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Modelling and forecasting energy demand in rural households of Bangladesh

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Abstract

Bangladesh, the eighth largest populous country in the world, has a significant rural population (70%), which is contributing to the energy demand of the country. The major portion in energy demand of rural households is biomass energy. With the improvement in GDP the rural energy demand would switch to more electricity intensive demand pathway. This paper focuses on a bottom up approach towards modelling the aggregated energy demand of rural households of Bangladesh form the year 2010 to 2050. The combination of four level scenarios of four variables (population, GDP electrification index, public energy conservation index) would forecast lowest, highest and optimum energy demand pathways for rural households of Bangladesh. The study not only considers the electricity demand of the rural household, but also it would render the opportunity to concentrate at the detail user end energy demands (e.g. liquid fuel, biomass etc.).

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Keywords: Energy demand; forecasting; rural households; Bangladesh

1. Introduction

Bangladesh had a population of approximately 151 million with a GDP per capita of 539.1 US $ (2005) in 2010[1]. According to World Bank 30.5% of total population lived in urban areas [2]. In other words, majority of the population (69.5%) of the population lived in rural areas and contributes in the energy demand of Bangladesh. Although 49.3% rural households had access to grid [3], majority of the households were utilizing biomass as cooking fuel [4-6]. But in 2011 the fuel types in cooking were same but the percentage in utilization of wood increased to 47.7% from 43.8% (2007) [7] in rural households with reduction in crop residue (40.1%) use [3] from 56.3% in 2007 [7]. It is evident that the rural household depended on the biomass for cooking, which dominated their energy demand. Despite being an inefficient

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cooking method [8], biomass fuelled cooking was main choice because of the availability of the biomass and the lower accessibility to electricity. Biomass energy would be replaced by more efficient energy system in the future [9]. The grid connected households were utilizing electric appliances, because of the increase in GDP per capita, which was elevating buying capacity. In 1996-1997 in the main electrical accessory were clock (41.6%), radio (29.1%) and television (5.8%) in rural households, while only 15.1% of the total rural population had access to electricity [6] and 316.7 US$ (2005) GDP per capita [2]. In 2007 and 2011 the rural electrified household percentage incremented to 36.6% and 49.3% respectively [3, 7]. Ownership of radio were 23.3% and 8.7% in 2007 and 2011[3, 7]. On the other hand, television and refrigerator were in 21.9% and 2.5% of the households in 2007[7]. The ownership of television and refrigerator increased to 29.8% and 6.2% respectively in 2011 and electric fan, DVD/VCD player and water pump owners were 41.2%, 8.2% and 4.2% respectively[3] and 568.7 US$ (2005) GDP per capita in 2011[2]. With the increase in accessibility to grid electricity and GDP per capita, the rural households were moving towards more electricity intensive consumption path. This paper will focus on this utilization characteristics of energy for appliance operations & cooking and a bottom up approach with different scenarios to model the future energy demand pathways up to 2050. The four variables (population, GDP electrification index, public energy conservation index) which drove the energy demand modelling had four scenarios each. The combination of these scenarios would calculate 256 different pathways. From these pathways, this paper would conclude in determining the highest, lowest and optimal energy demand pathways for rural households of Bangladesh.

2. Methodology

The total energy demand was calculated from the summation of electricity, liquid fuel and biomass demand. These demands were calculated with the following equations-

$$E_{ELEC} = A_{GRID} H F_{PEC} F_{GDP} \sum_{i=1}^{n} O_i N_i P_i \quad (1)$$

$$E_{LF} = (1 - A_{GRID}) H \sum_{i=1}^{n} O_i N_i P_i \quad (2)$$

$$E_{BIO} = H \sum_{i=1}^{n} O_i N_i P_i \quad (3)$$

Here, E_{ELEC}, E_{LF} and E_{BIO} denotes the electricity, liquid fuel and biomass demand, also A_{GRID} = Access to grid electricity, H= Number of rural household, F_{PEC} =Public energy conservation factor, $F_{GDP=}$ GDP electrification index, O_i= Operation hours of an appliance, N_i= Number of appliance (appliance ownership) and P_i= Rated power consumption of an appliance. Three types of assumptions were used in the model to forecast the energy demands-

a) Trajectory assumptions: Population, access to grid electricity (A_{GRID}), public energy conservation factor (F_{PEC}), GDP electrification index (F_{GDP}) and lighting technology choice were driven by trajectory assumptions.
b) Fixed assumptions: These assumptions were based on historical data. Rural household size which determines the number of rural household (H), appliance ownership (N_i), Operation hours of an appliance (O_i), Rated power consumption of an appliance (P_i) were driven by fixed assumptions.
c) Derived assumptions: These were based on the trajectory and fixed assumptions. Lighting technology choice, energy consumption per unit and solar home system (SHS) were forecasted in this assumptions.

The conclusive pathways were derived from the calculation stage with the aid of the trajectory, fixed and derived assumptions and compared, to suggest future energy demand pathways.

2.1. Trajectory assumptions

There were five main trajectory assumptions used in this model. These were population, access to electricity, GDP (Gross domestic product) electrification demand index, public energy conservation factor and lighting technology. In the study 2010 was considered as the base year in the model. **Population** of Bangladesh in 2010 was approximately 151 million according to the World Bank [2]. In the trajectory assumptions of population four level scenarios were considered. The level 1 denoted the constant fertility rate as per 2010. According to level 1 the population would reach 1.59 times (approximately 240 million) in 2050 of than that of 2010. On the other hand the level 4 assumed the low fertility rate, where the population would reach 1.14 times in 2050 of than that of 2010. The intermediate level 3 and level 4 represented the medium fertility and high fertility rates. Level 3 assumes that in 2050, the population would reach 1.34 times of the population in 2010. But level 4 assumes that in 2050, the population would be 1.56 times. Only 46.5% of the total population had **access to grid electricity** in Bangladesh [2]. Only 17.88% of the rural households had access to electricity in 2002[10], which was 23.25% in 2001 [1]. In 2010, rural access to electricity was 43.20% [1]. The Rural Electrification Board (REB) in its master plan of 2000, aimed to reach the 84% rural electrified household target by the year 2020 [11]. In this model level 4 (highly optimistic connectivity) would achieve the 84% mark by 2020 and saturate in 2050. In level 1 (connectivity as usual), at a current growth rate of 1.7% the access to grid would reach 57% by the year 2050. The access to grid would be 84% by the year 2050 was assumed in level 2 (easily achievable connectivity). In level 3 (moderately optimistic connectivity), the access to grid would reach to 84% target by 2045 and in 2050 it would be 90%. Causality between energy and GDP seemed more prevalent in the developed world than the developing world [12] and **GDP electrification demand index** represented this relation in this model. Bangladesh had a +6% GDP growth in 2010 [2], which puts Bangladesh in least developed country group. Slowly the GDP of Bangladesh is improving and it would influence the electricity demand. In 1980, the electric power consumption (kWh per capita) was 18.4 kWh in Bangladesh. Electric power consumption per capita was 657 kWh in Malaysia, 373 kWh for Philippines at the same time period [2]. This per capita electric power consumption elevated to 247 kWh for Bangladesh, 4136 kWh for Malaysia, and 641 kWh for Philippines in 2010 [2]. On the other hand, GDP per capita was 539.1 US $ (2005) for Bangladesh in 2010, while 6308.9 US $ (2005) for Malaysia and 1403.3 US $ (2005) for Philippines. But GDP per capita was 2,318.2 US $ (2005) in Malaysia and 1108.5 US $ (2005) Philippines in 1980 [2]. In level 1 it was assumed that Bangladesh would reach at the same stage in 2050, as Philippines was in 2010. This assumption gives the limit for level 1 of electricity use per capita in 2050, which would be three times of the electricity use per capita of Bangladesh in 2010 under business as usual (5%) GDP growth. In level 4, Bangladesh was assumed to reach the same stage as Malaysia in 2010. This assumption gives the limit for level 4 of electricity use per capita in 2050, which would be 6.5 times of the electricity use per capita of Bangladesh in 2010, where GDP growth would be high optimistic (8%). Level 2 (under easily achievable (6%) GPD growth) and level 3 (under moderately optimistic (7%) GPD growth) are working as intermediate levels of electricity demand index, with evenly interval between level 1 and 4. The **public energy conservation factor** represents the effect of awareness in using energy on the reduction of energy demand. Public monitoring, smart use and feedback of energy utilization improves the effectiveness of other information and advice in achieving better understanding and control of energy use [13]. In the model, level 1 was assumed to increase public energy conservation factor three times in 2050 than that of 2010. Level 4 assumed that the public would be more concern about utilizing energy, which would result in a 6.59 times increase in 2050 than 2010. Level 2 and 3 were evenly distributed between level 1 and 4. **Lighting technology choice** is a technology mix among available technologies. At present, mainly incandescent lights, fluorescent lights, compact fluorescent lights (CFL) [14] and light emitting diode

(LED) lights are available in rural households. In level 1, the technology mix would be incandescent light intensive (40%). Level 2 would be more dominated by fluorescent lights (60% of the total lighting demand in 2050). By 2050, CFL would dominate rural household in level 3 (60% of total lighting demand). In level 4, dominating lighting technology would be LED (80% of the total lighting demand by 2050).

2.2. Fixed assumption

There were four fixed assumptions in this model for calculating the scenarios. These were rural household size, appliance ownership, unit power consumed by the appliances and number of hours operated annually. **The rural household size** assumption would determine the number of households in the rural Bangladesh. According to BBS, in 2001 the rural household size was 4.89 [15] and in 2011 was 4.5 [1]. For this model the current household size of Malaysia in 2010 was considered as the basis of assumption for 2050 household size of Bangladesh. Because Malaysia is a Muslim country with similar sociocultural aspects of Bangladesh. With the development in GDP by the year 2050, Bangladesh may be able to reach at the similar GDP per capita level as Malaysia. In Malaysia the average household size was 4.2 in 2010 [16]. The energy demand of household largely depended on the **appliance ownership, rated power consumption and operation hour** of those appliances. The appliance ownership was projected with the utilization of logistic S-curve progression.

Table 1. Appliance ownership per household up to 2050.

Appliance	Rated consumption (*W*)[†]	Operation (*hrs/day*)	Ownership* in 5-year timescale (%)								
			2010	2015	2020	2025	2030	2035	2040	2045	2050
Lighting	16- 100**	4.6[╬]	396.8	397.8	398.8	399.6	400.7	401.7	402.6	403.6	404.5
Radio	11	1	18.5	13.5	9.8	6.5	5.0	4.0	2.5	1.8	1.5
TV	68	2	24.7	34.6	45.9	57.3	67.7	76.2	82.5	86.9	89.9
Computer	157	1	0.1	0.1	0.1	0.1	0.20	0.20	0.20	0.20	0.2
Refrigerator	669	12[╚]	5.5	12.3	24.9	43.8	63.9	79.0	87.6	91.8	93.6
Fan	39	24[┴]	45.1	56.92	71.54	89.30	110.5	135.5	164.2	196.4	231.6
AC	1500	12[╚]	0.4	0.12	0.37	1.13	3.37	9.33	21.78	38.30	50.7
Others	397	1	8.6	15.5	25.9	39.2	52.6	63.4	70.7	75.1	77.6
Cooking (biomass)	14082.02[#]	-	99.9	99.6	98.2	92.3	76.3	59.1	52.1	50.4	50.1
Cooking (electric)	825[##]	1.5	0.1	0.4	1.8	7.7	23.7	40.9	47.9	49.6	49.9

*Ownership is given as percentage (%). 100% refers to one installed unit.

†Power consumption data are obtained from [17]except for CFL and LED, which are adopted from [18].

The unit is in annual kWh and calculated from [4, 19]

Calculated from the average between lowest and highest power consumption [20]

**Rated consumptions of lighting technology defer from 16 Watt (LED) to 100 Watt (Incandescent). It depends on the Lighting technology mix choice.

╬ For the electrified households, electricity used for 4.6 hours and non-electrified households use lantern (51%) and kupee (49%) for average 3.05 hours per night for lighting [10]

┴ Overall, there are three main seasons in Bangladesh [21]. On the basis of the seasons, electric fans and air conditioners would be operational for seven months annually (except winter) and would operate for 24 hours daily, which would contribute in peak demand in monsoon and summer [22].

╚ The compressors in air-conditioners and refrigerators do not run continuously [23]. For this reason in the model refrigerators run for 12 hours daily.

2.3. Derived assumptions

There were three derived assumptions. The first assumption was lighting technology choice, which depended on the lighting technology choice of trajectory assumptions. The second assumption was solar home system (SHS), which depended on the rural household number and the access to the grid electricity. **The lighting technology choice** mix in the trajectory assumptions showed the mix at different levels in the year 2050. In the derived assumption, this 2050 assumption worked as the upper limit. The calculation of the other years projected the technology choice from 2010 to 2050. The rural households, which had no or little access to grid electricity, would utilize the **solar home system (SHS)** [24]. For this reason the number of rural households utilizing SHS depended on these trajectory assumptions. When the population and access to grid electricity in rural household both would be in level 1, the SHS installation would become highest. Because the high population results in a higher number of households, of which 57% has access to grid electricity. The lowest number of SHS installation would be in level 4 choice, because lower population and higher access to grid would reduce the SHS installation to 1%. The **annual energy consumption per unit** appliance was calculated by multiplying the unit power consumed by an appliance and the number of operating hours annually.
The aggregated energy demand, biomass and electricity demand was **calculated** in TWh using the assumptions (trajectory, fixed and derived) and equations (1-3).

3. Results and discussion

There were four driving variables (population, GDP, access to grid and lighting and appliance) in this model for energy projections with four scenarios each. Combinations of these scenarios created 256 different demand pathways from 2010 to 2050. Of these pathways, the lowest energy demand pathway for rural households in Bangladesh came with population, GDP, access to grid electricity and lighting and appliances levers at low fertility rate, business as usual (5%), connectivity as usual (57% by 2050)and low consumption technology mix respectively. These scenarios demonstrated reduction in the energy demand from 370.3 TWh in 2010 to 276.9 TWh in 2050. On the other hand the highest energy demand for rural Bangladesh would be for population, GDP, access to grid electricity and lighting and appliances levers at constant fertility rate, highly optimistic (8%), high connectivity (99% by 2050) and high consumption technology mix scenarios respectively. The pathway would show an increase in energy demand from 370.3 TWh in 2010 to an approximately three times increase to 1229.1 TWh in 2050. In the lowest energy demand pathway, the demand would be low, but the GDP and the access to grid electricity would not be at a satisfactory level. From the pathway analysis, the lowest would not be the most sustainable. When the population, GDP, access to the grid and light and appliance would be at high fertility, moderately optimistic (7%), high connectivity and low consumption technology mix scenarios, the energy demand would be 525.2 TWh in 2050, which would be first optimal energy demand pathway. The second optimal pathway denoted that energy demand would be 638.7 TWh in 2050. Because the population growth would be at lowest fertility, but the GDP growth would be more highly optimistic 8%. Access to grid and light and appliance would be in level 4, which means that maximum 99% houses would be electrified and lighting and appliance would be in low energy demanding and the public awareness would be high in utilizing the energy. The aggregated energy demand pathways does not demonstrate the energy types. The analysis showed that biomass demand for cooking dominated the energy demand in rural households. According to the model outputs the transformation from biomass to electric cooking would reduce the biomass demand. In the highest energy demand scenario, the population, GDP and access to grid would be highest, which resulted in the higher biomass demand. All the other scenarios showed an approximately similar level of biomass demand. But the major energy demand in 2050 would be electricity demand by replacing biomass energy (Fig. 1(b)), which was also evident in other developing countries [5, 25, 26].

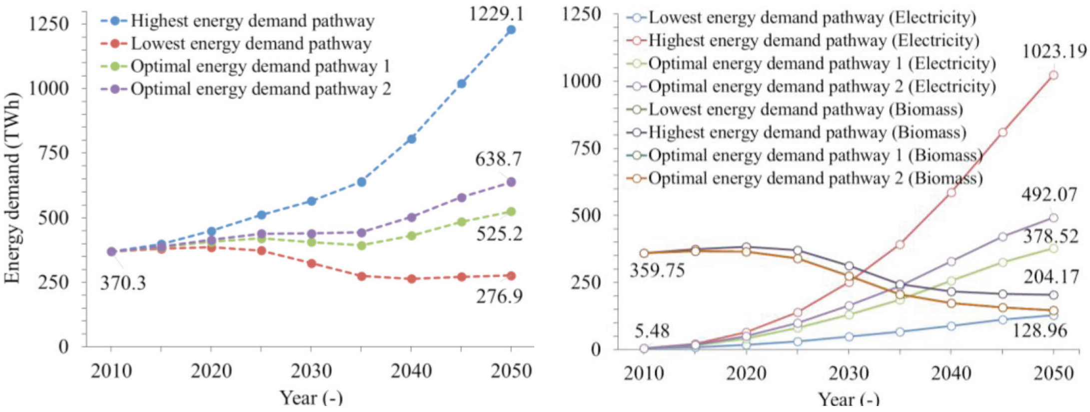

Fig. 1. (a) Aggregated energy demands (Left), (b) Electricity and biomass energy demand under different pathways (Right)

4. Conclusion

The energy demand pathway model demonstrated a significant rise in energy demand. In case of the highest demand the number can be three times of the demand of 2010. If the population, GDP, access to grid electricity and energy use awareness is not monitored and controlled, the demand can be devastating considering the unmet demand in 2010. Even the optimal pathways suggested an approximately two times rise in energy demand in 2050, than that of 2010. This model rendered an opportunity to focus on the detail energy use in households of rural Bangladesh and would work as a powerful tool for the future energy policy making process for the rural Bangladesh.

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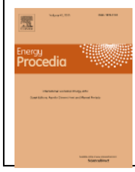

Biography

Kumar Biswajit Debnath is a doctoral researcher in the School of Engineering, Cardiff University, UK, working on "*2050 energy and carbon emissions pathways: Modelling the cost of decarbonisation*".