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Modeling Electricity Bill with the Reflection of CO_2 Emissions and Methods of Implementing AMI for Smart Grid in Bangladesh

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Abstract: Taking into consideration the lack of circumstantial alertness, automated fault analysis and labor-saving switches, the present-day electrical power grid system has been deteriorating day by day. The backbone technology of this grid system is too ill-fitted to the on-going demand for electricity. Despite the fact that the government of Bangladesh has set a new target of reaching the total power generation to be 40,000 MW by 2030. Hence the infrastructure and corresponding technology of the electrical power sector are required to be modernized to cope with this gigantic target within a short time. Another challenging fact is that the rapid expansion of population and power-intensive industrialization trigger off the carbon emissions that lead to global climate change. Also, the constraints of electricity generation capacity, unidirectional way of communication, failure of power equipment and dropping off conventional sources of energy impose burden on the existing electric power grid. This paper articulates the needfulness of reflection on CO_2 emissions or reduction in the electricity bill of the consumer in developing countries by employing a mathematical model and by proposing some fruitful methods to implement AMI for smart grid.

Index Terms: Carbon emission, Electricity, Smart grid, Advanced metering infrastructure (AMI).

1. Introduction

Located in the South Asian region, Bangladesh is considered as one of the densely populated countries spanning 148,460 square kilometers, exceeding 166 million people. This country is classified as “medium” in HDI (Human Development Index) with 0.632 points [1] which indicates that social and economic development has been implemented. This leads to one of the major environmental concerns such as carbon emission. Although compared to the developed countries, the carbon emission of Bangladesh is still as low as 0.2% only. From 1998 to 2018, per capita CO_2 emissions grew substantially from 0.19 to 0.56 metric tons. [2].

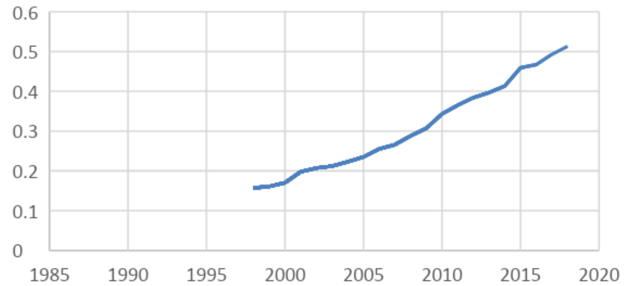

Fig.1. Per capita CO_2 emission from 1998-2018

In the developed countries, per capita carbon emission is 14-16 tons. On the contrary, per capita carbon emission at present in Bangladesh is less than 1 ton, which indicates that per capita carbon emission is still as low as in comparison with India, China and America. Besides, the power consumption rate of Bangladesh (320 kWh per capita) is comparatively low against the world average (3132 kWh per capita) [3]. But being an entrant of the developing nation, carbon emission has increased remarkably in this country in recent years. From 1970 to 2016, the rate of increment of carbon emission was 7% per year. Since then, the increment has been found as 9% per year. During the liberation war in 1971, only 3% of the total population of Bangladesh were under the coverage of electricity [4]. Whereas, the grid penetration rate of Bangladesh is now approximately 92% [5]. Rapid urbanization and industrialization are considered for this growing demand. In addition, the gradual increment of electricity usage and mass transportation are the two significant sectors responsible for the rise of carbon emission which is 72% of the total emitted greenhouse gas.

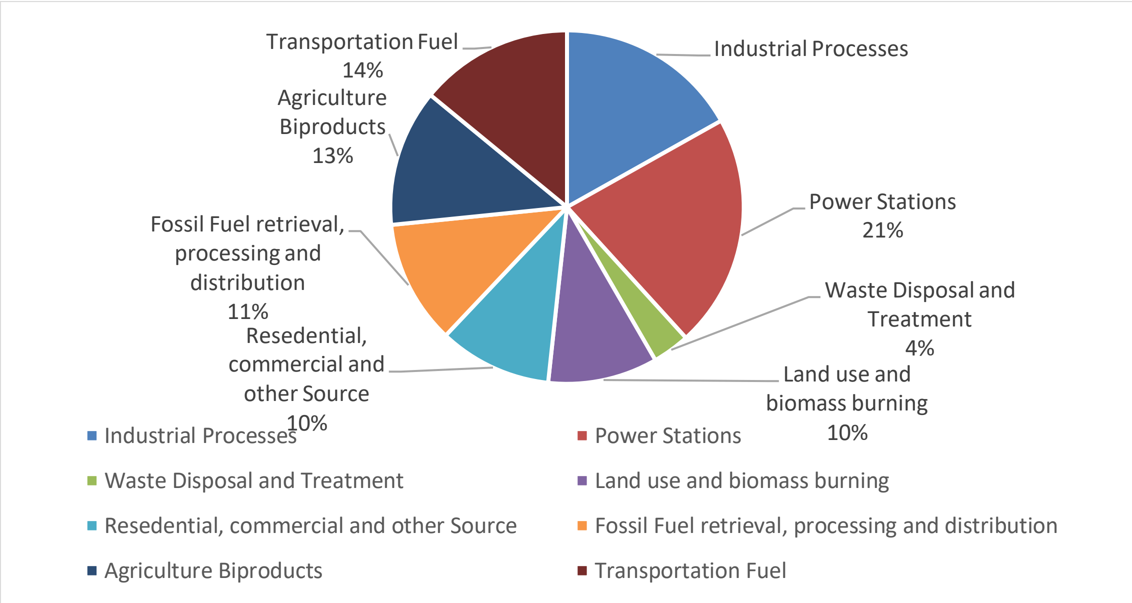

Fig.2. Annual greenhouse gas emission by various sectors

In order to reduce carbon emission, emphasis on the usage of renewable energy is essential. Though implementation of solar powered systems is challenging due to the unavailability of land for a congested country like Bangladesh. Despite this hindrance, carbon emissions per capita of Bangladesh could be lessened by fostering latest technology in the electric grid system and energy efficient methods to be implemented at household and commercial level.

To overcome these challenges, the technology called smart grid has come to light [6]. A supreme part of SG is advanced metering infrastructure which consists of bi-directional smart meters that conform both way communication and data transactions between utility and consumers. It is the preferred solution that can reduce electricity usage and CO_2 emissions by the electrical power grid.

The major research objectives include the followings:

- Employing a mathematical model to address the carbon emission on energy bill per consumer basis
- Proposing some fruitful methods to implement AMI for smart grid in Bangladesh, the first of its kind

At this instant electricity generation follows the distribution where the generation sector completely depends on fossil fuels and least amount on renewable energy as shown in the below figure of fuel mix.

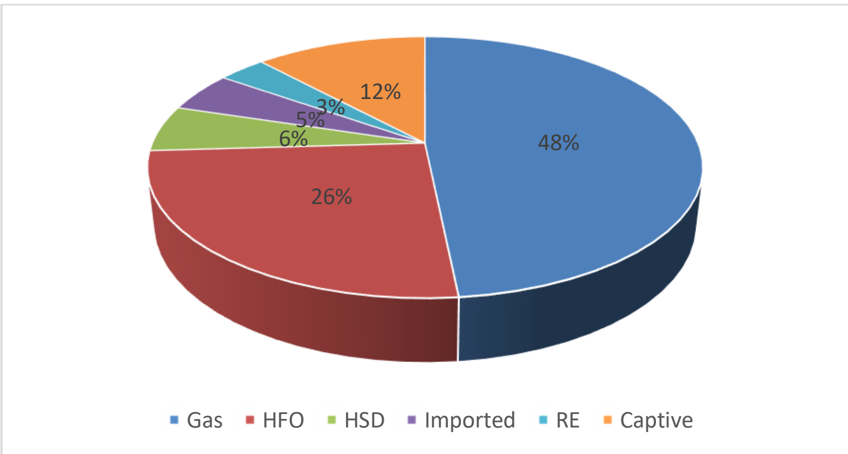

Fig.3. National fuel mix of Bangladesh in 2021

From the above pie chart, we can see the impact after two decades of the Kyoto Protocol, the national energy mix is still led by conventional energy sources. Natural gas, coal and oil consolidated 81.32% of the total energy generation and renewable energy contributes only 3% which should be reached 20% by 2030 [7]. This percentage was previously set to 10% by 2021 which was yet to be accomplished [8].

According to the PSMP-2016 [9], estimated fuel mix in 2030 will be as shown in below figure-

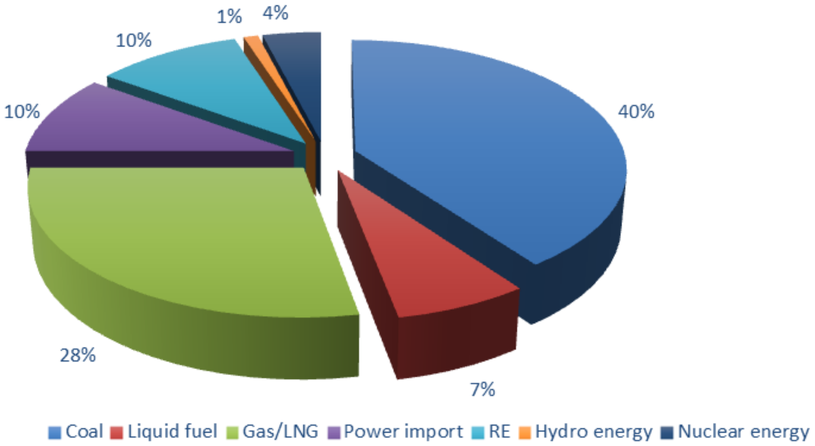

Fig.4. Estimated national fuel mix of Bangladesh in 2030

From the data given in the above figure, the lion's share of electricity generation comes from coal which is 40%. This type of hydrocarbon-based energy source is considered as one of the dirtiest solid fuels with highest environmental pollution compared to the other fossil fuel-based energy sources. Natural gas also shares 28% of the electricity generation in 2030 fuel mix. Natural gas contains methane which is known as a very powerful greenhouse gas. This methane is 87 times greater than an equivalent mass of CO_2 in respect of GWP [10]. For this reason, CO_2 emission to the electrical grid will increase sequentially to meet the rise of coal consumption. This issue could be partly offset by injecting renewable energy to the utility grid and by using energy efficient appliances. This should be measured and reflected in the consumer's electricity bills at the domestic, commercial and industrial sector by introducing AMI technology to the electrical grid of Bangladesh. Thus, the modernization of the conventional grid can reduce energy usage and carbon footprints consolidated with electricity generation and distribution.

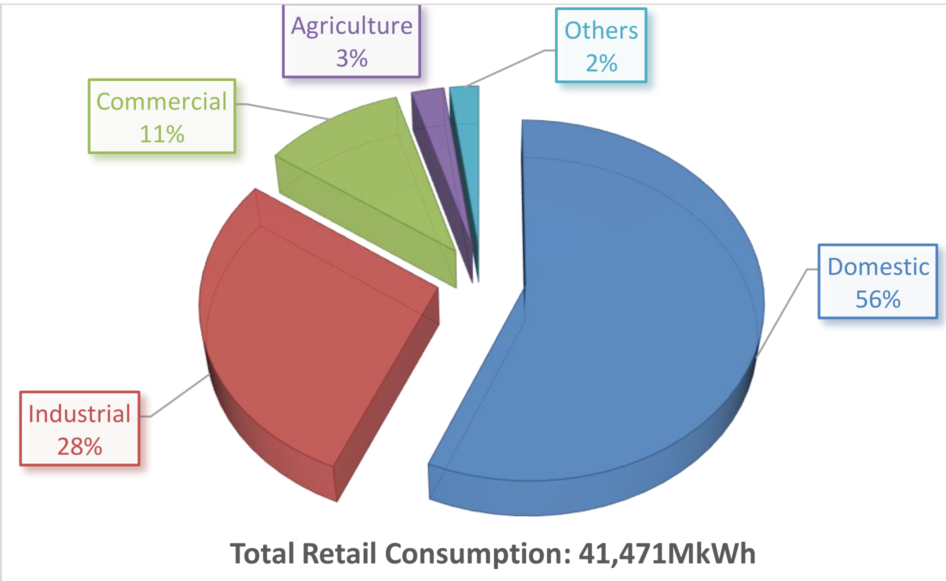

Fig.5. Energy consumption pattern of Bangladesh in 2020-21

Above figure shows energy consumption categories that are distributed in various sectors including domestic, industrial, commercial, agricultural and others [11]. Domestic sector is leading this chart by 56.42% while Industrial and commercial sectors are consuming 28.40% and 10.58% respectively. Nearly about the rest 5% are shared by agricultural and other segments of this country. Therefore, an aggregated amount of 95% are consumed by our targeted household, industrial and commercial sectors. Employing policies on these fields, reduction of energy can be achievable and thus carbon emission can be reduced accordingly.

2. Literature Review

Researchers from various corners of the globe have been actively involved in proposing solutions and architectures to implement AMI technology for smart grid. The functions of the AMI meter, detailed specifications for AMI systems and further consideration issues for AMI deployment were described in [12] which is similar to this paper. A study of the effects of aggregation on electrical energy demand modeling and multi-nodal demand forecasting were provided in [13]. This paper also presented a detailed assessment of the variables which affect electrical energy demand and how these effects vary at different levels of demand aggregation. Lastly, this study outlined an approach for incorporating AMI data in short-term forecasting at the local level, in order to improve forecasting accuracy. In [14], the Authors presented that meter data analytics such as peak demand identification, consumer profile analysis, load forecasting, abnormal energy pattern analysis etc. play a vital role in AMI systems which helps utilities to manage their resources and business processes efficiently. It is found that the main purpose of AMI is to enable two-way communication between consumer and smart grid control center of utility which involves remote monitoring and control of energy consumption as well as other parameters in real time. In [15], energy management system such as demand response, demand management and energy quality management that were implemented inside the electricity management gadget in smart grid is presented.

3. Methods

3.1. Methodologies for Implementing AMI for Reducing Carbon Footprints

In order to integrate carbon footprint on energy bills, some methods regarding the reduction of energy usage along with modern grid technologies [16] should take place as listed below:

- It is necessary for consumers to modify their consumption patterns in order to reduce electricity costs and investments, to avoid price spikes and to use power hungry appliances and energy more efficiently.
- Consumers can bring energy saving, energy efficiency and peak load shifts by using smart meters and information about the system.
- It is necessary to analyze and understand how consumers decide how much and how they want to consume energy.
- It is useful to understand how to encourage the reduction of consumption or how to transfer it to periods with lower demand.
- In a scheme where consumers can directly participate in demand management.
- It is necessary to find the best way to forecast the electric loads of individual consumers.
- Demand Response can provide competitive pressure to reduce energy prices. It can increase the awareness of energy use as well as to provide a more efficient functioning of markets.
- With Demand Response, consumers can make the system more efficient, and with a 5% increase in network efficiency the equivalent of many coal based power plants in Bangladesh would not be needed to meet the peak time load, which would bring benefits to the system and the community by reducing carbon emission.
- Finally, the electrical power grid system will be modified in such a way that the demand will follow the generation because of demand side management by adopting AMI technology in the distribution side of the existing electrical power grid system.

Currently the smart meters running in the consumer’s end are communicating only from utility service providers to the customers. Therefore, these unidirectional meters are not serving the needs and are not fulfilling the demand of both ways of communication. Replacement of these unidirectional meters is needed to achieve the smart grid technology.

3.2. Methodology for the Implementation of Carbon Emission or Reduction on Electricity Bill

Worldwide, there are two most common methods available for use. One is known as the top down approach and the other is called bottom up approach [17].

Top down approach: This approach is actually associated with the “top level” which is primary fuel sources in the case of environment impact and carbon emission. In this method, the general emission factor provided by the National level is used to multiply by the individual consumer's energy consumption to get the respective carbon footprint.

Bottom up approach: This method uses detailed data of specific fuel sources and the consumption based on the respective energy shared by those fuel sources. In this method, the effort of data gathering from the respective GHG inventories is the biggest challenge. For this reason, the bottom up approach is tough to be implement for a system without a good source of inventories. For example, local smallest sites such as offices or laboratories are more efficient to collect and gather data than that of the national level. For detailed reporting, the bottom up approach is much more suitable than the top down approach. It deals with all kinds of activities associated with the emission having strong control of information.

In this article, we have used the top down method due to the simplification of the calculated data that we have proposed here. Recalling the top down method, the emission calculation is as follow:

$$\text{Total CO2 emission by the consumer} \\ = \text{Grid Emission Factor (GEF)} \times \text{Energy consumption of the respective consumer (in kWh)} \tag{1}$$

Where, the grid emission factor is expressed in ton CO_2 per MWh (tCO_2/MWh) which will be equated with each unit of electricity generated by the energy producers. GEF differs from country to country and can be different because of the energy production system and the fuel resources of various countries.

Energy consumption of the respective consumer (domestic or industrial) is normally expressed in kilowatt hour (kWh) which is also known as unit (one unit = one kWh). This method is suitable to be integrated with both electricity energy users and natural gas users.

The consumed energy pattern will be different for domestic, industrial and commercial users.

4. Results and Discussion

The reference value used for the emission calculation known as GEF which is basically two types. CDM based grid emission factor and standardized baseline which is sector specific standard (regional, national or international) [18]. CDM based grid emission factor is generally calculated by the respective registered CDM project having specific project boundary and the data used for this type of project is collected from the UNFCCC website.

Here in this article, we have used the National grid emission factor published by the host country (Bangladesh, in this case) which is taken from locally available sources and is considered as the standardized baseline for calculating carbon emission.

The Department of Environment of the Government of the People's Republic of Bangladesh adopted a factor for the electricity system in August, 2013. As per the released note, the Grid Emission Factor (GEF) of Bangladesh is 0.67 ton CO_2 per MWh [19]. Thus, the reflection on the electricity bill will be presented as per CO_2 emission.

For example, if a utility user consumes 300kWh in one month, then the reflection of CO_2 on the electricity bill of the consumer is:

$$300 \text{ kWh} \times 0.67 \text{ ton CO2/MWh} = 0.201 \text{ ton CO2 which will be presented in the energy bill} \tag{2}$$

Applying this emission factor for multiplication with the expended energy can easily give the result of carbon emission for a specific account. Besides showing the result, this data will act as the awareness raising for environmental impact and control over the usage of excess electricity. Innovative policies and planning can be taken to penalize such cases of producing excess carbon emission. On the contrary, carbon credit policy can be introduced for the consumers who will be responsible for net zero emission. Net zero emission also refers to as "carbon neutrality" that means the balancing of production and emission of the gas. Fostering the net metering technology, Bangladesh already entered in this era a couple of years ago by releasing the guidelines of net metering policy in 2018. After that many projects have been installed and the excess energy which is known as unused energy can be given to the national grid. Policies should be taken for such consumers will be given reward by offsetting carbon from the energy generation side if the certain energy produced from renewable energy source.

A sample of the electric bill of Energy Australia Company (all figures displayed in the bill are indicative only and they do not reflect actual rates or charges) is given below for reference.

Total greenhouse gas emission is reflected in the second page of the above electricity bill. It is apparent that the comparison of electricity usage with the same time of last year is also presented in the utility bill. There are some changes in the monthly consumption which is noticeable for the consumer. Consumers can find out several factors that are responsible for these changes such as average daily usage, newly installed power-hungry appliances, change of season and change in daily habits etc. With the help of this comparison, a customer can effectively calculate the consumption of the electricity used over time and can also figure out the redefined pattern of the consumption.

In our calculation, we have only calculated the amount of CO_2 which has the major share of total emitted GHG and placed it as the reflection on the energy bill. The parameters can be improved by adding total GHG emission into the final result. Later, total GHGs could be integrated with the help of national data inventories in order to have the precise calculation. Another important issue is that the bottom up method can be implemented if the required resource data is available for use because the bottom up approaches will be more suitable to apply for it. Conventionally it is accepted that GHG emission is firstly converted to non- CO_2 GHGs such as methane and nitrous oxide to equivalent CO_2 which is represented as CO_2e. Thus, every single component is converted to CO_2 considered as the baseline of the calculation. For more precision, categories of power plants according to their fuel sources can be measured and integrated with the calculation. The accuracy of local GHG inventory and tracking should be more improved to cope up with this mechanism. Another important issue is that the nuclear power plant and renewable energy based power plant do not emit CO_2 directly. This means CO_2 could be emitted at the time of construction and any other time of the life cycle of these types of plant. At present in Bangladesh, there are no nuclear power plants actively running and less than 5% of the total energy share is run by renewable energy based energy systems. For this reason, this minimal amount of data is not taken into consideration for the gross calculation. In the near future, it should be taken under calculation only if there is available data for carbon emission in the renewable energy based power sector during the plant construction and energy generation process. We hope this publication will produce some discussion points on the impact of carbon emission and integration of smart grid technology to the electrical power system.

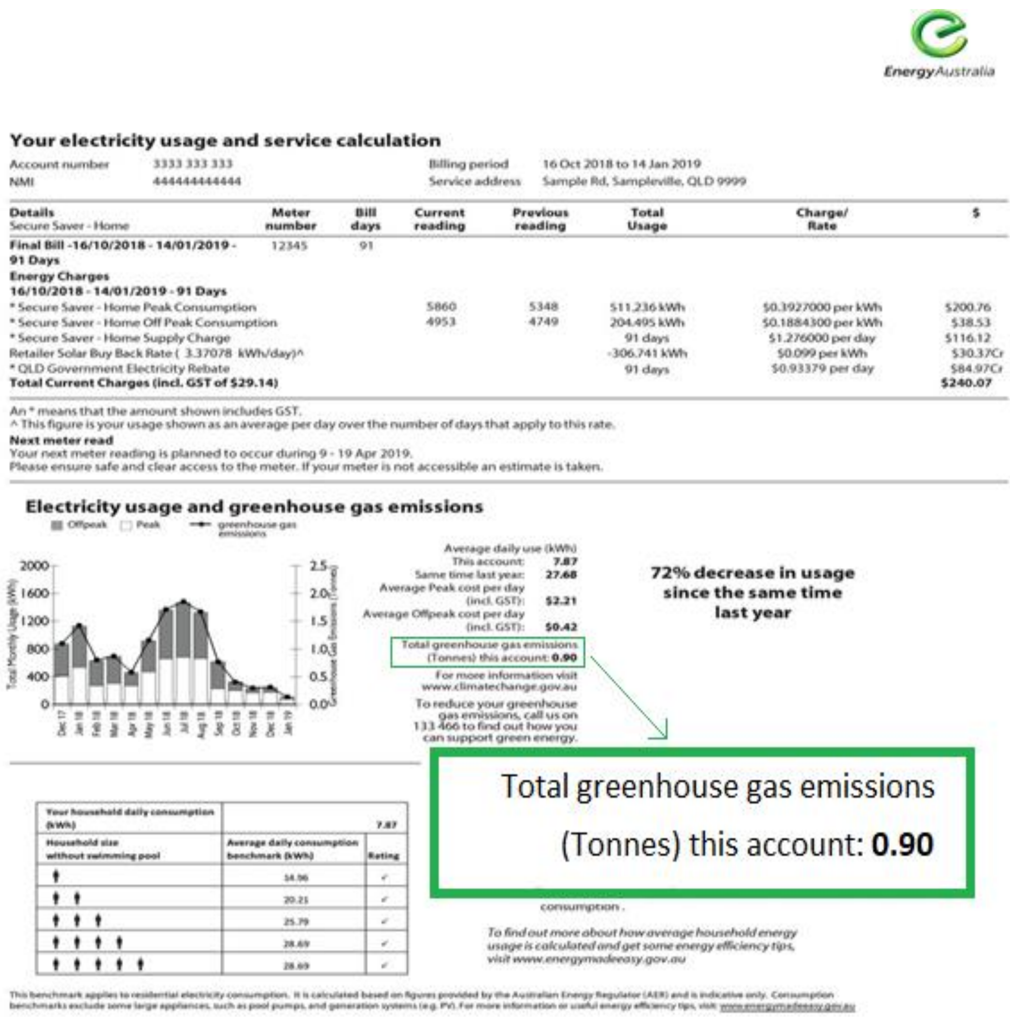

Fig.6. Sample utility bill showing GHG emission per account

5. Conclusions

This article constitutes some fruitful steps for grid modernization and the addition of carbon footprint on the utility consumer's bill that represents the amount of carbon emission the consumer causes every month. At present, yearly global carbon footprint is between 4 – 5 tons. Some Asian regions like China and India along with the United States and Russia are leading this chart. In order to limit global warming within 2°C, the global carbon footprint should be below or equal to 2 tons by 2050. Following this footprint, the energy sector has the highest share of the total GHG emission which is 60%. Therefore, major concerns need to be taken in this area for reducing the direct CO_2 emission.

Considering these issues, we have come up with the integration of advanced metering infrastructure technology to our conventional electrical grid system which will definitely cut down the direct carbon emission by implementing proposed methods. Besides this, the inclusion of the amount of carbon emission in the utility bill will certainly play an important role in raising the awareness of individuals as well as the community-based sector. As a part of this initiative, the UNFCCC secretariat launched a campaign called "Carbon neutral now" engaging non-party stakeholders. Likewise, Australia, Denmark, Sweden and some countries that are enjoying the outcome of implementing carbon emission on their utility bill, it is high time to follow the footsteps of the same. Being an over populated country, the challenges for taking these steps should be handled properly by implementing essential national strategies and planning which can attain the SDG no. 13: climate action correspondingly. We strongly believe that an orchestrated effort from each and every sector of this country will be certainly helpful for reaching the target of net zero emission.

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Abbreviations (Nomenclature)

CO_2	*carbon dioxide*
CO_2e	*carbon dioxide equivalent*
SG	*smart grid*
AMI	*advanced metering infrastructure*
MW	*megawatt*
MWh	*megawatt hour*
MkWh	*Million kilowatt hour*
kWh	*kilowatt hour*
CDM	*Clean Development Mechanism*
UNFCCC	*United Nations Framework Convention on Climate Change*
SDG	*Sustainable Development Goals*
FY	*fiscal year*
GWP	*global warming potential*
HFO	*Heavy fuel oil*
HSD	*High speed diesel*
RE	*Renewable energy*

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