

Biomass and Solar Energy for Rural Electrification and CO₂ Mitigation in Cambodia

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Abstract

Cambodia has the highest fuel oil dependence in the power sector among the Asian countries. In 2007, about 85% of fuel oil was supplied for electricity production consuming 1.6% of gross domestic product (GDP). Presently, only 18% of households in Cambodia have access to the electricity grid. Moreover, 75% of the electrified households are in the urban area and 9% are in the rural area. These figures are not satisfactory for Cambodian government. The less electrification in rural areas and the high electricity price are very harmful to Cambodian development. The competitiveness of the fuel oil price in power generation is very hard to increase electrification in the whole nation. By 2030, 70% of all rural households shall have access to the electricity grid, as per government plan. Cambodia has a good potential in renewable energy resources such as 10 GW of hydropower with 1.5% from small and mini hydropower, 1.5 million tones of biomass residues per year and annual solar radiation of 5.1 kWh/m² per day. These alternative resources are commonly preferred supplies for the decentralized system in the rural areas. To understand and promote the useful potential of renewable energy resources in the country for long term development plan on rural electrification in Cambodia, the objectives of the study are (1) to examine the future potential of biomass and solar power for rural electricity generation to reduce the fuel oil dependency, (2) to assess the electricity demand, and (3) to mitigate CO₂ emission by using the Long-range Energy Alternative Planning system (LEAP) model for the study period of 2007 to 2030. Results are presented of biomass potential and solar energy for Cambodian rural electrification and CO₂ mitigation.

Keywords Biomass, Solar energy, Rural electrification, CO₂ mitigation, LEAP model.

1. Introduction

Rural electrification is a very critical issue for developing countries in terms of socioeconomic development and improvement on quality of people's livelihood. In 2002, almost 1.6 billion people in the developing countries were still living without access to electricity and around 50% of these developing countries were situated in South (or southeast?) Asia [1]. According to the outlook projection of Millennium Development Goal (MDG), by the year 2015, the world population without access to electricity will decrease to 0.98 billion people, while in the South(or southeast?) Asia it is accounted for 43%. In 2009, among developing countries in Southeast Asia, Cambodia still has a very low rate of electrification, while many countries in the region such as Singapore, Malaysia, Thailand, Philippines and Vietnam have achieved a high level of electrification (Table 1).

As mentioned above, electrification is a main indicator of socioeconomic development. To extend the rural electrification coverage and to implement the electrification programs, many developing countries are still depending on the international financing. For example, rural electrification program in Bangladesh was developed by the Infrastructure Development Company Limited (IDCOL) with the help of the international institutions such as World Bank [2]. Similarly, Cambodia is also one of the developing countries which is getting the financing from the World Bank (WB) and Asian Development Bank (ADB) for the rural electrification. The program is being implemented by the Rural Electrification Fund (REF) Secretariat [3].

Table 1. Electrification in the Southeast Asia in 2009

Country	Electrification (%)
Cambodia	15.8
Indonesia	53.4
Lao PDR	n.a.
Malaysia	96.9
Myanmar	5
Philippines	87.4
Singapore	100
Thailand	98.5
Vietnam	75.8

Source: [2].

In 2007, only 18% of the Cambodian households had access to the electricity grid, increased by 2.2% from 2005. Only 9% of households in the rural area have been electrified. Government has target to achieve 70% electrification in the rural area by the year 2030. To meet this target, besides extending the access to electricity grid, the promotion of the mini-hydro and solar energy, which are being financed by the World Bank and Asian Development Bank, and biomass gasification technology are identified as suitable means to increase rural electrification by using the domestic resources, which are dominant in the country. Cambodia is an agricultural-based country. Around 70% of total population generates income from rice farming, other crops and agriculture products [4]. In 2007, Cambodian population reached 14.32 millions with an average annual growth rate of 1.9% [5], and with 103 kWh of per capita annual electricity consumption [6].

The total installed electricity capacity in the country is 330 MW. About 85% of electric power is produced from fuel oil (diesel oil and heavy fuel oil), followed by electricity imports (11%), and generation from hydro power (4%) as presented in Fig 1. These capacities are contributed mainly by Independent Power Producers (IPP), and accounted for 65% of total installed capacity. Its major supply is in Phnom Penh under power purchase agreement (PPA) with Electricité Du Cambodge (EDC), the state owned electric utility. The EDC operates within 12 provincial towns including Phnom Penh. It contributes about 20%, while 5% comes from the Private Electricity Company (PEC) operating in six provincial towns. The Rural Electricity Enterprises (REEs) are using the small diesel generators (gen-sets) to serve electricity in the rural area. It contributes about 10% with 143 registered licenses [7].

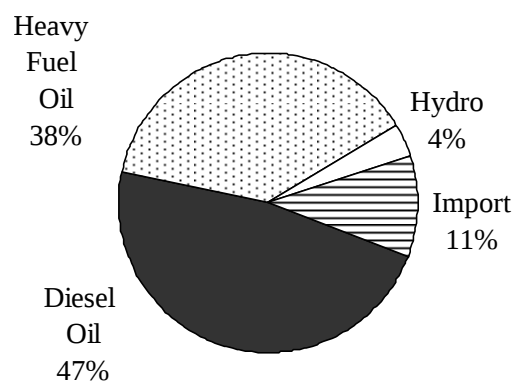


Fig 1. Electricity generation by fuel types in Cambodia in 2007.

In 2007, the electricity generation reached 1,464 GWh with 16% of annual growth rate [6]. The most of the supply was concentrated mainly in Phnom Penh City, and accounted for 73% of total electricity production. Fig 2 presents the share of electricity production by different types of fuels in the power sector in past decade, where the heavy fuel oil (HFO) and diesel (DO) were mainly used in

electricity production. In the rural area, which is supplied with electricity by the REE, the electricity generation comes from small diesel gen-sets at high fuel consumption of 0.38 liter per kWh and high losses of around 25%. It directly increases the electricity cost to the consumers. Cambodia has a highest electricity price in the region which varies from 0.5 to 0.75 US\$ per kWh in the different rural areas [7].

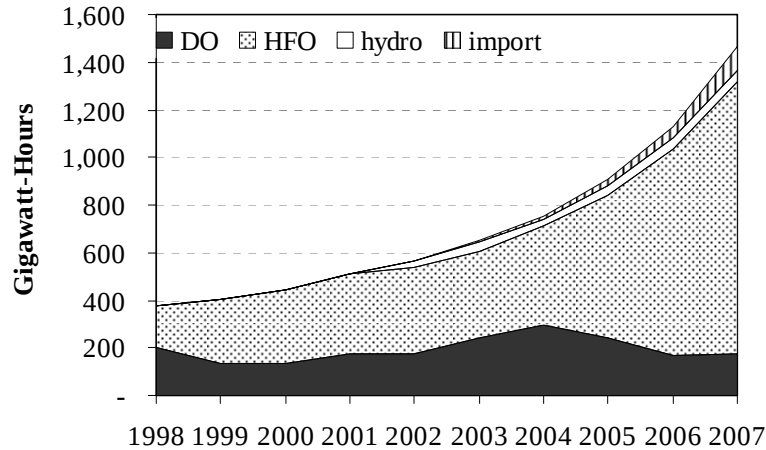


Fig 2. Electricity generation by fuel types in Cambodia during 1998-2007.

This paper is organized as follows: Section 1 presents the introduction, Section 2 presents the methodology of using the LEAP model, Section 3 discusses on the scenarios designed for projection of the future rural electrification, and Section 4 briefs on the renewable potential such as biomass residues and solar power in Cambodia. Finally, Section 5 presents the results and discussion of the biomass and solar power for future rural electrification, and Section 6 gives the conclusion of the paper.

2. Methodology

2.1 LEAP model

A scenario based energy-environment model, called Long-range Energy Alternative Planning system (LEAP), was used to examine the result of (1) the future potential of biomass and solar power for rural electricity generation, (2) forecast of rural electricity demand, (3) CO₂ mitigation from the power generation in the rural area by using the biomass and solar energy to replace the conventional diesel generators.

Originally LEAP was developed by Stockholm Environment Institute (SEI) [8]. It is a model which applies the bottom-up approach. The projections on the program are made to analyze on future energy demand and examine a wide variety of projects and technologies arriving at strategies that best address environmental and energy problems. LEAP allows for analysis as rich in technological specification and end-use details as per requirement and it incorporates a full range of energy system, which organizes as well known from the energy carriers, transformation with the losses in the process, and through the final form of energy end-use. Moreover, LEAP provides a very convenient background, easy to run on the window system and offers to meet the basic standard data of energy composition, energy contents, and emissions.

For environmental assessment, LEAP can provide the results of pollution emission factors from each stage of fuel processing in power generation, including the cost of generating electricity and greenhouse gas emissions, extraction process, distribution, and the end-use activities[9]. In some researches, LEAP model was used to simulate emission inventories and external costs of fossil electricity generation along with different future energy consumption patterns and pollutants

abatement policies under user-defined assumptions [10], and LEAP can provide an appropriated results of future energy demand based on the government policies as well as the characteristics of household consumers in different classes by income level and economic prospective in different areas between urban and rural, under the scenarios, to improve the quality of people's livelihood and reducing the wood dependency [11].

2.2 Key Assumptions

To use LEAP model, the data needs to be organized in current account such as types of energy intensity, activity level of energy uses, population, growth rate, GDP, etc. In 2007, Cambodia's population was 14.32 millions with the national gross domestic product (GDP) of 8.17 billion dollars [12]. Based on an estimate, Cambodian population will increase with an average growth rate of 1.9% per year, with the annual GDP growth rate of 6.3% up to 2020[5]. In this study, the population and the GDP growth rate are assumed to be stable and continuing to grow at the same rate until the end of 2030. According to the National Institute of Statistics (NIS), the average household size in the whole country is 5.3 persons [13]. The households size in Cambodia is also assumed to be same through the base year until the end year of this study. Urbanization is the main factor to limit the urban and rural population. Based on the world development indicators, urban area in Cambodia will increase to around 30% in the year 2030, while in the base year, the urban area is 17% [5]. In rural area, the household's electricity consumption varies from 10, to 18, and to 27 kWh per month for lower, medium, and high users, respectively [11]. An steady increase in the electricity consumption in the rural households is expected at all level of users, with an annual growth rate of 4.5% for the whole period. Today, the total installed capacity of diesel gen-sets is estimated around 65 MW, while 32 MW is contributed by REEs-licenses and the remaining capacity is accounted from REEs-non licenses.

3. Scenario Analysis

In this paper, there are two scenarios used in analysis. Firstly, the rural electricity demand pattern, and the second is the scenario of CO₂ mitigation by using the biomass and solar energy to replace the diesel gen-sets for the future rural electrification.

3.1 Business as Usual (BAU) Scenario

The household electricity demands in the rural area are derived from using all the key assumptions and applied to the government's target to achieve 70% of rural electrification by 2030. We assumed that all households in the rural areas are connected to the REEs mini-grid by using the diesel gen-sets with the process efficiency of 25% and capacity factor of 25%. Presently, the REEs are operating electricity service with the high losses in the distribution system, around 25%. We assumed that by improving the technical standard, the power loss will be reduced to 15% by the end of 2030.

3.2 Biomass and Solar (BIOS) Scenario

Accordingly, the purpose of this study is to promote the biomass and solar energy in rural electrification development. So, the biomass and solar power are introduced in the BIOS scenario. The biomass gasification technology will contribute in the rural electrification starting 5% in the year 2010, and increase to 95% at the end of the study period. This system would provide electricity services to rural consumers around 6 hours per day with process efficiency of 25%. In contrast, the diesel gen-sets, which are being used by REEs, will be replaced deeply by the biomass gasification technology for mini-grid. In 2030, only around 2% of the diesel gen-sets are assumed to still remain operating in some rural areas. Solar home systems (SHS) will be introduced to the rural households, which are far away from the mini-grid. Based on the data from Rural Electrification Fund (REF), it is assumed that the SHS will be provided for the lower households, with the financing support from the World Bank, for 12,000 systems in every 5 years. The capacity of the solar power is 40 W_p which is

preferred to supply the lower demand family around 5 kWh per month and responding to the daily operation of about 3 to 4 hours. Solar home system (SHS) will contribute to the government target in rural electrification about 3% by the year 2030.

4. Renewable Energy Potential

4.1 Biomass

In 2007, biomass covered around 80-85% of the national energy consumption of Cambodia [14]. Biomass potential comes from agricultural residue, which is abundant in the country after the farming harvests. The common agricultural products in the country are rice, sugarcane, corn and peanut are for common domestic consumption and export. The amount of agricultural products such as rice are increasing steadily with an annual growth rate of 2.3% [4]. Table 2 presents the available agricultural products in Cambodia reported by the New Energy and Industrial Technology Development Organization (NEDO) of Japan.

Table 2 Agricultural biomass resources in Cambodia.

Agriculture	Production (kton)	Conversion (%)	Residue (kton)
Rice	4026	20	805
Bagasse	1642	30	496
Maize	279	20	55.8
Peanut ^a	18.5	30	5.5
Cassava ^b	330.6	30	99.18
Rubber tree ^c	-	-	40
Total			1,501.5

Sources: NEDO-2002, (a, b, c) [7].

The potential of biomass residues in the country would be converted to electricity by using the biomass gasification technology. This technology is very useful for Cambodian rural electrification with the capacity factors of about 20-30%. The installed capacities ranging from 4 kW_e to 850 kW_e are commercially available in Cambodia [15]. It is recommended for supply to the consumer around 100 to 300 households at the mini-grid level. Based on the study of NEDO, the biomass residues have poor characteristics in low heating value (LHV). Table 3 presents the amount of biomass residues required to produce 1 kWh of electricity by biomass gasification process.

Table 3 Biomass power consumption.

Biomass residues	Fuel used (kg/kWh)
Wood	0.71 – 1.43
Rice husks	0.86
Bagasse	1.5 – 1.56
Maize cobs	0.8 – 0.92
Palm fibers	1.09

Sources: NEDO-2002.

4.2 Solar power

Besides biomass resources, Cambodia has a great potential for solar power which is the alternative source for off-grid option in the rural area, specially the solar home system (SHS). From a technical perspective, and regardless of market considerations, Cambodia has excellent potential for solar power generation. In 2002, NEDO has produced a solar radiation map for Cambodia, using data from National Aeronautics and Space Administration NASA's Langley Research Center (LaRC) and the US National Renewable Energy Laboratory (NREL). Solar radiation has increased gradually from the northwest of the country with an average low energy of 4.11 kWh/m² per day to the southwest of the country with an average high energy of 5.23 kWh/m² per day. Based on this study, the maximum

fluctuation in solar radiation throughout the year is relatively low. It is estimated at around 17%. The NEDO solar radiation map shows that Cambodia has good potential for solar power generation [16].

5. Results and Discussion

5.1 Rural electricity demand

Regarding the projection, the electricity demand in the rural area will reach 922 GWh by the year 2030. The medium and high-income consumers are accounted for around 85% of rural electricity demand at the end of 2030 (Fig 3).

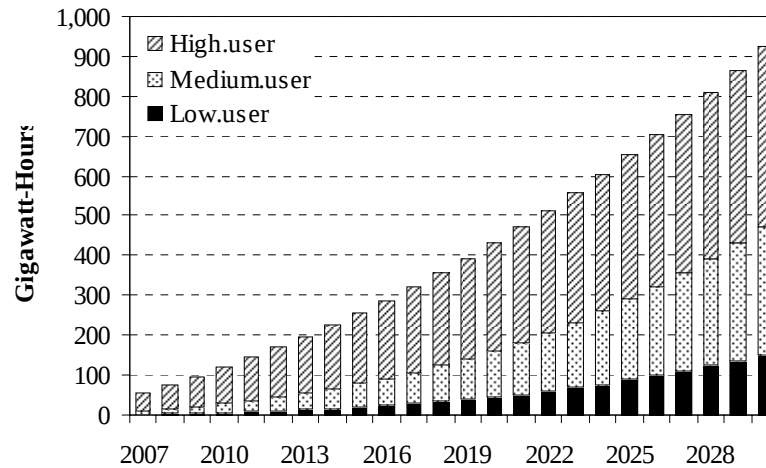


Fig 3. Rural electricity demand in the BAU scenario.

5.2 Electricity generation

Based on the key assumption and the projection in the BIOS scenario, the biomass gasification technologies are becoming the main electricity suppliers in the rural area. The total electricity production will increase to 1,083 GWh with a peak installed capacity requirement of 500 MW (Fig 4). The future electricity demand in the rural area is expected to be 922 GWh and the total capacity requirement of electricity generation is around 500 MW to meet the demand. The future biomass requirement to supply the system will be taken into account and discussed in the next section.

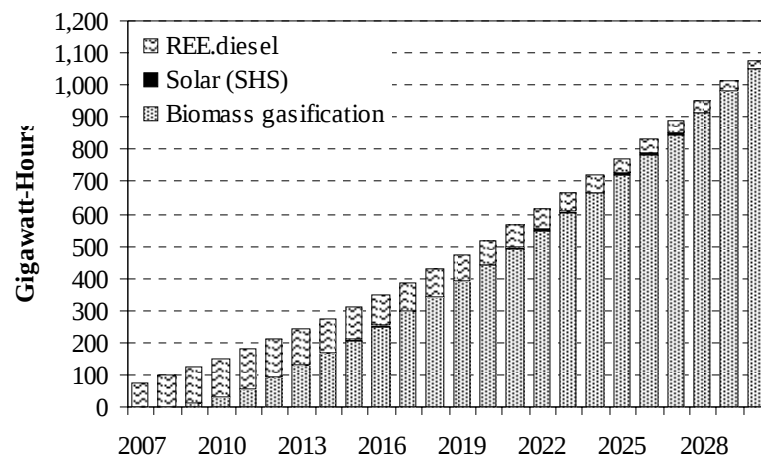


Fig 4. Biomass for rural electricity generation.

5.3 Household electrification

To meet the target of 70% of the rural households will have access to electricity by 2030, this paper defined that, in the future, most rural households will be electrified by the biomass gasification,

followed by solar home system (SHS) and diesel gen-set grid. As discussed in the previous section in the BIOS scenario, Table 4 presents the results of electrified household consumers.

Table 4. Number of electrified rural households.

Supplier	Unit: Thousand Households					
	2007	2010	2015	2020	2025	2030
Diesel	199.5	349.8	467.4	483.5	353	40.3
SHS	-	12.0	24.0	36.0	48.0	60.0
Biomass	-	27.8	244.6	602.3	1,147.3	1,916.8
Total	199.5	389.6	736	1,122.0	1,548.3	2,017.1

Based on the results, about 1,916 thousand households will be connected to the biomass mini-grid in 2030, while the solar home system (SHS) will supply electricity 60 thousand households. In contrast, the diesel gen-sets are very small and remain using in some rural areas. To reach the target of 70% electrification means providing around 2 million households with access to electricity in 2030, and expected average annual growth rate of household electrification is about 12% per year, from 2007 to 2030, as presented in Table 5. It is a very hard task for the government to find the suppliers and mechanism to promote the local participation in the project.

Table 5 Estimated electrified households in Cambodia during 2007-2030.

	Annual households electrifies growth rate (%)				
	2007-2010	2010-2015	2015-2020	2020-2025	2025-2030
Electrified households (Thousand Households)	389.6	736	1,122	1,548.3	2,017.1
Growth rate (%)	19%	18%	10%	8%	6%
Average growth rate (%)			12.2%		

5.4 REEs participants

The participation from the REE in the rural electricity services depends on the number of households connected to the mini-grid. In case of 200 households connected to the grid, the REEs are required around 3,560 to 9,786 suppliers in 2015 and 2030 respectively as presented in Table 6.

Table 6 Number of rural electricity enterprises.

No. of households connected to mini-grid	Number of REEs					
	2007	2010	2015	2020	2025	2030
100	1,995	3,776	7,120	10,858	15,003	19,571
150	1,330	2,517	4,747	7,239	10,002	13,047
200	998	1,888	3,560	5,429	7,502	9,786
300	665	1,259	2,373	3,619	5,001	6,524
400	499	944	1,780	2,715	3,751	4,893

5.5 Biomass requirement

Based on annual electricity production from biomass power generation in the rural areas as shown in Fig 4, the amount of biomass residues needed to produce 1 kWh of electricity varies from 0.71 kg to 1.56 kg, as presented in Table 3. The amount of 2 kg rice husks is needed to produce 1 kWh of electricity as studied by the World Bank group [17]. It is assumed that the amount of biomass residue requirement varies from 1.5 kg to 4 kg to produce 1 kWh of electricity.

By using the above assumption, the total amount of biomass requirement to supply the biomass gasification system is presented in Table 7. According to the availability of biomass residues in the country (as mentioned in Table 2), and if the biomass system consumes 2 kg to produce 1 kWh, it can be expected that Cambodia has enough potential of biomass residues to supply the electric system for the whole planning horizon.

Table 7 Total biomass residue consumption for power generation.

Consumption rate (kg/kWh)	Total biomass residue consumption (kton)					
	2007	2012	2015	2020	2025	2030
1.5	-	282	424	709	1,064	1,491
2	-	376	566	945	1,418	1,988
3	-	563	848	1,418	2,127	2,982
4	-	751	1,131	1,891	2,836	3,976

5.6 CO₂ mitigation

Biomass gasification and solar power systems do not just only improve the electrification in the rural area, but also improve the quality of the environment by displacing the huge amount of diesel used in power generation. For the economic prospective, even these technologies confront with the high investment cost, but have potential for long term planning. By comparing the BAU and BIOS scenarios, LEAP model showed that the biomass gasification has enormous potential to mitigate CO₂ emission from the rural power generation. About 1,050 thousand tons of CO₂ emission could be avoided. In addition, the diesel fuel is saved around 400 million liters by the year 2030.

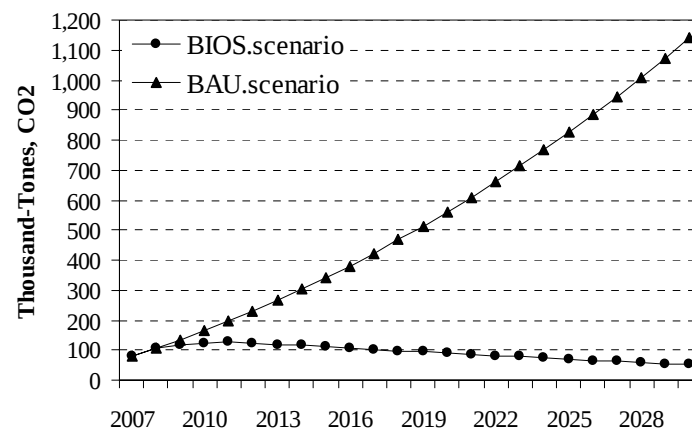


Fig 5. CO₂ mitigation in the BAU and BIOS scenarios.

6. Conclusions

The availability of agriculture biomass residues and the potential of the solar power in the country are very significant for socioeconomic development in order to improve the quality and opportunities of the rural area to get better electricity services. To reach the government's target of 70% electrification by 2030, around 2 million households need to be electrified in the rural area. At the same time, the rural households will have access to the mini-grid by biomass gasification systems about 1,916 thousand households, and 60 thousand rural households will be supplied by solar home power (SHS). Some households will still be supplied by the diesel gen-sets. To meet the future rural electricity demand and to provide better electricity service, about 9,786 of REEs would be required, considering 200 household connections per mini-grid by the year 2030. Moreover, the biomass residues and the solar power are the best options for the CO₂ emission mitigation, almost 1,050 thousand tons of CO₂ emission will be reduced and around 400 million-liters of the diesel fuel will be

saved by the year 2030. In addition, it can reduce the imported fuel dependency for the rural power generation. On the other hand, it is very useful to reduce the vulnerability from imported diesel by promoting and using the domestic renewable energy resources. Moreover, it is a positive mechanism to generate the national market and increase income for the rural communities.

7. Acknowledgement

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