage the private sector while enabling rural households the chance to use an energy supply that would be unaffordable in a liberalized market due to significant upfront costs. An impact evaluation revealed that the main benefits were: longer active days; more social meetings; improvements in student and staff performance as a result of new teaching techniques; and greater integration of schools within the community. The impact evaluation also revealed that many PV systems were not functioning optimally due a lack of knowledge concerning how to operate and maintain systems and the dispatch of inappropriately trained engineers by the concessionary company.

Brazil

The Brazilian government first implemented off-grid renewable energy programmes approximately two decades ago (Ruiz et al. 2007). Goldemberg et al. (2004) detail the Programa de Desenvolvimento Energetico de Estados e Municipios (PRODEEM). PRODEEM was established in 1994 by a presidential decree and is sponsored by international donors. Implementation was primarily through Brazilian utilities. The project used a top-down approach and provided a total capacity of 3MW in solar PV panels to 3,050 villages. The focus, however, was not on electrifying households but on electrifying public infrastructure: schools, health facilities and community centres. PV panels were distributed for free to municipalities upon demand. PRODEEM also experimented with mini-grid pilot projects, using hydro and biomass generation. An impact evaluation of PRODEEM, however, found that only 56% of the systems were operating. This poor success rate was attributed to: the top-down approach whereby installations were often installed in communities that lacked prerequisite skills and organization; a lack of maintenance funds; no responsibility by local communities for the equipment; a lack of coordination with grid expansion; and difficulties identifying suitable locations to deploy PV panels. These failures led to a parallel initiative, "Luz no Campo (light in the countryside)" which aimed to electrify one million rural households through extension of the grid (Gomes and Silveira 2010).

According to Gomez and Silveira (2012), approximately 500,000 households continue to not have access to electricity. Approximately 200,000 of these households cannot be reached by traditional grid-extension. A number of off-grid electrification projects for these communities have failed due to a lack of operational support. This has led to a current policy emphasis on off-grid energy systems that rely on diesel imports rather than locally available renewable resources.

Colombia

Cherni et al. (2007) and Henao et al. (2012) applied their Sustainable Rural Energy Decision Support System (SUREDSS) to the rural village of San Jose de Cravo Norte II where a 5kWh diesel generator supplied electricity to only 12% of the population and due to high operational costs, operated for only seven hours a day. The SUREDSS model suggested that a hybrid solution consisting of the existing diesel generator and of a micro-hydro power plant would result in the greatest livelihoods gain. Similarly, Silva and Nakata (2009) used goal programming to hypothetically assess the impact of rural electrification through off-grid renewable energy systems in the Non-Interconnected Zones of Colombia. Silva and Nakata (2009) found that substituting biomass, the traditionally used source of energy in the area, with renewable energy reduced emissions and employment generation. However, the simulation suggested that the cost of electricity incurred by consumers from renewable energy sources was between two to five times higher than biomass.

Cherni (2008) conducted a post-evaluation study in several villages in two regions, the Choco on the Colombian Pacific coast and the inland Andean district of Antioquia. The goal of the post-evaluation was to assess factors that contribute to sustainable energy in rural areas. Cherni (2008) found that the Colombian authorities did not know the degree of success or the current performance of off-grid energy installations in rural areas. Households also showed dissatisfaction due to the short life span of renewable technologies due to a lack of local technical capability to maintain modern equipment, such as solar PV panels and micro-hydro sources. This is responsible for limiting the impact of the beneficial impacts of energy provision, such as: allowing for basic health care facilities to operate, providing alternative sources of environment which reduced excessive drinking, and allowing for new agricultural techniques.

Cuba

Cherni and Hill (2009) studied the small, rural village of Manantiales in Cuba. The study found that off-grid renewable energy systems played a significant role in village development. In particular, off-grid energy extended workdays and provided energy for the school and for the refrigeration of medicines. Additionally, household finances improved due to a reduction in diesel consumption. Despite these benefits, it was noted that only a handful of jobs were created and that the impact on income was negligible. In addition, the importance of considering secondary effects is stressed. For example, improvements in education and communication due to off-grid energy sources could either help retain prospective emigrants or induce rural-urban migration through the lifestyles portrayed on radio and television.

Ecuador

Solana-Peralta et al. (2009) provide an overview of the off-grid situation in Ecuador. As a result of pressure from the international community, hybrid PV/diesel and wind/diesel minigrid systems replaced diesel gensets in the Galapagos Islands. The success of these systems has led to the Ecuadorian government promoting similar solutions to other off-grid areas of the country. This has partly been incentivized by an exemplary effort to promote off-grid renewable energy by defining an off-grid feed-in-tariff. This has arguably contributed to a relatively high level of interest shown by Energy Service Companies to introduce renewable energy systems into their off-grid diesel minigrid systems.

El Salvador

Balint (2006) presents the results of a market-based effort by a NGO to deliver solar home systems (SHSs) to relatively poor, off-grid community in El Salvador. The NGO established a partnership with a local business that had experience in PV equipment installation. The project began with the installation of SHSs in five houses as a demonstration. The five households committed to an agreement that beyond the demonstration period, they would need to make installment payments to keep the SHSs. At the end of the demonstration period, the only families who acquired PV systems were the five demonstration households who were able to make their purchases under favourable financing conditions that avoided prohibitively high upfront costs. The project showed that, in this particular village, a market-based approach to SHS was not feasible.

Guatemala

Moe and Moe (2011) detail a project undertaken by Engineers Without Borders – Marquette University Chapter to plan, design and implement an off-grid electrical system for a rural village in rural Guatemala. The project is considered generally successful. For example, the cost of candles – the original source of light in the village – is higher than the cost of electricity from the current solar PV/hydroelectric hybrid system. The project was implemented in phases to ensure that adequate attention was paid to detail. For example, wind and solar energy potential were assessed through nine months of monitoring. Additionally, significant effort was given to the operation and maintenance of the system. As many materials as possible were sourced from the area so as to ensure local capacity to provide long-term support for installed components. The project team also noted that ensuring the operation and maintenance of the system was hindered by the mindset of villagers where the idea of planning for future maintenance was not self-evident. To overcome this, a memorandum of understanding was drawn up that established the village's responsibility to create a fund for the maintenance of the system and any necessary future upgrades.

Nicaragua

Casillas and Kammen (2011) present an interesting case study showing the potential of demand-side interventions to result in significant cost savings for rural villages. In particular, two villages that are connected to the same 110dkW powered microgrid, Orinoco and Marshall Point, were subject to two demand-side interventions in 2009. Firstly, the national electric company installed meters at each client connection. This resulted in a 28% reduction in the electricity load. The second intervention was conducted by the Ministry of Energy and Mines after a request from a local NGO. This focused on improving energy efficiency by replacing incandescent lights with compact fluorescent lights. The end result was a 17% reduction in the electricity load.

Peru

Yadoo and Cruickshank (2012) detail the installation of a 40kW micro-hydro mini-grid that was installed in Tamborapa village in 2000. The project was undertaken by Practical Action with funding from the Inter-American Bank's Fund for the Promotion of Micro-Hydro Power Stations. The mini-grid is officially owned by the municipality but managed by villagers. Specifically, Practical Action helped the village form a micro-enterprise system that is able to manage and maintain the system. The system is financed through a block tariff system, where the marginal cost of electricity decreases in stages as consumption increases, that was designed to provide villagers with incentives to use electricity for income-generating activities. The system is audited every two years by an auditing committee composed of municipality staff and users. Yadoo and Cruickshank (2012) list a variety of positive impacts on the community: street lighting has improved safety at night, especially for women; lighting allows for a local sports field to be used by the youth in the evening; there have been notable improvements in health infrastructure and at schools; and communications and entertainment have improved. Most striking, is the observation that 55 businesses have been established since the installation of the minigrid with 42% of owners stating that electricity is important or essential to their enterprises.

MIDDLE EAST AND NORTH AFRICA

Morocco

Pode (2010) briefly overviewed a government-led project in Morocco (2004 – 2008). The project provided 101,500 rural households with photovoltaic systems (75.7WP), as well as installing necessary equipment for domestic electricity use (e.g. bulbs, plugs). The goal was to help rural households meet their basic energy needs. According to Pode (2010), the project was largely unsuccessful due to technical, economic and institutional barriers. Technical barriers included performance issues with the PV systems. Economic issues included a lack of funds to support the operation and maintenance of the systems. Institutional issues included poor communication of information to end users and a lack of capacity among end users to operate and maintain their PV systems.

SUB-SAHARAN AFRICA

Botswana

Ketlogetswe et al. (2007) examine a government effort to provide electricity to the village of Motshegaletau. Prior to 1995, off-grid PV systems were exclusively used to provide energy to public facilities (e.g. police stations, public schools, clinics and wildlife posts). As part of a government commitment to improve access to electricity for off-grid villages so as to build capacity for sustainable socio-economic development, 1995 saw the construction of a centralised PV power plant in Motshegaletau. The power plant was designed and installed by the state-owned Botswana Technology Centre with help from Botswana Power Corporation. The power plant was designed to provide AC power to houses, public schools, clinics and street lights. At the time of their study, Ketlogetswe et al. (2007) found that only 11 out of approximately 88 households were connected to the system. The authors attributed this to the high cost of connection (USD 100), especially as approximately 75% of inhabitants earned an annual income of USD 106. Another reason, that seems important but is mentioned only in passing, is that the village was that the grid was extended to cover the village.

Gambia

Frame et al. (2011) report on the current off-grid energy situation in Gambia where the government is determined on providing efficient, reliable and affordable energy to the population. Although a government strategy – consisting of both grid and off-grid electrification solutions – exists, the government has been unable to secure the necessary funding and institutional support. In order to generate funding and institutional support, the government has pushed forward with the Gambia Solar Project which has installed PV systems in seven schools, one health clinic and one laboratory for working animals since 2006. It is hoped that impact data from the schools will form the basis for another bid for funding from the international community.

Ghana

Kankam and Boon (2009) collected household data from four villages in Northern Ghana that were the beneficiaries of a number of government, NGO and donor projects disseminating PV systems to rural households. The data showed that although PV systems contributed to educational improvements, they had little impact on other aspects of rural development such as health, gender roles and job creation. This is largely attributed to the absence of rural infrastructure and markets that complement energy use. Obeng et al. (2008) studied the impact of solar PV systems on indoor pollution due to kerosene lanterns. Cross-sectional data from 16 villages in five regions in Ghana- where public-private partnerships supported by donor funding has resulted in the installation of PV systems with a total capacity of over 1 peak megawattfound that PV lighting is likely to reduce the proportion of household members being affected by indoor smoke from kerosene lanterns by 50%.

Kenya

Based on evidence collected from households who have benefited from the distribution of solar power, Jacobson (2007) reports on two findings with important ramifications for rural development. Firstly, the benefits of solar electrification are captured almost entirely by the rural middle class. Secondly, the impact of solar electrification on economically productive and education-related activities has been modest. The main benefits appeared to have been in allowing the use of "connective" applications (e.g. radio, television, cellular phones). The use of "connective" applications seems to have been a higher priority among end users than economically productive or education-related uses. Abdullah and Wilner Jeanty (2011), in a separate study, estimated the willingness to pay of end users in Kisumu district for rural electrification using contingent valuation. Their results suggested that end users are more willing to pay for grid electricity than PV and prefer to buy through monthly connection payments rather than an upfront lump sum amount.

Malawi

Adkins et al. (2010) reports on lessons learned from a market-based approach to introducing solar LED lanterns in rural Malawai. The trial was part of the Millennium Villages Project and focused primarily on building capacity among local commercial institutions. Sales and survey data suggest that the LED lanterns have been successful in providing households with brighter lighting for an equal to or lower cost than previous fuel-based approaches. One notable finding, however, is that financing mechanisms are required if a market-based approach is used to allow for poorer households to purchase solar LED lanterns. Additionally, the viability of local cooperatives and supply chains for lantern products over the medium-to-long term remains to be assessed

Frame et al. (2011) overviewed a community rural electrification development project that installed PV systems in two primary schools and three health clinics in the rural Chikwawa district. Prior to the installation, community sensitization meetings were held to facilitate a successful uptake of the technology. In addition, a c ommunity energy committee was trained in the basic operation and maintenance techniques and was encouraged to ensure appropriate use of the systems by the community. Financial support for operating and maintaining the systems was obtained from small enterprises run by the committee that used the electricity generated by the PV systems. This included mobile phone charging and the sale of refrigerated beverages.

Namibia

Wamukonya and Davis (2001) used data collected from households in Namibia – a country where the government has promoted both off-grid (solar home systems) and grid-electrification – to show that the main benefit from both approaches was the provision of high-quality lighting and access to televisions. For the Namibian case, it was found that both approaches provided a similar level of benefit with SHS being significantly more cost efficient than grid electrification.

Rwanda

Safari (2010) provides a review of the government's rural electrification strategy, of which off-grid sources figure prominently. Backed by donors and with private partnerships, the government is in the process of developing rural energy through the development of micro hydro power plants and PV systems for the electrification of districts, schools and hospitals. Theuse of wind power is also being considered to electrify households and to help pump water for both drinking and irrigation.

South Africa

Bikam and Mulaudzi (2006), Szewczuk (2009), Green et al. (2010) and Lemaire (2011) all describe government efforts to promote off-grid energy provision in rural areas. Bikam and Malaudzi (2006) described a joint venture project between the South African government and the Bavarian government that aimed to install PV systems in Folovhodwe village in 1998. The project failed due to poor planning. In particular, project initiators did not foresee issues related to the procurement of spare parts and maintenance costs. End users were also not taught how to operate the equipment properly. Green et al. (2010) overviewed a project run by the Solar Electric Light Fund (based in the USA) and the Solar Engineering Services (based in South Africa) to install solar home systems in off-grid areas in South Africa. The project was largely unsuccessful with only 5% of target communities adopting the new technology. This was attributed primarily to financial constraints and a lack of opportunities to try out the system before purchase. In addition, capacity building through the training of individuals to operate and maintain the solar home systems led to the danger of losing all locally trained individuals to towns or cities that were seen as providing more lucrative employment. Lemaire (2011) studied the off-grid electrification programme with fee-for-service concessions undertaken by the government in 1999. The main finding from this study was that small-scale utilities were able to solve the issues of high up-front costs and long-term maintenance for solar home systems.

Szewczuk (2009) presents a relatively unique case study in describing the three-year investigative project in the Eastern Cape Province. The aim of the project was to understand the complexity involved in achieving sustainable socio-economic development. Luncingweni village was among one of the sites chosen and a hybrid solar-wind mini-grid was installed as a pilot. The project is relatively unique in that measures were identified to improve the welfare of the community. For example, high value agricultural products were identified as the basis for new economic activities. In particular, energy would allow for the processing of high value agricultural products on-site to gain higher added value. In addition, the hybrid mini-grid energy system allowed for the provision of potable water through a water reticulation system.

Tanzania

Pode (2010) and Ahlborg and Hammar (forthcoming 2014) identify barriers to off-grid renewable energy sources in Tanzania. Pode (2010) focuses on Mwanza, and finds the following barriers to solar PV technology: limited awareness and experience with the technology; energy is a low priority for many end-users; high cost , low purchasing power and a lack of financing schemes; lack of an established dealer network; and inadequate policy support. Ahlborg and Hammar (forthcoming 2014) find that hydropower schemes (including at the micro-scale) are blocked, at least in part, by the natural gas lobby. Windpower tends to be received with skepticism due to costs and solar PV is seen as expensive and not suited to productive uses due to its low capacity.

Zambia

Ellegard et al. (2004), Gustavsson and Ellegard (2004) and Gustavsson (2007) have looked at the distribution of solar home systems in three rural areas: Nyimba, Chipata and Lundazi. Ellegard et al. (2004) found that a model where companies operate solar home systems and end users pay a fee increased the useful lifetime of the solar systems and allowed for the companies to operate without further support from the government or donors. Ellegard et al. (2004) and Gustavsson and Ellegard (2004) found the following benefits of solar home systems: improved quality of lighting which enabled activities such as studying and doing domestic work for longer hours; and entertainment from radios, televisions and videos. End users, however, cited that radios, televisions and videos were more attractive than productive appliances, such as water pumps. Gustavsson (2007) analysed data from Lundazi and found that clients appropriate and use an increasing number of appliances meaning that in many cases, the capacity of the solar systems will be exceeded.

SOUTH ASIA

Bangladesh

There have been a number of government, NGO and privately-led off-grid electrification projects in rural Bangladesh. Ongoing government projects include the Chittagong hill tracts solar electrification programme which is relatively novel for its emphasis on solar PV applications, especially water pumps and vaccine refrigerators. Notable NGO projects include BRAC's (Bangladesh Rural Advancement Committee) renewable energy program which has focused on providing micro-enterprises with electricity from solar home systems and biogas plants and Grameen Shakti (Mondal et al. 2010). Grameen Shakti, which is part of the Grameen Bank group, was founded in 1996 with the mandate of promoting knowledge and awareness about renewable energy, providing technical training on solar energy to the rural workforce, and overcoming the high upfront cost of installing solar and biogas systems. Grameen Shakti relies on a market-based approach similar to that of the Grameen Bank, but also focuses on local knowledge generation and entrepreneurship. For example, more than 5000 women were trained and employed to maintain solar home systems and assemble accessories such as inverters, charge controllers and lamp shades (Komatsu et al. 2011; Sovacool 2011).

India

India has a number of relatively successful off-grid energy case studies. Some examples focusing on biomass power include Gosaba island in West Bengal, Odanthurai Panchayat in

Tamil Nadu and Hosahalli and Hanumanthanagara villages in Karnataka. PV case studies Salepada Power Plant in Orissa, Mundanmudy village in Kerala and remote villages and hamlets in Uttaranchal (Ravindranath et al. 2004; Hiremath et al. 2009; Romijn et al. 2010). The majority of PV case studies focus on the Sundarban region in West Bengal, where the West Bengal Renewable Energy Development Agency has been electrifying the area through off-grid renewable energy sources since 1993. As of 2010, more than 40,000 households have benefited from electricity from 17 solar PV mini-grids and approximately 35,000 solar home systems (Bhandari and Jana 2010).

Ulsrud et al. (2011) studied the development of the solar PV mini-grids in the Sundarban region with the goal of gaining an understanding of the dynamics between technology and society. A particular issue identified was that end users were using more power consuming electric appliances than what had been planned for. Another interesting finding was that many end users eagerly participated in the implementation process due to their eagerness to get light and other electricity services, particularly in shops and market places. Following on with productive uses of rural electrification, Gupta (2003) overviewed several enterprises that have been successful due to energy from off-grid sources. These include, for example, Gasifier-based silk reeling ovens in Karnataka and Andhra Pradesh, polyhouses in the Himalayas and biogas based public toilets in Maharashtra.

Nepal

The case studies on Nepal found in the literature are relatively unique in that they emphasise the need for directional inputs in order for rural electrification to bring about economic development. Bastakoti (2003) examined the United Mission to Nepal's Andhi Khola Hydroelectric and Rural Electrification Centre which produces 5.1MW of electricity from Andhi Khola river in Syangja District in the western region of Nepal. What is unique about this project, is that the project focused a significant amount of their effort to the post-electrification phase during which various end-uses of electricity and dissemination of information on enterprise-related matters, as well as training, infrastructural and skills support were undertaken. The study emphasized the entrepreneurial drive of end users and the need to support would-be entrepreneurs through training, information and other relevant physical and financial infrastructure.

Yadoo et al. (2011) and Yadoo and Cruickshank (2012) look at the installation of a 22kW run-of-river hydro plant in Pokhari Chauri in Kavre district, central Nepal. The hydro plant was installed by the UNDP. In addition to the benefits of high quality lighting to education and health, agro-processing techniques have improved due to the installation of three rice mills, one flour mill and an oil grinder, whichwere all purchased by the community. Approximately 25% of respondents stated that the mills have allowed them to process extra crops and sell them in markets, thereby significantly increasing their incomes. Additionally, new privately-owned businesses have emerged. These include a milk chilling unit and three carpentry workshops. The UNDP continues to facilitate entrepreneurship by providing training in a number of areas (e.g. incense and soap-making, off-season vegetables, poultry farming, bee keeping, forest nurseries, the building of pit latrines, permanent toilets and garbage pits), so that members of the community can diversify their livelihood strategies and contribute to the community's overall development.

Sri Lanka

Wijayatunga and Attalage (2005) analysed survey data from 125 households with solar home systems in the Uva province of Sri Lanka. The majority of respondents were extremely satisfied with the SHS which have largely replaced kerosene lamps in providing household lighting. Despite this, the authors caution of the need to choose project sites carefully as many of the villages targeted for SHS deployment are relatively close to the national grid, which may prove a more effective electrification option.

BIBLIOGRAPHY

ABDULLAH, S. and JEANTY, P. W. 2011. Willingness to pay for renewable energy: evidence from a contingent valuation survey in Kenya. *Renewable and Sustainable Energy Reviews* **15**: 2974-2983.

ADKINS, E., EAPEN, S., KALUWILE, F., NAIR, G. and MODI, V. 2010. Off-grid energy services for the poor: introducing LED lighting in the Millennium Villages Project in Malawi. *Energy Policy* **38**: 1087-1097.

AHLBORG, H. and HAMMAR, L. 2014. Drivers and barriers to rural electrification in Tanzania and Mozambique - grid-extension, off-grid, and renewable energy technologies. *Renewable Energy* **61**: 117-124.

AJAN, C. W., AHMED, S. S., AHMAD, H. B., TAHA, F., ASUHAIMI, A. and ZIN, B. M. 2003. On the policy of photovoltaic and diesel generation mix for an off-grid site: east Malaysian perspectives. *Solar Energy* **74**: 453-467.

ALAZRAKI, R. and HASELIP, J. 2007. Assessing the uptake of small-scale photovoltaic electricity production in Argentina: the PERMER project. *Journal of Cleaner Production* **15**: 131-142.

ARRIAGA, M. 2010. Pump as turbine - a pico-hydro alternative in Lao People's Democratic Republic. *Renewable Energy* **35**: 1109-1115.

BALINT, P. J. 2006. Bringing solar home systems to rural El Salvador: lessons for small NGOs. *Energy Policy* **34**: 721-729.

BAMBAWALE, M. J., D'AGOSTINO, A. L. and SOVACOOL, B. K. 2011. Realising rural electrification in Southeast Asia: Lessons from Laos. *Energy for Sustainable Development* **15**: 41-48.

BASTAKOTI, B. P. 2003. Rural electrification and efforts to create enterprises for the effective use of power. *Applied Energy* **76**: 145-155.

BHANDARI, A. K. and JANA, C. 2010. A comparative evaluation of household preferences for solar photovoltaic standalone and mini-grid system: an empirical study in a coastal village of Indian Sundarban. *Renewable Energy* **35**: 2835-2838.

BIKAM, P. and MULAUDZI, D. J. 2006. Solar energy trial in Folovhodwe South Africa: lessons for policy and decision-makers. *Renewable Energy* **31**: 1561-1571.

BOND, M., FULLER, R. J. and LU, A. 2007. A policy proposal for the introduction of solar home systems in East Timor. *Energy Policy* **35**: 6535-6545.

BYRNE, J., ZHOU, A., SHEN, B. and HUGHES, K. 2007. Evaluating the potential of small-scale renewable energy options to meet rural livelihoods needs: a GIS- and lifecycle cost-based assessment of Western China's options. *Energy Policy* **35**: 4391-4401.

CALERO, R. and CARTA, J. A. 2004. Action plan for wind energy development in the Canary Islands. *Energy Policy* **32**: 1185-1197.

CASILLAS, C. E. and KAMMEN, D. M. 2011. The delivery of low-cost, low-carbon rural energy services. *Energy Policy* **39**: 4520-4528.

CHEN, F., DUIC, N., ALVES, L. M. and DA GRACA CARVALHO, M. 2007. Renewislands - renewable energy solutions for islands. *Renewable and Sustainable Energy Reviews* **11**: 1888-1902.

CHENVIDHYA, D., THONGPRON, J., SANGPANICH, U., WONGYAO, N., KIRTIKARA, K. and JIVACATE, C. 2003. *A Thai national demonstration project on PV grid-interactive systems: power quality observation*. 3rd World Conference on Photovoltaic Energy Conversion, Osaka.

CHERNI, J. A. 2008. Renewable energy for rural sustainability in developing countries. *Bulletin of Science Technology and Society* **28**: 105-114.

CHERNI, J. A., DYNER, I., HENAO, F., JARAMILLO, P., SMITH, R. and FONT, R. O. 2007. Energy supply for sustainable rural livelihoods. A multi-criteria decision-support system.

Energy Policy **35**: 1493-1504.
CHERNI, J. A. and HALL, Y. 2009. Energy and policy providing for sustainable rural livelihoods in remote locations - the case of Cuba. *Geoforum* **40**: 645-654.
CHERNI, J. A. and KENTISH, J. 2007. Renewable energy policy and electricitymarket reforms in China. *Energy Policy* **25**: 3616-3629.
CHIAN, W. S. 2010. Renewable energy policy in remote rural areas of western China: implementation and socio-economic benefits, Universitat Bonn. **PhD**.
DUMBS, C. and JUQUOIS, F. 2003. The French off-grid electrification program - an eight-year experience report. *3rd World Conference on Photovoltaic Energy Conversion*. Osaka.
ELLEGARD, A., ARVIDSON, A., NORDSTROM, M., KALUMIANA, O. S. and MWANZA, C. 2004. Rural people pay for solar: experiences from the Zambia PV-ESCO project. *Renewable and Sustainable Energy Reviews* **29**: 1251-1263.
FRAME, D. 2011. *A community based approach for sustainable off-grid PV systems in developing countries*. Power and Energy Society General Meeting, San Diego, CA.
GAN, L. and YU, J. 2008. Bioenergy transition in rural China: policy options and co-benefits. *Energy Policy* **36**: 531-540.
GOMEZ, M. F. and SILVEIRA, S. 2010. Rural electrification of the Brazilian Amazon - achievements and lessons. *Energy Policy* **38**: 6251-6260.
GREEN, D. 2004. Thailand's solar white elephants: an analysis of 15 yr of solar battery charging programmes in northern Thailand. *Energy Policy* **32**: 747-760.
GREEN, J. M., WILSON, M. and CAWOOD, W. 2010. Maphephethe rural electrification (photovoltaic) programme: the constraints on the adoption of solar home systems. *Development Southern Africa* **18**(1): 19-30.
GUPTA, C. L. 2003. Role of renewable energy technologies in generating sustainable livelihoods. *Renewable and Sustainable Energy Reviews* **2003**: 155-174.
GUSTAVSSON, M. 2007. With time comes increased loads - an analysis of solar home system use in Lundazi, Zambia. *Renewable and Sustainable Energy Reviews* **32**.
GUSTAVSSON, M. and ELLEGARD, A. 2004. The impact of solar home systems on rural livelihoods. Experiences from the Nyimba Energy Service Company in Zambia. *Renewable and Sustainable Energy Reviews* **29**: 1059-1072.
HAIN, J. J., AULT, G. W., GALLOWAY, S. J., CRUDEN, A. and MCDONALD, J. R. 2005. Additional renewable energy growth through small-scale community oriented energy policies. *Energy Policy* **33**: 1199-1212.
HAMMONS, T. J. 2008. Integrating renewable energy sources into European grids. *Electrical Power and Energy Systems* **30**: 462-475.
HENAO, F., CHERNI, J. A., JARAMILLO, P. and DYNER, I. 2012. A multicriteria approach to sustainable energy supply for the rural poor. *European Journal of Operational Research* **218**: 801-809.
HIREMATH, R. B., KUMAR, B., BALACHANDRA, P., RAVINDRANATH, N. H. and RAGHUNANDAN, B. N. 2009. Decentralised renewable energy: scope, relevance and applications in the Indian context. *Energy for Sustainable Development* **13**: 4-10.
HONG, G. W. and ABE, N. 2012. Sustainability assessment of renewable energy projects for off-grid rural electrification: the Pangan-an island case in the Philippines. *Renewable and Sustainable Energy Reviews* **16**: 54-64.
HWANG, S. W. 2013. Micro-grid research and business development in Korea. *KEPCO*: 1-26.
JACOBSON, A. 2007. Connective power: solar electrification and social change in Kenya. *World Development* **35**(1): 144-162.
KANKAM, S. and BOON, E. K. 2009. Energy delivery and utilization for rural development: lessons from Northern Ghana. *Energy for Sustainable Development* **13**: 212-218.
KARPENSTEIN-MACHAN, M. and SCHMUCK, P. 2007. Bioenergy village - ecological and social aspects in impelementation of a sustainability project. *Journal of Biobased*

Materials and Bioenergy **1**: 148-154.
KETLOGETSWE, C., MOTHUDI, T. H. and MOTHIBI, J. 2007. Effectiveness of Botswana's policy on rural electrification. *Energy Policy* **35**: 1330-1337.
KOMATSU, S., KANEKO, S. and GHOSH, P. P. 2011. Are micro-benefits negligible? The implications of the rapid expansion of Solar Home Systems (SHS) in rural Bangladesh for sustainable development. *Energy Policy* **39**: 4022-4031.
LAU, K. Y., YOUSOF, M. F. M., ARSHAD, S. N. M., ANWARI, M. and YATIM, A. H. M. 2010. Performance analysis of hybrid photvoltaic/diesel energy system under Malaysian conditions. *Energy* **35**: 3245-3255.
LEMAIRE, X. 2009. Fee-for-service companies for rural electrification with photovoltaic systems: the case of Zambia. *Energy for Sustainable Development* **13**: 18-23.
LIMING, H. 2009. Financing rural renewable energy: a comparison between China and India. *Renewable and Sustainable Energy Reviews* **13**: 1096-1103.
LIU, G., LUCAS, M. and SHEN, L. 2008. Rural household energy consumption and its impacts on eco-environment in Tibet: taking Taktse county as an example. *Renewable and Sustainable Energy Reviews* **12**: 1890-1908.
MARTINOT, E. 2010. Renewable power for China: past, present and future. *Frontiers of Energy and Power Engineering China*.
MEKHILEF, S., SAFARI, A., MUSTAFFA, W. E. S., SAIDUR, R., OMAR, R. and YOUNIS, M. A. A. 2012. Solar energy in Malaysia: Current state and prospects. *Renewable and Sustainable Energy Reviews* **16**: 386-396.
MOE, E. D. and MOE, A. P. 2011. *Off-grid power for small communities with renewable energy sources in rural Guatemalan villages*. Global Humanitarian Technology Conference, IEEE.
MONDAL, A. H., KAMP, L. M. and PACHOVA, N. I. 2010. Drivers, barriers, and strategies for implementation of renewable energy technologies in rural areas in Bangladesh - an innovation system analysis. *Energy Policy* **38**: 4626-4634.
MOROZUMI, S. 2007. *Micro-grid demonstration projects in Japan*. Power Conversion Conference, Nagoya, IEEE.
MUNDA, G. 2008. Social multicriteria evaluation of conflict over rural electrification and solar energy in Spain. *Environment and Planning C: Government and Policy* **26**: 712-727.
MUSTONEN, S. M. 2010. Rural energy survey and scenario analysis of village energy consumption: a case study in Lao People's Democratic Republic. *Energy Policy* **38**: 1040-1048.
NAKATA, T., KUBO, K. and LAMONT, A. 2005. Design for renewable energy systems with application to rural areas in Japan. *Energy Policy* **33**: 209-219.
NGUYEN, K. Q. 2007. Wind energy in Vietnam: Resource assessment, development status and future implications. *Energy Policy* **35**: 1405-1413.
OBENG, G. Y., AKUFFO, F. O., BRAIMAH, I., EVERS, H. D. and MENSAH, E. 2008. Impact of solar photovoltaic lighting on indoor air smoke in off-grid rural Ghana. *Energy for Sustainable Development* **12**(1): 55-61.
OUTHRED, H., HEALY, S., RETNANESTRI, M. and TUKUNGA, T. 2004. Experience with off-grid photovoltaic systems in Tonga and Indonesia. *14th International Photovoltaic Science and Engineering Conference*. Bangkok.
PACHAURI, S. and JIANG, L. 2008. The household energy transition in India and China. *Energy Policy* **36**: 4022-4035.
PEREIRA, M. G., SENA, J. A., FREITAS, M. A. V. and DA SILVA, N. F. 2011. Evaluation of the impact of access to electricity: a comparative analysis of South Africa, China, India and Brazil. *2011* **15**: 1427-1441.
PHUANGPORNPITAK, N. and KUMAR, S. 2007. PV hybrid systems for rural electrification in Thailand. *Renewable and Sustainable Energy Reviews* **11**: 1530-1543.

PODE, R. 2010. Solution to enhance the acceptability of solar-powered LED lighting technology. *Renewable and Sustainable Energy Reviews* **14**: 1096-1103.
RAVINDRANATH, N. H., SOMASHEKAR, H. I., DASAPPA, S. and REDDY, C. N. J. 2004. Sustainable biomass power for rural India: case study of biomass gasifier for village electrification. *Current Science* **87**(7): 932-941.
RETNANESTRI, M., OUTHRED, H. and HEALY, S. 2003. Off-grid Photovoltaic applications in Indonesia: an analysis of preliminary fieldwork experience. *Destination Renewables - ANZSES*.
ROMIJN, H., RAVEN, R. and DE VISSER, I. 2010. Biomass energy experiments in rural India: insights from learning-based development approaches and lessons for strategic niche management. *Environmental Science and Policy* **13**: 326-338.
RUIZ, B. J., RODRIGUEZ, V. and BERMANN, C. 2007. Analysis and perspectives of the government programs to promote the renewable electricity generation in Brazil. *Energy Policy* **35**: 2989-2994.
SAFARI, B. 2010. A review of energy in Rwanda. *Renewable and Sustainable Energy Reviews* **14**: 524-529.
SILVA, D. and NAKATA, T. 2009. Multi-objective assessment of rural electrification in remote areas with poverty considerations. *Energy Policy* **37**: 3096-3108.
SMITS, M. and BUSH, S. R. 2010. A light left in the dark: the practice and politics of pico-hydropower in the Lao PDR. *Energy Policy* **38**: 116-127.
SOLANO-PERALTA, M., MONER-GIRONA, M., VAN SARK, W. G. J. H. M. and VALLVE, X. 2009. "Tropicalisation" of feed-in tariffs: a custom-made support scheme for hybrid PV/diesel systems in isolated regions. *Renewable and Sustainable Energy Reviews* **13**: 2279-2294.
SOVACOOL, B. K. 2011. An international comparison of four polycentric approaches to climate and energy governance. *Energy Policy* **39**: 3832-3844.
---. 2012. Deploying off-grid technology to eradicate energy poverty. *Science* **338**: 47-48.
---. 2012. Off-grid solar electrification for rural development: the implications of the Renewable Energy Development Project (REDP) in China. *International Journal of Regulation and Governance* **12**(1): 19-48.
SOVACOOL, B. K., D'AGOSTINO, A. L. and BAMBAWALE, M. J. 2011. The socio-technical barriers to Solar Home Systems (SHS) in Papua New Guinea: "Choosing pigs, prostitutes and poker chips over panels". *Energy Policy* **39**: 1532-1542.
SOVACOOL, B. K. and DRUPADY, I. M. 2011. Examining the small renewable energy power (SREP) program in Malaysia. *Energy Policy* **39**: 7244-7256.
SZEWCZUK, S. 2009. Hybrid mini-grid systems - distributed generation systems for communities based on renewable energy resources. *Energy Institute, Cape Peninsula University of Technology Working Paper*.
TRUTNEVYTE, E. and STAUFFACHER, M. 2012. Opening up to a critical review of ambitious energy goals: perspectives of academics and practitioners in a rural Swiss community. *Environmental Development* **2**: 101-116.
TRUTNEVYTE, E., STAUFFACHER, M. and SCHOLZ, R. W. 2011. Supporting energy initiatives in small communities by linking visions with energy scenarios and multi-criteria assessment. *Energy Policy* **39**: 7884-7895.
ULSRUD, K., WINTHER, T., PALIT, D., ROHRACHER, H. and SANDGREN, J. 2011. The Solar Transitions research on solar mini-grids in India: learning from local cases of innovative socio-technical systems. *Energy for Sustainable Development* **15**: 293-303.
URMEE, T., HARRIES, D. and SCHLAPFER, A. 2009. Issues related to rural electrification using renewable energy in developing countries of Asia and Pacific. *Renewable Energy* **34**: 354-357.
WALKER, G. P., HUNTER, S., DEVINE-WRIGHT, P., EVANS, B. and FAY, H. 2007.

Harnessing community energies: explaining and evaluating community-based localism in renewable energy policy in the UK. *Global Environmental Politics* **7**(2): 64-82.
WAMUKONYA, N. and DAVIS, M. 2001. Socio-economic impacts of rural electrification in Namibia: comparisons between grid, solar and unelectrified households. *Energy for Sustainable Development* **5**(3): 5-13.
WIJAYATUNGA, P. D. C. and ATTALAGE, R. A. 2005. Socio-economic impact of solar home systems in rural Sri Lanka: a case-study. *Energy for Sustainable Development* **9**(2): 5-9.
WILKENS, I. and SCHMUCK, P. 2012. Transdisciplinary evaluation of energy scenarios for a German village using multi-criteria decision analysis. *Sustainability* **4**: 604-629.
WILSON, E.J. J., PLUMMER, M, FISCHLEIN and T.M., Smith H. 2008. Implementing energy efficiency: challenges and opportunities for rural electric co-operatives and small municipal utilities. *Energy Policy* **36**: 3383-3397.
WONG, S. Y. and CHAI, A. 2012. *An off-grid solar system for rural village in Malaysia*. Power and Energy Engineering Conference, Shanghai, IEED.
WUSTE, A. and SCHMUCK, P. 2012. Bioenergy villages and regions in Germany: an interview study with initiators of communal bioenergy projects on the success factors for restructuring the energy supply of the community. *Sustainability* **4**: 244-256.
YADOO, A. and CRUICKSHANK, H. 2010. The value of cooperatives in rural electrification. *Energy Policy* **38**: 2941-2947.
---. 2012. The role for low carbon electrification technologies in poverty reduction and climate change strategies: a focus on renewable energy mini-grids with case studies in Nepal, Peru and Kenya. *Energy Policy* **42**: 591-602.
YADOO, A., GORMALLY, A. and CRUICKSHANK, H. 2011. Low-carbon off-grid electrification for rural areas in the United Kingdom: lessons from the developing world. *Energy Policy* **38**: 6400-6407.
YAUNGKET, J. and TEZUKA, T. 2013. A survey of remote household energy use in rural Thailand. *Energy Procedia* **34**: 64-72.
ZHANG, X. and KUMAR, A. 2011. Evaluating renewable energy-based rural electrification program in western China: emerging problems and possible scenarios. *Renewable and Sustainable Energy Reviews* **15**: 773-779.
ZHOU, A. and BYRNE, J. 2002. Renewable energy for rural sustainability: lessons from China. *Bulletin of Science Technology and Society* **22**(2): 123-131.