New Birth for Green Revelation Started In India through Auto- Rickshaw

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1. INTRODUCTION

With continued economic growth, all sectors of Bangladesh are developing day by day. With this development, megacities of the country are experiencing more traffic. Buses, Rickshaws and Auto-rickshaws (Electric or Internal Combustion Engine run) are the main public transports in megacities (i.e. Dhaka, Chittagong, Rajshahi) [1]. The autorickshaw and the relatively modern iteration of the e-rickshaw (electronic rickshaw) because of their low cost are becoming more popular than taxis in current century [2]. In Asian megacities, like Mumbai, Dhaka, Kolkata, Bengaluru and Chittagong; this vehicle is mostly used for medium travelling distance (1 to 7 km's). Auto-rickshaws are a common means of public transportation in many developing countries in the world [1, 3].

Auto-rickshaw is a three wheeler mostly running on fuel (CNG/LPG) or electrical energy. Those running on batteries by means of electricity are often called "Easy Bikes", locally it is a very cost effective vehicle. LPG (Liquefied Petroleum Gas) and CNG (Compressed Natural Gas) are nonrenewable energy sources. At present in Bangladesh, the fuel price is increasing day by day. Burning of petrol, natural gas and oils produces carbon dioxide, which is responsible for global warming. Moreover, the exhaust gases release different types of deadly fluid aerosols and chemicals in the atmosphere which is very harmful for humans and animals [4, 5]. Presently, there are many types, designs and variations in auto-rickshaws.

The best way to redesign the rickshaw is to make the key power source hybridized. One way to do this is to use an energy system that can take advantage of several sources of renewable energy; i.e. Solar energy, wind energy etc. Auto rickshaws are a great prospect for electrification because of relatively low velocity and a relatively small distance protected in a day [6]. In this paper, a mechanism using micro hybrid system to run an engine driven rickshaw is shown and defined. Solar energy and thermal energy can be used to drive the auto-rickshaw jointly by means of hybridization. Solar energy is chosen here because Bangladesh gets huge amount of energy from the sun. Here, the best sunlight hours received in Khulna ranging from 2.86 to 9.04 hours and in Barisal it ranges from 2.65 to 8.75 hours [7]. Compared to other conventional vehicles, micro hybridized vehicles consume less energy and produces much less green house and toxic gases. However, a critical review of literature regarding several works done on auto-rickshaw in dissimilar fields is shown in Table 1.

Table 1. Different previous work done on Auto-rickshaw

Year	Purpose of Study	Major Findings	References
2007	Worked on developing the usage pattern for three wheeled auto-rickshaw in India.	Designed a drive cycle for auto-rickshaw and validated the cycle by Simulink software	[8]
2009	Worked on micro-hybrid system installation on engine operated auto-rickshaw.	Tested and made a prototype of micro-hybridized auto-rickshaw for India	[9]
2010	Used solar PV modules in auto-rickshaw as a green power source in normal electric auto-rickshaw	Designed and auto-rickshaw which was solar assisted and validated the design by ADVISOR software.	[10]
2010	Analyzed on economic and social	Surveyed on 200 operators and 100 passengers,	[11]

	parameters of threewheeler taxi service.	it analyzed the positive and negative aspects of these vehicles	
2012	Worked on time-dependent plug in hybrid electric vehicle.	Found a compact vehicle with 10.4 KW useable batteries travels 62.5% to 75.7% on battery electricity, depending on charging scenario.	[12]
2012	Worked on the role of auto-rickshaw on sustainable urban transport sector.	Examined the role auto-rickshaw can play in sustainable urban transport sector of India and found a very positive result	[13]
2014	Worked on Hybrid energy assisted auto-rickshaw three wheeler.	They used plug-in hybrid technology along with PV panel and validated the design by ADVISOR software	[14]
2016	Worked on the emission factors of auto-rickshaws using real world driving cycle.	They used Indian driving cycle and modified Indian driving cycle for predicting the emissions. In this study real-world DCs were developed for motor cycles and auto-rickshaw.	[15]
2017	Worked on solar assisted tri-wheeler rickshaw	Made a prototype of a solar driven tri-cycle and tested its feasibility	[16]
2017	Proposed a solar based micro-hybridized autorickshaw.	Mathematically analyzed the vehicle by adding a PV panel with microhybrid technology and did a feasibility analysis for Bangladesh	[6]

From Table 1, most of the works on auto-rickshaw comments about petroleum burning or renewable

source driven vehicle. This research was directed from T. Hofman *et al.* 2009; which was focused on hybridization of engine operated auto-rickshaws for India, but this research didn't mention any renewable source of input energy.

1.1. Power Train of the Vehicle

In this proposed vehicle, electrical and thermal energy sources are combined along with micro hybrid system. As energy sources ICE and Batteries are being used. These two power sources are hybridized. The battery is charged my means of national grid and solar energy. There are several hybridization methods available like Series, parallel, seriesparallel and complex; parallel hybridization is implemented here. The basic difference between a hybrid and a conventional vehicle is the braking system. Hybrid vehicles use regenerative braking system; an energy recovery module which slows down the vehicle by transforming its kinetic energy into a form and is used immediately to other

works or stored for further use. Hybrid vehicles are less fuel consuming [17]. Fig. (1) shows the schematic diagram of the vehicle power train.
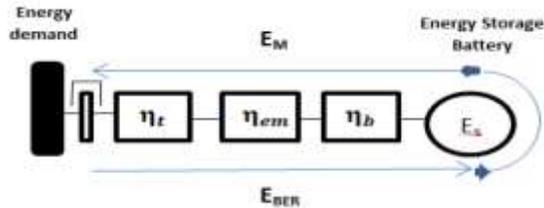

Fig. (1). Schematic diagram of the vehicle power train.

The fuel saving potential might be increased by recuperating brake energy and re-using this energy, EEBR denotes the recuperating brake energy (for electric driving). This electric energy is used for driving (EM). Fig. (1) shows the vehicle power drive. This recuperating/regenerating brake energy is calculated over the drive cycle in t_f time;

$$E_{BER} = -\int_0^{t_f} f_{br}.\min(0, P_v(t)).\eta_t.\eta_{em}.\eta_b.dt \tag{1}$$

In the above equation (1), *fbr* denotes brake friction (regenerative). The subscripts denotes namely the transmission, electric motor and battery efficiency which is respectively assumed 98%, 85% and 80% average constant. The engine assumed here is "shut off kind" and has no drag losses due to electric driving and braking.

1.2. Design Topology

In addition to the element sizing and control engine optimization, the topology selection also plays an important role in the general hybrid drive train optimization. In Fig. (1), an understanding is given of different locations of joining the hybrid system to the drive coach. If more hybrid driving modes can be used, then fuel saving potential rises. Depending on the topology, a number hybrid functions can be utilized very well other functions increase difficulties. In Table 2, an overview is given on the pros and cons of different topologies. Through this qualitative comparison, it can be concluded that topologies 1, 3, and 5 perform the same and are therefore favorable. The topological table here is based on quality and nature of the spare parts.

A Table showing the topological analysis is give below:

Table 2. Topological Analysis

Topological Options for Proposed Vehicle: ++ = very good, + = good, - = bad, () = not possible		1	2	3	4	5
Topology		1	2	3	4	5
Regenerative Braking		-	-	+	+	+
Electric Driving		++	()	+	-	++
Charging (Driving)		+	++	++	+	+
Easy Mounting		++	-	-	-	-
Compacting		-	-	+	-	-
Start-Stop		()	++	++	()	()
Motor-Assistance		+	+	+	++	++
Possibility Score		44%	22%	44%	22%	50%

Fig. (2) shows the topology designing of the proposed vehicle. The numbering indicates the possible locations of the components of the system. Here, ICE-Internal Combustion Engine, A-Alternator, FT-Fuel Tank of the vehicle, CLClutch (Wet-Plate type), BAT- Battery, Aux- Auxiliary Parts, MT- Manual Transmission.
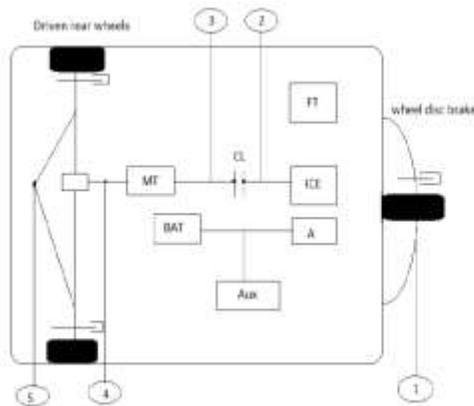

Fig. (2). Topology designing of the proposed vehicle.

2. POWER ANALYSIS

This paper focuses on micro hybridization of three-wheeler auto-rickshaw. Topology of the proposed system is shown in Table 2. This system has a conventional Internal Combustion Engine (ICE) and an electrical energy source namely, Li-ion battery used generally for medium load transfer. A micro hybrid vehicle uses a '*start-stop system*', a regenerative breaking technology is applied here for stopping an ICE when the system pulls to stop and to restart it by pushing the accelerator. Here the proposed vehicle is being designed and the power calculations along with fuel consumption have been done under typical conditions and the parameters (with dimensioning) of the machine elements are given as per local market specifications available in Bangladesh.
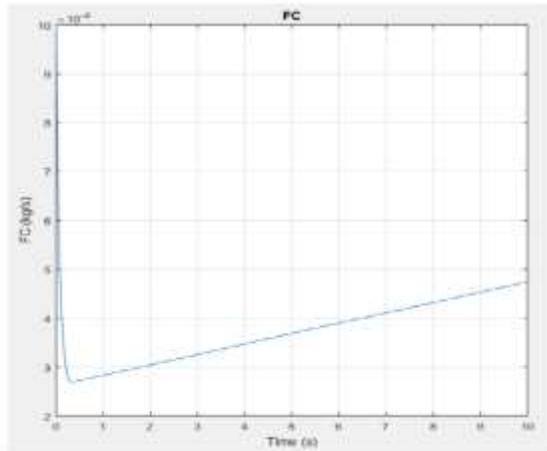
2.1. Engine Specifications, Testing of Performance with Simulation

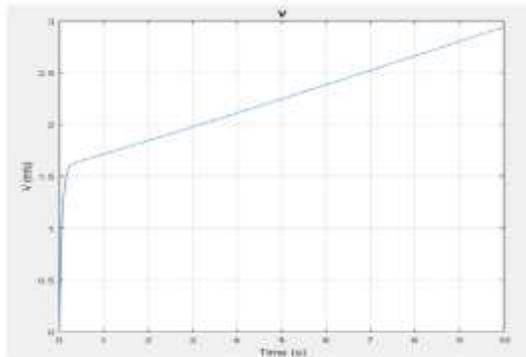The specifications of the experimental engine are given below in Table 3:

Table 3. Experimental Engine Specifications [18 - 20].

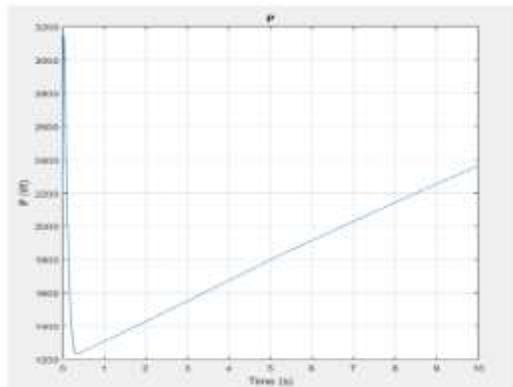| Parameters	Dimension (SI unit)
Piston Diameter	$.050228 \times 10^3$ Meters
Bore Radius	0.025114×10^3 Meters
Length of the Bore	0.046 Meters
Length of Stroke	0.042 Meters
Cubic Capacity	69.9×10^{-6} Cubic Meters
Type of Engine	2 Strokes
Number of Cylinders	01 pcs
Torque	12.591 Nm
Engine Efficiency	25%
Fuel	Petrol/Octane
Volume of Engine Cylinder	10 Cubic Meters (Approximate)
Brake Power	2.61 KW @ 5000 rpm speed

The performance of an ICE depends on various measures like bore, fuel consumption, Brake Mean Effective Pressure (BMEP), Displacement of piston and etc. Table 4 below shows the performance testing results of the engine stated in Table 3.

(a)

(b)

(c)

Fig. (3). Simulated results using Simulink platform. (a) Fuel Consumption vs time profile, (b) Velocity profile with respect to time and (c) Power consumption profile.

Vehicle simulation model driven by engine was done regarding the above data. The simulations were done using Simulink platform. For engine properties Table 3 and for vehicle properties Table 4 was used. Fig. (3) shows the simulated results.

Table 4. Engine Performance Testing [21].

Particulars	Equation	Value
Displacement of Engine	$\pi . S^2 . B . p$	Cubic Meters
Stroke	$\frac{4D}{\pi B^2 n}$	0.042 Meters
Bore	$\frac{4D}{\pi S n}$	0.046 Meters
BMEP	$(2\pi \times Torque) /(Displacement\ of\ Engine)$	1120777375 Pa
Fuel Consumption		10 kg hr (Measured) = 0.014 m³/h (As Slip sec = 1 m³/hr)
Mass Flow Rate	$(Volume\ of\ Engine\ Cylinder \times Sp.Gravity\ of\ Fuel) /(Time \times 1000)$	0.014 m³/hr = .0028 kg/sec
Angular Velocity	$2\pi N/60$	523.5 rad/sec (N = Engine Speed in rpm)
S.P. Fuel Consumption	(Wt. of Fuel) (Brake Power)	0.036 kg/kW (Approximately)

2.2. Solar Photovoltaic (PV) Module Specification and Power Consumption

The battery used as electrical energy source will be charged in two ways, from National Grid and Solar PV module, respectively. A perfect designed PV module is needed to charge the batteries. The specifications of the PV module are given in the following Table 5 below.

Table 5. Photovoltaic Module Specifications [22, 23].

Parameters	Dimension (SI units)
Solar Panels	2 Pcs
Rated Output	12V-100 W (Total)
Dimension	1.5 × 0.8 × 0.05 Meters
No. of Cells per Panel	N.A. (Variable)
Efficiency	10% (Approximately)
Battery	24 Volts, 4 pcs
No. of Solar Cells	60 Mono Crystalline Cells

Power Consumption for PV module:

Let, The total weight of the proposed Vehicle =500 kg (including all mountings and passengers)

Average speed = 35 kmph

Total Power = Total weight of vehicle × g × speed × gradient of velocity

= 500 × 9.8 ×35 kmph × .03 Watts

= 500 × 9.8 × 9.7 kmps × .03 Watts

= 1426 Watts

Here, the induction motor used is of 12V-1kW rated.

Load Current per Day = *Current Flow × Running Time per Day × 1.2*

= 42 × 5 hrs × 1.2 250 Amp.hrs/Day

Capacity of the Battery = Load Current per Day × 1.2

≈ 300 Amp.hrs/Day (overall 25% losses)

Power required to run the motor = Capacity of Battery × Voltage Difference

$= 250 \times 36 = 9000$ Whrs/Day

Now, here The Capacity of Solar Panel is 12V-180W,

Current Flow $= (180/12)/4 = 3.75$ Amp to each Battery

Charging Time $= 250/3.75 = 66.67$ hrs

If one Solar Panel is used then in 8 hrs of daylight the system will be charged or 12%. But if the numbers of solar panels are increased then this charging would be more efficient. This percentage of charging can be increased by increasing the number of solar panels. If two solar panels are used, then the system will be charged 24% using PV module.

3. RECHARGING INFRASTRUCTURE AND DRIVE CYCLE

This proposed power plant is designed according to charge 50 auto-rickshaws. As stated above, this type of auto rickshaw needs around 1430 Watts power to run 5 hours/day. If we want to provide the full power from solar charging then the power plant capacity should be $(50*1430) = 71.5$ kW.

A set of 18, 5 kW solar modules will be used to make the power station. The total output will be $90*0.9 = 81$ kW [24].

Fig. (4) shows the diagram of recharging infrastructure suitable for Bangladesh.

Fig. (4). Recharging infrastructure for proposed vehicle.

In this situation, a rickshaw administrator would go to neighborhood power stations (potentially the current service stations), where his released batteries would be swapped with completely charged batteries. The completely charged batteries would be brought from an off-site reviving station to the administration stations by electric truck, as shown in Fig. (4) [10, 25].

There are a few objectives set for the outline of the energizing station:

1. The battery replacing procedure must be as easy as filling the tank with fuel to a rickshaw driver. In Bangladesh most of the drivers are not skilled.

2. The use of renewable energy sources should be increased in Bangladesh to reduce the pressure on nonconventional energy sources.

3. In addition, in Bangladesh grid energy is not available in every place. This type of power station is effective in rural places.

Table 6. Optimizing Recharging Station Components [10, 25, 26]

	PV	Wind	Gen
Size (kW)	600	450	350
Output (MWh/yr)	1200	1125	895
Excess (%, MWh)		482.159	
% Renewable		73	

Table 6 shows the optimization of recharging components. For the re-charging solar and wind energy systems are used in combination. For avoiding connection to grid, propane generator is used as an energy buffer.

Drive cycle is assumed to be a vital part in outlining of a hybrid drive train. Normally, the auto-rickshaws go around 50–60 km per day. The federal test FTP-75 is used here to conduct the drive cycle considering typical auto-rickshaw dimensions and parameters and road conditions in Bangladesh. The normal drive cycle speed is taken 25 Km/hr, which compares the internal city activity circumstance. Drive cycle and drive power demand were done using ADVISOR platform.

Fig. (5) represents the graphical model of urban drive cycle. The drive cycle and the vehicle specifications listed in Tables 2 and 3 can be used to calculate the wheel torque, TW as follows:
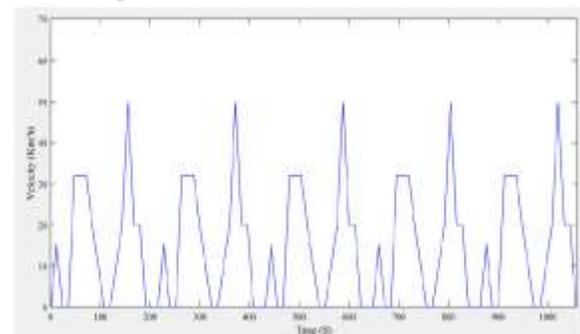
Fig. (5). Urban part of modified Bangladeshi drive cycle.

TW(t) = Cr.MV.g.RW + (1/2). [25]

Where, g = gravitaional accelertion

p = air density (1.225 kg/m3)

And wheel speed,

The drive power demand is,

In Fig. (6), the drive power request is computed at every moment for the whole length of the drive cycle. The drive power demand is utilized to compute the braking energy that is accessible for regeneration and henceforth select the extent of the energy storage system.
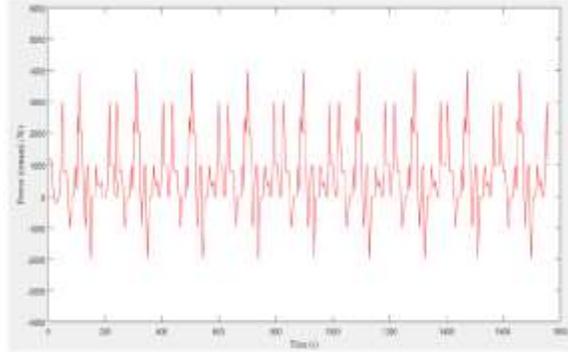

Fig. (6). Drive power demand

4. FEASIBILITY ANALYSIS

Feasibility is an analysis and evaluation of a proposed system to determine if it is (1) technically possible to make, (2) is practicable within the estimated cost, and (3) will gain profit. Feasibility studies are almost always conducted where the proposed system has some possibility of break-down issue [27].

Here we have considered installation cost and environmental risk as variable measure. If the installation cost of micro-hybrid to a conventional engine operated auto-rickshaw has a bearable cost and the payback period of this excess cost is suitable then this system would be cost-effective.

4.1. Installation Cost Calculations

In this section, installation cost of micro-hybrid system to a conventional engine operated vehicle is shown. Table 7 shows the cost assumptions for installing micro-hybrid system:

Table 7. Cost estimation of new component installation.

Component	Cost
Micro-hybrid system	Nearly same as normal gearing arrangement of conventional ICE operated auto-rickshaw.
PV Panel: 12V-180W (per pcs)	7000 BDT (Nearly 84.38 USD)
Battery: 36V (per pcs)	8000 BDT (Nearly 96.34 USD)
Induction Motor: 12V-1KW (1 pcs)	7000 BDT (Nearly 84.38 USD)

Here, as micro-hybrid system costs nearly the same of conventional gearing arrangement of ICE operated autorickshaw, so this cost can be omitted for the simplicity of cost estimation of new component installation.

In this system, it typically needs:

1-2 pcs of PV Panel(s) + 4 pcs of Battery + 1 pcs of Induction Motor = 46000-53000 BDT (554-638 USD approximately)

Thus, maximum installation cost of the proposed vehicle is 53000 BDT (Nearly 638 USD).

4.2. Payback Period of New Installation Cost

Payback period is the time required for the amount invested in an asset to be repaid by the net cash flow generated by the asset. It is a very simple way to evaluate the risk associated with a proposed project. An investment with a shorter payback period is considered to be better, since the investor's initial outlay is at risk for a shorter period of time [28, 29].

Formula of payback period is,

Payback Period = {(p-n)/p} + ny = {1 + ny − (n/p)} (unit: yrs)

Here,

ny = The number of years after the initial investment at which the last negative value of cumulative cash flow occurs.

n = The value of cumulative cash flow at which the last negative value of cumulative cash flow occurs.

p = The value of cash flow at which the first positive value of cumulative cash flow occurs.

In this proposed vehicle,

Total power calculated to run the system = 1426 Watts

Power required to run the motor 9 kwatts.hr/day = 9 unit

In Bangladesh, commercial electric line cost 25 bdt/unit [Source: DESCO, https://www.desco.org.bd/]

Requires = 9000/ 5* 36* 4 = 12.5 hours to charge the full battery.

Cost to charge the battery= 12.5*25 = 312.5 bdt/day

Table 8 shows the payback period for the system.
Table 8. Estimation of payback period against new installing cost.

Parameters	Case-1	Case-2
PV Panels	1 pcs	2 pcs
Batteries	4 pcs	4 pcs
Induction Motor	1 pcs	1 pcs
Power Supply from PV Module (per day)	12-14% of 9 kW	25-30% of 9 kW
Cost Reduction (per day)	27-32 BDT (around 0.35 USD)	55-62 BDT (around 0.75 USD)
Payback Period (yr.)	Around 4-4.5 yrs. maximum	Around 2-2.5 yrs. maximum

From the analysis above, Case-2 is more favorable.
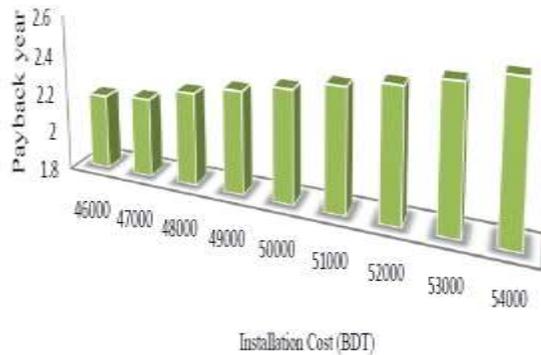Fig. (7) shows a graphical representation of Payback Period and Installation Cost.

Fig. (7). Payback Period *vs* Installation Cost graph.

So, the payback time of this proposed system is between 2-2.5 years (approximately). A typical auto-rickshaw running age is between 18-20 years without much fluctuation in its performance [30]. Fig. (8) shows the relation between the running age and performance of a typical auto-rickshaw of Bangladesh.
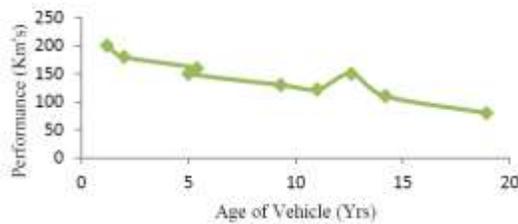

Fig. (8). Age *vs* Performance graph for sub-continental auto-rickshaws.

This proposed system needs 2-2.5 years to gain the installation cost, this payback time is only about 11-14% or less than 1/5Th of the total running lifetime of an auto-rickshaw. So, this proposed system seems to be a profitable one by cost estimation.

4.3. Environmental Impact Analysis

Environmental impact analysis of a system is a mathematical prediction of that shows how much environment friendly that system is or how much harm can it cause. It is a very important factor regarding feasibility measurement of a system. This research is mainly focused on lessen the conventional energy consumption *via* using renewable energy in Bangladesh.

In Bangladesh, electricity is mainly produced by using thermal power plants. Those thermal power plants are a key source of CO_2 gas emission resulting in enhanced greenhouse effect [4]. A 500 MW thermal power plant can produce up to 1 kg/kWhr production of electricity [31].

Fig. (9) gives a complete knowledge about CO_2 emission from the power plants of Bangladesh.
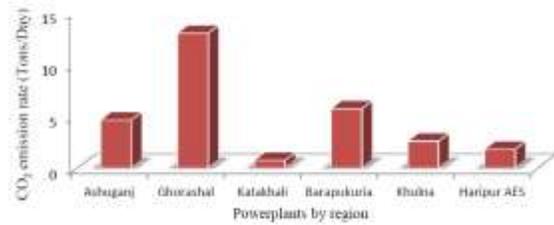

Fig. (9). CO_2 emission rates of various power plants in Bangladesh [31 - 35].

All these properties are approximate and some are estimated.

Our proposed vehicle system offers about 24% less power consumption from National Grid. So, a huge number of these proposed vehicles will save more electrical energy resulting in less emission of CO_2 from the fuel fired power plants.

Here, Katakhali Power Plant (Rajshahi) of 50MW capacity will be kept under consideration for calculation.

Assuming the plant as a 24 hrs/day working system,

Maximum electricity supplied by the plant = 50000 kWhr

The daily CO_2 emission from Katakhali = 0.72399 tons

Ashuganj Ghorashal Katakhali Barapukuria Khulna Haripur AES

CO2 emission rate (Tons/Day)

Powerplants by region

Daily emission of CO_2 per kWh energy =

$$\frac{\text{Daily } CO_2 \text{ emission}}{\text{Capacity of the Plant per Day in kWhr}}$$

$= 1.44798\times10\text{-}5$ tons

Now, if this proposed vehicle system is implemented on Rajshahi City then, let, the numbers of proposed autorickshaws = 2000 (estimated)

Energy savings per day per vehicle = 2.16 kWh [From previous feasibility calculation]

Total energy savings per day = (2000*2.16) kWh = 4320 kWh

CO_2 emission to produce 4320 kWh supply is = tons = 0.062553 tons (w.r.t. Katakhali Plant)

Lessen of CO_2 emission from Katakhali *via* using this system

$= \frac{0.062553}{0.72399} \times 100 = 8.64\%$

From the above analysis, it can be surely said that the proposed vehicle system if implemented in Rajshahi City, then per day CO2 emission can be reduced upto 8.64% and power can be saved upto 4320 kWhr per day. This analysis was performed considering no system loss; there remains a 25% system loss in thermal power plants. If the system loss is considered then actual percentage of CO2 emission lessens from Katakhali Plant will be about 20-22%.

This feasibility analysis shows this system not only a cost effective but also an environment friendly one. This analysis mathematically proofs that vehicle system to be an effective one.

4.4. Properties of Proposed Mechanism and Comparison with Other Systems

Below Fig. (10), shows the special properties of the proposed vehicle.
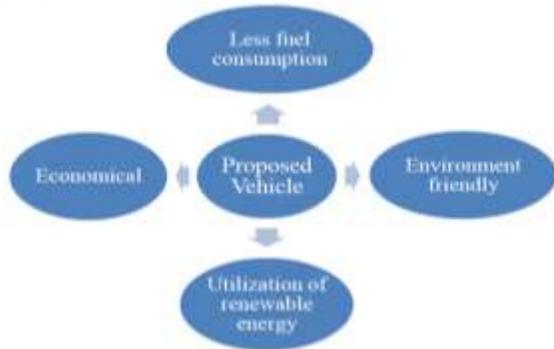

Fig. (10). Advantage of proposed vehicle.

CONCLUSION

In the above described hybrid system, a whole system combined with an ICE and electrical power source (rechargeable battery can be charged by solar power and national grid) was used which is not so familiar from the perspective of Bangladesh. Some of the data were collected from different auto rickshaw driver. Some data were neglected which were far away from the majority. Quite similar mechanism now a day, can be seen in different automobiles but here the system is applied to a three wheeler. The system ensures the proper use of the solar energy.

This vehicle could be a solution to the toxic greenhouse gases and particles. The vehicle would take the utilization of green energy to the next step, which would eventually help the world more safe and comfortable for living beings.

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