INTERNATIONAL CONFERENCE

Towards sustainable energy, solutions for the developing world

Domestic Use of Energy

Proceedings

12 & 13 April 2011

Cape Peninsula University of Technology

Cape Town

South Africa

PROCEEDINGS

of the

Nineteenth Conference on the

DOMESTIC
USE
OF ENERGY

11 - 13 April 2011

Organised by

The Cape Peninsula University of Technology

In association with
IEEE: Power & Energy Society
The South African Association of Energy Service Companies
The Southern Association for Energy Efficiency
The South African Institute of Electrical Engineers
Association of Municipal Electrical Undertakings
Sustainable Energy Society Southern Africa
National Energy Efficiency Agency
University of Cape Town
University of Stellenbosch
North-West University
City of Cape Town
Eskom

Published by

Cape Peninsula University of Technology, Cape Town, South Africa

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ISBN 978-0-9814311-4-7

Cape Peninsula
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WELCOMING MESSAGE FROM THE VICE-CHANCELLOR

Delegates, visitors and friends, welcome to the 19th international conference on the 'Domestic Use of Energy' (DUE). Thank you to the Conference Organisers and the Editorial Committee, who have worked hard to establish this annual focus on domestic energy. The inevitable electricity tariff hike has once again emphasised the importance of using available energy more effectively. This conference focuses the attention on energy efficiency and the importance of developing and promoting the use of renewable energy sources. At the Cape Peninsula University of Technology, our Energy Institute continues to address these issues of national importance. Solar water heating has, for example, been researched for the past 10 years.

The programme and the comprehensive conference proceedings you already received at the registration desk are indicative of yet another important energy conference. All delegates and visitors, especially those from countries as far as China, are most welcome to enjoy what our campus has to offer and please enjoy your stay in greater Cape Town, where our university has five campuses.

Prof L V Mazwi-Tanga
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Since its inception in 1992, the Editorial committee of the annual International Conference on the Domestic Use of Energy (DUE), has been upholding the following principles and editorial procedures:

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- In order to ensure a high standard, all abstracts of proposed conference papers are sent for evaluation to those members of the Editorial Committee, who are specialists in a particular DUE session

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- The collator collates all comments and makes the final recommendation to the Chairman, who informs the author(s) accordingly

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Table of Contents

Surname, Title Initial institution, City, Country
Co-Author
Paper Title ***Page***

Domestic Appliances

Bredekamp, Mr AJ CPUT, Cape Town, RSA
A Measured Based Analysis of Domestic Power Consumption due to Home Entertainment Devices 3

Hughes, Ms AG UCT, Rondebosch, RSA
Matsika, Ms R
Fuel use In Welverdiend, Mpumalanga: Socio-Economic Factors, Fuel Choice and Quantities of Fuel used 11

Jahmeerbacus, Mr I University of Mauritius, Reduiyt, Mauritius
Bhurtun, Prof C
Effect of Switch Mode Power Converters on Power Quality in Domestic Set-Ups 17

Kimemia, Mr DK University of Johannesburg, Auckland Park, RSA
Optimising the Imbaula Stove 21

Lodoysamba, Prof S National University of Mongolia, Ulaanbaatar, Mangolia
Pemberton-Pigott, Mr C
Mitigation of Ulaanbaatar City's Air Pollution - From Source Aportionment to Ultra-Low Emission Lignite Burning Stoves 27

Makonese, Mr T University of Johannesburg, Auckland Park, RSA
Annegarn, Prof H; Chikowore, Dr G
Potential and Prospects of Improved Cookstoves (ICS) in Zimbabwe 33

Makonese, Mr T University of Johannesburg, Auckland Park, RSA
Annegarn, Prof H; Robinson, Mr J; Pemberton-Pigott, Mr C
A Preliminary Comparison between the Heterogeneous Protocols and the Water Boiling Test 41

Mapako, Mr MC CSIR, Pretoria, RSA
Improved Stoves in Southern Africa: A Solution for All Seasons? 49

Matinga, Dr MN University of Johannesburg, Auckland Park, RSA
Annegarn, Prof H; Robinson, Mr JW
The Global Alliance for Clean Cookstoves: Implications for South Africa 55

Naidoo, Ms S University of Witwatersrand, Johannesburg, RSA
Piketh, Prof SJ
Quantification of Emissions Generated from Domestic Burning Activities from Townships in Johannesburg 61

Pemberton-Pigott, Mr CR New Dawn Engineering, Ontario, Canada
Development of a low smoke Mongolian coal stove using a Heterogeneous teting protocol 65

Robinson, Mr J University of Johannesburg, Auckland Park, RSA
Ibraimo, Mr M; Pemberton-Pigott, Mr C
Uncontrolled Cooking Test: Measuring Three-Stone Fire Performance in Northern Mozambique 71

Energy Efficiency in the Home

Da Silva, Dr I Makerere University, Kampala, Uganda
Ssekulima, Mr EB
Energy Efficient Building Envelope Designs for Institutional Buildings in East Africa 79

Davis, Mr SJ University of Cape Town, Rondebosch, RSA
Tools for Enabling Behaviour Change in the Residential Sector 85

Guy, Mr DM Peer Africa WC CC, Milnerton, RSA
Annegarn, Prof H
Trade-Offs between community Preference; Energy and Environmental Performance; and Passive and Active Surveillance as a Deterrence to Crime in Government assisted Human Settlements 93

Siweya, Mr NA Eskom, Sunninghill, RSA
Innovative Energy Efficiency Communication and Awareness through the "H" Factor 101

Thovhakale, Mrs TB University of Johannesburg, Auckland Park, RSA
Morton McKay, Ms T; Meeuwis, Ms J
Retrofitting to lower Energy Consumption: Comparing two Buildings 107

Wara, Prof ST Igbinedion University, Edo State, Nigeria
Abayomi-Alli, Mr A
Combating Co2 Emission and Global Warming through Energy Efficient Retrofitted Home Models 115

Kaputu, Mr C EldoAfrica, Fourways,
Energy Management for Domestic Users of Energy 123

Electrification and Energy Use in Rural Areas

Anderson, Prof GO University of Botswana, Gaborone, Botswana
Yanev, Mr KM
Non-conventional Substation and Distribution System for Rural Electrification 133

Prasad, Dr G University of Cape Town, Rondebosch, RSA
Universal Access to Modern Energy by 2030 - What does it mean for Africa? 145

White, Mr S Eskom, Sunninghill, RSA
Koopman, Mr S
The Viability of Off - Grid Electrification in the Deep Rural Areas of South Africa 149

Renewable Energy

Akpama, Mr EJ Cross River University of Technology, Calabar, Nigeria
Okoro, Prof OI, Chukuni, Prof E
Designing a Photovoltaic Sustained Power Sector: A Review of Current Practice. 155

Bvumbe, Mr T University of Kwazulu-Natal, Durban, RSA
Inambao, Dr FL
Solar powered Absortion Cooling Systems for Southern Africa 161

Fritz, Mr WLO CPUT, Bellville, RSA
Tsikata, Mr M
Modelling a Geothermal Source with Cogeneration Applications in a Residential Area 167

Karanitsch, Mr W Andritz Hydro (Pty) Ltd, Bedfordview, RSA
South Africa's Hydropower Option's 173

Katametsi, TOA University of Pretoria, Pretoria, RSA
Zhang, J
An Intelligent Switch System for Car Batteries 177

Keen, Dr GA Rondebosch, RSA
Lloyd, Prof P
Domestic Application of a PV System 183

Kilimo, Mr A CPUT, Bellville, RSA
Kahn, Prof MTE
Small Hydro for Rural Electrification 189

Omar, Mr I CPUT, Bellville, RSA
Sebezo, Ms N; Matshoba, Mr V
Investigating the Feasibility of Small Hydropower: A Case Study 193

Raji, Mr AK CPUT, Bellville, RSA
Kahn, Prof MTE
Distributed Energy Resources for Residential Electricity Users 197

Tazvinga, Mrs H Council for Scientific & Industrial Research, Pretoria, RSA
Mapako, Mr M; Stafford, Mr WHL; Amigun, Dr B
Can Solar -Biogas Hybrid Systems be the Solution to Sustainable Energy Supply in Rural Areas? 203

Tsikata, Mr M LTE Energy (Pty) Ltd, Midrand, RSA
Fritz, WLO
Combined Heat and Power Applications for Residential Application from a Biogas Plant 211

Water Heating and Heat Pumps

Fritz, Mr WLO CPUT, Bellville, RSA
Kallis, Mr D; Kahn, Prof MTE
The Role of Geothermal Energy in Bavaria 219

Mukuna, Mr JG CPUT, Bellville, RSA
Kilfoil, Mr M
Testing of Combined Regrigerator/Heat Exchanger and Geyser 225

Tao, Mr H; Ruicheng, Mr Z National Centre for Quality Supervision & Testing of Solar Heating Systems, Beijing, China
Jiven, Mr J; Lei, Ms Z
Introduction of Standards and Testing of Solar Water Heating in China 233

Wlokas, Ms H University of Cape Town, Rondebosch, RSA
What can Solar Water Heating Contribute to the Livelihoods of Low-Income Households? 241

Zhiqiang, Prof Y Tsinghua Solar Systems Ltd. , Beijing, China
Xiaowen, Mr Z
Developments of Solar Thermal Utilization in China 249

CAN SOLAR -BIOGAS HYBRID SYSTEMS BE THE SOLUTION TO SUSTAINABLE ENERGY SUPPLY IN RURAL AREAS?

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ABSTRACT

Access to modern energy services is a fundamental prerequisite for poverty reduction and sustainable human development. Many remote rural South African communities are characterised by low energy demand and low population densities, making centralised energy generation and transmission prohibitively costly. However, most rural areas are endowed with renewable energy resources that can be transformed into usable energy appropriate to rural and remote areas. This study explores the use of modern and hybrid energy supply for poverty reduction and environmental protection in remote rural areas of South Africa. A conceptual and practical framework is presented that incorporates sustainable livelihoods thinking with the provision of sustainable energy services to inform poverty reduction policy.

1. INTRODUCTION

The majority of the population in South Africa continues to reside in the rural areas [1]. The importance of providing renewable and sustainable energy to rural areas therefore cannot be overemphasised. Extension of the national grid to the rural areas has been hampered by several factors such as long distances, high cost of establishing the transmission grid, and distribution losses. The availability and accessibility of other modern energy sources is very low due to the high cost of these fuels, exacerbated by high supply costs to rural areas. Provision of renewable and affordable energy is crucial for the reduction of extreme poverty and the attainment of the Millennium Development Goals (MDGs). Energy supply in rural South Africa consists mainly of biomass, typically wood, dung and crop residues for heating and cooking [11]. Electricity where available is used mainly for lighting and low power appliances. Electricity costs are escalating in South Africa and renewable energy technologies are therefore becoming increasingly attractive. Petroleum products in the form of paraffin, and liquefied petroleum gas (LPG) are also used. .. There have been numerous efforts by Governments and donors in Africa to promote renewable energy technologies including improved cook stoves and solar cookers (RETS) but the uptake has been low, due to poor institutional frameworks and infrastructure, inadequate RET planning policies, lack of co-ordination and linkage in the RET programme, pricing distortions that ignore externalities and place renewable energy at a disadvantage; high initial capital costs; weak dissemination strategies; lack of skilled human resources; poor baseline information, and weak maintenance service and infrastructure [1; 2; 8].

In South Africa, the accelerated National Electrification Programme (1994-1999) aimed at widening access to electricity in rural areas. However remote rural areas could not be reached in the medium term for reasons highlighted above and off-grid technologies were perceived as an attractive electricity delivery mechanism. The global promotion of off-grid technologies as a clean energy source, particularly by certain funding agencies was also a driver [3]. In an effort to ensure access to electricity in rural areas and stimulate the renewable energy market, the Department of Minerals and Energy (DME) adopted the concessionaire model as the delivery mechanism for the off-grid electricity service to poorer communities [4]. Five private companies were each granted concession areas to establish off-grid energy service utilities (fee-for-service) as shown in table 1.

Table 1 Concessionaires and concession areas

Concessionaire	Concession Area
Nuon-Raps (NuRa)	Northern Kwa-Zulu Natal
Solar Vision	Northern Limpopo
Shell-Eskom Replaced by 3 smaller companies in 2005/6	Northern parts of the Eastern Cape and Southern Kwa-Zulu Natal
EDF-Total (KES)	Interior Kwa-Zulu Natal
Renewable Energy Africa (REA)	Central Eastern Cape

Source: ERC, 2004.

The geographic areas allocated to these consortia are broadly defined and include areas with access to the electricity grid. The off-grid service providers were to target small pockets within these broader areas, which are to be identified on an annual basis in consultation with the appropriate grid utility and service-provision authority. The licensing agreement entitles the concessionaire to install and maintain off-grid electricity technologies in allocated rural areas and these have been largely limited to the provision of PV solar home systems (SHS), producing electricity for household use.

Biogas is a renewable energy source whose feedstock (human manure, animal manure, poultry manure) is readily available in most rural areas. Use of biogas can save the labour and time of gathering and using firewood for cooking, minimise the harmful effects of smoke in homes, and reduce deforestation and greenhouse gas emissions as well as reduce reliance on fossil- fuels such as paraffin. Additionally, the residue from the biogas production process can be used as fertiliser by farmers. Solar energy can generate both heat and electricity and can be used for various applications such as solar drying, water heating and providing electricity for lighting and powering televisions, radios and cell phone chargers. The use of solar (PV) systems can improve the quality of life, for example, the provision of lighting in rural schools, evening education and community activities, and refrigeration at health care clinics.

This paper proposes the integration of solar/biogas hybrid systems in the rural energy supply mix. It also uses systems dynamics to enhance the understanding of the opportunities for off-grid energy technologies in poor rural communities that can improve rural livelihoods. System dynamics is an aspect of systems theory, an approach that can be used to understanding the behaviour of complex systems over time (dynamic). It deals with internal feedback loops and time delays that affect the behaviour of the entire system

ENERGY PROFILE, NEEDS AND BARRIERS

A study carried out by ERC (2004) showed that two thirds of the SHS households interviewed experienced problems with the system and that reduced the enthusiasm for solar power and confidence that it could supply the communities' energy needs. Three factors weighing heavily on customer's appreciation for the SHS included: the cost of the monthly fixed charge; limitations on what appliances can be used, and the cost of other additional fuels that must be purchased despite having solar power. SHS households still had to use other fuels for cooking, ironing, and water heating-59% of SHS-users rely on paraffin as their main cooking fuel, 27% use gas and 12% use fuel wood [3]. Compared to non-electrified households, SHS-users spent less on candles and dry cell batteries, because part of the lighting is catered for by the SHS. There was no significant change in the use of fuel wood. The SHS can only cater for lighting and entertainment and hence people still turn to non-renewable fuels within their proximity, mostly wood, to meet their heating and cooking requirements. Some of the issues associated with continued use of non-renewable fuels are that:

- Traditional energy sources such as firewood are becoming scarce and expensive
- The collection and use of traditional fuels at the current rate is not sustainable (woody biomass harvested at a rate greater than trees are being planted and allowed to mature) and therefore exhausts natural resources and damages the environment on which people depend.
- The collection of firewood utilises valuable time, in particular for women and children, which could have been spent otherwise at school or in more productive activities such as alternative income generation [11].
- Use of firewood and paraffin as fuels results in indoor air pollution, causing respiratory and eye problems. Some studies [5; 6] have linked exposure to indoor smoke to asthma, cataracts, tuberculosis, heart disease, lung disease, cancers and adverse pregnancy outcomes, in particular low birth weight. More than 1.6 million deaths were attributable to indoor smoke from solid fuels in 2000 [7]. About 2.6% of the global burden of disease (3.6% in developing countries) is considered to be due to cooking with solid fuels and acute lower respiratory infections (ALRIs) in young children account for 59% of all attributed premature deaths [5].
- Other problems include high cost of paraffin further straining scarce cash resources, dangers of fire outbreak and risk of explosions from paraffin appliances, and
- Production of greenhouse gases thus contributing to climate change [8]

In light of the above problems associated with non-renewable fuels, there is a need for clean, renewable sources of energy such as biogas to cater for the cooking requirements and solar collectors for household hot-water requirements. Biogas typically refers to the gas produced by the anaerobic digestion of organic matter including manure, sewage sludge, municipal solid waste, or any other biodegradable waste. Biogas technology is one of the mature renewable energy technologies to produce energy from bio-wastes [9]. The organic materials needed for producing biogas are readily available and often considered as waste or pollutant and are available in most rural areas. The wastes (human and animal wastes) that fuel biogas digesters present an environmental health threat when left untreated and this justifies use of the technology. Use of biogas can save the labour of gathering and using wood for cooking, minimise harmful smoke in homes, and reduce deforestation and greenhouse gas emissions. The residue from the production process can also be used as fertilizer by farmers. Solar collectors or solar water heaters (SWH) for household hot-water requirements are also a mature technology which has been implemented globally and is being implemented at various household income levels in South Africa under Eskom's demand side management programme [4].

There is, however no single solution to cater for rural energy requirements due to site-specific energy needs/profile and the characteristics of each location. Therefore, appropriate technology choice should be guided by the availability of resources in each location; energy needs of the community, distance from current (and future planned transmission grid) and take cognisance of not only access, but also the affordability of the current and proposed energy services.

Sustainable energy service provision for the poor is important in the transition from subsistence livelihoods to increased productivity, income generation, and improved living standards. Developing economies face energy challenges in meeting the needs of billions of people who still lack access to basic, modern energy services while at the same time participating in a global transition to clean, low-carbon energy systems. There is therefore a need to provide access to reliable and affordable energy services as a pre-requisite to alleviating extreme poverty and meeting other societal development goals. This justifies the use of more decentralised forms of power supply systems built near the locations of use and benefit from being modular in nature to incorporate future development.

2. SOLAR/BIOGAS HYBRID SYSTEM

2.1 HYBRID CONCEPT

Options for providing energy in rural communities include stand-alone renewable energy systems, diesel generator sets, or a combination of these forms of energy in a hybrid system. While stand alone systems such as solar home systems have been implemented in some rural areas, they cannot meet the demand due to the resource intermittence and cannot meet thermal. The hybrid concept is therefore an attractive option for power supply in rural areas as it eliminates most of the disadvantages of both diesel and solar systems. Hybrid systems have the potential to significantly increase the reliability and security of power supply due to the use of two or more energy sources. The decentralised nature of renewable energy technologies means that they require local installation, operation and maintenance capabilities thereby creating local employment opportunities. In addition, the modular nature of these technologies means the initial investments can be sized to meet the needs of the end-users, and as these needs grow, the investments can be increased [10].

While biogas will cater for the thermal and lighting needs of the rural communities, solar energy can be complimentary by providing energy for lighting, entertainment, battery charging, cell phone charging (SHS) and hot water (SWH). Such solar systems (SWH-SHS) can be implemented both at household and community levels. Biogas has been generated for centuries in small digesters, built to supply households with gas for cooking and heating. The interest in biogas technology in Africa has been stimulated by the promotional efforts of various international organizations and foreign aid agencies [5]. However, most of these initiatives are donor driven and this has contributed to failed biogas technologies in South Africa. Despite the many challenges, the value proposition of the biogas industry attracts governments and investors across both developed and emerging societies. Agama [14] has been successfully implementing biogas projects on a commercial basis around Cape Town although the considerable upfront capital cost limits this to the middle and high income families. It is estimated that there are 400000 households that do not have access to electricity, but have sufficient bio-wastes (at least two cows that can generate valuable animal manure bio-waste) to use biogas digesters that will generate sufficient biogas to supply the household cooking fuel needs. Other positive aspects are that biogas technology is simple and reliable, construction and repair maintenance cost can be lowered by use of local labour who can easily be trained, the use of local construction materials and the plant has a long-lifetime little operation and maintenance cost. The sale of both biogas and solar electric systems can also create jobs for installers in rural areas, as well as opportunities for urban and cottage industries in the manufacturing and maintenance.

2.2 RENEWABLE ENERGY SYSTEM MODELLING

A decrease in green house gas emission/pollution leads to a decrease in air pollution related health problems that are caused by the pollutants that are emitted by petroleum fuels. This has a positive effect on the general well-being of individuals and societies. A decrease in petroleum (diesel) use leads to a decrease in green house gases especially, carbon dioxide build-up in the atmosphere. This is due to the fact that the combustion of petroleum releases carbon dioxide that had been previously stored underground in oil reserves into the atmosphere. A decrease in carbon dioxide in the atmosphere reduces the effect of global warming. Income and job diversification/creation could lead to small enterprises development which will in turn reduce poverty and promote sustainable rural livelihood.

Reduction in poverty in turn will decrease the traditional use of biomass (wood) and related activities such as deforestation, overgrazing and over-cultivation (there is a correlation between poverty and environmental degradation).

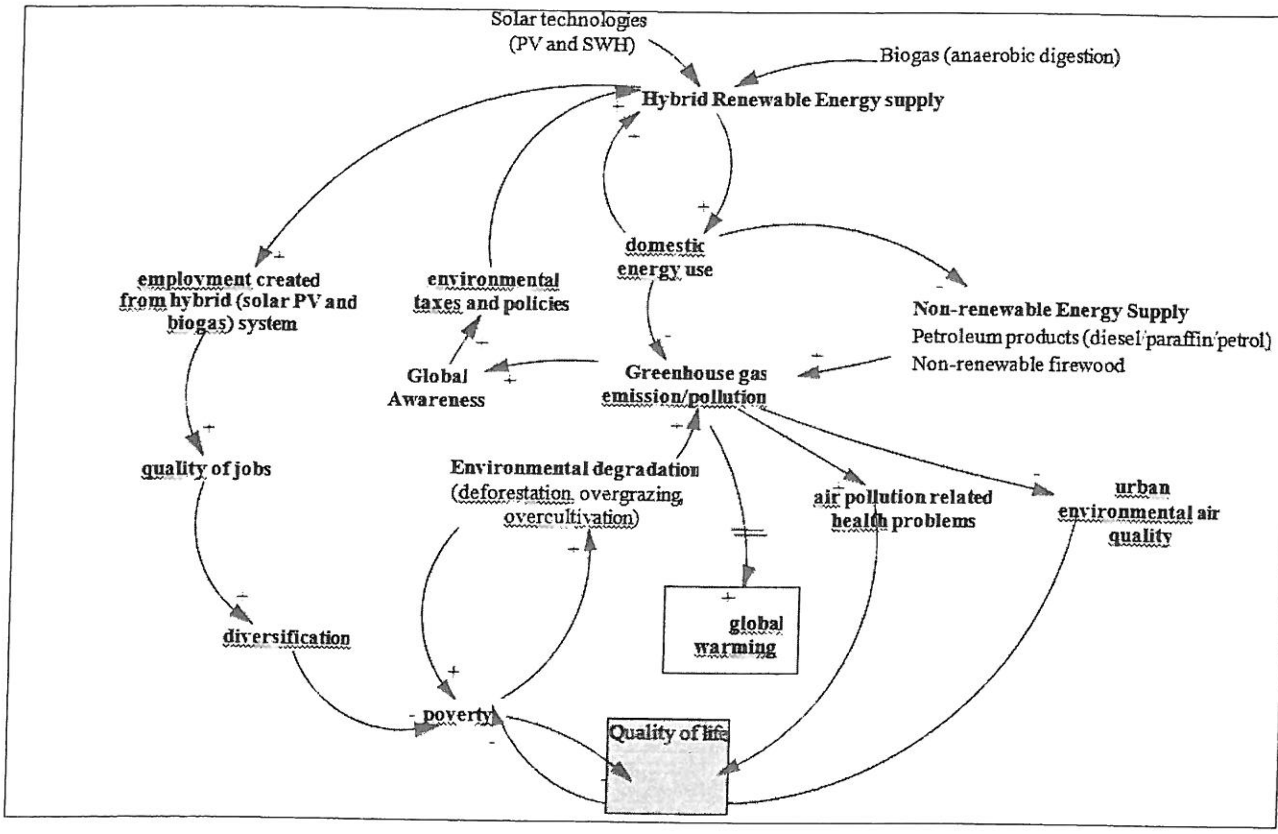

Fig. 1. Economic, environmental and social benefits of solar-biogas energy system

3. IMPLEMENTATION MODELS

3.1 RENEWABLE ENERGY IMPLEMENTATION MODELS

Renewable energy technologies have been implemented world-wide with both donor supported programmes and projects as well as through market initiatives. However, a sustainable renewable energy market has not developed due to a number of factors including high capital cost and lack of financing resulting in a small market potential for an entrepreneurial investment. Other factors include the lack of clear local ownership of the technology, lack of maintenance and rejection of the technology.

A number of innovative renewable energy implementation models that have been developed [10] and used in order to encourage widespread affordability and acceptance. When developing a new market for renewable energy, it is vital that an informed choice on the most appropriate implementation model is made. It is important to recognise that local conditions will demand tailored solutions and approaches, or perhaps combinations of the models described here. The three generic ones are [10]:

Model 1, Cash Sales: A renewable energy supplier sells the renewable energy system directly or via a dealer to the end-user. The end-user immediately becomes owner of the system.

Model 2, Credit sales: the end-user acquires the renewable energy system on credit. Credit sales are divided into three categories:

- Dealer Credit, the renewable energy supplier/dealer sells the renewable energy system to the end-user, who enters into a credit arrangement with the renewable energy supplier/dealer. Depending on the arrangements, the end-user immediately becomes the owner of the system, or when all payments are made.
- End-user Credit, the renewable energy supplier/dealer sells the renewable energy system to the end-user, who obtains consumer credit from a third party credit institution. The end-user usually becomes the owner of the system immediately, but this can be delayed until all payments are made.
- Lease/Hire purchase, the renewable energy supplier/dealer or a financial intermediary leases the renewable energy system to the end-user: At the end of the lease period, ownership may or may not be transferred to the end-user, depending on the arrangements. During the lease period, the lessor remains owner of the system and is responsible for its maintenance and repair.

Model 3, Fee for service: an ESCO (electricity supply company) owns the system, and provides an energy service to the end-user, who pays a periodic fee (e.g., monthly) to the ESCO. The end-user is not responsible for the maintenance of the renewable energy system and never becomes the owner, although the end-user may own for example the battery and lamps/radio or gas stove.

3.2. CASE OF THE RWANDA BIOGAS PROGRAMME

Many modern energy service delivery projects have been implemented in Africa, though in most cases these have failed [11]. Many lessons can be learnt from these experiences, including needs identification, institutional and financial factors, operation and maintenance capacity, market research and quality control. The biogas programme in Rwanda is a recent initiative that seems to have taken into consideration the lessons learnt from past failures. It is presented here to illustrate the roles of the public and private sector stakeholders may be synchronised, and how the financing arrangement could be arranged as well as the maintenance and training issues.

A need was identified in the Rwanda domestic cooking fuel market in view of the very high population density, high power tariff and problems with deforestation [12]. The programme is supported by the Netherlands Development Organisation (SNV) which has extensive experience and notable successes in Asia, Nepal being a case in point. SNV provided technical assistance for market development and the aim was to have a self-sustaining programme. The program was initiated in 2007, with a target for the Rwanda national biogas programme as 15 000 units by 2011. By 2008, some 175 household biogas plants had been completed, including 100 initial demonstration units, and 185 contracts for new biogas digesters had been signed by farmers. Ten private companies were undertaking construction. A minimum of 2-3 cattle are required for the typical 6m^3 digester, and fertilizer from biogas digesters was sometimes sold.

The biogas digesters were more expensive than in Asia, with a 6m^3 family digester costing around US$1 200 in Rwanda compared to US$250-$400 in Nepal. In Rwanda cement was about $13 per bag, and 18 bags were required for the average digester, while in Nepal cement cost about US$2 per bag in 2008. The designs that were promoted in Rwanda were based on the Nepalese model with modification to reduce the amount of cement used. In Rwanda the walls were constructed with stones (due to the ban on using firewood for brick firing), and the dome with cement. The farmer's contribution was labour and materials including sand, stones and water. Biogas had significant benefits at the individual and community levels, and if carbon emission reduction was considered, the benefits are even greater. Users saw smoke reduction as a greater benefit than financial benefits and the promotional message highlights this benefit to users [13]. The capacity to pay for biogas digesters was not a constraint since it was estimated that 100 000 farmers had the capacity to pay for the biogas digesters, hence the plan for 15 000 units by 2011[11]. The zero grazing of cattle (feeding of cattle in feed-lots) also made the choice of biogas technology favourable since all dung and urine was collected. The digested dung can still be applied to the fields and does not lose its fertiliser value since only carbon compounds; carbon dioxide (CO_2) and methane (CH_4) are removed in the biogas production process of anaerobic digestion. The steps involved in a successful application for a biogas digester are as follows:

Farmer submits application form, installer inspects/certifies site as suitable, farmer and company sign contact, and contract endorsed by MININFRA, company builds digester. First inspection by MININFRA, and payment of first portion. Second payment disbursed after digester is operational. A balance of 7.5% is paid at 12 months, after 3 compulsory visits at 2, 6, and 12 months have been completed.

The financing for the biogas digesters was structured as follows: [12]

- 1/3 subsidy from programme (split government 25% and programme 75%).
- 1/3 farmer contribution in labour and materials (sand, stone, water).
- 1/3 cash by farmer, this can be through a loan, normally payable over three years.

The biogas loan interest was 13% per annum, which was the same as for agricultural finance. Banks had no problems in extending credit for biogas as the criteria for installation link the digesters to income generating activities, especially milk sales. Eligibility for payment was restricted to trained and certified builders, and refresher courses included the rectification of existing faults. The financing arrangement ensured that participating companies had sufficient initial capital to start operating. The users need to be trained to deal with minor maintenance issues like leaks in pipes, and the installing company had to undertake the required maintenance visits. User manuals had to be in the local language with contact details for both the installing company and the programme. [13]. Installing companies were contractually bound to train local maintenance technicians, and there were refresher courses for technicians, funded by Netherlands Ministry of Foreign Affairs (MININFRA). Records books were kept at the client's premises for inspection when necessary.

Companies were encouraged to cluster installations to minimise costs through the phased simultaneous construction of digesters in one area. Additionally, the following training components were required to be in place: user training courses held; training capability enhanced; entrepreneurship and management training provided to the installing companies and the school curricula amended to have a renewable energy component. Government and institutional acceptance was an important criterion for SNV to decide to become involved. In Rwanda, the Government responded well, engaged additional personnel as required and signed a memorandum to show its commitment. Various stakeholders including the Kigali Institute of Technology, SNV and the private sector brought in technical capacity. Model farmers who adopt and pioneer new ideas would receive visitors who can see new ideas in action. The initial farmers for the biogas demonstration phase were chosen on this basis and biogas digesters would sell on the basis of clients seeing working digesters and satisfied users. To avoid dissatisfaction of users, construction should not proceed where the basic conditions were not met, for example minimum number of cows and availability of sufficient water.

Institutional plants were selected on the basis of availability of funds, for example through the parent ministry for prisons, and donor support for schools and by 2008, 13 of the 20 prisons had biogas digesters. Human wastes were added to the digester as well as the animal manure The easy availability of dung was assured due to two other projects [12] whereby selected farmers got a free heifer together with veterinary and artificial insemination services. These projects were run by Heifer Project (USA) and Send a Cow (UK) and required each recipient of a free heifer (or other animal) to pass on for free the first female calf to another farmer as a way to propagate heifer ownership. These farmers sold milk from their cattle and in most cases the loans for the biogas digesters were being paid off with the proceeds of the milk sales. The cattle were zero-grazed and the farmers grew the fodder for their cattle.

4. DISCUSSION AND CONCLUSION

A major pitfall in many rural development projects has been the top down approach where the interventions are developed with little or no understanding of the priority needs of the recipient communities. In Rwanda, there were district level plans for all sectors and stakeholders involved. Coordination was via local structures, such as the farmer organisations. Leaders had performance contracts for each year. Institutional biogas digesters were installed in response to critical sanitation and energy needs due to prison overcrowding. Schools copied from the prisons and funded themselves or found sponsors. To avoid disillusionment it was crucial to be up-front with users about the limitations. Interestingly, users prioritised lighting (mantle lamps) very highly, in some cases above cooking [12]. Clearly, this raises the opportunity to incorporate SHS and SWH with biogas systems so that both the lighting and communication (electricity) and thermal needs (heating and cooking) are met.

South Africa could successfully implement the solar-biogas hybrids by applying lessons-learnt from successful projects elsewhere such as bottom-up approach to needs identification, private-public partnerships, quality control, maintenance and operation capacity and the provision of suitable finance for projects. A model that could be implemented is one where proceeds from commercial activities from the solar-biogas hybrid are used to pay either the loan or the maintenance fees depending on the financial arrangements.

Use of demonstration models can be useful so that adoption is enhanced on the basis of clients seeing working systems and evidence from satisfied users.
There is need for Government and institutional acceptance and support to enable coordination and dissemination of information via provincial and local structures in order to raise awareness and educate the public of the benefits of renewable energy technologies. There is also need to identify areas where the grid may not reach, and give these priority in the provision of off-grid renewable energy technologies.

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