Applied Energy 132 (2014) 308–316

Contents lists available at ScienceDirect

Applied Energy

journal homepage: www.elsevier.com/locate/apenergy

Affordability for sustainable energy development products

Paul H. Riley *

The University of Nottingham, Department of Electrical and Electronic Engineering, Nottingham NG7 2RD, UK

HIGHLIGHTS

- Clean cookstoves that also generate electricity improve affordability.
- Excel spreadsheet model to assist stakeholders to choose optimum technology.
- Presents views for each stakeholder villager, village and country.
- By adding certain capital costs, affordability and sustainability are improved.
- Affordability is highly dependent on carbon credits and social understandings.

ARTICLE INFO

Article history:
Received 8 May 2013
Received in revised form 12 May 2014
Accepted 19 June 2014

Keywords:
Thermo-electric
Thermo-acoustic
Score-Stove
Cookstove
Affordability

ABSTRACT

Clean burning products, for example cooking stoves, can reduce household air pollution (HAP), which prematurely kills 3.5 million people each year. By careful selection of components into a product package with micro-finance used for the capital payment, barriers to large-scale uptake of products that remove HAP are reduced. Such products reduce smoke from cooking and the lighting from electricity produced, eliminates smoke from kerosene lamps. A bottom-up financial model, that is cognisant of end user social needs, has been developed to compare different products for use in rural areas of developing countries. The model is freely available for use by researchers and has the ability to assist in the analysis of changing assumptions. Business views of an individual villager, the village itself and a country view are presented. The model shows that affordability (defined as the effect on household expenses as a result of a product purchase) and recognition of end-user social needs are as important as product cost. The effects of large-scale deployment (greater that 10 million per year) are described together with level of subsidy required by the poorest people. With the assumptions given, the model shows that pico-hydro is the most cost effective, but not generally available, one thermo-acoustic technology option does not require subsidy, but it is only at technology readiness level 2 (NASA definition) therefore costs are predicted and very large investment in manufacturing capability is needed to meet the cost target. Thermo-electric is currently the only technology that can be used worldwide every day of the year and is available without research. However, it is not yet self-financing and therefore requires subsidy or diversion of more household income to be affordable. A combination of photovoltaic and clean cookstove may be suitable in areas where sufficient solar radiation is available on most days. Affordability is shown to be highly dependent on the income that can be derived from carbon credits.

1. Introduction

In rural areas of developing countries, there are two main problems; 3 billion people suffer smoke inhalation with the associated ill health and 1.6 billion do not have access to electricity. In most rural areas there is an overall economic (as well as health) benefit to reducing smoke through the use of improved cookstoves [1]. Interestingly, although most recent effort for reducing smoke inhalation has concentrated on smoke produced from wood [2], there are also benefits of electric lighting on health by reducing smoke from kerosene lamps used for lighting [3]. Although off-grid electrically generating technologies are available in remote rural areas of Nepal, penetration of mains electricity to rural areas is only 1% of total energy consumption [4].

An analysis of off-grid renewable energy systems based on a literature review covering Bangladesh and Fiji [5] shows that key requirements for success require cognisance of the social, institutional, economic and policy aspects of implementation. This view is supported by work done in India [6] where small-scale power

* Tel.: +44 (0) 115 9515356.
E-mail address: paul.riley@nottingham.ac.uk

http://dx.doi.org/10.1016/j.apenergy.2014.06.050
0306-2619/

generation systems based on the renewable energy sources are more efficient and cost-effective than providing mains supplies, particularly to remote communities. Early work on providing sustainable energy for development concentrated on providing the lowest cost solution [7]. Other work has shown that the social context is highly influential to large-scale sustainable energy uptake [8]. A study on Renewable Energy (RE) policy [9] shows that awareness levels in adopting RE-technologies and willingness of people to access and pay for electricity have increased significantly. However, there is a huge financial gap between the cost of electrification and the affordability. Bridging this gap is a crucial issue that needs to be addressed for the smooth expansion of rural electrification in the country.

The term "affordability" is used in different ways. There are a number of empirical studies on energy access and affordability, drawing lessons based on the experience of three developing countries—Brazil, Bangladesh, and South Africa, and [10] cites the Energy Sector Management Assistance Programme, 2003; "Affordability is a politicized concept". Many researchers take a statistical view of affordability, particularly when discussing UK energy systems [11]. This top-down approach is suitable for analysing energy systems in affluent areas, where there are multifaceted spending choices and mature energy generation and distribution systems in place. In the case of the low-income rural households, a bottom-up approach to the analysis is required as no energy infrastructure is in place and lack of income is the major constraint.

To remove any bias due to politics and make the results more applicable to people at the Bottom of the Pyramid (BoP), this paper defines affordability in a different and very specific mathematical way: when a technology intervention is made, it is considered affordable when the net change in income – expenditure is greater or equal to zero. The term is then applied at the householder, village or country level. Where income is less than expenditure, the amount of subsidy needed for implementation is a measure of the relative affordability between technological interventions.

Little bottom-up work has been done on comparing the economics across different stakeholders of different methods of delivering off-grid rural electricity in combination with clean cookstoves, or in how to package products together to improve affordability. This paper presents a model to compare an energy product from three views: the villager in a rural area, the local shopkeeper, and the region or country with the goal to provide both sustainable electricity and clean cooking stoves, thus improving health by removing the two main smoke problems. By providing a business case at all these three levels, many social barriers to large-scale deployment are removed.

Affordability alone is not sufficient to make an impact on the global scale; any solution also needs to be sustainable. Sustainability has three facets: it should be built from sustainable materials, use renewable fuel and be accepted by all the stakeholders. Only the latter two are within the scope of this paper.

Indoor household air pollution (HAP) is thought to prematurely kill 3.5 million people each year [12]. Recent, as yet unpublished research indicates that removing the smoke from cooking is not sufficient to improve health in all cases. Kerosene lamps used for lighting also produces significant smoke [13] and people often revert to smokier stoves for a variety of reasons [14].

Thus, the motivation behind this paper is to provide a means via an MS Excel™ spreadsheet model to compare a set of technological interventions that have the potential to improve health due to HAP and in so doing, assisting decision makers and implementers to choose affordable, sustainable and holistic solutions. The model can be used to predict outcomes for households at different income levels. This paper presents data for those at the BoP only; people earning £2 or less per day.

2. Methodology

The need for clean cooking stoves has been around for 50 years and yet outside China coverage is only 8%. Additionally, rural electrification is among the priority areas of government policies, particularly in Nepal. The methodology of this paper is to produce a mathematical model in MS Excel™ that shows the financial benefits of combining a clean cooking stove with electrical generation. In doing so, the total benefits are greater than the sum of the parts. We chose a number of technologies for the model, some that provided clean cooking and electrical generation in one unit such as thermo-acoustic and thermo-electric and others such as hydro and photovoltaic that required combination with a clean cookstove to meet the combined smoke free and electrical generating requirement. Previous research has shown that socio-technical interactions can make a significant difference to householder finances and so the model also includes additional functions such as mobile phone charging and both indoor and torch lighting systems. The latter is essential to remove the need for kerosene lighting; without torches, kerosene is used as mobile lighting to tend animals, go to the toilet etc. at night.

The hypothesis is that adding additional product functionality and hence cost to the solution reduces the net financial burden on the householder, village and country, thus improving the affordability of the intervention as a whole. Products such as photovoltaic are mature technology and easily available, whereas thermo-acoustic technology is in its infancy as far as large-scale production is concerned. In order to compare products at such a divergent technology release levels, the model breaks down the solution into a number of functional elements and uses simple rules for each element. If a function is common to more than one solution, for example the cooking hob itself, only one cost for that function is used across all solutions. For products at an early technology release level, the predicted cost in volume using a method previously developed by the author [8] is used.

To test the hypothesis seven examples of technologies, are used to meet the overall goal stated earlier. In two cases, a combination of technologies forms the overall solution. The model clearly defines the assumptions used, which are described in detail below. For testing specific cases, or as commodity prices alter over time, the assumptions can be changed to see the effects at each level from householder to country.

3. Affordability versus cost

This paragraph outlines how correct application of additional cost can significantly improve affordability of the product. However, any extra cost has to take cognisance of the social context so that the cost is targeted to improve affordability. By concentrating on affordability in addition to product cost, packaged solutions emerge that increase uptake, remove barriers to implementation and so improve acceptability of the product.

3.1. Social context: villager

Trials in Nepal and Kenya [15], and other areas [16] installed Photovoltaic panels and clean cookstoves in village households, the electricity was mainly used for lighting, radio and charging mobile phones. The lighting provided was static and internal to the dwelling. Part of the early business case for the installation was that the lighting provided would mean that kerosene use would fall to almost zero. (Kerosene lamps are used for lighting in many villages and consume the vast majority of kerosene purchased.) Follow-up studies revealed that kerosene use had only