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Energy Consumption Levels And Technical Approaches For Supporting Development Of Alternative Energy Technologies For Rural Sectors Of Developing Countries

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Abstract: Delivering contemporary energy services to developing countries (DCs) continues to be a difficult task. The traditional energy decisions made by 2.67 billion people, the majority of whom reside in rural parts of DCs, have significant effects on economies, the environment, and human health. Due to a lack of information on energy demand from the necessary load centres, renewable energy resources in rural areas of DCs are largely untapped. This article identifies indicative energy usage information to aid in the creation of creative alternative Energy-related innovations for DCs' rural off-grid regions. Through an analysis of energy demand and consumption, the study a thorough study of the literature on the measured energy needs of rural DCs' households, institutions, productive industries and infrastructure. Different energy requirements are indicated, along with their normal consumption rates. analysed. The findings will encourage additional investigation and aid in the creation and advancement of substitute solutions for energy supply that reduce energy poverty, spur growth, and encourage sustainable energy for all (SE4All).

1. Introduction

Since the beginning of the industrial era, the capacity to capture and utilise various sources of energy has drastically improved the quality of life for billions of people, allowing them to live in comfort and mobility unheard of in human history and releasing them to carry out ever-more-productive work. For the majority of the previous 200 years, there has been a direct correlation between growing levels of affluence and economic opportunity throughout most of the world and the steady development in energy consumption. However, a major energy crisis is currently facing civilization. There are at least two important dimensions to this problem. It is now obvious that the way we currently consume energy is not environmentally sustainable. Particularly, the heavy reliance on fossil fuels poses a major danger to the integrity of both important natural systems and human systems by drastically altering the temperature of the planet. The 'haves' and the 'have-nots' continue to be separated by the availability of energy. According to some estimates, more than two billion people worldwide still don't have access to electricity, clean cooking fuel, or reliable transportation, which together make up a significant portion of essential energy services.

Fighting poverty and achieving economic growth in developing countries require access to clean, secure, dependable, and safe energy services (DCs). However, access to modern electricity is severely lacking in many DCs. 2.67 billion people rely on conventional fuels, whereas 1.1 billion people globally lack access to electricity. Fig. 1 shows how the majority of people rely on traditional biomass instead of electricity in rural parts of emerging nations.

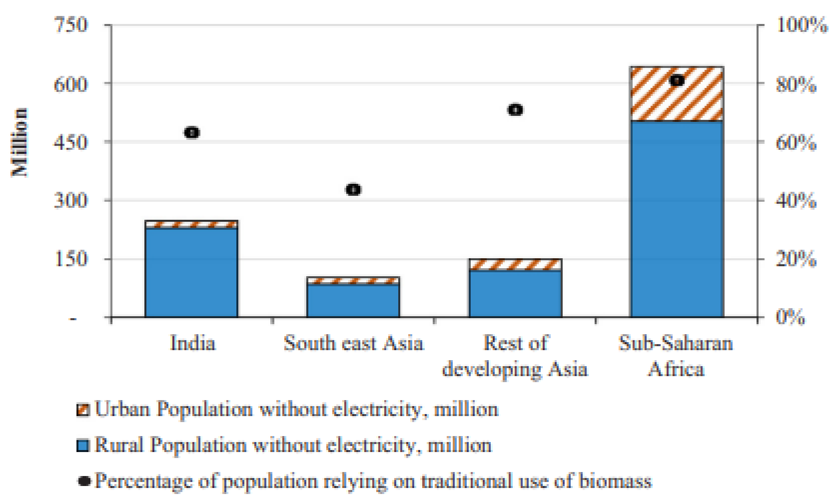

Fig. 1. Number and percentage of population without electricity and dependent on traditional biomass for cooking and heating needs

This results in health dangers linked to air pollution resulting from using traditional fuels and inefficient technologies. 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. 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. 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.

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.

1.1 Historic Energy Trends

The energy use of human societies has historically been marked by four broad trends:

• Rising consumption as societies industrialize, gain wealth and shift from traditional sources of energy (mostly biomass-based fuels such as wood, dung and charcoal) to commercial forms of energy (primarily fossil fuels).

• Steady increases in both the power and efficiency of energyproducing and energy-using technologies.

• De-carbonization and diversification of fuels, especially for the production of electricity, throughout most of the 20th century.

• A reduction in the quantities of conventional pollutants associated with energy use.

Each of these trends has contributed to the shaping of our current energy situation. All will be important in determining the nature and magnitude of the sustainability challenge that humanity confronts in the decades ahead. In particular, much will depend on how the last three of the four trends described above interact with the first. In other words, the ability of developed and developing countries to manage the consequences of rising consumption and demand for commercial forms of energy seem likely to depend on whether it will be possible to greatly accelerate progress toward higher efficiency, more de-carbonization, greater fuel diversity and lower emission of pollutants.

1.2 What does renewable energy offer rural areas?

The global deployment of RE has been expanding rapidly. For instance, the RE electricity sector grew by 26% between 2005 and 2010 globally and currently provides about 20% of the world's total power (including hydro-power). Rural areas attract a large part of investment related to renewable energy deployment, tending to be sparsely populated but with abundant sources of RE.

New revenue sources. RE increases the tax base for improving service provision in rural communities. It can also generating extra income for land owners and land-based activities. For example, farmers and forest owners who integrating renewable energy production into their activities have diversified, increased, and stabilised their income sources.

New job and business opportunities, especially when a large number of actors is involved and when the RE activity is embedded in the local economy. Although RE tends to have a limited impact on local labour markets, it can create some valuable job opportunities for people in regions where there are otherwise limited employment opportunities. RE can create direct jobs, such as in operating and maintaining equipment. However, most long-term jobs are indirect, arising along the renewable energy supply-chain (manufacturing, specialised services), and by adapting existing expertise to the needs of renewable energy.

Innovations in products, practices and policies in rural areas. In hosting RE, rural areas are the places where new technologies are tested, challenges first appear, and new policy approaches are trialled. Some form of innovation related to renewable energy has been observed in all the case studies. The presence of a large number of actors in the RE industry enriches the "learning fabric" of the region. Small and medium-sized enterprises are active in finding business niches as well as clients and valuable suppliers. Even when the basic technology is imported from outside the region, local actors often adapt it to local needs and potentials.

Capacity building and community empowerment. As actors become more specialised and accumulate skills in the new industry, their capacity to learn and innovate is enhanced. Several rural regions have developed specific institutions, organisms, and authorities to deal with RE deployment in reaction to large investment and top-down national policies. This dynamic has been observed both in regions where local communities fully support RE and in regions where the population is against potentially harmful developments.

Affordable energy. RE provides remote rural regions with the opportunity to produce their own energy (electricity and heat in particular), rather than importing conventional energy from outside. Being able to generate reliable and cheap energy can trigger economic development.

2. Defining a classification framework for sectors of the rural energy economy

2.1 Rural sector stratification in the energy access context

Rural areas are an important sector in national development. For DCs in particular, rural areas are collectively home for large populations as compared to population aggregates of urban areas. In rural areas, the most basic unit is a household1 where the majority of the people live and thrive on opportunities within their communities. Like their urban counterparts, rural dwellers require the same kind of services to satisfy their survival needs (food, housing, and sanitation), affordable social services such as education, health, communication and transportation as well as employment. Improving the energy access levels of rural areas is just one way to provide rural people the best chance to escape poverty and promote development. However, the situation in rural areas of most DCs is dire. Rural people are left behind by their urban counterparts. Progress for accessing many essential amenities such as clean water, equipped health facilities, electrical energy and efficient cooking appliances is slow. To enable targeted interventions, rural areas can be subdivided into key strategic sectors. Indeed, various subdivisions of the rural sector in the context of rural energy demand have been proposed but there is no uniformly agreed upon categorisation framework for rural areas. Therefore, drawing from these prior efforts, this article proposes an overarching decomposition of the social energy end-use market into four main categories i.e. households, social services, infrastructure and productive use enterprises. The quantified energy use metrics published in literature can be effectively categorised according to this classification.

2.2 Energy use in rural households

The rural household energy sector is fundamental as it constitutes the largest proportion of the energy demand of rural areas. However, electrical loads powered in households with access to electricity are typically small and end-uses are typically restricted to lighting, television, radio and phone charging. For rural households without electricity, all their day-to-day energy needs are typically supplied by biomass for which they have to spend considerable time and labour gathering from near and afar. Other fuels commonly in use are kerosene as well as dung and agricultural residues for cooking, water/ space heating and lighting. Research has shown that even within nonelectrified households, there are diversities and nuances with regard to end-uses for biomass energy. For instance, in Cambodia, not only do households use fuelwood for cooking human food, they also commit a substantial amount of biomass energy towards repelling insects and preparing feeds for their piggery. Elsewhere, studies suggest that if alternative modern energy carriers such as LPG and efficient appliances are accessible, rural households which can afford them will add them to their stack of total fuel mix. Otherwise, poor rural households will maintain a stack of diverse low quality fuel sources to raise their fuel security. Comparisons between world regions for all the biomass fuel types and electricity use indicates that rural households in Africa have the lowest aggregated electrification rate at 28% and the highest reliance on traditional biomass at 69%.

2.3 Energy for social services

The service provision sector of rural areas encompasses education institutions, health care facilities, church buildings as well as government and public institutions such as police posts and recreation centres. Whichever of these facilities exist in an area, electricity is often necessary for powering lights, public address systems, television, information technology and others. Researchers have found a relationship between electrification of social service facilities and attraction and retention of professional workers. For instance, the lack of electricity in schools in Papua Guinea was identified as a significant issue contributing to the crisis of poor retention of elementary and secondary teachers in rural schools. It is also essential to state that a significant amount of centralised cooking energy needs in this sector is derived from biomass fuel sources, particularly in schools where meals have to be provided to students.

Energy access is also crucial for improving the literacy levels amongst poor households since with it, higher enrolment levels are attained in rural schools, leading to improved income earning opportunities. In health clinics, energy for evening lighting to extend patient access hours, refrigeration of vaccines, sterilisation and autoclaving among others is essential for improving the health services standards in rural areas. Finally, electrification of public institutions strengthens service delivery, facilitates social gatherings and cohesion.

2.4 Infrastructure

Infrastructure energy needs in rural areas such as water pumping and street lighting for security at night are considered in this section. Water pumping infrastructure is essential in improving access to potable clean water to rural communities for institutional and household use. The World Health Organisation has reported that the lack of access to improved sources of drinking water contributes to over 3.4 million deaths annually of which about 99% occur in developing countries. Due to most rural areas' remoteness from the national electrification networks, alternative technologies are essential for this sector. The commonly promoted technological interventions for water pumping include distributed energy generation configurations such as standalone solar and solar-wind-generator hybrids. Although, just as street lights are essential in facilitating night movement and safety in urban areas, they are also essential in rural areas and should be promoted as well. In rural areas without installed street lighting, people use handheld devices like torches to enable their night movement, spending their limited income on purchasing dry-cell batteries. A survey conducted in 568 rural households in Sierra Leone established that 93% of households used dry-cell battery powered torches as their main light source while 3% used kerosene lamps. Provision of street lighting can be formulated for rural areas as either part of distributed community mini-grids or as standalone renewable energy technologies. Either way, data is required concerning rural areas and street lighting infrastructure.

Table 1 Proposed classification framework for rural energy sector

Sectors	Sub-sectors	Main end uses
Households	–	Electricity, Cooking, Space Heating
Social Services	Health posts, Clinics, Public Institutions	Definitions of differences between Health posts and clinics Energy end-uses in public institutions are located in such facilities as government administrative offices, police stations, religious buildings, prisons, community centres, public libraries, orphanages and sports facilities.
Infrastructure	–	Rural infrastructure energy end-uses including street lighting and water pumping (for irrigation, livestock watering, and potable water for human use). Excludes large-scale infrastructure such as transport and telecommunication towers.
Productive activities/ enterprises	Small shops, Micro, Small and Medium Enterprises (MSMEs), Farmers	Examples of farmer energy end use activities may include egg incubation, crop spraying, electric fencing, forced ventilation in greenhouses, crop dryers, lighting, refrigeration for veterinary applications, refrigeration (crops, products, and veterinary medicines), ice making, grinding, hulling of grains.

2.5 Productive activities/enterprises

This category of rural energy sector consists of rural activities that can contribute towards the development of the rural economy. Although most rural areas are a mix of informal non-farm enterprises as well as subsistence activities, agriculture is the most widespread. Since outputs from agriculture are an essential aspect of developing a rural economy, they are mainly considered the central focus for this classification, as previously shown in Table 1. This is evidently the sector where energy access requires systems of higher capacity and cost than those needed for households, infrastructure and community services. For example, in a study by Practical Action, it was found that the size of the distributed energy system is an important factor for enterprises. While access through distributed energy systems such as mini-grids could be technically viable, they may generate electricity at a higher per kW h price than the price from a central grid which can be a burden to enterprises. However, further knowledge is necessary in order to understand the sufficient energy consumption levels to facilitate agro-processing enterprises, trade between rural and urban areas and to create local employment in rural communities.

3. The Energy Challenge

Global consumption of commercial forms of energy has increased steadily over the last four decades and has been recently marked by especially dramatic growth rates in many developing countries. Yet, stark inequalities persist throughout the world in the access to modern energy services. Between 1970 and 1988, the developing countries' share of global primary energy consumption rose from approximately 13 percent to about 30 percent. In 2005, the non-OECD countries accounted for just over half (52 percent) of global primary energy consumption. This increase in energy consumption has not, however, resulted in a more equitable access to energy services on a per capita basis. In 2005, the average per capita consumption of energy in the OECD countries was more than four times the per capita average in all non-OECD countries, and nearly seven times the per capita average in Africa (IEA, Key Energy Statistics 2007, p. 48). Overall, at least one quarter of the world's 6.6 billion people are unable to take advantage of the basic amenities and opportunities made possible by modern forms of energy. The inequities in per capita use of electricity are even greater than the inequities in per capita use of primary energy. In 2005, the average citizen in the OECD countries used 8,365 kwh of electricity. In contrast, the average citizen in China used 1,802 kwh and the per capita average for the rest of Asia was 646 kwh. The per capita average use of electricity in 2005 in Latin America and Africa were 1,695 kwh and 563 kwh respectively.

Table 2. Typical Electricity Requirements for Off-Grid Populations in Developing Countries.

Energy Service/Development Need	Typical energy services	Electricity demand kWh/month per household
Lighting	5 hours/day @ 20 W/household	2.0-6.0
Radio/Music	5 hours/day @ 5 W/household	2.0-6.0
Communications	2 hours/day @ 10 W/household	2.0-6.0
Potable Water	Community electric pump providing 5 liters/day/capita	2.0-6.0
Basic Medical Services	2.5 kWh/day for 100 households	0.5-1.0
Education	2.5 kWh/day for 100 household	0.5-1.0
Income generating productive uses	5 kWh/day for 10 households	0.0-20.0
TOTAL	—	3.0-30.0

These regionally or nationally aggregated figures mask even starker within-country disparities, since the energy consumption patterns of elites in many developing countries are similar to those of the general population in developed countries. In fact, although it has been estimated that developing countries were spending as much as $40 to $60 billion annually on electricity systems by the end of the 20th century (G8, RETF, 2001), approximately 40 percent of the population in these countries remained without access to electricity. This means that the number of people throughout the world who had no access to electricity has hardly changed in absolute terms since 1970 (UNDP, 2000, p. 374). Not surprisingly, the rural poor in developing countries account for the vast majority (nearly 90 percent) of households that have no access to electricity.

The immediate obstacle to access to energy for many poor households and governments in developing countries is a lack of financial resources. Moreover, where access to energy is lacking, other urgent human and societal needs also are often not met, meaning that energy needs must compete with other priorities. Fortunately, people need only a relatively modest amount of electricity to be able to read at night, pump a minimal amount of drinking water and listen to radio broadcasts (G8-RETF, 2001). In other words, it is possible to greatly improve the quality of life for many poor households with a level of energy consumption that is far below that of the average citizen in an industrialized country.

3.1 Rural energy needs, potential technologies and future research challenges for DCs

In this section, potential technological pathways for addressing the energy needs in the context of off-grid locations of DCs are highlighted. The energy needs categories represent enablers for security, entertainment, social service delivery, wellbeing and rural economic activity. The International Renewable Energy Agency (IRENA) proposed several potential renewable energy technologies for off-grid locations, is an expanded list with regrouped energy needs that suggest potential research areas. The checkmarks indicate confirmed applications while the question marks indicate areas of interesting research. Solar photovoltaic-thermal (PVT) systems are included as an interesting technology for further research and development for energy needs of off-grid locations of DCs. PVT systems are a class of solar energy harvesting technologies that can generate electricity and lowgrade heat simultaneously thereby attaining higher solar conversion efficiencies. For instance, PVT systems could be developed to energize a variety of combined low power electrical and thermal energy applications thereby replacing kerosene and biomass use in remote off-grid households. Although most of the work to-date has largely focused on the development and experimentation of PVT collectors as building integrated elements, Solar energy harvesting technology is particularly of interest owing to a number of benefits. It is environmentally benign, durable, has low maintenance and operating costs, low investment risks, draws on permanently abundant resource, and can facilitate the initiation of income generating activities capable of developing local technical expertise and boosting the rural economy in DCs.

Table 3 Categories of rural health clinics of DCs and their estimated energy requirements.

Category	No. of beds	Typical end uses	Demand (kW h/year)
I (low energy requirement)	0–60	Evening light, cold chain for vaccines, blood and medical supplies, basic lab equipment (centrifuge, haematology mixer, incubator)	1825–3652
II (medium energy requirement)	60–120	More sophisticated diagnostic medical equipment, communication device, separate refrigerators for food storage and cold chain in addition to Category I loads	3650–7300
III (high energy requirement)	> 120	Information technology equipment, x-ray machine,CD4 counters, blood typing equipment etc.	7300–10,950

The availability of energy efficient appliances for the off-grid energy market is a theme of increasing importance as they influence the affordability of the overall system. International development experts know too well that energy by itself will not change lives, but rather, what people can be able to do with it, will. the status quo of electrical appliances in off-grid systems and shown that a move from business as usual appliances to energy efficient appliances can significantly reduce system cost and transform the effectiveness and widespread use of modern energy in rural locations. Low voltage super-efficient DC appliances powered by off-grid solar systems are available and are likely to receive significant support in programs funded by governments and international development agencies.

Finally, future research activities could modernise certain traditional activities in rural areas of DCs through novel ways by capturing, utilising and storing various forms of energy. Low-grade heat naturally existing in air and water and heat stored under the earth's surface can be of significant use in many developing countries. Researchers from high-income countries are demonstrating promising concepts in agriculture, space cooling and space heating among others. Agro-processing activities are a source of significant organic wastes and could be important supplementary fuel sources in waste-toenergy technologies particularly Combined Heating and Power (CHP) and Combined Cooling, Heating and Power (CCHP) systems. Other research efforts may advance techniques for harnessing waste heat in such decentralised energy systems to improve their techno-economic viability.

4. The Technology Challenge

The various energy supply technologies that will probably be used in a carbon-constrained future have been extensively reviewed elsewhere. The usual list includes renewable energy technologies (e.g., wind, solar and biomass), nuclear technology and advanced fossil-fuel systems with carbon capture and sequestration. Natural gas systems are widely viewed as a crucial ‘bridge’ technology. In addition, energy efficiency is often cited as a critically important and an often lower-cost complement to supply side improvements. In principle, the same supply- and demand-side options are available to all countries. Nevertheless, some options, especially technologies that are in very early stages of commercialization or require very large, initial capital investments or substantial outside expertise to operate, are likely to face additional obstacles to their use in developing countries.

A number of renewable energy technologies have been so improved that they can now provide electricity at a lower cost than other supply options wherever extension of the grid is prohibitively expensive or uneconomic. There are six broad categories of renewable energy technologies. They are biomass, wind, solar, hydro, geothermal and marine. They can be tapped by using a variety of conversion technologies or processes to produce a range of energy services, including electricity, heat (or cooling), fuels, mechanical power and illumination. The competitiveness of different renewable technologies in different settings depends on their cost and performance, as well as the local cost and availability of fossil-based energy. All of these factors still vary widely and depend strongly on local conditions. For example, many renewable energy sources are inherently intermittent. Thus, their integration into a unified electricity grid can pose challenges, especially on a large scale, and may make them less competitive with conventional generating systems.6 In dispersed, off-grid applications, intermittency may pose less of a problem and renewable technologies may be more cost-effective than the next available conventional option. In addition, the modularity of many renewable energy technologies facilitates their deployment in relatively small increments. This can be advantageous in cost and risk to many developing countries.

Conclusion

Since the start of the industrial revolution, the capacity to capture and utilise various sources of energy has drastically improved the quality of life for billions of people, allowing them to live in comfort and mobility unheard of in human history and releasing them to carry out ever-more-productive work. For the majority of the previous 200 years, there has been a direct correlation between growing levels of affluence and economic opportunity throughout most of the world and the steady development in energy consumption. However, a major energy crisis is currently facing civilization. There are at least two important dimensions to this problem. It is now obvious that the way we currently consume energy is not environmentally sustainable. Particularly, the heavy reliance on fossil fuels poses a major danger to the integrity of both important natural systems and human systems by drastically altering the temperature of the planet. The 'haves' and the 'have-nots' continue to be separated by the availability of energy. According to some estimates, more than two billion people worldwide still don't have access to electricity, clean cooking fuel, or reliable transportation, which together make up a significant portion of essential energy services.

The current energy outlook is challenging to say the least. Whether governments are chiefly concerned with economic growth, environmental protection or energy security, it is clear that a continuation of current energy trends will have many undesirable consequences at best, and risk grave, global threats to the well-being of the human race at worst. The situation in developing countries is in many ways more difficult than that for developed countries. Not only are there obvious resource constraints, but also a significant part of the population may lack access to basic energy services. Yet, developing countries also have some advantages. They can learn from past experience, avoid some of the policy missteps of the last half century and have an opportunity to "leapfrog" directly to cleaner and more efficient technologies. Fortunately many essential elements of a sustainable energy transition can be expected to mesh well with other critical development objectives, such as improving public health, broadening employment opportunities, nurturing domestic industries, expanding reliance on indigenous resources and improving a country's balance of trade. This does not mean that cleaner, more efficient technologies will usually be the first choice or that difficult trade-offs can always be avoided. In the near term, many sustainable energy technologies are likely to remain more expensive than their conventional counterparts. Even when they are cost-effective, as is already the case for many efficient technologies, powerful market failures and barriers often stand in the way. Changing the incentives and overcoming those barriers is now more a question of political will and coordination than one of adequate resources (at least at the global level).

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