Renewable and Sustainable Energy Reviews 97 (2018) 90–102

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

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

Energy consumption levels and technical approaches for supporting development of alternative energy technologies for rural sectors of developing countries

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ARTICLE INFO

Keywords:
Developing countries
Energy systems
Rural off-grid
Energy consumption
Energy poverty
Renewable energy

ABSTRACT

The delivery of modern energy services in developing countries (DCs) remains a pressing challenge. The traditional energy choices of 2.67 billion people most of whom living in rural areas of DCs have far-reaching implications to health, the environment and economies. Rural areas in DCs have renewable energy resources, which are largely untapped due to lack of energy demand information of requisite load centres. This article formulates indicative energy consumption data to support the design and development of novel alternative energy technologies for rural off-grid areas in DCs. The study examines energy demand/consumption through an extensive literature review of quantified energy needs in rural sectors of DCs including households, institutions, infrastructure and productive sectors. Various energy needs are identified and their typical consumption levels analysed. The study will stimulate further research and support the design and development of alternative energy supply technologies to mitigate energy poverty, trigger development and support sustainable energy for all (SE4All).

1. Introduction

Access to clean, secure, reliable and safe energy services is essential for fighting poverty and achieving economic development in Developing Countries (DCs). However, many DCs have high deficits in modern energy access. There are 1.1 billion people worldwide with no access to electricity and 2.67 billion people relying on traditional fuels [1,2]. Fig. 1 illustrates that the majority of populations in rural areas of developing regions of the world depend on traditional biomass in lieu of electricity. This results in health dangers linked to air pollution resulting from using traditional fuels and inefficient technologies [3–6]. The challenges with the grid-based rural electrification approach, which include: expensive grid extension; unreliable infrastructure; lack of political will and institutional weaknesses, further complicates this scenario and impacts energy delivery to rural households, institutions and enterprises [7–9].

Another area gaining interest is quantifying energy needs in the various social units in DCs. Many have conducted studies and surveys to garner data concerning end-user demands in rural settings such as lighting and cooking [10–13]. Such micro-level data is essential in developing the design and sizing of novel energy technologies for DCs and can be instrumental in addressing some of the pitfalls that engineers face when designing for the resource-poor in DCs [14].

There are typically two kinds of problems when designing and developing energy technologies. The first involves design and development of new or novel energy technologies and associated components targeting specific energy end-uses. The second involves the sizing of existing energy supply systems to satisfy current and future energy needs. In the second case, designers have access to the facility being designed for; either physically or in blueprint form. From this, load/energy demand is ascertained. In the first case, this is not always possible and alternative approaches are sought such as a survey or a data collection exercise at the site of interest. This data would feed into the new/novel energy supply technology design process. However, where timelines, financial resources and administrative restrictions are involved such elaborate approaches would be difficult to undertake.

Therefore, an alternative approach could borrow from data generated by other authors. Such an approach could make use of quantified energy consumption metrics such as per capita, daily, monthly and/or annual concerning targeted end uses in rural energy sectors of DCs [15–18] as a crucial starting point. Other metrics such as energy consumption per unit floor area are useful when considering designing

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https://doi.org/10.1016/j.rser.2018.08.021
Received 3 November 2017; Received in revised form 1 August 2018; Accepted 15 August 2018

Nomenclature

AGECC	Advisory Group of Energy and Climate Change
CCHP	Combined Cooling, Heating and Power
CHP	Combined Heating and Power
EDI	Energy Development Index
GJ	Gigajoule
IEA	International Energy Agency
IRENA	International Renewable Energy Agency
kg	Kilogram
kgOE	Kilogram(s) of oil equivalent
kW h	Kilowatt hour
L	Litre
LPG	Liquefied petroleum gas
MEPI	Multi-dimensional Energy Poverty Index
MSMEs	Micro Small & Medium Enterprises
PV	Photovoltaic
PVT	Photovoltaic-thermal
SEforAll	Sustainable energy for all
USAID	United States Agency for International Development

systems for individual households [19]. Similar metrics can be devised for rural health centres [15,20], schools [16] and micro, small and medium enterprises (MSMEs) [21,22].

Due to rural sectors often being heterogeneous between countries, minor differences are inconsequential in a majority of DCs. Therefore, this data provides vital baselines for sizing and designing new technological interventions targeted at specific rural sectors in DCs. The macro-level metrics are distinct from aggregated macro-level metrics, which tend to be nationwide and mask greater error margins.

Researchers and development experts have quantified energy consumption levels in rural sectors of DCs. In particular, some have quantified minimum energy requirements for supplying the energy needs of the rural poor [23–27]. Others have conducted field surveys to ascertain the energy use requirements of the rural poor considering different energy carriers such as electricity, LPG, kerosene, biogas, ethanol, fuelwood and charcoal [8,28]. Energy requirements for rural schools, health centres, public buildings, irrigation and potable water service, among others are also considered but not as widely as for households [10,29]. Work by international organisations has also often mentioned the importance of these metrics [15,30–33].

This article is a step towards understanding the energy needs in sectors of rural areas with a goal of warranting innovative energy technologies that target specific applications in DCs. This article helps to harmonise published quantified micro-level energy use metrics pertaining to rural settings of DCs and to derive meaning from them. Since there's no research that analyses the context of quantified energy consumption/demand metrics for rural areas of DCs the paper is organised as follows. Section 2 reviews the concept of energy poverty and published data on energy consumption in DCs and provides examples of energy consumption metrics of interest. Section 3 defines a suitable classification framework for the rural energy sector. Section 4 presents the methodology and highlights research trends. Section 5 analyses and develops energy consumption baselines from published data. Section 6 presents a matrix of quantified energy needs for supporting the sizing of energy technologies for rural sectors of DCs. Section 7 proposes possible technological pathways for energy supply in rural areas of DCs and identifies future research challenges. Section 8 concludes with key highlights.

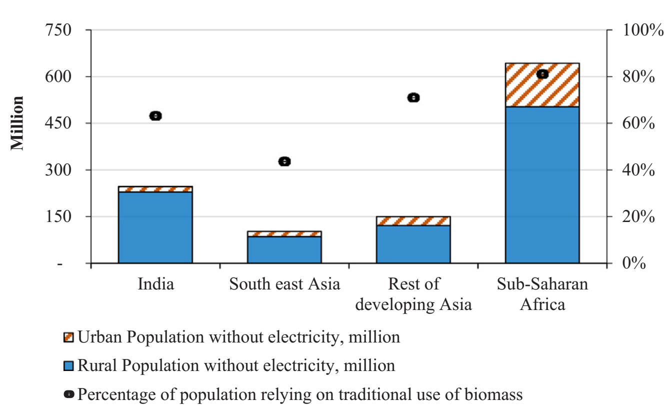

Fig. 1. Number and percentage of population without electricity and dependent on traditional biomass for cooking and heating needs (2016) [1,2].

2. Energy poverty, energy use metrics and definitions of basic energy needs

2.1. *The aspect of energy poverty*

Poverty in DCs results in the lack of: means to satisfy basic needs; access to essential amenities; and opportunities [34]. Even if economic improvements are made at a country level, significant numbers of individuals may still lack adequate basic amenities such as shelter, food, health, education, clean water, clothing, sanitation, employment opportunities and energy. However, energy has been internationally recognised as an essential component to increasing social amenities, resulting in the adoption of 'energy poverty' as a commonplace phrase [32,35]. According to Bhatia and Angelou [32], 'energy poverty' is:-

> "the state of being deprived of certain energy services or not being able to use them in a healthy, convenient, and efficient manner, resulting in a level of energy consumption that is insufficient to support social and economic development."

This definition reveals that 'energy poverty' can be applied meaningfully to individuals, as well as entities, of rural settings in DCs such as households, education, health institutions and enterprises. Authors have attempted to determine the energy poverty line at a household level in several countries (see Fig. 2). Although typical micro-level energy demands in rural settings of DCs is insufficient, the need for innovative technologies to meet this and even higher demand levels, in a sustainable manner is irrefutable.

Efforts have been made to distinguish the energy poor from the non-energy poor, particularly for households [36,37], by using certain quantified energy use metrics or indicators. These indicators, often derived either from macro or micro-level data, have been commonly referred to as simple unidimensional quantities, for instance kW h consumption per capita [32]. Although the simple unidimensional quantities are widespread, there is a growing shift towards the use of multidimensional quantities, for instance Energy Development Index (EDI) and Multi-dimensional Energy Poverty Index (MEPI) [38,39] to enable comparability between countries.

This study does not focus on energy poverty or human development and does not consider multidimensional quantities. Also, it does not

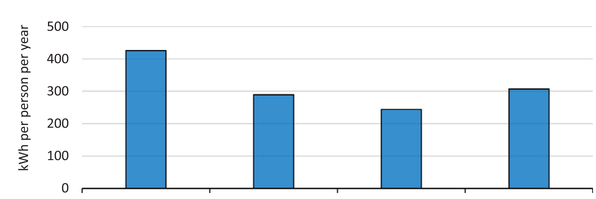

Fig. 2. Energy poverty line for different countries as estimated by researchers [24,25,36,97].