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Overview of engine-based power plants in Bangladesh

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Abstract: Engine based power plant in Bangladesh had significant growth over the last 12 years. In the year 2008, it was 231 MW but in year 2020, the capacity increased to 7,808 MW. An analytical and quantitative exploration was performed on the growth of engine-based power plants in the present work. Six variables like total generation capacity of different types of plants, electricity consumption, fuel oil price, GDP, population and growth in production of manufacturing industries (i.e. rate of industrialization) of Bangladesh were considered as main contributors on the growth. Regression analysis was performed to determine the relationship between the growth of engine-based power plants and the six chosen variables. It was found that except fuel oil price and population of Bangladesh, other four variables have a notable co-relationship with the growth of engine-based power plant in the country.

Keywords: *Bangladesh, Engine based, Growth, Regression analysis, Power plant*

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Nomenclature	
APSCL	Ashuganj Power Station Company
BERB	Bangladesh Rural Electrification Board
BPDB	Bangladesh Power Development Board
DESCO	Dhaka Electric Supply Company
DPDC	Dhaka Power Distribution Company
EGCB	Electricity Generation Company of Bangladesh
GDP	Gross Domestic Product
JICA	Japan International Cooperation Agency
HFO	Heavy Fuel Oil
MW	Megawatt
NESCO	Northern Electricity Supply Company
NWPGC	North West Power Generation Company
PGCB	Power Grid Company of Bangladesh
REB	Rural Electrification Board
RPCL	Rural Power Company Limited
PSMP	Power System Master Plan
WAPDA	Water and Power Development Authority
WZPDC	West Zone Power Distribution Company

1. INTRODUCTION

1.1. Initial History of Electricity in Bangladesh

It is a tale of about a century and a quarter ago. The king of Bhawal of Gazipur of the then East Bengal (presently Bangladesh) under British India is known as the first user of electricity in East Bengal. He illuminated his palace with the electricity using a generator imported from England in the nineteenth century. This royal and fancy initiative was a big surprise to the people of Bhawal who were far away from the modern civilization.

After that, a generator was installed at the residence of Mr. Ahsanullah, the Nawab of Dhaka in 1901. In 7th December, 1901 Mr. Bolton, a British citizen inaugurated electrification of Ahsan Manzil by pressing an electric switch. A company named Octavious Still, gradually brought a few elite buildings including the Ahsan Manzil and some important roads of Dhaka under electrification by the financial support of Nawab Ahsanullah. As the company's power generation capacity was limited, the power supply was also confined to only some posh areas [1].

In 1919, 'DEVCO' a British company introduced the commercial power distribution system within a limited area of Dhaka. Later in 1933, the company built "Dhanmondi Power House" with the generation capacity of about 06 MW at Paribag in Dhaka and started to distribute power commercially. Residents of the elite society of the city were the consumers of this electricity. The use of this costly electricity added a new feather in the crown of their aristocracy [1]. Power generation and distribution used to be handled by the private sector in the year 1947 during the partition of Indo-Pak sub-continent. Only major towns received power supplies in limited range, and in most cases only during day time. At that time power generation was 400 V in the towns except in the Dhaka city which received up to 6.6 KV generated from two generators of 1500 kW capacity. There was no system for long distance transmission. A handful of industries and workshops like tea, sugar and textiles mills generated their own power. The entire country was only capable of generating about 21 MW in a scattered manner.

Electricity Directorate was established in 1948 with the goal of planning and improving the situation of the power supply. All private sector power plants and transmission lines were taken over by the government in 1957. When the Water and Power Development Authority (WAPDA) was established in 1959, the power industry finally got to perform satisfactorily [2,3]. The Electricity Directorate and WAPDA amalgamated in 1960. At that time, new power plant were constructed at Siddhirganj, Chittagong, and Khulna. Among them, the biggest capacity power plant was at Siddhirganj with power generation capacity of 30 MW and it was steam turbine power plant. This power station was crucial at that time in meeting the Dhaka's requirements for electricity. Kaptai Dam was being built concurrently by the Department of Irrigation [4]. By utilizing the potential energy of the water in the 300 square mile lake that had been artificially formed by building a dam in the Karnafuli river, the Karnaphuli hydro-power plant began producing electricity in 1962 from its two units, each of which had a capacity of 40 MW. At that time, Kaptai was regarded as the biggest power plant in the country [5]. The 273 km-long Kaptai-Siddhirganj 132 KV transmission line's parallel construction was finished, and both power plants Siddhirganj and Kaptai were integrated into the same grid [6].

1.2. Bangladesh Power Development Board

Bangladesh Power Development Board (BPDB) was created in 1972 as a statutory body to boost the power sector. Several organizations later took over the generation and distribution work in different areas of Bangladesh while BPDB engaged in purchasing power from power generation companies. Later BPDB's transmission and some part of generation and distribution was handed over to other

organizations such as REB, DPDC, DESCO, PGCB), APSCL, EGCB, WZPDC, NWPGC, NESCO and RPCL etc., as part of reformation and restructuring [7].

As a single buyer BPDB was engaged in purchasing power from IPPs, SIPPs, Rentals and Government own generation companies and sale, power generation and power distribution in urban areas of the country excluding the operational area of REB, DPDC, DESCO, WZPDC and NESCO.

There was a significant growth in engine-based power plants in Bangladesh over the last 12 years if it was compared with the total growth in generation capacity. It was because the engine-based power plants could be installed faster and with less investment. It had more flexibility in operation and could be started and stopped quickly which was very suitable to meet the wide variable demand of Bangladesh. As per the Government's Power Sector Master Plan (PSMP), larger and base load power plants such as turbine, coal and thermal were coming into operation in the last several years. In the revised PSMP, the Government of Bangladesh was given more emphasis to generate power from renewable energy. Considering the above factors, the future prospects of engine-based power plants in Bangladesh was performed in the present study.

1.3. Literature Review

In present study, different historical data on the different types of power plants in Bangladesh was collected from the annual reports of BPDB [8]. Analysis of current energy resources and their usage conditions in Bangladesh was described [9]. In Ref. [9], a projection was made from the current situation for predicting the possible energy scarcity in the near future. A cost analysis and relative challenges to implement that technology were also explored with a greater details.

The present renewable energy scenario in Bangladesh has been focused and also the future prospect of this energy has been outlined in Ref. [10]. The performance of the power and energy sector over the last one decade with a view to identify the areas of weaknesses and challenges and to put forward a set of recommendations on long term sustainability are analyzed in Ref. [11]. A brief overview of current electricity generation status and energy scenarios of Bangladesh has been presented in Ref. [12]. In Ref. [13], a review on the power generation, transmission and distribution is demonstrated and also power crisis of Bangladesh and future plans and programs of power sector has been discussed. With the support from the Japan International Cooperation Agency (JICA), Bangladesh developed a comprehensive energy and power development plan that incorporates tariff plans, power balance, and energy balance up to the year 2041 [14]. From the literature review, present study does not find any discussions for engine-based power plant in Bangladesh.

2. PRESENT ELECTRICITY GENERATION CAPACITY AND TYPES OF POWER PLANTS OF BANGLADESH

As on 2020, total installed capacity including captive power and renewable is 23,517 MW. Power plants connected to the grid is 20,383 MW (public sector 10,339 MW, private sector 8,633 MW, REB 251 MW and power import 1,160 MW). The main fuel used for power generation is indigenous gas.

Table 1. Types of power plants in Bangladesh.

	Types of Plants	Installed Capacity (MW)	% of Capacity
1	Hydro	230	1.13%
2	Steam Turbine	2,966	14.55%
3	Gas Turbine	851	4.18%
4	Combined Cycle	7,330	35.96%
5	Reciprocating Engine	7,808	38.31%
6	Solar PV	38	0.19%
7	Power Import	1,160	5.69%
	Total	20,383	100.00%

In the fiscal year 2019-20, a total of 69,641 GWh electricity was generated (public sector 35,316 GWh, private sector 27,651 GWh and power import 6,674 GWh). The maximum demand served during peak hours is 12,738 MW in 2020 and 13,792 MW in 28 April, 2021. The transmission network is about 12.283 ckt km long comprising 400, 230 and 132 KV lines. The total grid sub-stations capacity is about 45,478 MVA as on end 2020. Table 1 shows the types of power plants in Bangladesh. Based on the fuel used for the generation of Electricity of Bangladesh, the generation capacity mix mentioned in Table 2.

Table 2. Types of power plants in Bangladesh based on fuel.

	Types of Fuel Used	Installed Capacity (MW)	% of Capacity
1	Hydro	230	1.13%
2	Gas	10,979	53.86%
3	Furnace Oil	5,540	27.18%
4	Diesel	1,290	6.33%
5	Coal	1,146	5.62%
6	Solar PV	38	0.19%
7	Power Import	1,160	5.69%
	Total	20,383	100.00%

The total net energy production in 2020 was 71,419 GWh, which was about 1.26% more than the net generation of 70,533 GWh in 2019. In the public and private sector (including REB), net energy generation was 35,316 GWh and 29,429 GWh respectively. Through the interconnection in Bheramara and Tripura 6,674 GWh was imported from India. In 2020, the public-sector power plants net total thermal efficiency was 39.72% which was 38.4 % in previous year. Table 3 shows the total net energy generated in public and private sector power plants for different types of fuels.

Table 3. Generation of electricity in 2020 based on fuel.

	Types of Fuel Used	Electricity Generate (GWh)	% of Generation
1.	Hydro	825	1.16%
2.	Natural Gas	51,290	71.82%
3.	Furnace Oil	9,461	13.25%
4.	Diesel	139	0.20%
5.	Coal	2,968	4.16%
6.	Solar PV	62	0.07%
7.	Power Import	6,674	9.34%
	Total	70,533	100.00%

Based on the types of plants, generation capacity of Bangladesh from *2008 to 2020* is shown in the *Table 4.*

Table 4. Electricity generation capacity of Bangladesh from 2010 to 2020.

	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Hydro	230	230	220	220	230	230	230	230	230	230	230
Steam Turbine	2,638	2,211	2,193	2,193	2,115	2,217	2,578	2,404	2,404	2,344	2,966
Gas Turbine	1,466	932	1,145	1,295	1,616	1,838	1,193	1,105	1,322	1,607	851
Combined Cycle	1,263	1,166	1,292	1,455	1,757	2,162	3,293	4,625	5,730	6,364	7,330
Reciprocating Engine	226	2,100	3,250	3,374	3,603	3,992	4,471	4,591	5,604	7,226	7,808
Power Import	--	--	--	--	500	500	600	600	660	1160	38
Solar	--	--	--	--	--	--	--	--	3	30	1,160
	5,823	6,639	8,100	8,537	9,821	10,939	12,365	13,555	15,953	18,961	20,383

3. PRESENT SCENARIO OF ENGINE BASED POWER PLANTS IN BANGLADESH

In the earlier days, when the people used to think about power plants, they considered hydro power plants, thermal power plants or combined cycle power plants. Engines are usually considered for transportation or marine purposes. Engines were also used for electricity generation but in small scale, in the industry as captive power plants. Later, due to easy and quick installation time and less investment requirement, engines become popular to be used as prime mover in many power plants. Engines also have advantage that it can be started quickly and reach from zero to full load in a very short time. This

makes engine-based power plant popular as a peaking power plant and where there are variable demands.

Even 20 years ago, when talked about power plants, normally about turbine and thermal power plants were considered. Reciprocating engines were not used for generation of electricity. At that time generation was much lesser than the electricity demand of Bangladesh. Some industries used to use reciprocating engines to generate electricity for their own consumption and to maintain their uninterrupted operation/production.

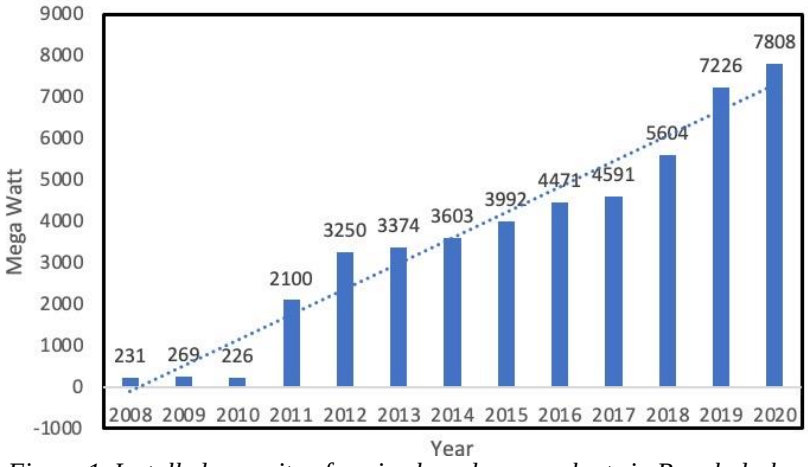

Figure 1. Installed capacity of engine based power plants in Bangladesh.

In 2008, the installed capacity of engine-based power plant was 231 MW, which was only 4.44% of the total capacity. But in 2020, the installed capacity of engine-based power plant is 7,808 MW, which is 38.31% of the total capacity of Bangladesh. Fig. 1 shows the growth of engine-based power plants in Bangladesh in the last 12 years. A comparison between the growth of engine-based power plants and the total growth of electricity generation capacity is also shown in Table 5. It is seen from Table 5 that the growth of engine-based power plant as of total growth of electricity generation in Bangladesh is quite remarkable.

Table 5. Total capacity vs engine based power plant capacity from 2008 to 2020.

Year	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Reciprocating Engine	231	269	226	2,100	3,250	3,374	3,603	3,992	4,471	4,591	5,604	7,226	7,808
Total Capacity	5,202	5,493	5,823	6,639	8,100	8,537	9,821	10,939	12,365	13,555	15,953	18,961	20,383
Engine-based Power Plant as % of Total Capacity	4.44	4.90	3.88	31.63	40.12	39.52	36.69	36.49	36.16	33.87	35.13	38.11	38.31

As on December 2020, there are total 96 nos. engine-based power plants in operation in Bangladesh and supplying electricity to the national grid. Out of these 96, 81 nos. are under BPDB and 15 nos. are under Bangladesh Rural Electrification Board (BREB). The locations of 81 power plants of BPDB are shown in the Table 6.

Table 6. Location of engine based power plants in Bangladesh.

Sl. No.	Zone	Number of Plants	Capacity Installed
1	Dhaka	21	2,324.8
2	Chittagong	14	1,322
3	Rajshahi	13	943
4	Khulna	7	615
5	Sylhet	5	291
6	Barisal	3	238
7	Rangpur	1	113
8	Mymensingh	4	432
9	Cumilla	13	1,282
	Total (BPDB)	81	7,560.8

The ownerships of the 81 nos. reciprocating engine-based power plants under BPDB are shown in the following Table 7.

Table 7. Ownership status of engine based power plants in Bangladesh.

Sl. No.	Ownership	Number of Plants	Capacity Installed
1	Gov. Owned Company	18	1505
2	IPP / SIPP	43	4,776.3
3	Rental	19	1,249.5
4	Captive	1	30
	Total (BPDB)	81	7,560.8

The fuel used by the 81 nos. reciprocating engine-based power plants under BPDB are shown in the Table 8.

Table 8. Fuel used in engine based power plants in Bangladesh.

Sl. No.	Fuel Type	Number of Plants	Capacity Installed
1	Gas	20	1,120.5
2	Furnace Oil	55	5,440.3
3	Diesel	6	1,000
	Total (BPDB)	81	7,560.8

4. ANALYSIS OF PRESENET SCENARIO OF ENGINE BASED POWER PLANTS IN BANGLADESH

4.1. Methodology

For present study, the capacities of engine-based power plants of Bangladesh for the last 12 years were collected from [8]. Six variables were chosen which may have influence the capacity growth. Thereafter, 12 years' data of these six variables were collected from [8, 15, 16]. Then line chart of each variable was drawn against the dependent variable i.e., capacity of engine-based power plant to compare the trend between two series. Later, a regression analysis was carried out to find out the relationship between the growths of engine-based power plants with the six variables that were chosen. Finally, the relationship between the variables was expressed in the form of a mathematical term.

4.2. Analysis of Variables Influencing Growth of Engine-Based Power Plants

The growth of engine-based power depends on many factors. For this study the following variables were considered:

1. *Total generation capacity of different types of plants in Bangladesh,*
2. *Electricity consumption in Bangladesh,*
3. *Fuel oil price,*
4. *GDP of Bangladesh,*
5. *Population in Bangladesh,*
6. *Growth in production of manufacturing industries (rate of industrialization).*

4.2.1. Generation capacity

When generation capacity increased, it is assumed that some of these additional generation has come by establishing power plants using reciprocating engine as prime mover. In Fig. 2, it was found that the growth of engine-based power plant and total generation capacity in Bangladesh increase in a similar pattern. From the Table 5, it can be found that from 2011 to till date, engine-based power plants are within 30 to 40% of the total generation. Thus, there is a positive relationship between engine-based power plant capacity and the total generation capacity.

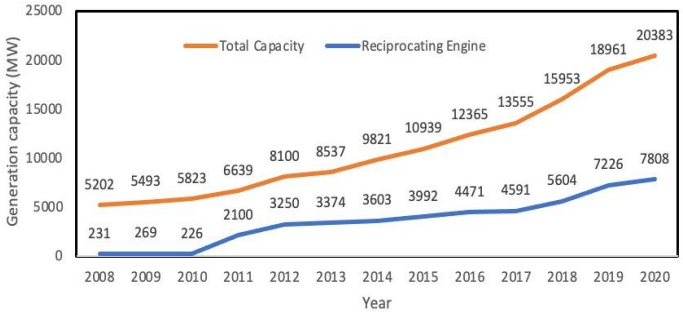

Figure 2. Engine based power generation capacity versus total generation capacity from 2008 to 2020.

4.2.2. Electricity consumption

When consumption of electricity increased, it is assumed that some of these additional consumptions are supported by establishing power plants using reciprocating engine as prime mover. The growth of engine-based power plant and increase in electricity consumption in Bangladesh are shown in Figs. 3 and 4. From the Figs. 3 and 4, it is seen that the growth of engine-based power plant and increase in electricity consumption in Bangladesh is almost in a similar pattern.

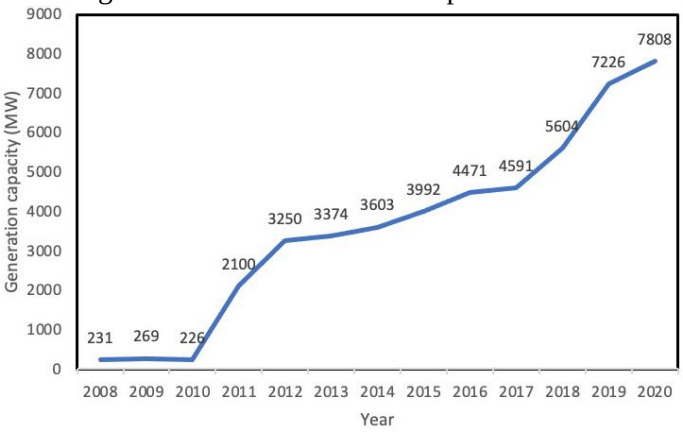

Figure 3. Growth of engine-based power plant capacity from 2008 to 2020.

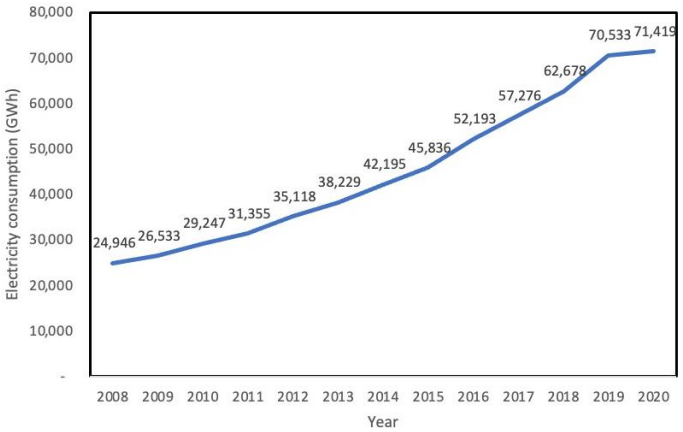

Figure 4. Growth of electricity consumption (GWh) in Bangladesh from 2008 to 2020.

4.2.3. Fuel oil price

When the fuel price decreases, it is assumed that the entrepreneurs/government will be more interested to establish engine-based power plants as these plants mostly use furnace oil or HFO or diesel oil. Thus, there should be an inverse relationship between these two figures: If the engine-based power plant capacity graph (Fig. 3) is compared with the fuel price graph (Fig. 5), it will be found that the line chart

in these two figures is not similar. It is due to the fuel market is very volatile and there are too much ups and downs in the fuel price due to various reasons, thereby there may be or may not be any relation between engine-based power plant capacity and fuel price.

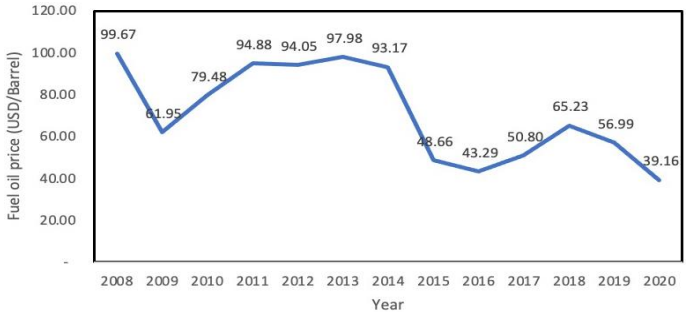

Figure 5. Historical fuel price trend in the world market from 2008 to 2020.

4.2.4. Gross domestic product (GDP) of Bangladesh

Energy security and economic development goes hand in hand for Bangladesh since it is looking to excel her economic growth to achieving middle income country status by 2021 and developed country status by 2041. Its economy is growing at a staggering rate of more than 7% for last 3 years in a row and eying at 8% growth in coming years. So, it is assumed that with the increase in GDP, the people of Bangladesh would consume more electricity and when consumption of electricity will increase, some of these additional consumptions will be supported by establishing power plants using reciprocating engine as prime mover. If the two line-charts of engine-based power plant capacity graph (Fig. 3) and the GDP graph (Fig. 6) are compared, almost similar pattern of growths are observed. Therefore, a positive relationship between engine-based power plant capacity and the GDP of Bangladesh exists.

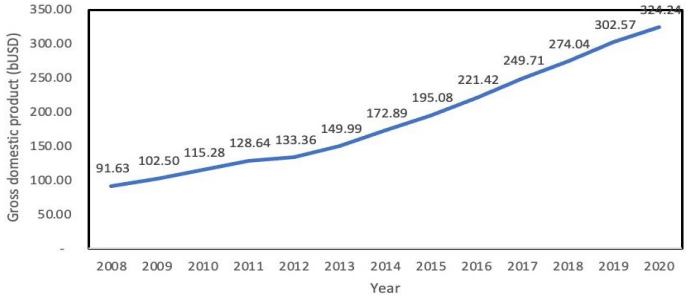

Figure 6. Gross Domestic Product (GDP) of Bangladesh from 2008 to 2020.

4.2.5. Growth of population of Bangladesh

With the increase of population in Bangladesh, the consumption of electricity will also increase and when the consumption of electricity will increase, the additional consumptions will be supported by establishing power plants using reciprocating engine as prime mover. If the line chart of engine-based power plant capacity graph (Fig. 3) is compared with the increase of population in Bangladesh (Fig. 7), it is found that the line charts are both upward but not in proportional. So, a positive relationship between engine-based power plant capacity and the increase of the population of Bangladesh.

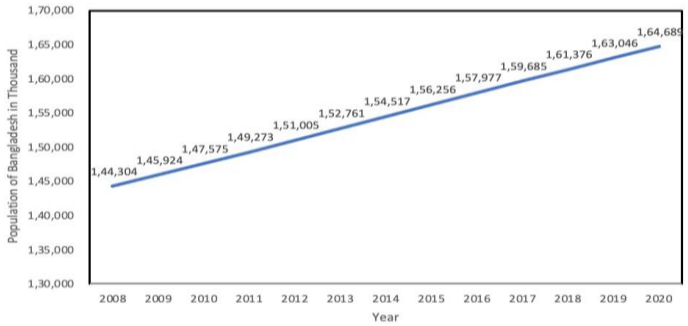

Figure 7. Growth in Population in Bangladesh from 2008 to 2020.

4.2.6. Rate of industrialization in Bangladesh

The growth of production in the manufacturing industries largely depend on the availability of electricity. Without electric power there would likely be no modern industry exist. When consumption of electricity increased, it is assumed that some of these additional consumptions are supported by establishing power plants using reciprocating engine as prime mover. If the line charts of engine-based power plant capacity graph (Fig. 3) and the growth of production in the manufacturing industry (Fig. 8) are compared it will be found that the line charts are almost similar pattern. It may be concluded that there is a positive relationship between engine-based power plant capacity and the production in the manufacturing industry in Bangladesh.

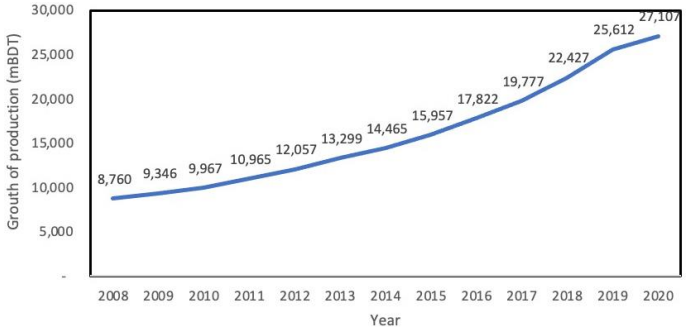

Figure 8. Growth of production in the manufacturing industries of Bangladesh from 2008 to 2019 (1 USD=85 BDT).

4.3. Summary of Results of the Present Scenario

In this study, six variables were chosen which were assumed to have influence in the growth of engine-based power plants in Bangladesh. The data of engine-based power plant and these six variables were collected for the last 12 years. The summary of the findings are listed below:

i. *With the increase in electricity generation capacity in Bangladesh, the number of engine-based power plants also increase.*
ii. *As the electricity consumption in Bangladesh increased, the additional electricity is being generated by establishing new engine-based power plant.*
iii. *It was assumed that when the fuel price decreases, more engine-based power plants will be established. But as there are too much ups and downs of the fuel price in the international market in the last decade, which did not impact on the growth of engine-based power plants in Bangladesh.*
iv. *With the increase of GDP, the consumption of electricity in Bangladesh will also increase and this additional consumption was met by establishing engine-based power plant.*
v. *The growth of population of Bangladesh and the increase of electricity generation by engine-based power plant are not in similar pattern.*
vi. *In the last decade, the growth in the production industries found proportional to the growth in the capacity of engine-based power plants.*

4.4. Regression Analysis of Engine-Based Power Plants in Bangladesh

To ascertain the relationship between the capacity of engine-based power plants and the independent variables and to find out a mathematical relationship, a regression analysis was conducted. As the capacities of engine-based power plant are too low in the year of 2008-2010 (Table 5). The data used for the regression analysis in the present study are mentioned in Table 9. The model of the present investigation is given by Eq. 1.

$$Y = f(X_1, X_2, X_3, X_4, X_5, X_6) \quad (1)$$

Here, Y = Capacity of Engine based power plant (Dependent variable)

The independent variables are,

X_1= Total generation capacity of different types of plants of Bangladesh.
X_2= Yearly electricity consumption in Bangladesh.
X_3= Fuel oil price.
X_4= GDP of Bangladesh.
X_5= Population of Bangladesh.
X_6= Industrial growth / GDP from manufacturing industry.

Microsoft Excel were used for the regression analysis in the present study. Three cases were analyzed as,

- *Case 1: considering all the independent variables;*
- *Case 2: two independent variables yearly electricity consumption (X_2) and GDP from the manufacturing industries (X_6) are omitted;*
- *Case 3: independent variable fuel price (X_3) is considered.*

It is to be mentioned here that in regression analysis, null hypothesis, H_0 is equal to zero means variable has no effect and alternate hypothesis, H_A is not equal to zero means variable has an effect.

Table 9. Data used for regression analysis.

Year	Engine power plant capacity (Y) in MW	Generation capacity (X_1) in MW	Yearly electricity consumption (X_2) in GWh	Fuel price (X_3) in USD/barrel	GDP (X_4) in bUSD	Population (X_5) in thousand	Industrial growth/ GDP from manufacturing industry in (X_6) mBDT
2011	2,100	6,639	31,355	94.88	128.64	149,273	10,965.10
2012	3,250	8,100	35,118	94.05	133.36	151,005	12,056.70
2013	3,374	8,537	38,229	97.98	149.99	152,761	13,299.40
2014	3,603	9,821	42,195	93.17	172.89	154,517	14,465.30
2015	3,992	10,939	45,836	48.66	195.08	156,256	15,956.80
2016	4,471	12,365	52,193	43.29	221.42	157,977	17,822.30
2017	4,591	13,555	57,276	50.80	249.71	159,685	19,776.50
2018	5,604	15,953	62,678	65.23	274.04	161,376	22,427.00
2019	7,226	18,961	70,533	56.99	302.57	163,046	25,611.80
2020	7,808	20,383	71,419	39.16	324.24	164,689	27,106.70

4.4.1. Case 1

All independent variables will be checked by using *t*-test to see whether each of the independent variable that have been included in the function has an effect on the dependent variable. The output of the regression analysis is shown in Table 10.

In this analysis,

Number of observations, n = 10
Number of parameters, i.e., number of right hand side variables plus the constant, k = 7
From t-table, value of t at (n-k) or 3 degrees of freedom (df) = 1.637744 at 0.20 significance level [17].

The findings of the analysis are summarized in a tabular form and shown in Table 11.

Table 10. Results of the regression analysis for Case 1.

Regression Statistics								
Multiple R	0.9997							
R Square	0.9993							
Adjusted R Square	0.9980							
Standard Error	80.8229							
Observations	10.0000							
ANOVA								
	df	*SS*	*MS*	*F*	*Significance F*			
Regression	6	29131493.86	4855248.976	743.2624584	7.61958E-05			
Residual	3	19597.04377	6532.347923					
Total	9	29151090.9						
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 90.0%*	*Upper 90.0%*
Intercept	-20832.5217	7741.8618	-2.6909	0.0744	-45470.5812	3805.5378	-39051.9362	-2613.1072
Generation Capacity (X1) MW	0.5287	0.1599	3.3067	0.0455	0.0199	1.0376	0.1524	0.9051
Electricity Consumption (X2) GWh	-0.0046	0.0316	-0.1456	0.8935	-0.1051	0.0959	-0.0789	0.0697
Fuel Price (X3) USD/barrel	-4.9465	2.7530	-1.7968	0.1702	-13.7076	3.8146	-11.4252	1.5322
GDP (X4) bUSD	-48.3421	9.2325	-5.2361	0.0136	-77.7242	-18.9600	-70.0697	-26.6146
Population (X5) Thousand	0.1512	0.0544	2.7789	0.0691	-0.0220	0.3243	0.0231	0.2792
Industrial Growth/ GDP from Manufacturing Industry (X6) mBDT	0.3366	0.2227	1.5119	0.2278	-0.3720	1.0452	-0.1874	0.8606

Table 11. Results of the regression analysis for Case 1.

Variables	Sign	Calculated T-value	Comparison with T-test tabular value [17]	Status of null hypothesis, H_0	Effect of alternate hypothesis, H_A
Total generation capacity of Bangladesh	X_1	3.3067	Greater	Rejected	Yes
Yearly electricity consumption of Bangladesh	X_2	0.1456	Less	Not rejected	No
Fuel price	X_3	1.7968	Greater	Rejected	Yes
GDP of Bangladesh	X_4	5.2361	Greater	Rejected	Yes
Population of Bangladesh	X_5	2.7789	Greater	Rejected	Yes
GDP from manufacturing industry of Bangladesh	X_6	1.5119	Less	Not rejected	No

4.4.2. Case 2

Now, the two independent variables, yearly electricity consumption (X_2) and GDP from the manufacturing industry of Bangladesh (X_6) are omitted from capacity function of engine-based power plants in Bangladesh. The output of the regression is mentioned in Table 12.

In this analysis,

Number of observations, n = 10
Number of parameters, i.e., number of right-hand side variables plus the constant, k = 5
From t-table, value of t at (n-k) or 5 degrees of freedom (df)= 1.475884 at 0.20 significance level [17].

The findings of the analysis are summarized in a tabular form and shown in Table 13.

Table 12. Results of the regression analysis for Case 2.

Regression Statistics								
Multiple R	0.9994							
R Square	0.9988							
Adjusted R Square	0.9978							
Standard Error	84.1767							
Observations	10							
ANOVA								
	df	*SS*	*MS*	*F*	*Significance F*			
Regression	4	29115662.3509	7278915.5877	1027.2670	1.80068E-07			
Residual	5	35428.5491	7085.7098					
Total	9	29151090.9000						
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 90.0%*	*Upper 90.0%*
Intercept	-18365.0315	6659.4593	-2.7577	0.0399	-35483.7165	-1246.3465	-31784.1640	-4945.8990
Generation Capacity (X1) MW	0.7653	0.0467	16.3779	0.0000	0.6452	0.8855	0.6712	0.8595
Fuel Price (X3) USD/barrel	-2.3685	2.2427	-1.0561	0.3393	-8.1335	3.3965	-6.8877	2.1506
GDP (X4) bUSD	-36.1243	4.7940	-7.5352	0.0007	-48.4478	-23.8009	-45.7846	-26.4641
Population (X5) Thousand	0.1357	0.0466	2.9138	0.0333	0.0160	0.2555	0.0419	0.2296

Table 13. Results of the findings of the regression analysis for Case 2.

Variables	Sign	Calculated T-value	Comparison with T-test tabular value [17]	Status of null hypothesis, H0	Effect of alternate hypothesis, HA
Total generation capacity of Bangladesh	X_1	16.3779	Greater	Rejected	Yes
Fuel price	X_3	1.0561	Less	Not rejected	No
GDP of Bangladesh	X_4	7.5352	Greater	Rejected	Yes
Population of Bangladesh	X_5	2.9138	Greater	Rejected	Yes

4.4.3. Case 3

The independent variables, yearly electricity consumption (X_2), GDP from the manufacturing industry of Bangladesh (X_6) and fuel price (X_3) are omitted from capacity function of engine-based power plants in Bangladesh. The output of the regression is mentioned in Table 14.

In this analysis,

Number of observations, n = 10
Number of parameters, i.e., number of right-hand side variables plus the constant, k = 4
From t-table, value of t at (n-k) or 6 degrees of freedom (df) = 1.439756 at 0.20 significance level [17].

The findings of the analysis are summarized in a tabular form and shown in Table 15.

Table 14. Output of regression analysis for Case 3.

Regression Statistics								
Multiple R	0.9993							
R Square	0.9985							
Adjusted R Square	0.9978							
Standard Error	84.9820							
Observations	10							
ANOVA								
	df	*SS*	*MS*	*F*	*Significance F*			
Regression	3	29107759.2134	9702586.4045	1343.4861	7.18056E-09			
Residual	6	43331.6866	7221.9478					
Total	9	29151090.9000						
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 90.0%*	*Upper 90.0%*
Intercept	-20454.7244	6419.5529	-3.1863	0.0189	-36162.8046	-4746.6443	-32929.0731	-7980.3758
Generation Capacity (X1) MW	0.7441	0.0426	17.4801	0.0000	0.6399	0.8482	0.6613	0.8268
GDP (X4) bUSD	-35.0022	4.7195	-7.4164	0.0003	-46.5505	-23.4539	-44.1731	-25.8313
Population (X5) Thousand	0.1482	0.0455	3.2562	0.0173	0.0368	0.2595	0.0597	0.2366

Table 15. Summary of the findings of the regression analysis for Case 1.

Variables	Sign	Calculated T-value	Comparison with T-test tabular value [17]	Status of null hypothesis, H0	Effect of alternate hypothesis, HA
Total generation capacity of Bangladesh	X_1	17.4801	Greater	Rejected	Yes
GDP of Bangladesh	X_4	7.4164	Greater	Rejected	Yes
Population of Bangladesh	X_5	3.2562	Greater	Rejected	Yes

From in Table 14, the following points can be addressed.

i. *The value of Multiple R is 0.9993, which indicates that there is a strong correlation between the variables and the growth of engine-based power plants. As in Table 14, the Multiple R will not tell us if the correlation is positive or negative.*
ii. *R-Squared indicates how well the model or regression line "fits" the data. The adjusted R-square is 0.9978, which indicates that 99.77% variance in the growth of engine-based power plant can be explained by the independent variables which was chosen.*
iii. *The standard error is a measure of the precision of the model. As the standard error reflects how wrong the analysis could be, it is expected that the standard error should be as small as possible. In the model, the standard error is 84.982, which is relatively small.*

From the analysis of Case 3, the capacity function of engine-based power plants in Bangladesh can be defined by equation (2).

$$Y = -20454.7244 + 0.7441\,X_1 - 35.0022\,X_4 + 0.1482\,X_5 \qquad (2)$$

Here,

Y = Capacity of Engine-based power plants in Bangladesh.
X_1 = Total generation capacity of different types of plants of Bangladesh.
X_4 = GDP in Bangladesh
X_5 = Population in Bangladesh.

Correctness of equation (2) is checked with some previous data of total generation capacity of Bangladesh shown in Table 9. From Table 9, data of 2012, 2015 and 2018 were taken. The derived capacity by using the equation (2) and the actual capacity of the engine-based power plants (in Table 9) are shown in the Table 16.

Table 16. Comparison of derived capacity with actual capacity.

Year	Derived capacity in MW	Actual capacity in MW	Deviation in percentage
2012	3,277	3,250	0.83
2015	4,007	3,992	0.37
2018	5,732	5,604	2.28

It is found from Table 16 that deviation between the derived capacities and the actual capacities of engine-based power plants is very less. There, Eq. 2 can be used to predict the future demand of engine-based power plants of Bangladesh.

The Government of Bangladesh has been implementing a master plan to generate 24,000 MW of electricity by 2021; 40,000 MW by 2030 and 60,000 MW by 2041 [14]. These three figures will be used to find out the future capacity of engine-based power plants in Bangladesh. Eq. 2 is used to find out the future demand of engine-based power plant in Bangladesh. The forecasted data of population and GDP for the year of 2021, 2030 and 2041 are collected [8]. The forecasted demand for the engine-based power plant is mentioned in Table 17.

Table 17. Future demand of engine-based power plant of Bangladesh

Year	Generation Capacity (X_1) in MW	GDP (X_4) in bUSD	Population (X_5) in thousand	Derived future capacity (Y) in MW
2021	24,000	388.00	166,303	8,461
2030	40,000	800.00	178,993	7,825
2041	60,000	2,580.00	189,066	(38,106)

From Table 17, it was found that, the capacity of engine-based power plant will decrease in future. It may be due to too high GDP was forecasted for the year of 2041 and as higher GDP has negative impact on the capacity of engine-based power plants. Other reasons may be induction of large base load power plants and atomic power plant, country's shift towards renewable energy and import from neighboring countries.

5. CONCLUSION

In this analytical and quantitative investigation, the growths on engine-based power plants have been clarified by considering six variables as total generation capacity of different types of plants in Bangladesh, yearly electricity consumption, fuel oil price, GDP, population and growth of production in the manufacturing industries. It is seen that except fuel oil price and population in Bangladesh, other four variables have notable co-relationship with the growth of engine-based power plant in Bangladesh. Later, the regression analysis is realized to explore the relationship between the dependent and independent variables and this relationship is expressed in a mathematical term.

Government policy, political and socio-economic factors play a great role in the growth of engine-based power plant and the power sector. There are some advantages of engine-based power plants, which will play positive role on its growth like short installation time, less investment, less land requirement, large variable demands of electricity in our country, easy start and stop, short ramping period, fuel advantage in terms of price and availability, increased efficiency of new generation engines etc.

There are also some factors having negative impact on the growth of engine-based power plants, such as import electricity from the neighbor country, start operation of big base load power plants, discourage generation of electricity from fossil fuel, moving towards green energy and present overcapacity which

causes huge financial burden on the Government, industrialization has not been developed in the expected rate and slowdown of economic activities all over the country due to Covid 19 pandemic.

In Bangladesh, the reliable data remains a scarcity. The outcome of the present study would be beneficial for the policy makers and possible investors in the energy sector of Bangladesh. It would also be beneficial to all stakeholders, involved in operation and maintenance of engine-based power plants and the vendors of these plants. Furthermore, it would also serve as a reference material and stimulate further research in the Bangladesh's power sector.

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