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MECHANICAL ENGINEERING | RESEARCH ARTICLE

Household energy and environmental analysis to highlight the impact of modern energy access in Bangladesh

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Abstract: Access of modern energy is the critical challenge in many developing countries to improve the socio-economic status and quality lifestyle. This paper illustrates the comparative energy and environmental analysis among three categories residential household in a developing country Bangladesh. The households are categorized based on types of energy access, since different communities adopted combination of different types of energy access. The aim of this study is to reflect the impacts of modern energy access and better combination the types of energy access in residential household to emphasize how to mitigate residential energy loss, reduce energy expenses, avoid limited fossil resources, reduce environmental impact, enhance modern facilities and improve the way of life. The study reveals that, household having combination of electricity access, metered gas connection and adoption of modern cooking appliances would be better option recommended in this study compared with other options.

Subjects: Power & Energy; Clean Tech; Built Environment

Keywords: energy; environmental impact; modern energy access; Bangladesh

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Md. Shazib Uddin has received Bachelor degree (Mechanical Engineering) from Rajshahi University of Engineering & Technology (RUET), Bangladesh and Master Degree (Energy Technology) from Asian Institute of Technology (AIT), Thailand. Now he is Assistant Professor of RUET. Uddin has research background on engine emissions with alternative fuels at undergraduate level and life cycle embodied energy and environmental impact assessment of energy technologies at graduate level. Recently completed key research works are energy efficiency, energy security, solar energy, HVAC, GHG emission and carbon footprint associated with energy technologies. The information reported in this article could be useful to the national and international energy management as well as energy conservation project and environmental regulatory team in developing countries for better management the energy access and environmental issues.

PUBLIC INTEREST STATEMENT

About 1.2 billion populations of the world have no access to electricity of which 95% populations are in developing countries. Availability of electricity in most of the developing countries is limited. So, electricity access in residential households is not widely distributed everywhere within the country. Therefore, different communities of the country adopted different combination of types of energy access to meet their energy needs. But which combination is better suited in the context of energy expenses, energy loss, environmental impact, modern facilities and quality life style and what are the impacts of modern energy access need to discover. Comparative energy and environmental analysis has been carried out in this article for three different category household in developing country Bangladesh to discover such answer. This article will be encouraging document to take initiatives for other developing countries for better management the energy and environmental issues.

1. Introduction

Energy access in all aspects of living activities is crucial for developing countries. About 17% of world populations (1.2 billion) have no access to electricity of which 95% peoples are in sub-Saharan Africa and Asian developing countries where 80% people living in rural areas (World Energy Outlook (WEO), 2015). They are directly using traditional fossil energy and biomass resources to meet their daily energy needs. As a result, they are affected by health problems and deprived from facilities of modern energy (Legros, Havet, Bruce, & Bonjour, 2009). On the other hand, increasing trend of global greenhouse gas (GHG) emission due to combustion of fossil energy emphasized on human threats in future (Uddin & Kumar, 2014). Currently, contribution of developing countries on global carbon emission is 63% (Center for Global Development, 2015) pinpointing the significance of controlling and mitigating such issues to make better environment. Residential households are the major sources of energy consumption and environmental emission (Heinonen & Junnila, 2014) and communities have combination of different types of energy access to meet the energy needs. Networking such households by modern energy and optimization the types of energy access combination could be an important step to control and mitigate such severe issues in developing countries.

Literatures on household energy analysis have been published. There are quite number of research paper based on Asian developing country China are available online (Chun-sheng, Shu-wen, & Xin, 2012; Liu, Wu, & Hu, 2012; Luo, Yang, Liu, & Xia, 2015; Meng et al., 2015; Wei, Li, & Zhang, 2015; Xiaohua, Kunquan, Hua, Di, & Jingru, 2017). These literatures have presented the energy analysis in residential and commercial household in rural and urban areas. Comparative energy analysis, assessment of indoor air quality and role of fossil sources are emphasized in their literatures. Household energy analysis for Finland and Netherland (Guerra Santin, Itard, & Visscher, 2009; Heinonen & Junnila, 2014) emphasized the effect of consumer behavioral aspects on household energy consumption. Carbon footprint analysis of Greek household (Markaki, Belegri-Roboli, Sarafidis, & Mirasgedis, 2017) have made correlation of household income with carbon emission. Life cycle energy consumption and GHG emission of low density house in Australia have investigated the impact of household activities on energy consumption (Stephan, Crawford, & de Myttenaere, 2013). Assessment of energy consumption of a hotel building in South Africa emphasized the price regulation and climatic condition has strong impact on energy consumption (Idahosa, Marwa, & Akotey, 2017). Investigation the influencing factors as determinant to adopt the renewable energy in Africa household emphasized the effect of wealth, education and gender on lighting energy (Rahut, Behera, & Ali, 2017). Household energy consumption in rural area of sub-Saharan Africa highlighted the energy consumption for cooking and lighting. Breakdown of household energy expenses are also analyzed in this study (Adkins, Ooppelstrup, & Modi, 2012).

Aforementioned review of the literatures shows that, most of the studies are reported for developing countries considering multiple aspects. Few of the literatures (Guerra Santin et al., 2009; Heinonen & Junnila, 2014; Markaki et al., 2017; Stephan et al., 2013) are reported for developed countries. Similar study for fast growing developing country Bangladesh is limited to single literature (Debnath, Mourshed, & Chew, 2015) emphasized only the expected future energy demand and recommended for further detail study. Environmental emissions and their impacts are less highlighted and unusual found in the available literatures. Moreover, comparative analysis among the household categories based on combination the types of energy access are important to optimize the household energy mix and to highlight the significance of modern energy access. Addressing these issues, a study on household energy consumption and environmental impacts has been undertaken at Rajshahi, Bangladesh. The salient feature of this study is that, households are classified based on combination the types of energy access and categorized namely, household have only electricity, household have electricity, gas and household have no electricity, gas. Questionnaire and survey type data is considered for the analysis.

The objectives of this study are to reflect the impacts of modern energy access and to recommend better combination the types of household energy access through comparative energy and environmental analysis. The manuscript is organized in the sequence as: Section 2 describes the

methodological approach, Section 3 describes the result and discussions and Section 4 presents the conclusion.

2. Methodological approach

This section describes the details of study area, data collection and estimation procedure of energy consumption and environmental impact for the selected residential households.

2.1. Description of the study area

The study conducted in Rajshahi is one of the largest divisional headquarter of Bangladesh. The temperature at Rajshahi in May–October is typically 25–40°C and in November–April is 8–20°C. Private type households are selected to ensure the reliable data as there are lacking's of energy management in public households. The households are divided in to three categories based on combination the types of energy access. The descriptions of the households are given below:

2.1.1. Household Category 1 (HC1)

Households adopted in this category are from apartment buildings and located in semi urban area. Number of family member is four and monthly average income is BDT 25,000. They have only electricity as the energy source for their daily energy needs except for cooking. LPG is used for cooking in this category.

2.1.2. Household Category 2 (HC2)

Urban households from apartment buildings are adopted in this category. Number of family member is five and monthly average income is BDT 24,900. They have electricity and natural gas as the energy source. They use natural gas for cooking and all other domestic loads are connected with grid electricity. Consumers pay fixed charge for monthly gas consumption and there are no gas flow meter installed in the domestic supply line.

2.1.3. Household Category 3 (HC3)

Rural households from detached buildings are adopted in this category. Number of family member is five and monthly average income is BDT 8,500. They have no access to grid electricity and natural gas. They consume solar energy, oil for their daily energy needs and wood biomass for cooking.

The number of sample household is selected based on the available family size of 4–5 members, since the availability of larger family size is very few. Average monthly income for HC1 and HC2 is very similar where HC3 is 66% lower than that of those two categories. Still have demand-supply gap for the above households and have expectation to increase the energy demand in future.

2.2. Data collection procedure

The data is collected from three types of residential houses for a month of extreme summer season. The surveyed and investigated number of household per each category for the study is 15. The information is collected from senior family members including male and female age of 40–50 years. More than 40 households are investigated of which 30 households are considered for the study based on maximum information collected and data reliability. Two students are sent to the selected location for data collection. One student gave the survey questions to the consumer and other one recorded the answers on survey form. After interview, the students measured and visited wherever necessary to check the reliability, neutrality and consistency the collected data. The investigation is conducted from May–June of the year 2016 based on the number of questions covered are number of family member, monthly income status, forms of energy use, types of appliances used, number of appliances, operating hour, energy expenses, etc. Feedback of the consumer is recorded in details as an energy report. The sample survey form and consumer feedback is shown in Table 1.

Table 1. Sample survey form and consumer feedback recorded for each household

Sample household	For Household category 1					Rating	Daily average use
	Number of family member	Monthly income (BDT)	Types of energy use	Type of appliances used	Nos.		
1	04	25,000	(i) Electricity (ii) LPG Gas	T8 Tube light	03	18 W	8 h
				CFL light	03	23 W	3hrs
				Ceiling Fan	03	65 W	10 h
				Colour TV	01	90 W	6 h
				Smart Mobile	02	5 W	4 h
				Refrigerator	01	100 W	15 h
				Water pump	01	1hp	0.5 h
				Induction cooker	01	1800 W	1 h
				Desktop Computer	01	100 W	4 h
				Gas cooker	01	LPG	0.41 kg

2.3. Estimation procedure

Total energy of a particular household is estimated by summing up the energy consumption for individual domestic appliances. Energy consumption for a particular electrical appliance is estimated by the following equation:

$$\text{Energy from electrical appliances (kWh)} = W \times n \times t \times d \tag{1}$$

where,

W = Power rating of the appliance (kW); n = Number of appliance; t = Daily average consumption hour (hr); d = Number of days per month.

Cooking energy is estimated by using the average quantities used (oil, wood) multiplied with their respective heating value. Energy from LPG consumption is calculated using the following equation:

$$\text{Energy from LPG use (kWh)} = N \times m \times CV \times \frac{1}{3600} \tag{2}$$

where,

N = Number of cylinder used per month; m = Amount of LPG per cylinder (kg); CV = Calorific value of LPG (kJ/kg)

Total energy consumption for a particular category is estimated by summing up the individual household energy consumption fall within the category.

In Bangladesh, domestic gas consumer pay fixed amount per month irrespective to consumption. Till now the consumers have freedom to consume natural gas as their wish. Hence, energy from natural gas consumption is estimated using the following equation:

$$\text{Energy from natural gas (kWh)} = v \times t \times d \times CV \times \frac{1}{3600} \tag{3}$$

where,

v = Volume flow rate (m^3/s); t = Daily average consumption hour; d = Number of days per month; CV = Calorific value of natural gas (kJ/m^3)

The household gas flow rate $600 \times 10^{-6} \text{ m}^3/\text{s}$ is used for the estimation and this information is collected from the gas supplier.

The forms of energy use by household categories are oil, LPG, natural gas, wood biomass, electricity and solar. The grid electricity in Bangladesh is depends on coal, oil, natural gas and renewable sources. Their share percentages are natural gas 64.5%, coal 2%, oil 25%, renewable 3.5% and imported 5% (Alam & Islam, 2015). Transmission and distribution loss in Bangladesh is 11% (Islam & Khan, 2017) and average generation efficiency of fossil based power plant is 34% (Uddin, Ahmed, & Ahmmed, 2016). Primary energy for the electricity generation is estimated using the following equation:

$$\text{Primary energy for electricity generation} = \frac{U}{\eta} \times 1.12 \quad (4)$$

where,

U = Unit electricity use by the consumer (kWh); η = Average generation efficiency (%); 1.12 is the coefficient due to transmission and distribution loss.

GHG emission for stationary combustion is estimated using the following equation:

$$\text{Emission due to stationary combustion} = m_f \times CV \times EF \quad (5)$$

where, m_f = Mass of fuel (kg); CV = Energy content (MJ/kg); EF = emission factor (kg/MJ)

Environmental impacts of these GHG emissions are estimated in terms of carbon di-oxide equivalent (kg CO_2 -eq). The conversion of CO_2 -eq for each emission is calculated multiplied by their individual global warming potential (GWP) with the quantities of emission estimated using the following equation:

$$\text{Env. impact for a particular gas (kg } \text{CO}_2\text{-eq)} = m_g \times \text{GWP} \quad (6)$$

where, m_g = Mass of a particular gas (kg); GWP = Potential of global warming

Total CO_2 -eq for the category is estimated by summing up the estimated value for individual GHG gas falls within the category. GWP values for the gases CO_2 , CH_4 and NO_x are 1, 28 and 265 respectively adopted to estimate the environmental impact in this study (IPCC, 2014).

3. Results and discussion

Energy analysis, GHG emission and environmental impact of the household categories are presented in this section.

3.1. Energy analysis

3.1.1. Energy consumption per household

The average energy consumption per household for a month of extreme summer season is 404, 4,345 and 1,169 kWh for HC1, HC2 and HC3 respectively. It is seen that, energy consumption in HC2 is significantly higher than that of HC1, though life quality and modern facilities are similar for these two categories. This is due to the household in HC2 have unmetered natural gas supply which lead to uncontrol gas consumption by the consumer. They are habituate to use natural gas not only for cooking but also heating as well as drying cloth is the reality investigated by the author in practice. On the other hand, energy consumption in HC3 is much higher than HC1, though the people in HC3 survive in a local area and deprived from modern facilities. This is due to the use of primary energy as their first preference and inefficient biomass cook stove for cooking. Thus, energy loss can be prevented in HC2 through well managed the natural gas consumption and domestic supply. Energy situation as well as modern facilities in HC3 could improve through integrating the modern energy access.

3.1.2. Energy consumption by types of appliance

Table 2 shows the household energy consumption for different types of appliances. It is seen that, HC1 and HC2 shows the similar characteristics of energy consumption except cooking. Cooking energy for HC1 estimated is 248 kWh where in HC2 is 4171 kWh. This is due to the fact that, HC1 adopted electric cooker and LPG for cooking where public supply of unmetered natural gas adopted in HC2. Obviously, modern electric cookers are most efficient cooking appliances rather than normal domestic cookers. Though, natural gas is more modern than LPG but uncontrolled consumption of natural gas in HC2 is responsible for higher cooking energy in HC2. On the other hand, HC3 consume solar energy and oil to meet energy demand for limited number of appliances like mobile charging and lighting. Cooking energy for HC3 estimated is 995 kWh which is much higher than HC1. They use wood biomass for cooking and unimproved cooking appliance is responsible for higher energy consumption in HC3.

Figure 1 shows the household energy consumption share by different appliances for the categories. It is seen that, contribution of cooking energy in total consumption is significant for all three types of categories. Around 52% of total consumption share by conventional cooker in HC1 where 95% in HC2 and 85% in HC3. Hence, provision of modern energy facilities with modern cooking technology could be an important driver to mitigate the loss of fossil energy use in conventional cooking and to build better environment as well as quality life.

3.1.3. Energy consumption in terms of final forms

Table 3 shows the energy consumption in terms of final forms for the categories. It is seen that, HC1 adopted LPG and electricity where HC2 adopted natural gas and electricity in their total household energy consumption. LPG and natural gas are the dominated form of energy in HC1 and HC2 respectively rather than electricity. HC3 adopted oil, wood biomass and solar energy of which wood biomass is dominated form of energy in this category.

Figure 2 shows the share of final form of energy consumption for the categories. It is seen that, electricity and LPG are quite balance in HC1 where 95% share of natural gas in HC2 and more than 80% share of wood biomass in HC3. Hence, final form of energy consumption is dominated by primary form of energy.

Table 2. Household energy consumption for types of appliances for the categories

Categories	Energy consumption for types of appliances (kWh)								
	Light	Fan	TV	Mobile	Fridge	Water pump	Computer	Electric cooker	Conventional cooker
Household Category 1 (HC1)	18.32	52.62	16.68	1.0	45.56	18	4.0	34.82	213 (LPG)
Household Category 2 (HC2)	23	65.25	22	0.43	42	15.22	6.52	-	4,171 (NG)
Household Category 3 (HC3)	173	-	-	0.6	-	-	-	-	995 (Biomass)

Figure 1. Household energy consumption share by different appliances for the categories.

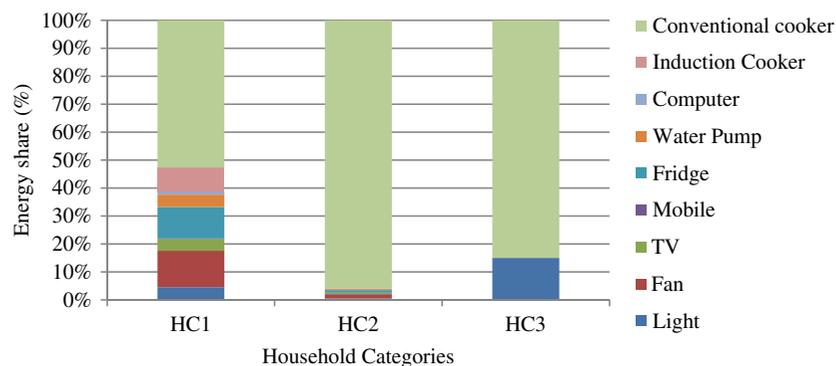
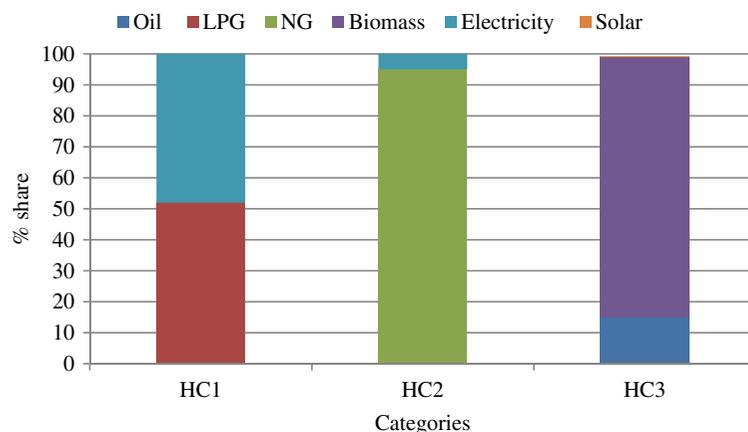


Table 3. Energy consumption in terms of final form for the categories

Categories	Energy consumption (kWh)					
	Oil	LPG	Natural Gas	Wood biomass	Grid Electricity	Solar energy
HC1	-	213	-	-	191	-
HC2	-	-	4,171	-	174	-
HC3	171	-	-	995	-	2.94

Figure 2. Share of final form of energy consumption for the categories.



3.1.4. Energy consumption in terms of primary form

The breakdowns of primary energy consumption for the categories are shown in Table 4. Table shows that, primary energy consumption due to electricity use for HC1 and HC2 is similar but distinction is in cooking energy i.e. direct use of energy. Estimated primary energy for cooking is 17 kg LPG in HC1 where 375 m³ natural gas for HC2. Oil is used for lighting in HC3 and wood biomass is used for cooking. Estimated oil and wood biomass consumption in HC3 are 14 and 231 kg respectively.

3.1.5. Energy analysis per capita and per thousand income level

Table 5 shows the energy consumption per capita and per thousand income level for the categories. Per capita energy consumption for HC1 is 90% and 56% lower than that of HC2 and HC3 respectively. Interesting is that, people in HC2 are consuming much more energy per capita and per thousand income level rather than HC1 for similar modern facilities. Again, people in HC3 are consuming significant energy per capita and per thousand income level rather than HC1 without modern facilities. Hence, energy loss in HC2 and lack of modern facilities in HC3 are realized. Integration of better combination and management of energy access is important to mitigate these issues.

Table 4. Breakdowns of primary energy consumption for the categories

Categories	Direct use				Indirect use (Grid electricity)		
	Oil (lit)	LPG (kg)	Natural gas (m ³)	Wood biomass (kg)	Coal (kg)	Oil (lit)	Natural Gas (m ³)
HC1	-	17	-	-	2.26	12.5	36.5
HC2	-	-	375	-	2	11.5	33
HC3	14	-	-	231	-	-	-

Table 5. Energy consumption per capita and per thousand income level for the categories

Categories	Energy consumption per capita (kWh/capita)	Energy consumption per thousand income level (kWh/BDT 1000)
HC1	101	16
HC2	1,086	177
HC3	234	137

3.1.6. Energy expenditure for final energy consumption

Table 6 shows the energy expenditure for final energy consumption for the categories. The local market price in May–June, 2016 for LPG, oil (diesel/kerosene), natural gas, wood biomass and electricity are BDT 72/kg, BDT 67/lit, BDT 7/m³, BDT 5.5/kg and BDT 5.5/kWh respectively is used to estimate the expenditure. Table shows that, Maximum expenditure found in LPG and natural gas for HC1 and HC2 respectively where in biomass for HC3. Total expenditures estimated are BDT 2,274, 3,582 and 2,208 for HC1, HC2 and HC3 respectively. Interestingly is that, expenditure in HC1 and HC3 is similar though the peoples in HC3 are far away from modern energy access as well as facilities. Around 50% expenses for LPG in HC1, 57% expenses for wood biomass in HC3 where 73% expenses for natural gas in HC2.

Figure 3 shows the household energy expenditure with monthly average income level for the categories. It is seen that, energy expenditure for HC1 and HC3 is similar but income level of HC3 is three times lower than that of HC1 implies the people in HC3 investing much more money for energy consumption with limited facilities compared with HC1. This also implies that the low income peoples so called poor peoples are paying much more money for their energy use rather than high income people, though poor peoples have no provision of modern facilities. On the other hand, average monthly income and modern facilities for the household HC1 and HC2 is similar but energy expenditure for HC2 is 36% higher than that of HC1 indicate there are energy losses in HC2.

Table 6. Energy expenditure for final energy consumption

Types of resources	Energy expenditure (BDT) in different categories		
	HC1	HC2	HC3
Oil	-	-	938
LPG	1,224	-	-
Natural gas	-	2,625	-
Wood biomass	-	-	1,270
Electricity	1,050	957	-
Total	2,274	3,582	2,208

Figure 3. Energy expenditure with monthly average household income level.

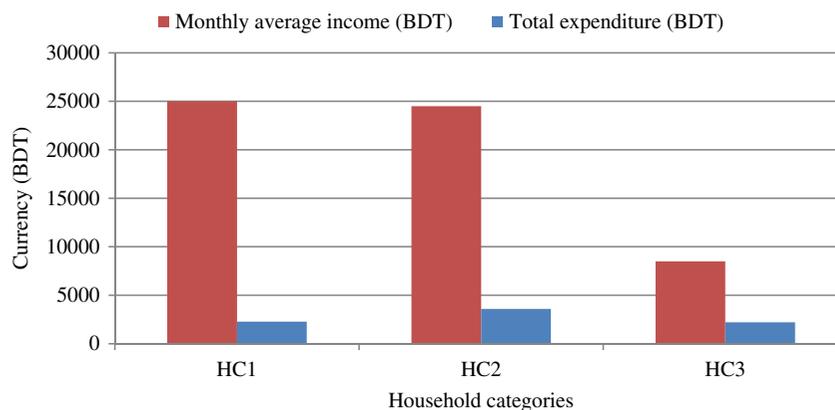


Table 7. Estimated GHG emissions for the household categories

Categories	GHG emissions		
	CO ₂	CH ₄	NO _x
HC1	153 kg	3.89 gm	27 gm
HC2	956 kg	18 gm	2 gm
HC3	440 kg	2 kg	0.5 kg

3.2. GHG emission and environmental impact analysis

Greenhouse gas (GHG) emissions namely, CO₂, CH₄ and NO_x are considered for the analysis based on the national data availability. The environmental impact expressed in terms of CO₂ equivalent (CO₂ eq) which comprises GWP value of the individual greenhouse gases over a period of time.

3.2.1. GHG emission analysis

GHG emissions are estimated based on primary energy consumption for the categories. The emission values for the stationary combustion of coal, oil, natural gas, LPG and wood biomass are taken from (Diana & Ahmed, 2015; Islam, 2016). Table 7 shows the estimated GHG emissions for the categories. The most important emission is CO₂. The estimated CO₂ emission is 153, 956 and 440 kg for HC1, HC2 and HC3 respectively. It is seen that, CO₂ emission for HC2 is significantly higher due to uncontrolled consumption of natural gas. CH₄ and NO_x emission for HC3 is higher due to higher emission factor of wood combustion. NO_x emission in HC1 is higher than HC2 due to higher emission factor of LPG in HC1.

3.2.2. Environmental impact analysis

Table 8 shows the breakdown of environmental impacts for different energy sources within the categories. It is seen that, total environmental impact estimated for HC1, HC2 and HC3 are 160, 957 and 628 kg CO₂-eq respectively implies that HC1 has lower environmental impact compared with other categories.

Table 8. Breakdown of environmental impacts for the categories

Energy sources	Environmental impacts (kg CO ₂ -eq) for the categories		
	HC1	HC2	HC3
Coal	4	4	-
LPG	32	-	-
Natural gas	82	915	-
Oil	42	38	47
Biomass	-	-	581
Total	160	957	628

Figure 4. Effect of primary energy sources on environmental impacts for the categories.

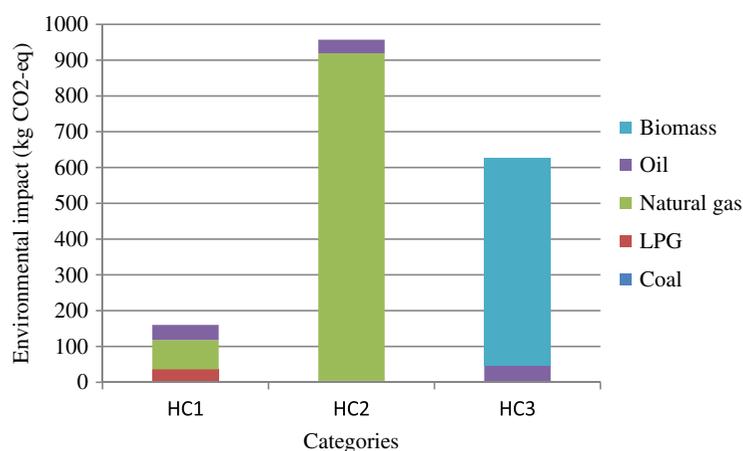


Figure 4 shows the effect of primary energy sources on environmental impact for the categories. It is seen that HC2 and HC3 are contributing much more environmental impact rather than HC1, though the quality of lifestyle in HC2 is similar as HC1 and life style in HC3 is lower due to they are deprived from facilities of modern energy. It should be noted that, biomass, oil, natural gas and LPG are responsible for cooking and they are the major driver to make distinction among the categories. Natural gas and biomass are the most dominated energy sources contributed in environmental impact significantly in HC2 and HC3 respectively, where coal is less dominated in HC1.

4. Conclusion

Energy consumption and environmental impact for the selected three categories residential household are investigated and analyzed. The study is conducted in Developing country Bangladesh as a case study to highlight the significance of modern energy access in residential sectors and better combination the types of energy access. Findings from this study reveals that, monthly energy consumption, GHG emission and environmental impact is comparatively lower for the household having provision of electricity access and LPG as cooking energy (HC1). Though, natural gas as cooking energy in HC2 is better than LPG in HC1, HC2 would be better than HC1 only when metered gas connection is possible. Contribution of cooking energy in total household energy consumption found to significant for all three categories. There are significant energy loss is realized in HC2 and HC3. Hence, provision of electricity access, metered gas connection and modern cooking technology instead of conventional cooker are recommended to mitigate such energy loss, reduce the stress on limited fossil sources, reduce energy expenditure, integrate modern facilities and improve the quality of life.

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