PERFORMANCE ANALYSIS OF SOLAR CAR CONSIDERING THE ENVIRONMENTAL IMPACT

By

Mahmudul Islam

17121007

Mohammad Shakhawat Hossain Fahim

17121101

MD Tazzammul Hossain Tamim

17121065

Nazmus Sakib

17121106

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Declaration

It is hereby declared that

1. The thesis submitted is our own original work while completing degree at Brac University.
2. The thesis does not contain material previously published or written by a third party, except where this is appropriately cited through full and accurate referencing.
3. The thesis does not contain material which has been accepted, or submitted, for any other degree or diploma at a university or other institution.
4. We have acknowledged all main sources of help.

Student's Full Name & Signature:

Mahmudul Islam	**Mohammad Shakhawat Hossain Fahim**
17121007	17121101
MD Tazzammul Hossain Tamim	**Nazmus Sakib**
17121065	17121106

Approval

The thesis titled "PERFORMANCE ANALYSIS OF SOLAR CAR CONSIDERING THE ENVIRONMENTAL IMPACT" submitted by

1. Mahmudul Islam (17121007)
2. Mohammad Shakhawat Hossain Fahim (17121101)
3. MD Tazzammul Hossain Tamim (17121065)
4. Nazmus Sakib (17121106)

of Fall, 2020 has been accepted as satisfactory in partial fulfillment of the requirement for the degree of Bachelor of Science in Electrical and Electronic Engineering on 13th January 2021.

Examining Committee:

Supervisor:
(Member)

Dr. Md. Mosaddequr Rahman
Professor, Department of EEE
Brac University

Program Coordinator:
(Member)

Dr. Abu S.M. Mohsin
Assistant Professor, Dept. of EEE
BRAC University

Departmental Head:
(Chair)

Dr. Md. Mosaddequr Rahman
Professor, Department of EEE
Brac University

Abstract

The aim of this project is to analyze the performance of a solar powered car considering environmental impact. A solar powered car which has taken into consideration has already been developed. Though the theoretical analysis of the previous research did not perform the environmental study. In this study the performance of the solar car has been analyzed considering input incident energy calculation along with the battery model and the electrical output analysis with changing in different masses and environmental parameters. Moreover, an analysis has been studied about the environmental impact, based on the Carbon dioxide emission from burning fossil fuels and power plants comparing the gasoline and the solar car. Where the results are very promising as the Solar Car can eliminate up to 60% of the carbon dioxide emission related to the transportation sector from Dhaka city and improve public health. Furthermore, a life cycle cost analysis has also been studied. Lastly, the advantages of replacing conventional gasoline cars with Solar cars has been proposed to control the CO_2 emission from the transportation sector, based on the performance, environmental and economic analysis done.

Keywords: Solar Powered Electric Vehicle; Performance Analysis; Incident Solar Energy; Environmental Impact; Global Warming; Life Cycle Cost Analysis;

Dedication

This thesis is dedicated to our beloved parents by whose love and cooperation we have reached this far.

Acknowledgement

All praises are for Almighty Allah. We are grateful to our creator for making it possible to complete the thesis work in due time. We must show our gratitude to our honorable supervisor Dr. Md. Mosaddequr Rahman for his guidance, suggestions, and cooperation throughout the time.

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List of Acronyms

AM	Air Mass
CO_2	Carbon-di-Oxide
KWHr	Kilo-Watt Hour
PP	Power Plant
PV	Photovoltaics
sqrt	Squire root
Sr	Sunrise Time
Sr	Sunrise Time

Chapter 1

Introduction

1.1 Introduction

In Dhaka City, traffic jam and air pollution are two most alarming issues, being a threat for both our economy, public health and overall advancement. Due to uprising in prices, the fuel expenses have increased. Moreover, the uncontrolled emission of greenhouse gases deteriorating the air quality day by day. According to Air Quality Index (AQI)'s publication on 2nd May 2020, Dhaka has been ranked the worst in term of air quality with a score of 176 and was classified as an unhealthy city [1]. So, to ease the effects of using fossil fuel as a part of using renewable sources the concept of solar powered car is revolutionary. Although there are many electric vehicles rated as ZEV (Zero Emission Vehicle), however they are somehow more dependent on the fossil fuels compared to the solar mounted electric vehicles as typical ZEVs require electrical power form the grid and the production of this power includes a good portion of existing fossil fuel.

Back in 2012, Toyota launched "Prius PHV", an Electric Vehicle having the features of solar charging system with having solar panel mounted in the roof producing electricity sufficient for 6.1km/day [2]. Another Dutch startup, Lightyear built a fully solar powered Lightyear One car for long-range having 54 sqft of solar panels that cover its bonnet and roof. While one single charge of its battery lasts about 450 miles(725km) (compared to the Tesla Model S's 379 miles or 609km), the solar panels can add 7.5 miles (12km) every hour to the vehicle's range [3]. To meet the demand for the Dhaka city commuters BRAC University also started a research on preliminary design and economic analysis of a two-seater light-weight solar powered clean car [4]. Later it was built with necessary components and the simulation and analysis of battery performance both on Simulink [5] and under different traffic and weather condition were performed [6]. In this report an extended investigation has been done to clarify the Solar car as an efficient medium of transport, both economically and environmentally. The report considers all marginal factors and eventually shows a clear comparison between fuel-based vehicles and Solar car, proving its necessity in our day-to-day life, especially for those who are part of polluted cities like Dhaka and also believes protecting the environment rather than producing more pollutants. However, it somehow also proves its ground of being a better option than ZEVs.

All the analytical operations in this work have been performed using MATLAB based on the near to constant factors due to its structure and also some factors provided by the manufacturer of the components used in the car. Scarcity of real-life data has been a big issue due to the arrival of COVID-19 virus.

1.2 Background

The rapid use of fossil fuel is one of the most basic reasons of Global warming, slowly destroying the world and so endangering our existence, Also the sources of fossil fuel is limited and unnecessary use of it will force us to look for new sources in near future. According to the environmentalists, burning fossil fuel has become a leading source of $CO2$ emission which is the main reason for global warming issues and as fuel-based transport performs through same process, contributing a huge sum of related pollutants in the environment. In Bangladesh transportation sector alone contribute to 14% emission of greenhouse gas [7]. And recently Dhaka has been ranked several times in top 3 for having the worst air quality index. To reduce the emission rate solar powered electric vehicle is the best choice. However, the following sections describe some noticeable factors that proves our ground more descriptively.

1.2.1 Solar Availability

Bangladesh can be a perfect place for solar car industry due to its geographical position. Stats show that the bright sunshine hours in the coastal region of Bangladesh differs from 3 to 11 hours daily, where the isolation differs from 3.8 kWh/m^2 to 6.4 kWh/m^2 per day at an average of 5 kWh/m^2 per day, this estimated result shows that Bangladesh have a good possibility for solar thermal and photovoltaic applications for mass implementation. According to world economic forum, Bangladesh has one of the largest Domestic solar energy programs and this provide electricity to more than 4 million households and about 20 million people in rural areas, roughly one-eighth of country's population [8]. So, it is clear that Bangladesh has the suitable environment and scope to use this source for not only its availability but also for being clean energy. Moreover, as the source being cheap city commuters can be much beneficiary by proper using.

1.2.2 Emission of Greenhouse gas

This fast-forwarding world has to bear great environmental costs to keep the developing process operational. One of the major environmental costs is the global warming and the greenhouse effect is responsible to escalate global warming with the help of greenhouse gases. Greenhouse effect mainly occurs due to the trapping of radiated heat in the earth's atmosphere by the gases like Carbon dioxide, Water vapor, Methane, Nitrous oxide and Ozone. According to UN's World Meteorological Organization, record amount of three main heat-trapping gases- carbon dioxide (CO2), methane (CH4), and the nitrous oxide(N2O) emitted into the atmosphere in 2018 which has caused a 43% increase in total radiative forcing or the warming effect on the climate since 1990. Among the greenhouse gasses Carbon dioxide contributes highest in the global warming. According to the Carbon Brief the world produced around 36.81 billion tons of CO_2 in 2019 which increased by 0.6% from the previous year [9]. The burning fossil fuels of the transportation sector contributes nearly 30% of the overall carbon emission in the world [9].

The emission data of 2016 mentions that Bangladesh emitted 74,476,230 tons of CO_2 in the following year and the country contributed around 0.21% to the global carbon emission [10]. Based on the population data of 2016 Bangladesh has a per capita CO_2 emission of 0.47 tons per person with a population of 157,977,153 [10]. Transport plays an important part in economic growth and globalization, but as well as being the part and parcel of our daily life it also causes severe air pollution by emitting CO_2 emission. The following pie chart gives an idea of sector wise CO_2 emission in Bangladesh.

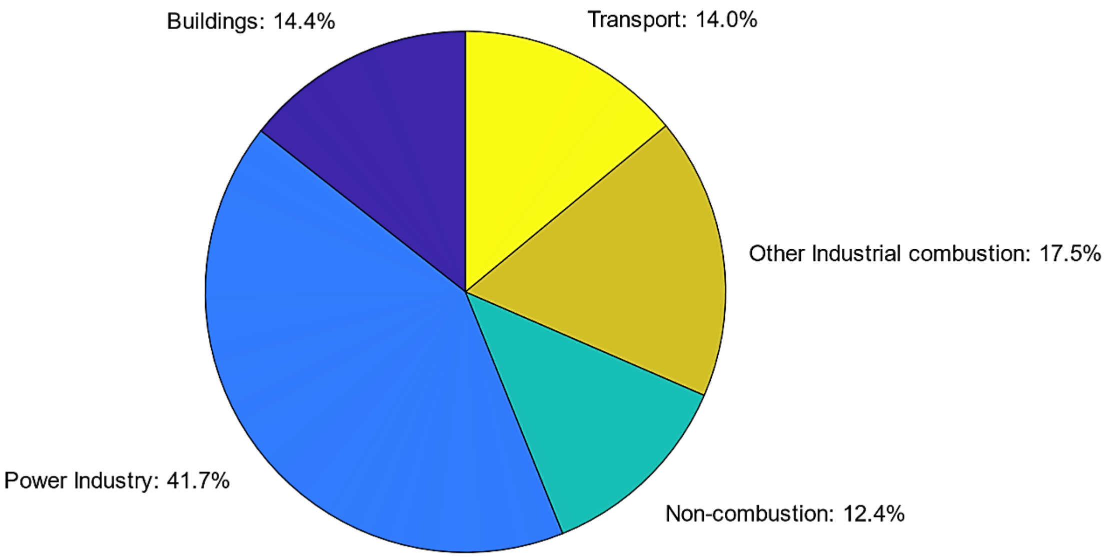

Figure 1.1: Carbon emission from different sectors in Bangladesh [10]

From **Figure 1.1** we can see that the transportation sector of Bangladesh contributes around 14% to the total CO_2 emission in Bangladesh [10]. Nowadays a cleaner environment is our biggest concern to ensure our existence.

1.2.3 Pollutants and Human Health

Except the greenhouse effect, there are some more effects questioning human lives. We know that almost all fuel-based cars emit CO (Carbon-monoxide) when the fuel doesn't get burnt properly. Breathing it can show side effects like headache, dizziness, vomiting, nausea and so on and if by any chance the inhaled pollutant level turns out high, person can even die. Again, the exposure of hydrocarbons contributes to eye and respiratory irritation due to the photochemical smog. Sometimes due to the faulty engine, a little amount of fuel particles gets exposed to the air. As we breath, it gets into our respiratory systems and get mixed with the blood, leaves a major effect into our lungs, heart and brain. As we result thousands of people are becoming victims of heart and lung problems, depression, memory loss, asthma and even premature deaths. [11] [12]

1.2.4 Planning for a better future

With the growth of the global warming countries all over the world are now giving a serious thought to improve the quality of the air by reducing carbon emissions from different sectors. Among them the transportation sector has been on the focus of many countries with a view to reduce sufficient amount of carbon emission which comes from the burning of fossil fuels like gasoline and diesel. Moreover, some countries have taken targets to reduce carbon emission from the transportation sector specially focusing on the light commercial vehicles like passenger cars. The table below shows the targeted amount of carbon emission of different countries with their targeted year [13].

Table 1.1:Carbon emission reduction target of different countries from transportation sector [13].

Country – Region	CO_2 Target (kg/km)	Targeted Year
European Union (Passenger cars)	0.095	2021
United States and Canada	0.097	2025
Japan	0.122	2020
China	0.117	2020

India	0.113	2021

Here **Solar Car** can play an effective role to decrease the carbon emission amount in the near future.

1.2.5 Increasing Price of Fossil Fuel

Except the above issues, the rising price of fossil fuel is going to be a threat for the daily commutators in the far future. We have a limited source of fossil fuel which is decaying day by day. In Bangladesh, Natural gas is the leading fossil fuel which accounts almost 73% of the commercial energy of the country. According to the federal Energy Information Administration, in U.S. total energy used in different sector in 2018 was equivalent to 101.2 quadrillion Btu, highest level since 1949, where almost 80% was fossil fuel. [14]. In the World Energy Outlook 2019, the Paris-based policy advisor claimed that though the concept of carbon-neutral world is appreciated worldwide, unless the policy makers introduce any significant steps, the world scenario is not going to change [15].

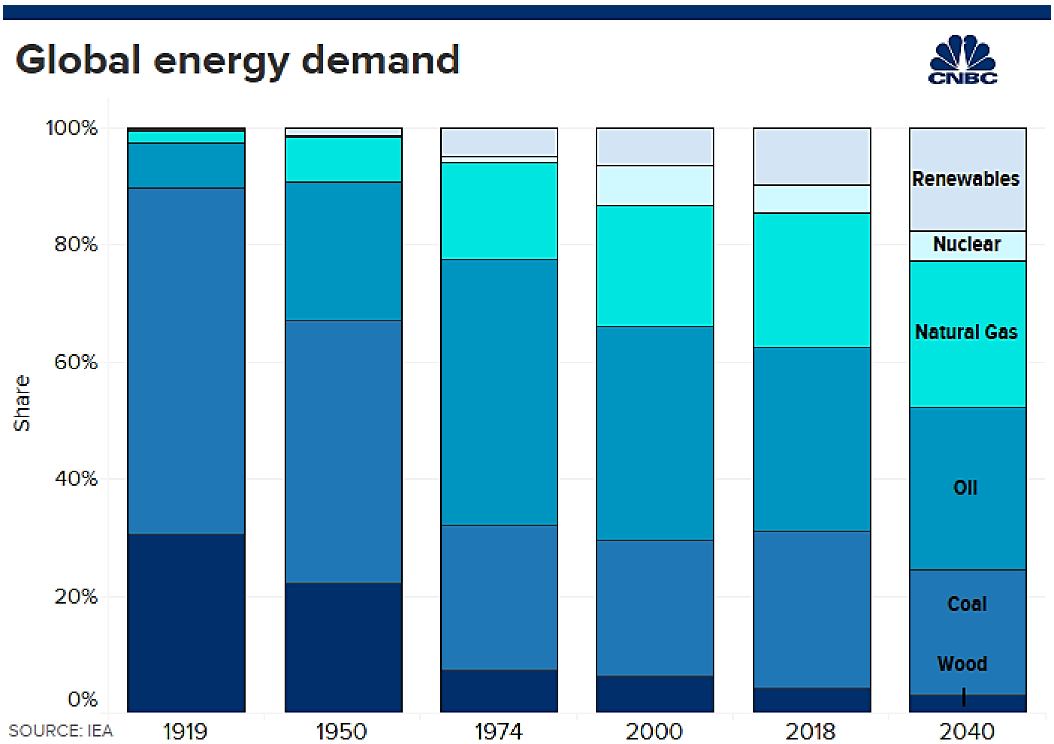

Figure 1.2: Global Energy Demand (1919 - 2040) [15]

On the other hand, in Bangladesh up to march,2018 the number of registered motor vehicles was 3,419,894, where up to 2010 it was 1,498,244 which indicated a clear increase in demand of the motor vehicles and most of these vehicles predominantly depends on fossil fuel [16].We can clearly predict that if in far future we do not switch to renewable energy, this limited fossil fuel will fail to fulfill our regular demand and consequently will face a severe increase in price. From **Figure 1.2** we notice that from 2000-2018 the global energy demand was principally fulfilled by fossil fuels (almost 80-82%) and this dependency is expected to be decreased by 5%-10% by 2040 [15]. Moreover, the global price index of gasoline from 1992 to 2016 explains how the price is increasing.

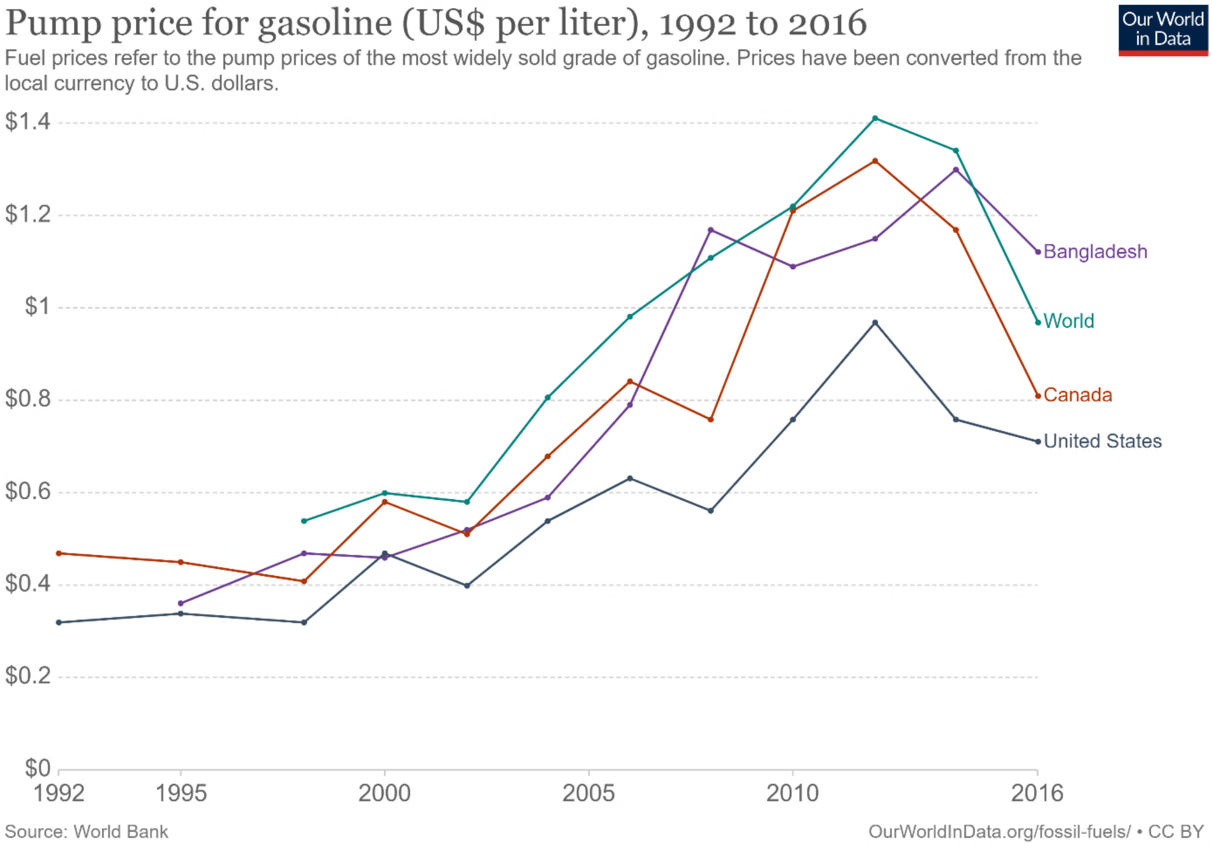

Figure 1.3: Fuel prices refer to the pump prices of the most widely sold grade of gasoline. Prices have been converted from the local currency to U.S. dollars [17]

1.3 Project Objective

In our brief work, our sole purpose is to evaluate the performance of the **Solar Car** under different environmental condition through the extended investigation of its efficiency in power management. Furthermore, evaluating the impact of **Solar Car** over the environment and how it can be proven as a benefit for daily commutators in regular use are other major points that will be discussed in the following segments. However, if we consider the geographical aspect, Bangladesh receives strong sunshine throughout the whole year (3.8-6.42 $KWHr/m^2$) and it has been found that the average sunshine hours are respectively 6.69, 6.16 and 4.81 in winter, summer and monsoon [18]. Being more specific, in Dhaka city every day we receive almost around 3.832 $KWHr/m^2$ solar irradiation. [19]. So, the country has an eminent source of solar energy.

Again, Dhaka city is famous for its long traffic jam. According to World Bank report Dhaka city eats up to 3.2 million working hours daily which cost the economy billions of dollars [11]. Most of the city commuter used the longest distance in the Dhaka city, which is Motijheel to Uttara, a round trip of 35km and often they have to spend long hour traffic congestion. This increases the consumption of fuel, eventually increasing the fuel cost and adding up more pollutants in the environment. On the other hand, Solar powered electric vehicle will turn this wasted hour to charge up the battery for further travel whenever it will face stoppage. Moreover, as it is an electric car, so like other cars it can also charge its battery from the grid when it is necessary.

Solar energy is one of the strongest among the green energies and it has the most reliable source for at least next few billion years. Moreover, like fossil fuel, there is no burning and so no emission. The solar irradiation gets converted to electrical energy through solar panels and gets stored into batteries, from where we use the energy to run our car when necessary. So, there are comparatively less power loss. As a result, switching to solar car can be a better solution for cutting down these unnecessary costs and by using clean energy, greenhouse gas emission can be reduced. In addition to that Solar car can be a better choice for the daily commuters of Dhaka city due to its uniqueness and better cost efficiency.

Figure 1.4 : The Solar Car manufactured & assembled by BRAC University.

Figure 1.4 shows a fully functional prototype of the car. The whole mechanism has two parts, electrical which includes almost all input parts and the mechanical which can be regarded as the output parts. Later we will have detailed understanding over them.

1.4 Motivation

Solar energy has the largest potential among all renewable energy resources. The geographical location of Bangladesh has blessed it with a good sum of solar irradiance throughout the year and on the other hand, due to the rapid increase of the public transports' day by day, Bangladesh is turning into a prism full of greenhouse gases, warming up this city every single day. Another impact is that the drastic change in seasons and their periods, which is not a national but a global issue in today's date. Moreover, being dependent on the fossil fuel may soon drive the mankind to look for more fuel sources, as the existing sources are limited and may soon end up, if the existing pressure on the fossil fuel continues in long run. Again, not only the fuel will lead to an end but also the price of the remaining fuel may reach high. In this situation, depending solely on fossil fuel is not a good option and that is why the next option that comes in the list is using the renewable energy as the source of the energy is Sun that contains nearly infinite energy and not going to end in near future.

1.5 Outline

The book has been organized such a way that it explains the ideas behind our ground both theoretically and analytically. There are 5 chapters in total, each of them serving their individual purpose. The book starts with **Chapter 2** where we have given overview of the total work that we have planned to get the expected outcome and also establish our ground. Then in **Chapter 3,** detailed explanation of all the necessary theories and related equations have been provided. Using the provided equations, we have performed some simulations using MATLAB and the results that we have received have been presented in **Chapter 4** with detailed explanation behind them. Finally, we present our concluding statements in **Chapter 5** followed by the references that we have used for our work.

Chapter 2

Methodology

2.1 In Quest of a Suitable Motor

Our primary challenge is to look for a suitable motor that can ensure sufficient power to run the car, while taking minimum acceleration time. With this purpose we will calculate the required motor power against a set of acceleration time and hence, will select our desired motor. As we come up with the desired motor, we will put the car under some real time scenario so that we can illustrate the changes in parameters, such as power consumption of the vehicle, required energy to run the car for a significant distance, state of charge of batteries etc. with time. This will help us to work out the demand and further satisfying it.

2.2 Fulfillment of Required Energy

The study of Fulfillment of Required Energy will be taken forward in two steps. First of all, we will find out the amount of available energy we are getting from the sun. After then we will conduct the analysis of additional energy drawn from the grid to meet the remaining energy requirement to run the car throughout the months.

For the first step, to study the amount of available energy we will receive from the sun to charge our battery, we will assume a scenario. In this scenario, we will consider the car is at rest, facing the south and all the 5 PV panels are mounted on the car as shown in **Figure 2.1**. Besides, we will also consider that all the PV panels are mounted horizontally on the car which means there will be no inclination. Considering all this, we will perform a simulation of the input solar energy for the stationary car. Next, from this input solar energy we will find out the amount of electrical energy we will get out of the 5 PV panels using the panel efficiency.

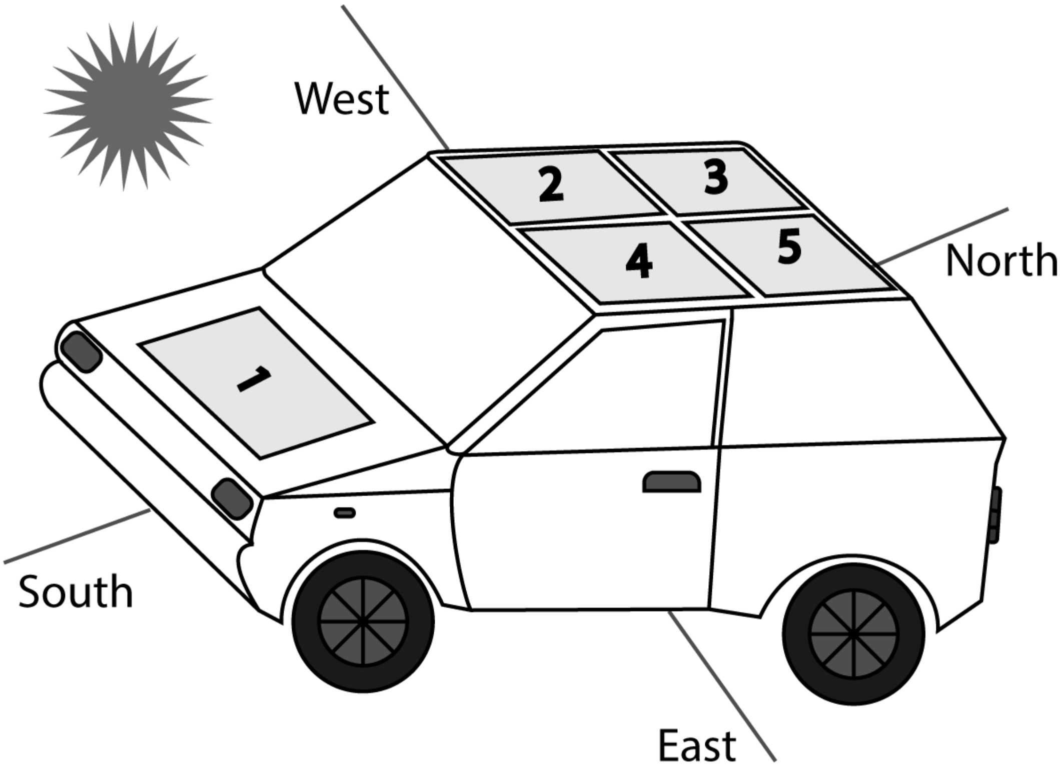

Figure 2.1: Pictorial representation of the car with all the panels mounted on it.

After then for the second step we will calculate what portion of required energy can be fulfilled by the energy we will get from our PV panels and additionally what portion of energy must be supplied from the grid to cover the remaining portion of required energy. Here we will also consider three different masses while performing the calculation of the second step. To see the effect of clouds on grid dependency we will consider two cases for the car with mass 500kg, one is without cloud impact (meaning no cloudy days) and another one is with cloud impact (having cloudy days). But for 1000kg and 1500kg we will only calculate taking account the cloud impact. Since Bangladesh encompasses a subtropical monsoon climate so it will not be a good analysis if we ignore the impact of clouds. So, from now on for all the analysis cloud impact will be taken accounted.

In this way we will find out how the required energy to drive the car throughout the months will be partially fulfilled by the PV panels and the remaining portion by the Grid.

2.3 Environmental Impact Scheme

The solar car will be evaluated for environmental impacts considering only Carbon Dioxide emission. It will also be evaluated to gain a prospect on how the solar car can impact the environment of different areas of Dhaka city. The whole study will be conducted in three steps by considering 300 days per year time frame. Firstly, the annual carbon dioxide emission related to the solar car for different masses will be evaluated. Secondly, a comparison will be studied on the annual amount of carbon dioxide emission related with different gasoline cars and the solar car respectively. Thirdly, carbon dioxide emission hotspot areas in Dhaka city will be identified and will also be evaluated considering a gasoline car. Finally, the three steps of evaluating Carbon Dioxide emission considering different solar car masses, Gasoline cars and evaluating hotspots areas in Dhaka city will provide a clear picture of the environmental impact of the solar car.

First of all, the annual carbon dioxide emission related to the solar car for different masses will be evaluated. For this, three different masses of 500 kg, 1000 kg and 1500 kg will be considered for a 35 km round trip per day. Moreover, two different carbon dioxide emissions will be pictured together where at first, the solar car will be only dependent on grid energy means no contribution from the PV panels and on the other hand, the solar car will be partially dependent on the grid energy as now the PV panels will contribute to the required energy considering cloud impact. Although the solar car has no direct emission, but an indirect emission comes from the power plants to meet the required energy demand. So, the carbon dioxide emission for per KWHr from Natural Gas fired power plant will be considered to calculate the carbon dioxide emission related to the solar car.

Secondly, a comparison will be studied on the amount of carbon dioxide emission related with different gasoline cars and the solar car with different masses respectively. For this comparison gasoline cars with three different engine sizes and a solar car with three different masses will be considered. Both the types of cars will be evaluated for Carbon Dioxide emission for a round trip of 35 km per day. The carbon dioxide emission from the gasoline cars will be calculated by depending on the liters of gasoline burned for the round trip also millage for different cars will be taken into consideration. Whereas the solar cars emission will depend on the power plants. The comparison will be elaborated as the effect of cloud and without cloud will be illustrated on the carbon dioxide emission.

Lastly, carbon dioxide emission hotspot areas in Dhaka city will be identified and will also be evaluated considering a gasoline car. For this, congested areas in Dhaka city will be identified and among the areas the percentage of 1200cc passenger cars which are gasoline driven will also be identified. Then the specified cars will be evaluated in specific areas for annual carbon dioxide emission with relevant rates.

Finally, after following all the mentioned steps the complete impact on the environment which the solar car can play will be visible for better understanding.

2.4 Economic Analysis Scheme

In this section we will both calculate and analyze the overall economic perspective of using a solar car over fuel based traditional car for a long period of time. To go more further into the analysis part, we will divide our calculation into two parts. First of all, we will do the analysis of Cost against Grid dependency and after that we will do the analysis of the life cycle cost.

When the solar energy does not become sufficient enough to run our solar car annually then the only cost associated with it will be the cost of energy drawn from the grid. For this reason, in the first step we will find out how the annual cost of energy to run the car is going to vary as the dependency on grid varies (from 0 to 100 %).

Secondly, we will do the analysis of life cycle cost. Life cycle cost is mainly done for analyzing the total expenses for a product during its lifetime. It is a very important assessments tool even before implanting a project. Here for the betterment of analyzing the LCC will be further divided into two more steps. Firstly, we will calculate the LCC for the solar car over a specific period of time. For this reason, we will calculate the total initial cost for setting up the solar car by collecting the price of each and every component. After that we will calculate a yearly expense considering two cases,

i. partially dependency on grid (best case)
ii. fully dependency on grid. (worst case)

Then, using necessary formula, we will find out the LCC for the solar car. Like before the analysis will be conducted considering 3 different masses for the solar car, which are 500 kg ,1000kg and 1500kg. In the next step we will find out the LCC for fuel-based car. For this step we will select 3 different fuel-based vehicles which are Suzuki Alto of 660cc, Toyota Corolla XSE of 1200cc and Toyota Land Cruiser Prado of 4000cc. All of them are traditional and currently available on the market. After that we will do the same LCC analysis for the above-mentioned fuel-based vehicles.

This is how, we will find out whether the solar car will be a good choice over a traditional fuel-based vehicle to meet the city commuter demands by analyzing the life cycle cost in respect of economic perspective.

Chapter 3

Theoretical Overview

3.1 Energy Consumption & SOC

Evaluating the performance of solar car, especially the motor and the battery under different condition has been always our first priority and nothing better than the assessment of energy consumption can be a good start. The purpose can be served in following steps-

- Selecting a suitable DC motor
- Observing the changes in major components in real time simulations

The first part of the work can be easily done by monitoring how the value of required power from the motor changes as we change the duration of acceleration. As we will spend a quality time over these data, we will come up with the decision regarding the motor that provides sufficient power to run the car smoothly, also requires less time to reach its highest speed, which is 60 kph for our car.

The second part is where we are placing the car under a real time scenario to see that will the car show the same potential that we are expecting. This also shows the capability of the motor in satisfying the continuous need of the car while on run. Being an electric car makes this part easier. Unlike combustion engine, the performance of DC motor can be evaluated by comparing the motor power rating against the required power through the journey.

From the required power we are calculating the required energy throughout the journey which will lead us to calculate the state of charge of battery, also the required input into the battery.

3.1.1 Acceleration Time

For any particular vehicle, **acceleration** is the change in velocity with time. From that we can say, the time it takes to accelerate to a certain speed is called the **acceleration time**. It changes with the value of acceleration and the change of voltage that we are trying to overcome. For easy calculations, we have considered the acceleration time as the time to reach its max speed with a constant acceleration. **Eq. (3.1)** shows the relation between acceleration time (t) and change in velocity (Δv), while the object is under constant acceleration (a). It shows higher the acceleration, lower the acceleration time.

$$\boldsymbol{t = \frac{\Delta v}{a}} \qquad (3.1)$$

3.1.2 Motor Power Rating

Power is the calculation of energy per unit time. We can estimate the necessary power to run the vehicle by combining the forces applied to the vehicle to make it move with the velocity at which the vehicle is moving. We do not consider all the forces but some significant of them, cover major portion of the necessary demand.

As the motor runs, it generates a driving torque for the wheels, producing the driving force at the road-tire contact that moves the car along the surface. As it is easier to perform calculation in terms of driving force rather than the driving torque, all the calculations have been done for the driving force. Further combining with the set of velocities at which the car moves, the driving power is found.

The calculation of driving force to run the car integrates all other individual force components resulting from several physical effects. Some of the such leading forces are as follows-

- Force to control the rolling resistance of the wheels with the drive surface.
- Force to control aerodynamic drag.
- Force to accelerate the vehicle.

3.1.2.1 The Rolling Resistance

Resistance that resists the natural rolling motion of the car is called the **rolling resistance** and the force is called **rolling resistance force.** Some of the worth mentioning factors that stimulates rolling resistance are damage of wheels, deformation of rolling surface and the movement below the surface. Some other factors like speed, load on wheels, the wheel diameter etc. also contributes a significant amount of rolling resistance. Therefore, rolling resistance force can be expressed as [20]

$$F_{Rolling} = \mu_r * W \qquad (3.2)$$

Where **W** signifies the weight of the transport and μ_r is the coefficient of rolling resistance, which is constant for any specific type of tire in association with the type of surface the car is moving on. As example tire with thicker surface and wider steps while rolling over ruff surface gives higher rolling resistance. On the other hand, the motor provides lower force to defend rolling resistance force while using thinner wire over smoother surface. So, we can say increasing tire surface area gives rise to the rolling resistance.

Table 3.1: change of coefficient of rolling resistance with wheels/surface.

μ_r	**Description**
0.0003 - 0.0004	Railroad steel wheel on steel rail
0.001 – 0.0015	Steel ball bearings on steel
0.0045 – 0.008	Large truck tires
0.01 – 0.015	Ordinary car tires on concrete
~0.3	Ordinary car tires on sand

We have used thinner tire in our car and considering that the car is moving over concrete surface. Observing **Table 3.1** we agreed that the coefficient of rolling resistance for our car is 0.01. [20]

3.1.2.2 Aerodynamic Drag Force

The **Aerodynamic Drag Force** is the force applied by the air medium, restricting the movement of the vehicle through it. It works against the vehicle as it makes its move as it tries to penetrate the air medium. The estimation of the force can be done as, [20]

$$F_{Drag} = [\,(1/2)C_D * A_{Cross} * \rho * V^2] \qquad (3.3)$$

Where C_D is the coefficient of drag, A_{Cross} is the cross-sectional area of the vehicle front, ρ is the air mass density constant and V is the velocity of the car. Considering all other factors as constant, for any value of coefficient of drag the overall drag force can be minimized by reducing the frontal area.

3.1.2.3 Force of Acceleration

The concept of acceleration comes after the Newton's second law of motion which states acceleration of an object is directly related to the net force and inversely related to its mass. Therefore, we can express the force responsible for acceleration as,

$$F_{Acceleration} = [\,m * a] \qquad (3.4)$$

Where m is the mass of the car and a is the acceleration of the car. So, we can say for any specific vehicle the force changes with its tendency of changing the velocity with time.

As we know the individual forces responsible for the inertia of rest, the total driving force is the sum of all individual forces that the motor must overcome to run the vehicle. It acts against these major drawbacks and can be expressed as, [20]

$$F_{Total} = F_{Rolling} + F_{Drag} + F_{Acceleration} \qquad (3.5)$$

Considering all the tangible factors, we have come up with some fixed parameters for our car stated in **Table 3.2.**

Table 3.2: Parameters used for calculating Motor power.

Car weight, $W = mg$	**500 * 9.81 N**
Top speed, V_{max}	**60 km/h (16.67 m/s)**
Coefficient of rolling resistance, μ_r	**0.01**
Coefficient of Drag, C_D	**0.35**
Cross-sectional Frontal Area, A_{Cross}	**1 m * 1.1 m**
Mass Density of Air, ρ	**1.2 kg/m^3**

Using the stated parameters, the required power gets calculated as,

$$P_{Total} = F_{Total} * V \qquad (3.6)$$

Where V is the instantaneous velocity of the car.

3.1.3 State of Charge

State of charge is the ratio between the available capacity against the maximum possible charge that a particular battery can store. In general, we express this as a percentage value and differs between 0 to 100 when fully charged. The state or charge can be estimated as, [6]

$$SOC\ (new) = SOC\ (old) - \frac{Q_{dis}}{C} \qquad (3.7)$$

Where $SOC\ (new)$ and $SOC\ (old)$ are respectively the current SOC and the SOC past the moment, Q_{dis} is the amount of charge lost and C is the charge capacity of the battery.

The amount of lost charge is dependent on the load current, I_L and can be stated as, [6]

$$Q_{dis} = I_L * t \qquad (3.8)$$

Again, the calculation of load current for any particular battery is also dependent of the value of series resistance (R_S), open circuit voltage (V_{oc}) and potential difference between the electrodes (V_d), where each of them can be calculated as, [6]

$$V_{oc} = 1.4667 * SOC + 11.023 \quad (3.9)$$

$$V_d = 0.086 * SOC - 0.011 \quad (3.10)$$

$$R_S = -0.0531 * SOC + 0.066 \quad (3.11)$$

Form the above equations we get, [6]

$$I_L = \frac{(V_{oc} - V_d) - \sqrt{(V_{oc} - V_d)^2 - 4R_S P}}{2R_S} \quad (3.12)$$

Where, P is the amount of power provided by the motor at that instance.

3.1.4 Input energy of battery

In ideal case, the energy we get from different sources is expected to be transferred fully into the motor. While in real life, a small portion of the energy gets dissipated due to different loss factors and what we get into the motor is not the full energy that the battery has stored in itself. By performing reverse calculation, we can estimate the actual input as follows, [6]

$$E_{Bat.inp} = E_{mot.out}/(\eta_{mot} * \eta_{bat.cap} * \eta_{bat.dis.cap} * \eta_{ch.cont.}) \quad (3.13)$$

Where, $E_{mot.out}$ is the motor output, η_{mot} is the efficiency of the motor, $\eta_{bat.cap}$ is the charging efficiency, $\eta_{bat.dis.cap}$ is the discharging efficiency and $\eta_{ch.cont.}$ is the efficiency of the charge controller.

However, as we know the battery capacity, we can calculate the stored energy using the following equation,

$$E_{Stored} = Capacity\ of\ the\ Battery * Battery\ Voltage \quad (3.14)$$

3.2 Incident Solar Energy

3.2.1 Solar Radiation

By the term solar radiation, we usually mean the radiant energy which is emitted by the sun and this electromagnetic energy is formed due to the nuclear fusion reaction. After then, this electromagnetic energy comes to the earth in many different forms such as visible light, radio waves, heat (infrared), ultraviolet rays etc. Since about half of the radiation is in the visible short-wave part of the electromagnetic spectrum, it is also known as short wave radiation. However, capturing this solar radiation we can convert it to other useful forms of energy such as electricity using various technologies. At a specific location the available solar resource defines how much energy we can harvest from this solar radiation by using our PV panels. Sunlight reaches almost every place on the earth at least part of the year. The amount of solar radiation at any spot on the earth's surface varies according to:

- Geographic location
- Day time
- Season

So, we need to develop our idea on some key features for the sake of calculating the available incident solar energy. In the following section all the relevant features will be described briefly.

3.2.2 Solar Angles

Since the shape of the earth is closer to an ellipsoid, the sun rays do not strike the surface at a fixed angle rather they strike the surface at various angles, ranging from 0° (just above the horizon) to 90° (directly overhead). The Earth's surface receives maximum possible energy when the sun's rays are exactly vertical to the surface. That is why it is important to know about the solar angles for our calculation.

3.2.2.1 Latitude Angle (φ):

Latitude angle is defined with respect to an equatorial reference plane which passes through the center O of the sphere, the earth. Moreover, the plane also contains the great circle which represents the equator. Now if consider any point P on the sphere then the latitude of P point will be nothing but the angle between the straight-line OP and the equatorial plane.

There are two types of latitude angle:

- **Northerly:** If the object point, P is above the reference plane, then the latitude angle is positive or northerly (0 to +90^0 or 90^0 North)
- **Southerly:** If the object point, P is below the reference plane, then the latitude angle is negative or southerly (0 to -90^0 or 90^0 South) [21]

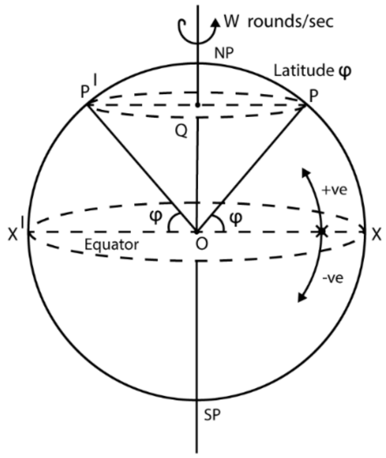

Figure 3.1: Latitude Angle (φ)

3.2.2.2 Declination Angle (δ):

In order to determine the amount of sunlight which strikes the Earth at a particular location, the 23.5° tilt in the Earth's axis of rotation plays a vital role. If there were no tilt, the declination would always be 0^0. The solar declination is the angular distance of the sun's ray's north or south of the equator. Usually, declinations that are north of the equator are positive and for south are negative. The declination angle varies throughout the year and it can be calculated for any particular day of the year by **Eq. (3.15),** [21]

$$\delta = 23.45^0 sin\frac{360(n-80)}{365} \tag{3.15}$$

3.2.2.3 Sunrise and Sunset Time:

The sun is said to rise and set when the solar altitude angle is 0^0. From there, on a particular day the sunrise and sunset time can be calculated as follows, [21]

$$S_r = 12 - \frac{1}{15} * (cos^{-1}(-tan\,\delta\,tan\,\varphi)) \tag{3.16}$$

$$S_S = 12 + \frac{1}{15} * (cos^{-1}(-tan\,\delta\,tan\,\varphi)) \tag{3.17}$$

Finally, we can get the available total day hour by subtracting them,

$$t = S_S - S_r \tag{3.18}$$

3.2.2.4 Sunrise angle (ω_s):

Sunrise angle is the angle when at dawn the sun is exactly positioned on the horizon. It is represented by ω_s and can be calculated by the following **Eq. (3.19)**, [21]

$$\omega_s = \cos^{-1}(-\tan\delta\tan\varphi) \tag{3.19}$$

3.2.2.5 Hour angle (ω):

The hour angle of a point on the earth's surface is the angle through which the earth would turn to bring the meridian of the point directly under the sun. Since, the earth is rotating, so this angular displacement represents time. If we observe the sun from earth, then the solar hour angle is an expression of time, expressed in angular measurement, usually degrees, from the solar noon. The hour angle is 0^0 degrees at solar noon, on earth at the observer's longitude, with the time before solar noon expressed as negative degrees, and the local time after solar noon expressed as positive degrees. For example, at 3:00 PM local apparent time the hour angle is 45° (15° per hour times 3 hours after noon). The equation which expresses the hour angle is given below, [21]

$$\boldsymbol{\omega = -\omega_s + ((2 * \frac{\omega_s}{t}) * (T - S_r))} \quad \textbf{\textit{(3.20)}}$$

Here,

T = Particular time of a day

t = Available total day hour

$\mathbf{S_r}$ **=** Sun rise time of the day

3.2.2.6 Solar Altitude Angle (α)*:*

The solar altitude angle refers to the angle between the sun's rays and the earth's horizon. The solar altitude angle is represented by $\boldsymbol{\alpha}$ as shown in **Figure 3.2,**

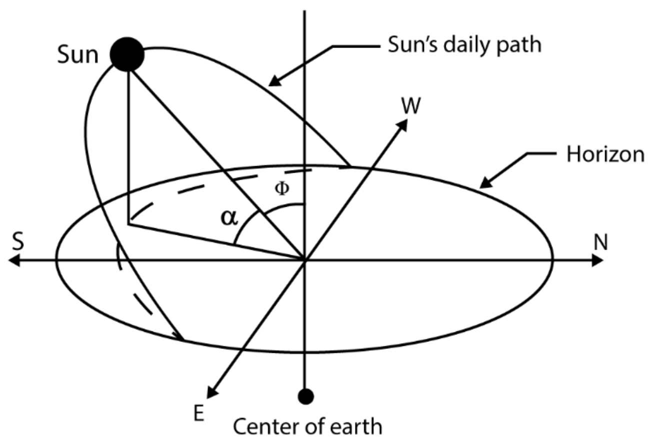

Figure 3.2: Solar Altitude Angle and Zenith Angle

Thus, solar altitude angle can be calculated using the following **Eq. (3.21),** [22]

$$\boldsymbol{\alpha = sin^{-1}(sin\,\delta\, sin\,\varphi + cos\,\delta\, cos\,\varphi\, cos\,\omega)} \quad \textbf{\textit{(3.21)}}$$

3.2.2.7 Zenith Angle ($\boldsymbol{\Phi}$):

The angle between the sun's rays and the vertical is known as the solar zenith angle. The zenith angle $\boldsymbol{\Phi}$ is shown in **Figure 3.2.** Since the zenith angle and solar altitude angle are complementary, the angle can be calculated by **Eq. (3.22),** [22]

$$\boldsymbol{\Phi = 90^0 - \alpha} \qquad \textit{(3.22)}$$

3.2.2.8 Incidence Angle ($\boldsymbol{\theta}$):

The solar incidence angle is the angle between the sun's rays and the normal on a surface. In **Figure 3.3** the incidence angle is shown as $\boldsymbol{\theta}$. Here, $\boldsymbol{\beta}$ is the surface tilt angle from the horizontal. For horizontal surfaces $\boldsymbol{\beta = 0^0}$ and then $\boldsymbol{\theta = \Phi}$. [22]

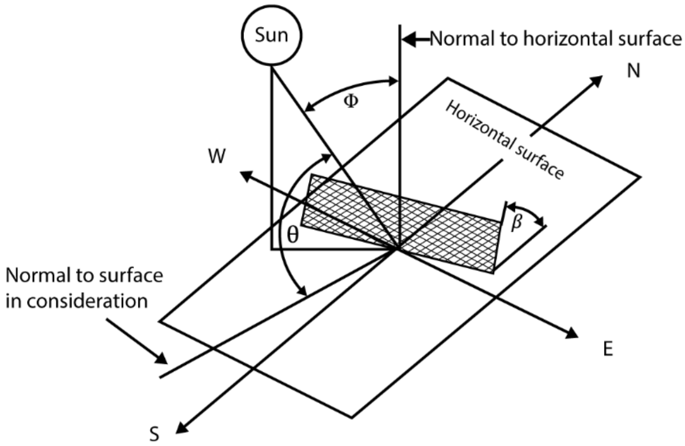

Figure 3.3: Incidence Angle ($\boldsymbol{\theta}$)

3.2.3 Key Factors to Determine Solar Energy

3.2.3.1 Air mass

While passing through the atmosphere some part of the sunlight gets absorbed, scattered, and reflected by:

- Air molecules
- Water vapor
- Clouds
- Dust

As a result, on the way to Earth's surface the more atmosphere the sun light will encounter, the less solar energy we can expect to get. That is why it is important to determine Air Mass which is a measure of how much atmosphere the sun's rays will face throughout their way while coming to the earth's surface. The following equation can be used to calculate it. [3, 5, 6, 7, 8]

$$AM = \csc \alpha \tag{3.23}$$

3.2.3.2 Solar Irradiance

Solar irradiance is the power per unit area received from the sun in the form of electromagnetic radiation. The solar irradiance gets measured in space or at the Earth's surface after getting absorbed and scattered by the particles in the atmosphere. Usually, it is measured perpendicular to the incoming sunlight and the total solar irradiance (TSI) is the amount of irradiance over all wavelength per unit area incident on the Earth's upper atmosphere. The SI unit of Solar Irradiance is (W/m^2) and the equation is,

$$I = I_o * (0.7)^{AM^{0.678}} \tag{3.24}$$

Where $I_o = 1367\ W/m^2$ which is the solar irradiance in space outside the atmosphere. For fixed axis, solar irradiance can be calculated as,

$$I_{inc} = I \cos \delta \cos \theta \tag{3.25}$$

Here, both $\boldsymbol{\theta}$ and $\boldsymbol{\delta}$ changes with time and season.

3.2.3.3 Cumulative Incident Energy

Cumulative Incident energy is the summation of all intensity values which are calculated over a given period of time. To get an idea of total energy generated on a particular day we can perform a numerical integration of Intensity from dawn to dusk for the available day hours as given in Eq. **(3.26)**,

$$\boldsymbol{E_{inc} = A \int_{Sr}^{Ss} I_{inc}\ \cos\delta\ \cos\theta\ dt} \qquad \textit{(3.26)}$$

Where A is the area of the module, Sr and Ss are the sunrise and sunset time respectively. Here, both $\boldsymbol{\theta}$ and $\boldsymbol{\delta}$ changes with time and season.

3.3 Environmental Impact

An environmental impact can be defined by the changes in the environment. The change can be adverse or beneficial for the environment. Mostly, the changes in the environment are introduced due to human activities. For example, the environment can be polluted by the emission of toxic gases from industries which can be defined as a negative impact on the environment. On the other hand, the environment can be benefited by using Renewable energy sources like PV panels. Transportation sector plays a significant role in impacting the environment. This sector mostly contributes to pollute the air which ultimately results in polluting the environment. Moreover, many greenhouse gases are produced from this sector, but amount and impact of Carbon dioxide is more compared to other gases.

3.3.1 Emission of a Typical Passenger Car

A typical passenger car has an internal combustion engine which requires fossil fuel like gasoline. This type of engine burns gasoline to produce the required mechanical power for the car and most the emission comes from the combustion process. Due to the burning of gasoline on the combustion process, Carbon Dioxide and Water Vapor are produced ideally [25]. However, gases like Nitrogen, Carbon Mono-oxide and unburned Hydrocarbons along with few pollutants are also emitted through the exhaust of the car. The emitted gases hamper the air quality and thus pollutes the environment. The focus is on the Carbon Dioxide among the emitted gases as the amount and percentage of this gas is more compared to other emitted gases from the car's exhaust. According to United States Environmental Protection Agency a typical passenger vehicle emits **2.35 kg** of CO_2 while burning only a liter of gasoline. It also emits **0.251** kg of CO_2 per kilometer [23] [24]. However, the amount of CO_2 emission per kilometer may vary because different passenger cars have different millage and engine sizes. The table below shows the millage and engine sizes of three different types of passenger cars [26] [27] [28].

Table 3.3: Types of passenger cars in terms of engine size and Millage

Car Model	Type	Engine CC	Millage (KPL)	Fuel Type
Suzuki Alto	Kei car / Japanese Microcar	660	20	Gasoline
Toyota Corolla XSE 2020	Sedan	1198	13.18	Gasoline
Toyota Land Cruiser Prado Gas AT	SUV	3956	7.3	Gasoline

3.3.2 Emission of a Solar Car

The solar car is basically an electric vehicle which is battery powered and uses an electrical motor for the mechanical power. It can be considered as a Zero Emission Vehicle (ZEV) as it has no combustion engine and thus no exhaust emission. As a result, the solar car has no direct emission of Carbon Dioxide gas in the air and not harming the Environment. However, there are indirect emissions related to the solar car. Firstly, the solar car needs to recharge its battery to operate. Although it has mounted PV panels, it requires grid energy because the panels always may not provide the sufficient energy required to fully charge the battery at a desired time frame. So, the required energy from the grid indirectly impacts the environment on behalf of the solar car as there is Carbon Dioxide Emission related to produce power in Power Plants.

3.3.3 Emission of Power Plants

Power plant generates required electrical energy to meet the day-to-day electrical energy demand. There are different types of power plants which uses different types of fuels for power generation, for example Coal fired Power Plant and Natural Gas fired Power Plant uses fossil fuels like coal and natural gas respectively, Hydroelectric Power Plant uses hydro power fueled by water. However, there is CO_2 emission associated with the Coal and Natural Gas based

Power Plant as fossil fuels are burned to generate power. To produce 1 KWHr of energy the Natural Gas fired Power Plant emits 0.566 kg of CO_2 whereas the Coal fired Power Plant emits 1.6 times more than the gas based [29]. On the other hand, the Hydroelectric power plants do not have any significant Carbon Dioxide emission which is beneficial for the environment.

3.4 Life Cycle Cost Analysis

Life cycle cost analysis is an engineering method for evaluating all the relevant cost over time for a project or for a product. When several numbers of competing alternatives are available under consideration to find out which is the best cost effective and efficient one in the long run, life cycle costing analysis is a useful tool to select the best alternative. For this analysis firstly and more importantly all kind of cost are taken under consideration. Cost including initial costs for example principal cost, purchase and installation cost, future cost such as energy cost, operating and maintenance cost, capital replacement costs, financing costs and also to include any resale, salvage or disposal cost if necessary and most important and necessary factor is all kinds of cost are taken into consideration over the lifetime of the selected project or product also [30].

Sorting out all cost is the most important and very first step before digging into the overall calculation. In speaking of its importance according to George Paul Demos, estimating engineer at CDOT, echoes this and notes that, "The first component in an LCC equation is cost. There are two major cost categories by which projects are to be evaluated in an LCCA: initial expenses and future expenses. Initial expenses are all costs incurred prior to occupation of the facility. Future expenses are all costs incurred after occupation of the facility. Defining the exact costs of each expense category can be somewhat difficult at the time of the LCC study. However, through the use of reasonable, consistent, and well-documented assumptions, a credible LCCA can be prepared." [31]

So far after sorting out the cost the main calculation can be started but before moving to the calculation some important factors need to be discussed for getting crystal clear idea about the life cycle costing analysis. The coming section will be fulfilled with all the elaboration of the parameters.

3.4.1 Inflation Rate

Inflation is the measurement of the declination of the purchasing power of the currency. In economy when the value of currency drops out the purchasing power drops which is veritable by the sudden price hike of the commodities and common services. For simplicity if any customer from any country buys a product by spending 5% more money from the previous value then that country is experiencing 5% inflation rate. Inflation rate is the annual percentage change in the consumer price index. As the inflation rate goes up the price increases and people tend to purchase less. Inflation rate may vary time to time it cannot be fixed but many countries try to limit it around nominal value. To find out the price of an item taking inflation rate in consideration if the cost of an item during the initial investment is $\boldsymbol{c_o}$,then the cost of that item after n years assuming the inflation rate for 100i% per year, will be [32]

$$\boldsymbol{C(n) = C_o(1 + i)^n} \qquad \textit{(3.27)}$$

3.4.2 Discount rate

Discount rate or interest rate refers to the amount of interest that can be earned after a specific period of time by saving some principle. It is important to choose a realistic number for the discount rate or an educated guess is also appreciated. But if the discount rate is positive over any amount principle that is saved, the principle will increase from year to year. For better understanding assume an initial amount of money is invested which is expressed as $\boldsymbol{N_o}$

,assuming 100d% per year here d is the percentage rate expressed as a fraction. After n years the value of the investment will be [32]

$$\boldsymbol{N(n) = N_o(1 + d)^n} \qquad \textit{(3.28)}$$

3.4.3 Present Worth Factor

When $C_o and\ N_o$ are equal it generates a dimensionless quantity, which is known as $Present\ worth\ factor\ (Pr)$**.** From the economic point of view Present worth factor helps us to determine the current value of money which is to be received in the future. More elaborately present worth factor help us to find out how much the present value of interest will turn out after $\boldsymbol{n}$ years later of initial investment. In our coming calculation this factor helps us to determine the present worth of each and every item of our solar car after using the solar car at its full capacity around its lifetime $\boldsymbol{n}$ years later of purchasing and using at its full capacity. Using the inflation rate and discount rate we got **Eq. (3.29)** for present worth factor [32]

$$\boldsymbol{Pr = \left(\frac{1 + i}{1 + d}\right)^n} \qquad \textit{(3.29)}$$

3.4.4 Present Worth

To find out the present worth or value or price of a purchased item or for any system we use $Present\ Worth\ (PW)$. After finding the $Present\ worth\ factor\ (Pr)$, the calculation of PW becomes more easier and simpler. But Present worth analysis can be classified into two categories depending on the type expenses.

3.4.4.1 Present Worth for an item (PW)

In this part the analysis is done for those items which are initially brought for once. These products do not need to be bought again and again. And for these types of items the present worth analysis is usually done after n years later of purchasing. And here n is consider as the life span of that item. The life span is provided by the manufacturer. By using the $Present\ worth\ factor\ (Pr)$ the $Present\ worth\ for\ an\ item$ which can be brought after $\boldsymbol{n}$ years later can be calculated by the following equation **Eq. (3.30)** [32]

$$\boldsymbol{PW = Pr * C_o} \qquad (3.30)$$

In the above equation $\boldsymbol{C_o}$ is considered as the initial cost of the product or item during the initial purchase.

3.4.4.2 Present Worth for Recurring Expenses (PW)

The expenses which occurred at a frequent or regular interval is known as Recurring expenses. For example, phone bill, monthly rent, subscription fees and many more. For our analysis the maintenance, fuel consumption and energy taking from the national grid are the area where we see recurring expenses and for those expenses, we find the present worth by the following equation Eq. **(3.31)** [32]

$$\boldsymbol{PW = \frac{1 - \frac{1+i^n}{1+d}}{1 - \frac{1+i}{1+d}} * C_o} \qquad (3.31)$$

Here, $\boldsymbol{n}$ represent time and $\boldsymbol{C_o}$ is the initial cost.

Chapter 4

Results Analysis & Discussion

4.1 Motor Selection

Using the knowledge shared in **Chapter 3** section **(3.1.1)** and **(3.1.2)**, we have calculated the power that the motor will supply to have a transition in speed (0 - 60kph) against different time of acceleration and plotted them in **Figure 4.1** to see the change.

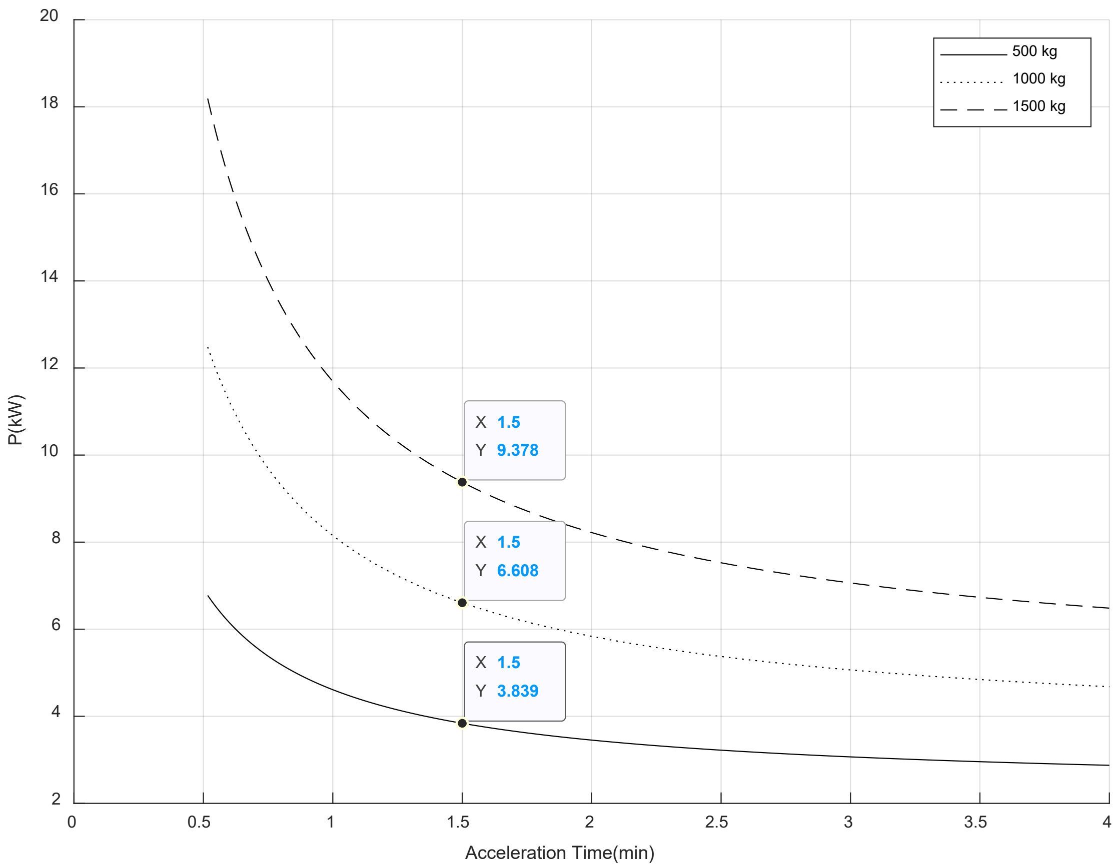

Figure 4.1: Plots of required power vs acceleration time to reach 60 kph for different car mass.

Looking at **Figure 4.1** we see, longer acceleration period requires lesser power to reach to the expected speed. Also, the vehicle mass brings out a change into the requirement of power as with increasing mass, the demand is also increasing. However, observing the power rating and also the time, we have finally reached to the conclusion that 1.5 min of acceleration time will be a good choice for our car [20]. Therefore, the motor rating will be more than 3.84 kW. Finally, we have installed a 4-kW motor into our car.

4.2 Energy calculation

Using the knowledge shared in **Chapter 3** section **(3.1.2)** and **(3.1.3)**, a real-life simulation has been done where the outcome is visible in **Figure 4.2.**

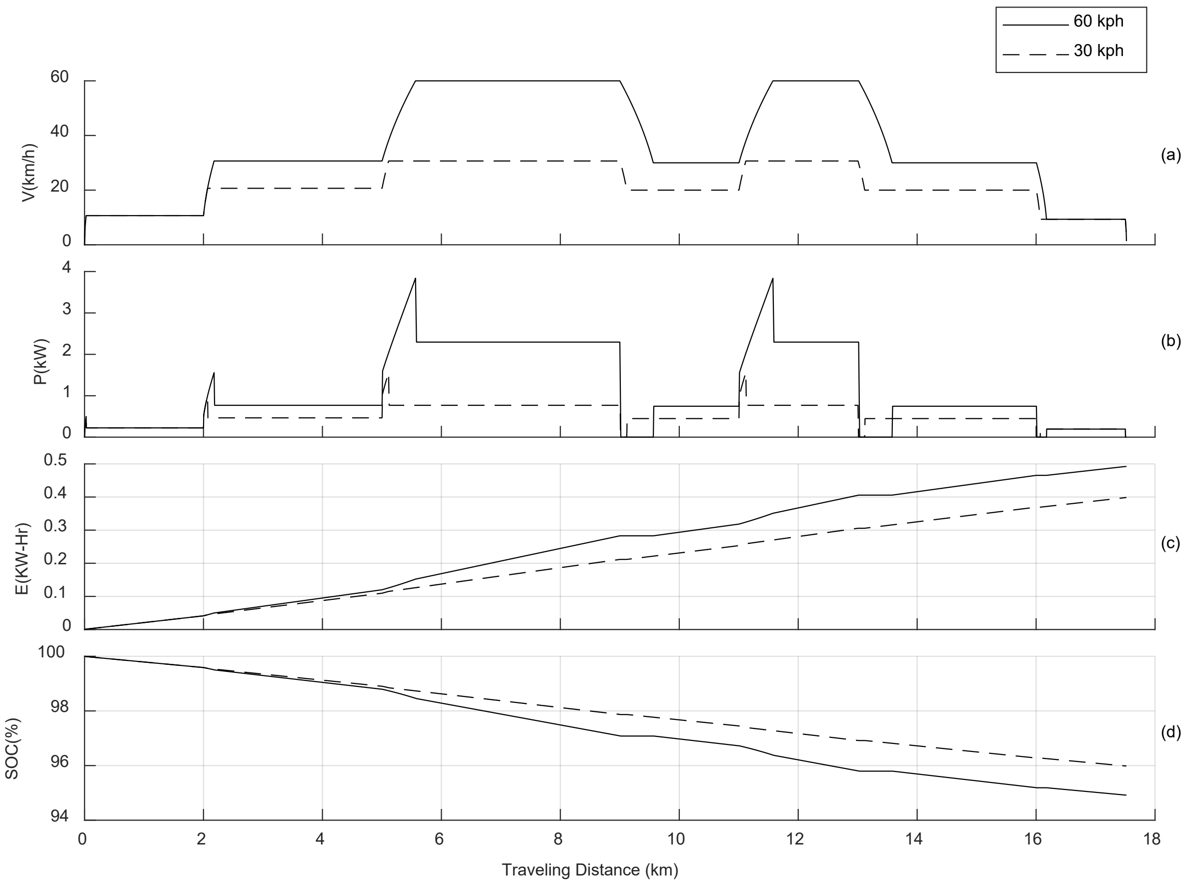

Figure 4.2: Plots of (a) car speed, (b) required power, (c) required energy and (d) state of charge where the car completes a single trip of 17.5 km as follows:

1. ***34% distance at 60 kph, 46% distance in 30 kph and 20% distance at 10 kph***

2. ***34% distance at 30 kph, 46% distance in 20 kph and 20% distance at 10 kph***

In **Figure 4.2** we have considered a 17.5 km trip covering the path from Uttara to Motijhil and investigated the changes in required power. Throughout the trip we fluctuated the speed at different point, tried to relate with the real life as in real life we can hardly get a constant velocity for a longer period. Also, we have considered two different scenarios where once the maximum velocity throughout the journey is 30 kph and in the other one it is 60 kph. This picturizes two different time of the day, considering the traffic congestions. From the analysis we have got that with increased speed increased motor power gets required and at different time of the day, the power consumption also become different.

Energy is the summation of the individual power consumption per unit time. So, for higher speed variation, required energy also become higher and vice-versa. Again, at different time of the day, this value also become different due to the traffic congestion and lower speed variation.

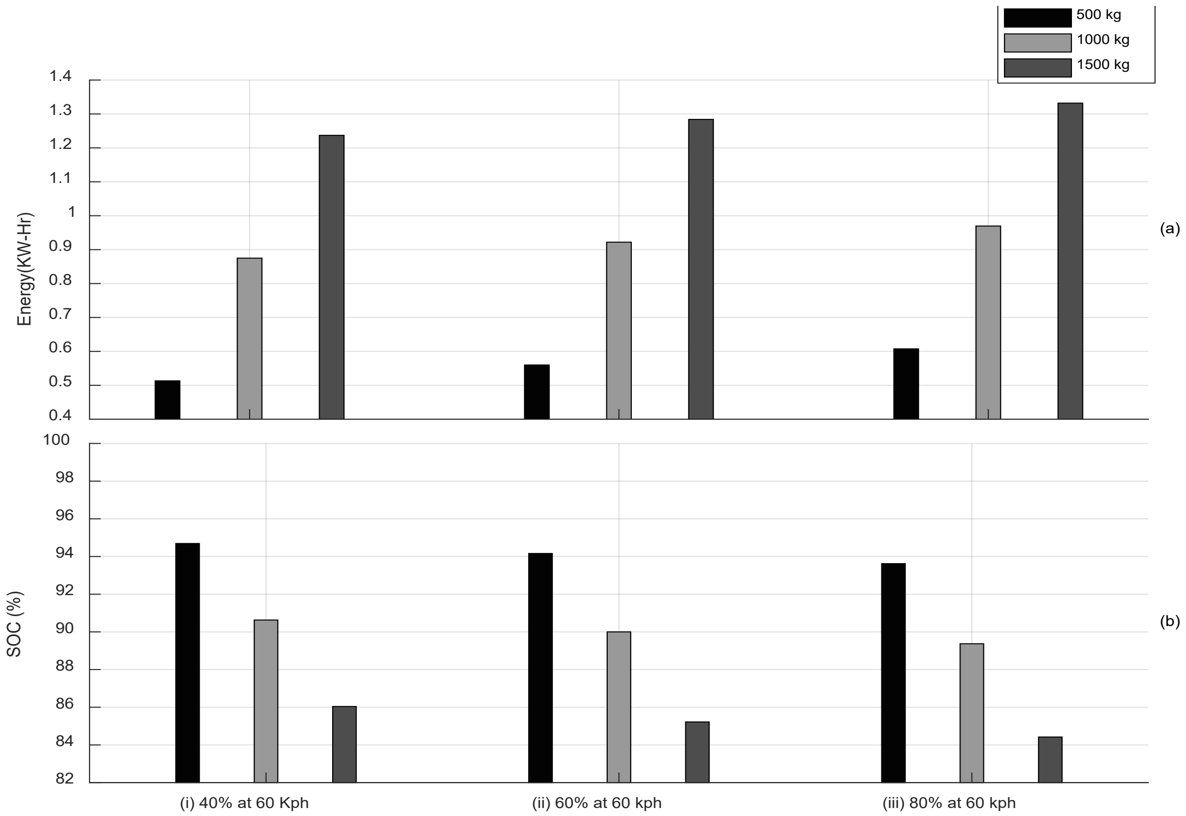

Figure 4.3: Plots of (a) total energy drawn by the motor and (b) SOC of the battery after completing a single trip.

Again, required power is proportional to the change in state of charge, at different period of time depending on how much power is getting drawn from the battery, the State of Charge drops.

To have a clear view over this matter and to see the impact of mass over the stated parameters, we have done some more analysis, while kept the total trip distance. We have considered three mass value; 500 kg,1000 kg and 1500 kg and repeated the whole calculation and calculated the amount of required energy and state of charge following the conditions as below-

i. The car runs 40% distance at 60 kph, 50% distance at 30 kph and 10% distance in 10 kph.
ii. The car runs 60% distance at 60 kph, 30% distance at 30 kph and 10% distance in 10 kph.
iii. The car runs 80% distance at 60 kph, 15% distance at 30 kph and 5% distance in 10 kph.

We plot the outcomes in **Figure 4.3** and see that car of higher mass requires more energy to complete the trip compared to the car of lower mass. **Chapter 3** section **(3.1.2.1)** and **(3.1.2.3)** clears the reason behind it. Also, the amount of distance the car runs in higher speed also has an impact over the energy consumption. As the period becomes longer, the energy consumption becomes higher.

Again, as energy consumption is related to the power and so do SOC, as consumption increases the SOC drops rapidly.

As we are done with the calculation of energy in the output side, we move to the calculation of required energy at the input side. As stated in **Chapter 3** section **(3.1.4),** the efficiency parameters for our car are as follows, [20]

Table 4.1: Efficiency Parameter

Parameters	
Motor Efficiency, $\boldsymbol{\eta_{mot}}$	90%
Charging efficiency, $\boldsymbol{\eta_{bat.cap}}$	90%
Discharging efficiency, $\boldsymbol{\eta_{bat.dis.cap}}$	90%
Efficiency of the charge controller, $\boldsymbol{\eta_{ch.cont.}}$	90%

Using these parameters, we have found that in a single trip of 17.5 km, the motor draws 0.77 KWHr energy from the battery. Above that the total capacity of the batteries used in the car is 180Ah that we have found is capable of providing 10.8 KWHr energy while fully charged. From the information we have found that our car can travel approximately 245 km at a single charge.

4.3 Distribution of Energy for the System

The monthly energy we may get from our PV panels alone may not be sufficient enough to drive our car throughout the months. That is why it is important to have a look how the energy is going to be distributed throughout the months among the PV panels output and the Grid. To get a detailed idea we have separated this analysis in 2 sub sections. First of all, in sub section **(4.3.1)** we are going to observe the amount of Electrical Energy we are getting from our PV panels considering cloud impact. After then in sub section **(4.3.2)** we will see what percentage of required energy will be covered by the energy we are getting from our PV panels and additional what percentage of energy needed to be supplied from the Grid to meet the energy requirement.

4.3.1 Available Solar Energy

Using the knowledge discussed in **Chapter 3** section **(3.2)** we have calculated the Solar Irradiance theoretically for a particular day in a particular month. The Solar Irradiance for Jan 15 starting from Sunrise to Sunset is shown in **Figure 4.4**.

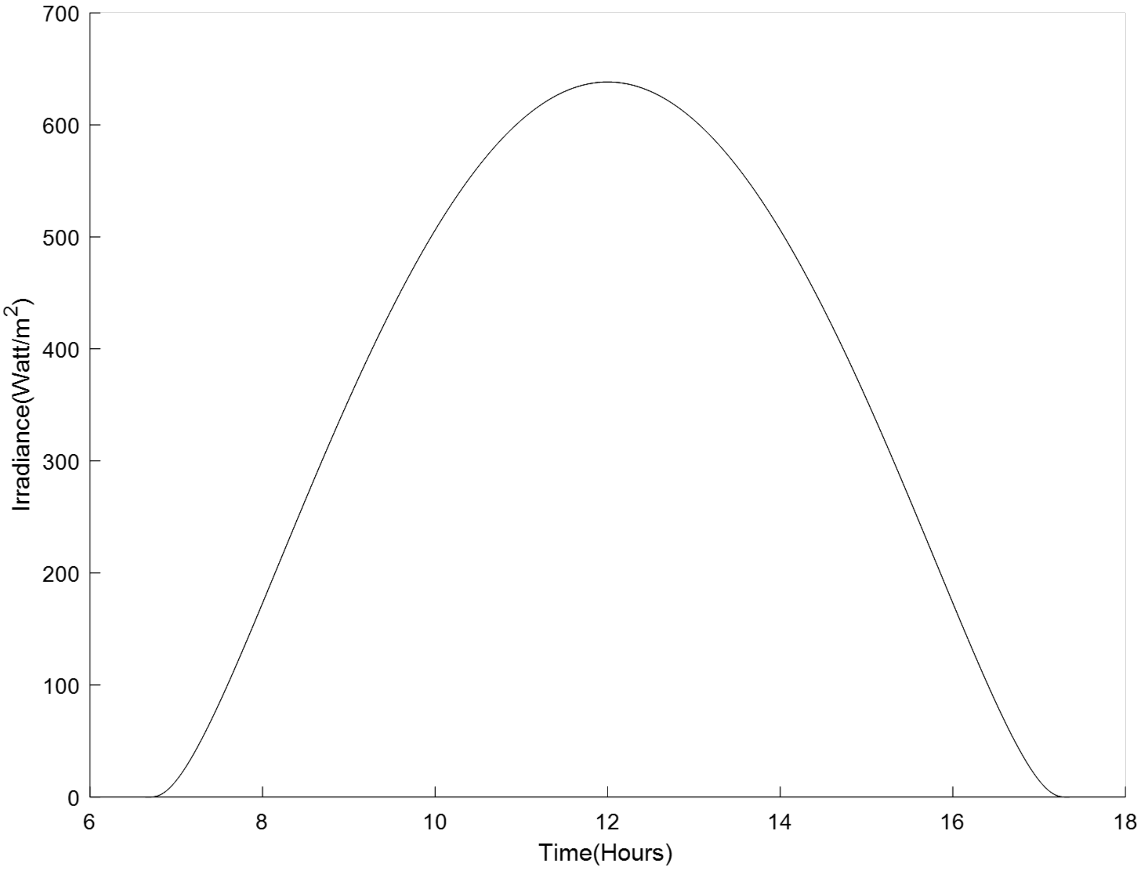

Figure 4.4: Input solar irradiance for Jan 15

From this **Figure 4.4** , we can see that at Sunrise time the Irradiance value is zero and it is gradually increasing with time. Following the fashion at 12 PM when the sun is directly overhead at that time maximum irradiance is achieved and after then as time goes on the value of Irradiance starts to decrease and comes down to zero again at Sunset time.

4.3.1.1 Cloud Impact

It is a common phenomenon that sun does not shine the same way all around the year as there are changes in seasons and coverage of clouds. So, the incident solar energy is not same all over the year, it also varies, and cloud has a serious impact on it. During the monsoon period the sky remains cloudy for most of the time and as a result we end up harvesting less energy from the PV panels. So, it is important to see the effect of clouds on our energy harvesting and to do so we need to know the number of sunny and cloudy days in different months of the year. One of the methods which can be used to determine that is the knowledge of Insolation [21]. From there, after performing some calculations the following **Table 4.2** is obtained containing the no of sunny and cloudy days in each month of the year. [21]

Table 4.2: No of Sunny and Cloudy Days

Month	Sunny Days	Cloudy Days
Jan	28	3
Feb	23	5
Mar	25	6
Apr	20	10
May	18	13
June	12	18
July	9	22
Aug	11	20
Sep	13	17
Oct	21	10
Nov	25	5
Dec	26	5

Next, to calculate the energy on sunny days as well as on cloudy days, we have considered that energy on a sunny day is the energy that is received on a pure shiny day while having the sun directly overhead. On the other hand, for energy on a cloudy day, 20% of the sunny day energy is considered as cloudy day energy. [21]

This is how we have calculated monthly available incident solar energy for this system over the year, for total area of the 5 PV panels which is **1.2m²** [20]. In this energy calculation impact of clouds is also given priority to observe the effect of clouds. Finally, from this calculation, we have figured out the total output electrical energy out of the 5 panels due to the incident solar energy in the input. The efficiency of the panels used in the actual car, is experimentally calculated to be **18.8%** [20].Finally, Monthly available input and output energy for this system is shown in Bar charts in **Figure 4.5** .

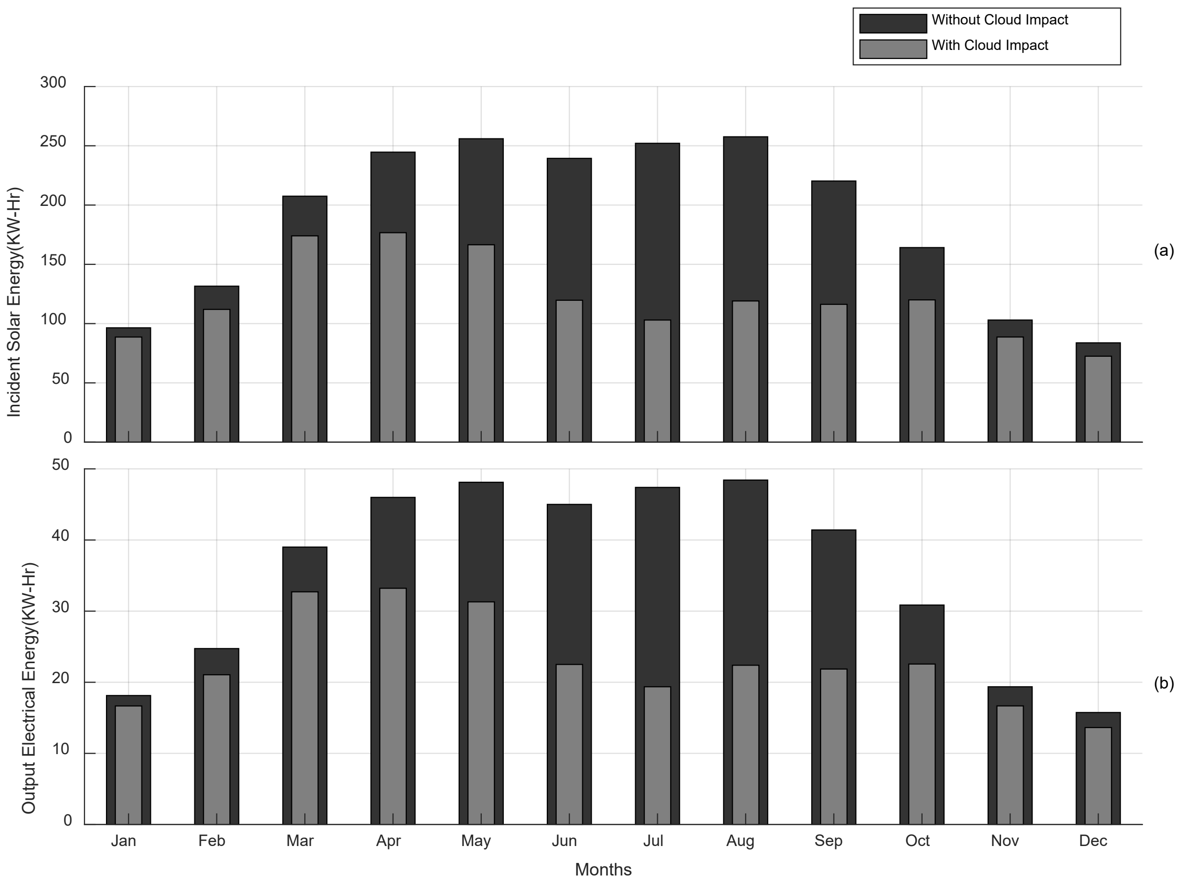

Figure 4.5: Monthly available (a) incident solar energy, (b) output electrical energy

In the above figure, we can observe a variation of available energy throughout the months. Now, considering the impact of clouds we can see that we are losing a significant portion of available energy because of the cloud coverage.

Usually, there are three distinct seasons in Bangladesh:

1. Hot, humid summer starting from March to June.
2. Rainy monsoon season from June to October
3. Cool winter season from October to March

Here in **Figure 4.5(b)**, we can observe the same thing that during March, April and May month we are getting more electrical energy from the PV panels because the Earth is closer to the sun in summer and farther from the sun in winter. On the other hand, due to rainy season we are getting less amount of energy from Jun to Oct since the sky remains heavily clouded most of the times and from Nov to Feb, the impact of winter season is clearly visible.

Now to see whether this output electrical energy will be sufficient enough or not to drive the car throughout the months, we will move to sub section **(4.3.2)** to dig further.

4.3.2 Required Energy from Grid

If the amount of electrical energy out of the panels are not sufficient enough to drive the car throughout the months, then we have to take some additional power from grid to fulfil our energy requirement. Following the same fashion like before we have performed the analysis of grid dependency for 3 different masses. For the car with 500kg mass two cases are considered to have an idea how cloud is going to affect the grid dependency for this car. But for 1000kg and 1500kg we have only analyzed taking account the cloud impact only. This is how the required energy from grid to fulfil the energy requirement, addition to the solar panel's output is calculated and the bar charts in **Figure 4.6** represent the monthly dependency on grid for different masses.

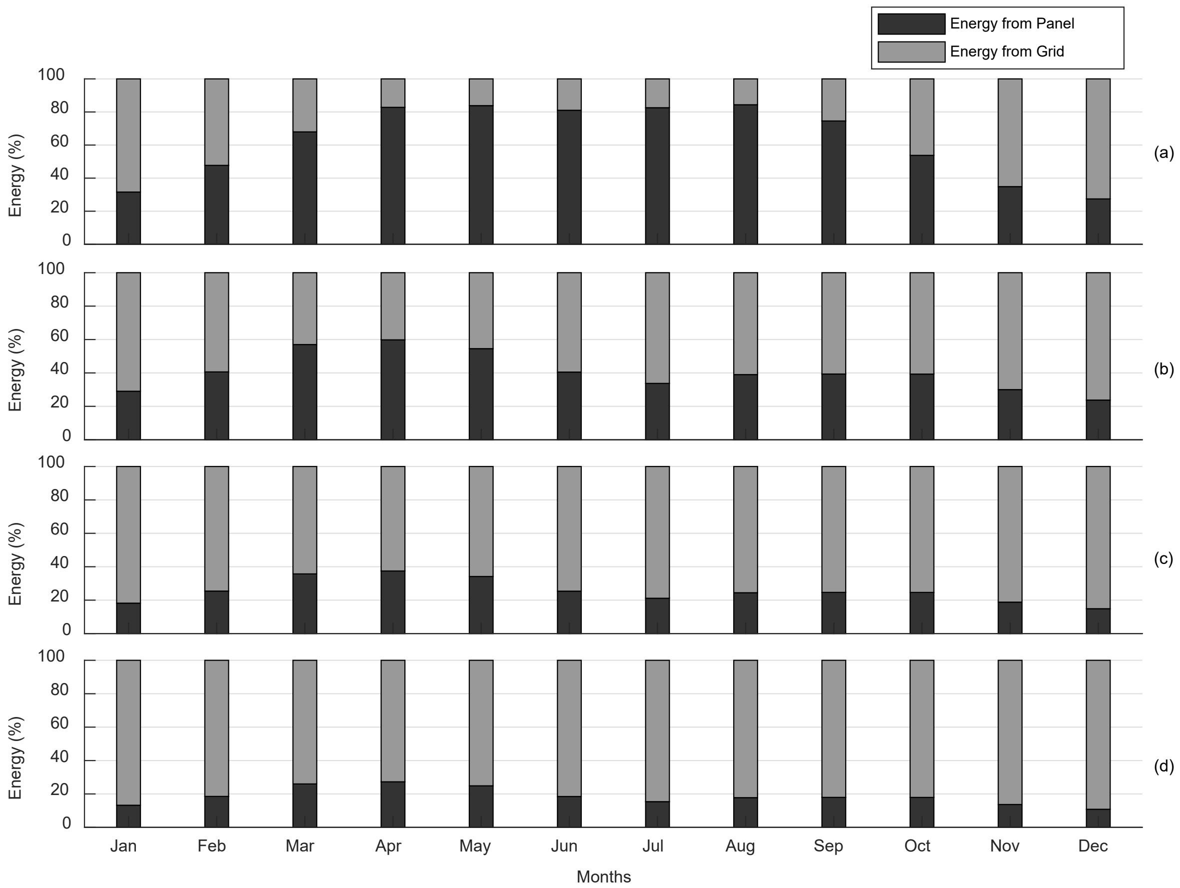

Figure 4.6: Monthly dependency on grid for (a) 500kg without cloud impact, (b) 500kg with cloud impact, (c) 1000kg with cloud impact, (d) 1500kg with cloud impact

Observing the above bar charts if we consider no cloud impact, we observe comparatively less dependency on the grid for the car with mass 500kg, shown in **Figure 4.6(a)**.

On the other hand, if we consider the cloud impact we can say,

- During Summer season (Mar-May), lower dependency on grid.
- During Rainy season (Jun-Oct), comparatively higher dependency on grid.
- During Winter season (Nov-Feb), maximum dependency on grid.

Besides, dependency on the grid increases as the mass increases.

4.4 Environmental Impact from the Solar Car

Solar car is basically an electric vehicle powered by D.C. lead acid battery. Electric vehicles are usually rated as Zero Emission Vehicles (ZHV) because these types of vehicles never emit any exhaust gas. So, we can primarily consider that the solar car will positively impact the environment. To develop the idea strongly several analyses has been done based on the Carbon Dioxide emission related to the solar car. We have organized the analysis in three sub sections. At first, we have analyzed the carbon dioxide emission that the solar car emits in a year with fully and partially grid dependency and we have also considered different masses of the solar car. Secondly, a comparison has been done between a gasoline and solar car to get a clear perspective about the emission and thus the environmental impact. Lastly, we have analyzed the Carbon Dioxide emission hotspots areas in Dhaka city with a view to providing an idea of the role of the solar can play in those areas in reducing carbon dioxide emission and developing human health.

4.4.1 Carbon Dioxide Emission from the Solar Car

The solar car has no direct Carbon dioxide emission directly associated as it is an electric vehicle and has no exhaust. However, the solar car has associated Carbon Dioxide emission for its dependency on the energy sources like Power Plants. The installed 250 W PV panel is always not able to charge the battery fully in a desired time frame. So, the solar car is partially dependent on energy from the grid to meet its energy requirement and that is where the emission comes from. Every power plant emits a certain amount of carbon dioxide to generate power. As discussed earlier a Natural gas fired power plant emits 0.566 kg of Carbon dioxide to generate 1 KWHr of energy and it is 1.6 time more for a coal fired power plant.

Our solar car is assumed to travel a distance of 17.5 km for a single trip from Uttara to Motijheel which becomes 35 km in a round trip for a single day. The base model of the solar car which has a mass of 500 kg and a 4 KW motor requires 1.8515 KWHr of energy in a single day following the specific velocity pattern. Moreover, the required energy also increases in proportionate with the mass of the car. We have also considered 1000 kg and 1500 kg mass of the solar car to observe the impact of the increased mass on environment. So, the annual energy requirement considering 300 operational days in a year gives such a value of energy that we need to consider. As a result, to generate this amount of energy the power plant will emit certain kgs of carbon dioxide. To contrast the annual amount of carbon dioxide emission from the power plants, we have generated a graph considering two scenarios. At first, the solar car is assumed to be in an extreme case where the car is fully grid dependent. And secondly, the solar car is assumed to be partially grid dependent where both the grid and the PV panels supply the required energy. The mentioned three masses of the solar car have been evaluated for the scenarios. The PV panels are considered to be supplying energy with cloud impact and the grid energy comes from a Natural gas fired power plant. The graph consisting of both scenarios together is given below:

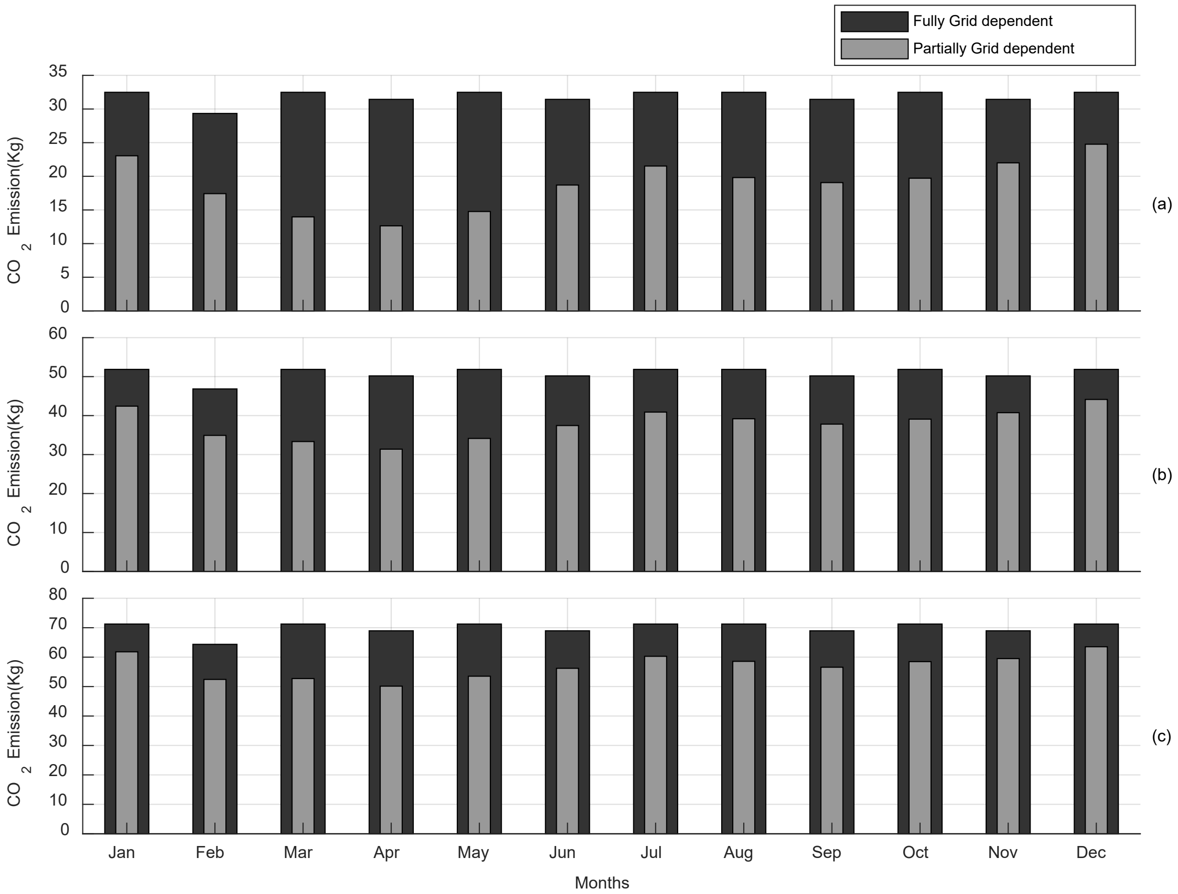

Figure 4.7: Annual Carbon Dioxide emission from a Natural gas fired Power plant to generate the required energy for the solar car with a mass of (a) 500 kg, (b) 1000 kg, (c) 1500 kg.

From the **Figure 4.7** it can be seen that the amount of carbon dioxide emitted for the fully dependent scenario is leading the partially dependent scenario all over the year. It is because, the amount of energy the Power plant supplies in the fully grid dependency scenario is more compared to the other scenario. So, the power plant emits more carbon dioxide to generate the additional energy. In this case the PV panels helps reducing the amount of carbon dioxide significantly. It can be seen that the emission has dropped to nearly 50% in March and April for 500 kg mass of the in the partial grid dependency scenario where the PV panels are contributing to the required energy. Moreover, the emitted carbon dioxide has been less in the rest of the moths also for all the masses. Therefore, the effectiveness of the installed PV panels in the solar car can be seen in reducing the Carbon dioxide emission. Hence, which indicates a positive impact of the solar car on the environment.

In case of the three different masses, it can be observed from the **Figure 4.7** that the solar car is associated with more carbon dioxide emission when the mass is 1500 kg and has less when the mass is 500 kg. It is because the increased mass requires more energy to travel the same 35 km distance and increased energy also increases the carbon dioxide emission from the power plant. The solar car with 1000 kg emits 54% more carbon dioxide compared to the 500 kg variant whereas the 1500 kg variant emits around 115% more in full grid dependency condition. So, the solar car with a compact design and less mass will contribute more to reducing the carbon dioxide emission.

4.4.2 Emission from passenger cars compared to solar car.

Passenger cars have internal combustion engines which burns fossil fuel to generate the required mechanical power for the car and gets rid of the greenhouse gases and pollutants through the exhaust which were produced during the combustion process. The exhaust gas contains carbon dioxide with other gases as well, but our main focus is on the carbon dioxide gas. We have considered three different types of passenger cars and the detailed specification is given in **table ().** For the sake our analysis, we have taken all the passenger cars which are gasoline driven and with different engine sizes like 660 cc, 1200 cc and 4000 cc. On the other hand, solar cars are considered to be zero emission vehicle (ZHV) as its source of power is electric and has no exhaust to consider direct emission from the car. However, associated emission to produce the required energy for the solar car, by the power plants are considered to be the emission from this car. We have calculated the amount of carbon dioxide emitted in a year by the mentioned three passenger car types and compared it with the emission from the solar car with three masses of 500 kg, 1000 kg and 1500 kg. Both the gasoline driven passenger car and the solar car travels a distance of 35 km in a single day where the solar car needs different amount of energy for three different masses and the passenger cars burn fuel according to their engine sizes and millage. We have also included the carbon dioxide emission from the solar car considering extreme scenario which is full grid dependency and the suitable case for the solar car which is partially grid dependency in the same calculation. The carbon dioxide emission from the gasoline passenger car and solar car is given in the **Figure 4.8** below.

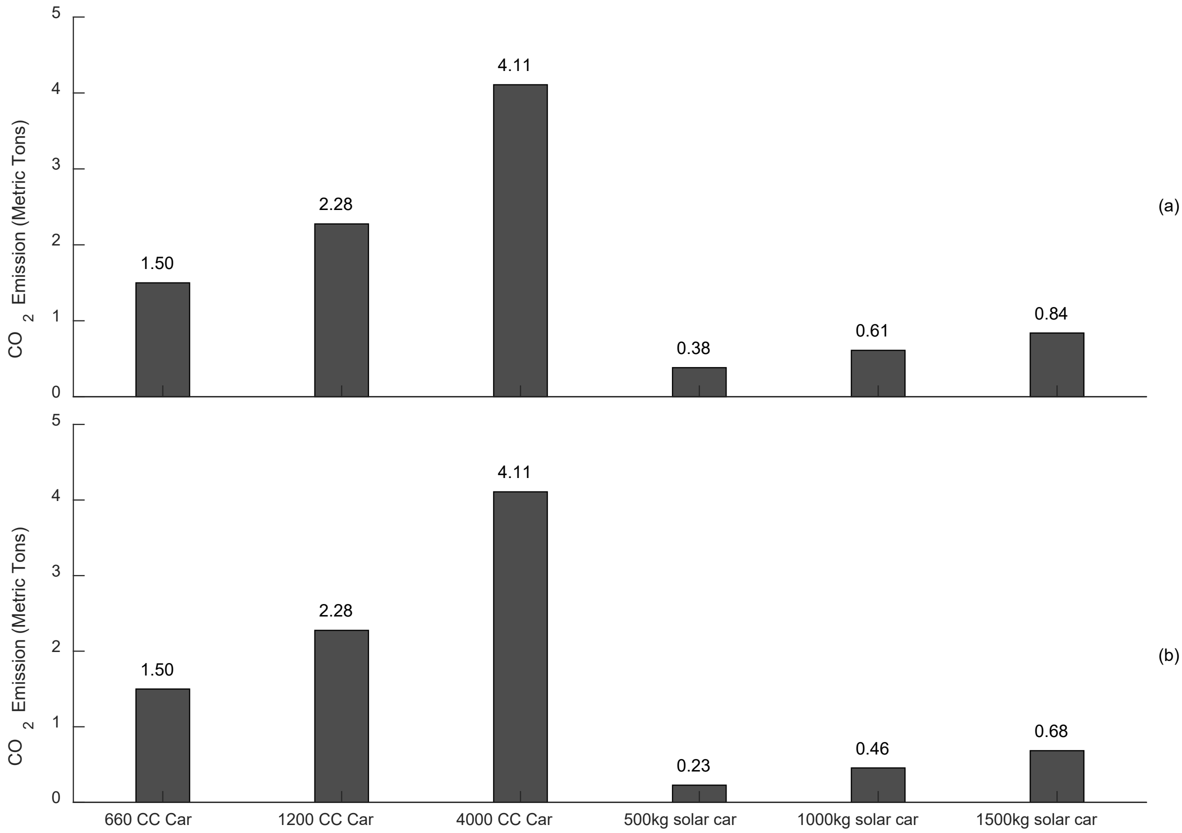

Figure 4.8: Yearly carbon emission from the average passenger car burning gasoline along with emission from the Natural gas-based power plant to generate the required energy for the solar car (a) fully dependent on grid, (b) partially dependent on grid.

It can be observed from the **Figure 4.8** that the gasoline driven passenger cars are leading the yearly carbon dioxide emission from all the mass variations of the solar car. The smallest 660 cc kei/ Japanese micro car out passes the worst possible emission from the 1500 kg solar car by 79% more emission. The standard 1200 cc and 4000 cc gasoline driven passenger car emits

144% and 327% more carbon dioxide in a year compared to the 1500 kg solar car's emission considering full grid dependency. Although, all the models of the gasoline driven passenger cars are latest and updated to be fuel efficient and ecofriendly but emits a huge quantity of carbon dioxide per year. On the other hand, being fully grid dependent the solar car can easily cover day to day travel distances with significant low amount of carbon dioxide emission which keeps the environment pollution free. The emission further decreases if we consider the solar car to be partially grid dependent where the required energy demand from the power plants further decreases resulting significant reduction in the carbon dioxide emission. As a result, it can be seen that in terms of eco friendliness and low carbon dioxide emission, the solar car is dominating compared to a gasoline driven passenger car or even a normal electrical car which is fully grid dependent. Moreover, the solar car also impacts the environment positively in this way. So, using a solar car in a regular basis will drastically reduce the carbon dioxide emission and thus benefit the environment.

4.4.3 Reduction of Carbon Dioxide emission in Dhaka city

Dhaka has been the most densely populated city for a long time with a staggering population of more than 20 million [33]. This huge number of populations in this city need a huge number of vehicles to meet daily traveling needs. However, the increased number of vehicles come with a greater cost of pollution, whether it is air or sound. The air pollution in Dhaka city has now become a massive problem for the city dwellers. A significant portion of the total emission in the Dhaka city comes from the transportation sector as the vehicles emit massive amount of carbon dioxide through its exhaust. Although, some areas in the city are more vulnerable of this emission than others.

4.4.3.1 Vehicle Composition

The carbon dioxide emission in an area from the vehicles depend on the vehicle composition of that area. So, the vehicle composition and the carbon dioxide emission are proportionally related which means the vehicle composition the larger the carbon dioxide emission. The **Figure 4.9** below shows the vehicle composition of gasoline driven passenger cars and other vehicle types of different areas [34].

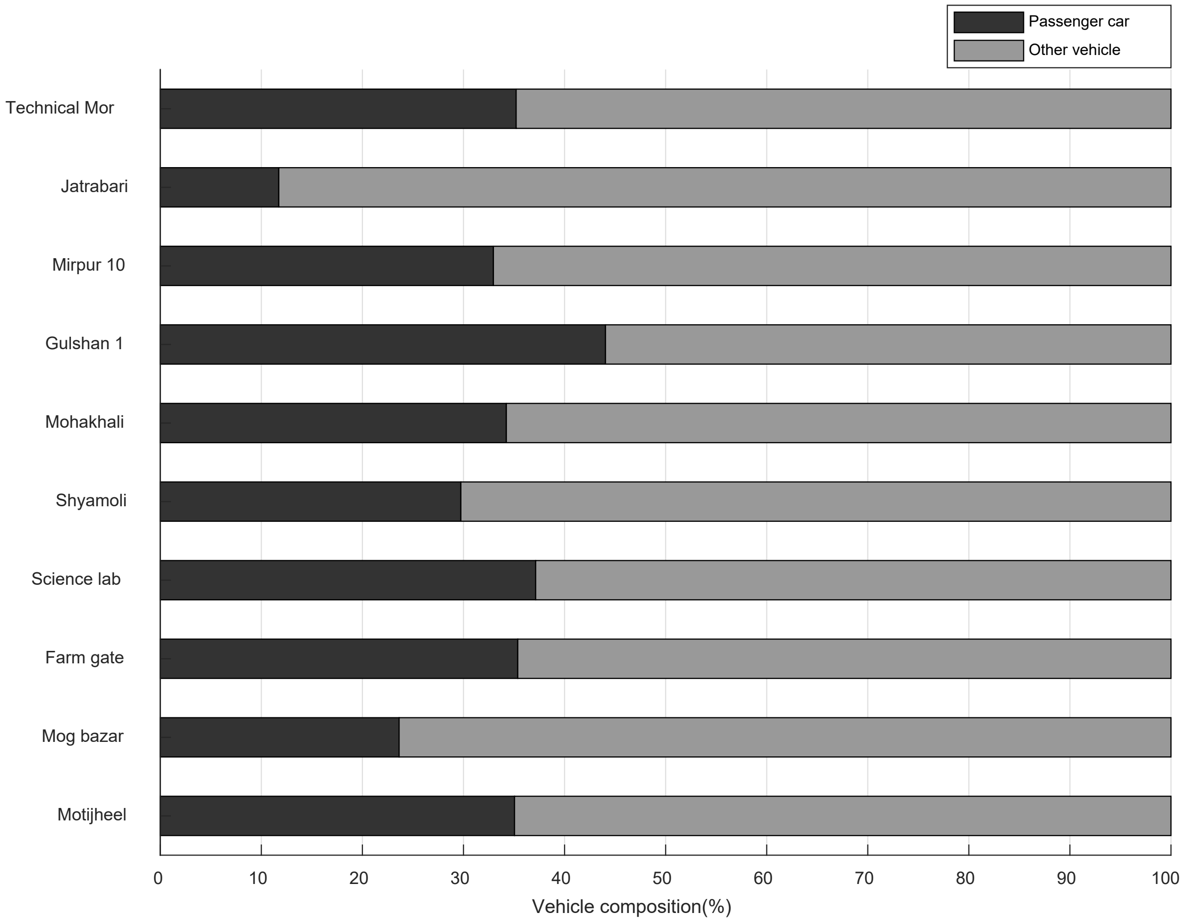

Figure 4.9: Region wise vehicle composition in Dhaka city.

The **Figure 4.9** shows the percentage of gasoline driven passenger cars and other vehicle type in different areas of Dhaka city. A sample of 100 cars has been taken from each of the mentioned areas in the figure and from which the percentage of the passenger car and the other vehicle type has been found [34]. Our interest of analysis is the passenger cars which are gasoline driven because it is comparable with the solar cars and more than 65% of the carbon dioxide emission comes from the passenger car type vehicles [34]. We have considered the passenger car to be 1200cc 4 seaters gasoline driven sedan. The percentage of the composition of the passenger cars defines the potential hotspots areas for carbon dioxide emission in Dhaka city. It can be seen that Gulshan 1 area has the greatest number of passenger cars which suggests the area to be a potential hotspot zone for carbon dioxide emission in Dhaka city. On the other hand, the Jatrabari area has the lowest number of passenger cars which indicates the area to be less carbon dioxide emission zone.

4.4.3.2 Reducing Carbon Dioxide Emission from the Emission Hotspots Areas

In our early discussion it has been illustrated that the areas in Dhaka city with greater number of passenger vehicles are potential hotspot areas for carbon dioxide emission. A graphical figure has been generated to illustrate the yearly carbon dioxide emission from these hotspot areas due to the gasoline driven passenger cars. The figure below shows the yearly carbon dioxide emission from the mentioned areas.

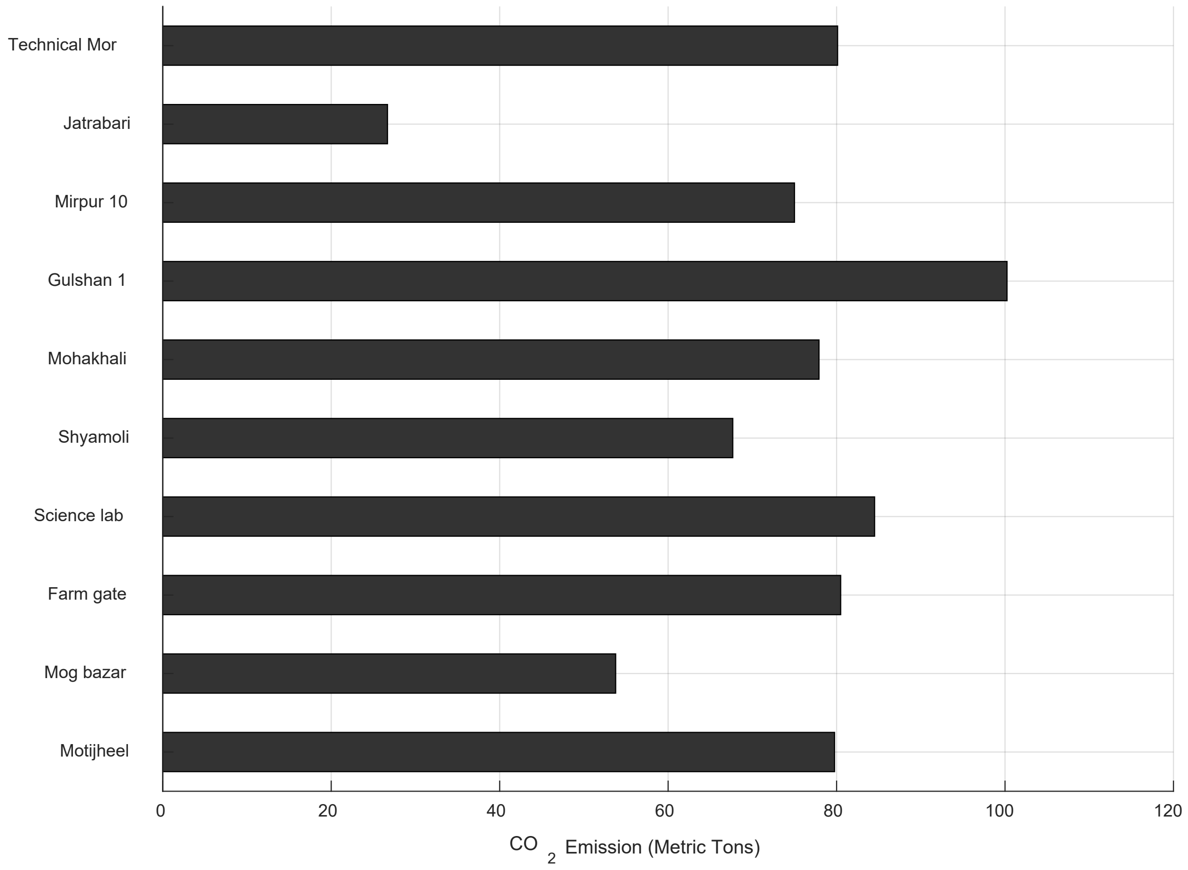

Figure 4.10: Yearly carbon dioxide emission from gasoline driven passenger cars in different areas of Dhaka city.

The **Figure 4.10** shows the annual carbon dioxide emission of different areas in Dhaka city. Among all the areas Gulshan 1 has nearly 100 Metric Tons carbon dioxide emission per year which is the highest in Dhaka city. The amount of emission is high in Gulshan 1 because the area had highest numbers of passenger cars. On the other hand, the Jatrabari area had the lowest passenger vehicle composition and thus the area has the lowest carbon dioxide emission in a year.

The emitted carbon dioxide is directly tampering the air of the Dhaka city. The solar can play a surprising role to diminish the carbon dioxide emitted in the Dhaka city. If we replace all the gasoline driven passenger cars with the solar cars the emission goes to nearly zero. It is because the solar car has no exhaust and thus no direct carbon dioxide emission, which can positively impact the environment. Moreover, the emission related with the solar cars are the power plans and the power plants are out of the Dhaka city area, so the emission from those sources will not affect the environment of Dhaka city. For example, if we replace all the passenger cars with the solar car in Gulshan 1, the yearly carbon dioxide emission of this area will become 0 Metric Tons which was previously 100 Metric Tons. There we can see a tremendous reduction in carbon dioxide emission. Therefore, if we can extensively replace all the gasoline driven passenger cars with the solar cars the carbon dioxide emission of Dhaka city from the transportation sector will be reduced by 60% which will greatly benefit the environment.

4.4.4 Improving public health in Dhaka city

As Dhaka is a densely populated city the number of vehicles in this city is huge. The dwellers of the Dhaka city use private and public transportation to move in the city. But there is a scarcity of public transportation in this city. That is why the dwellers prefer private transportation and more than 60% of the vehicles in Dhaka city are private passenger cars [16]. With the increasing number of private transportations, the amount of emitted carbon dioxide also increases. All these bears a negative impact on the environment as well as on the public health. The burned gasoline exhaust from a passenger car carries greenhouse gases, unburned hydrocarbons and pollutants which are highly injurious for public health. Although, the number of other components in the exhaust is less compared to the carbon dioxide but their effect on health cannot be ignored. The health impact varies according to the place and way of exposure to the vehicle emissions. The elderly persons, children, drivers, passengers and pedestrians are more vulnerable to get affected with various health diseases. The elderly persons are sensitive to any change in the environment as their body feels difficulties to cope up with the harmful gases and particulates from the vehicle exhaust. Moreover, the children usually spend their school time in a confined area as there is scarcity of free spaces in schools in Dhaka which makes them more vulnerable to get affected with health-related problems because the emissions get trapped in such confined places. Furthermore, the drivers, passengers and pedestrians are highly exposed to vehicle emission which results in a very harmful health impact. There are many harmful health effects which occurs from the vehicle emission. The list below contains few health effects [33].

- Vomiting
- Headaches
- Dizziness
- Cough
- Phlegm
- Breathing difficulties
- Increased mortality risk because of respiratory and cardiopulmonary reasons
- Coronary heart disease
- Lung cancer
- Chronic bronchitis
- Genetic mutation, and chromosomal DNA damage
- Irritation of the eyes and respiratory tract
- Lightheadedness
- Nausea

The mentioned health effects bear long term and short-term consequences. The solar car can help in the prospect of reducing the health-related problem from Dhaka city due to vehicle exhaust. As, the solar car has no emissions in city it can easily replace the conventional gasoline driven internal combustion engine passenger vehicles. As result it not only eliminates the carbon dioxide emission but also eliminates all the other greenhouse gases [35] and pollutants as well. So, the environment of Dhaka city becomes habitable and reduces health risk for its dwellers. The solar car can further positively impact the environment if it uses renewable energy sources like hydroelectric power, wind power and solar power instead of the fossil fuel-based grid power it relies on to meet the required energy demand.

Finally, using solar cars instead of conventional gasoline driven passenger car can benefit both the environment and the public health.

4.5 Yearly Cost of the Required Electrical Energy from the grid

Solar car may not fully fulfill its necessary energy from PV panels in that case solar car needs to draw energy from national grid. And there is cost associated for power being drawn from the grid. So, it is inevitable to get an idea how the cost will turn out annually along with the total amount of required energy drawn from the grid.

In this section we have tried to give an idea about the annual cost of necessary required electrical energy drawn by the solar car from the grid. Besides how the annual cost will differentiate if the percentage of drawn required energy by the solar car from the grid also varies. For this calculation we have considered Tk 9.94 per KWHr according to the latest electricity price for residential consumer, applicable for average usage above 401 kw hour regulated by the Dhaka Power Distribution Company Limited [36]. For this calculation we have considered solar cars considering three masses which are for 500 kg,1000 kg and lastly for 1500kg.

The yearly cost variation along with percentage of required energy skimmed from grid by the solar car is shown below in the following ***Figure 4.11.***

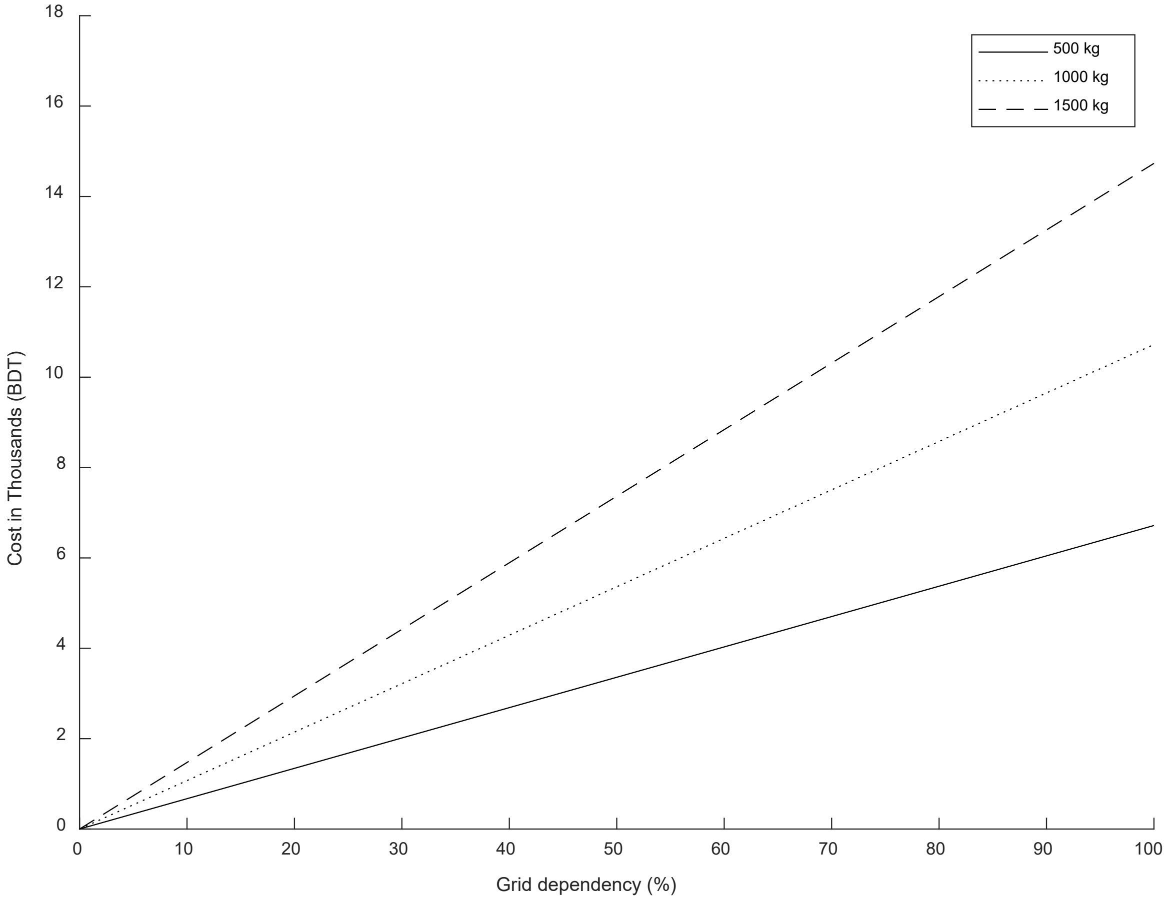

Figure 4.11: Yearly Cost corresponding to yearly drawn electrical energy from the grid.

From this **Figure 4.11** we have observed that when our solar car does not take any electrical energy (0%) which is considered as the best case for our solar car performance, the cost in that case is also BDT 0. But if solar car depends fully on the national grid to meet up its required energy the yearly cost is also maximum. And for all weights (500,1000 and 1500) the scenario is the same.

4.6 Life Cycle Cost Analysis

To know the operational cost for a product over its lifetime Life cycle cost analysis is done. Using LCC we may have the idea of how solar car would be a cost-effective choice over our traditional fuel-based car in order to meet the demand of the city commuters over the individual lifetime of solar car and fuel-based car. To get a clear-cut idea we have divided this section into two sub-section. First of all, in the first sub-section **(4.6.1)** we are going to calculate the

LCC of solar power car over the life span which is about 20 years. Later in the subsection **(4.6.2)** we are going to calculate the same LCC for three different fuel-based cars over the same life span of 20 years. For both of the subsection we have used the knowledge in the **Chapter 2** section **(2.4)**.

4.6.1 Life Cycle Cost Analysis of Solar Car

For starting this analysis, we have first collected all the necessary costs and enlisted on a table. And using necessaries formula we have done all the calculation and showed in the below **Table 4.3.**

Table 4.3: Life Cycle Cost Analysis of a solar Car (500 kg)

Components	Number of Units	Unit Cost per watt (BDT)	Initial Cost (BDT)	PW (After 20 years) (BDT)
Solar Panel	250 Watts	80	20,000	20,000
Battery (12Volt,180 Ah)	5	15875	80,000	80,000
Battery 5 years Battery 10 years Battery 15 years	5		80,000	83,000 85,500 88,000
Charge Controller	1	10,000	10,000 10,000	10,000 11,000

Charge Controller 10 years					
DC Motor	1	28,700	34,000	34,000	
DC Motor 20 years	1		34,000	39,000	
Annual Maintenance			7,000	1,50,000	
Partially dependent on grid			4,000	85,000	
Fully dependent on grid			6,700		1,42,500
Life Cycle Cost (Partially dependent)				6,85,500	
Life Cycle Cost (Fully dependent on grid)					7,43,000

From the above table we have got the total life cycle costing analysis for solar car considering the weight of our solar car for 500 kg. Following the same procedure, we have similarly calculated Life Cycle Costing for solar car considering weight 1000 kg and 1500 kg which have showed in the below **Table 4.4**

Table 4.4: Life Cycle Cost Analysis of solar Car Considering 1000 kg and 1500 kg.

Solar Car	**Total LCC Cost for 20 years (Partially dependent on grid) (BDT)**	**Total LCC Cost for 20 years (Fully dependent on grid) (BDT)**
1000 Kg	**13,25,000**	**13,83,000**
1500 Kg	**19,05,000**	**19,63,000**

4.6.2 Life Cycle Costing Analysis for Fuel Based Car

For this section following the similar procedure we have first selected three different traditional fuel powered car and then we have collected all the necessary cost. And then we have done the same Life Cycle Cost Analysis for all of the three cars. In **Table 4.5** we have showed all the calculation regarding the fuel-based car

Table 4.5: Life Cycle Cost Analysis of Fuel powered Car

	Suzuki Alto		**Toyota Corolla XSE 2020**		**Toyota Land Cruiser Prado Gas AT**	
Engine Power	650 cc		1200 cc		4000 cc	
Components & Expenses	Initial Cost (BDT)	PW (After 20 years) (BDT)	Initial Cost (BDT)	PW (After 20 years) (BDT)	Initial Cost (BDT)	PW (After 20 years) (BDT)

Fuel	43,600	9,30,000	66,000	14,05,000	1,20,000	25,54,000
Annual Maintenance Engine Oil, Filter Replacement Servicing, Fitness Test	5,000	12,77,800	7,000	17,88,000	15,000	38,30,000
Total Operational Cost	48,600	22,07,800	73,000	31,93,000	1,35,000	63,84,000

4.7 LCC Comparison between Solar Car and Fuel based Car.

In this part we have used the previous section calculated data of the LCC around 20 years and put the both the solar car and the fuel-based car data side by side into a bar chart for getting a clear visual idea if solar is cost effective choice over traditional fuel-based car.

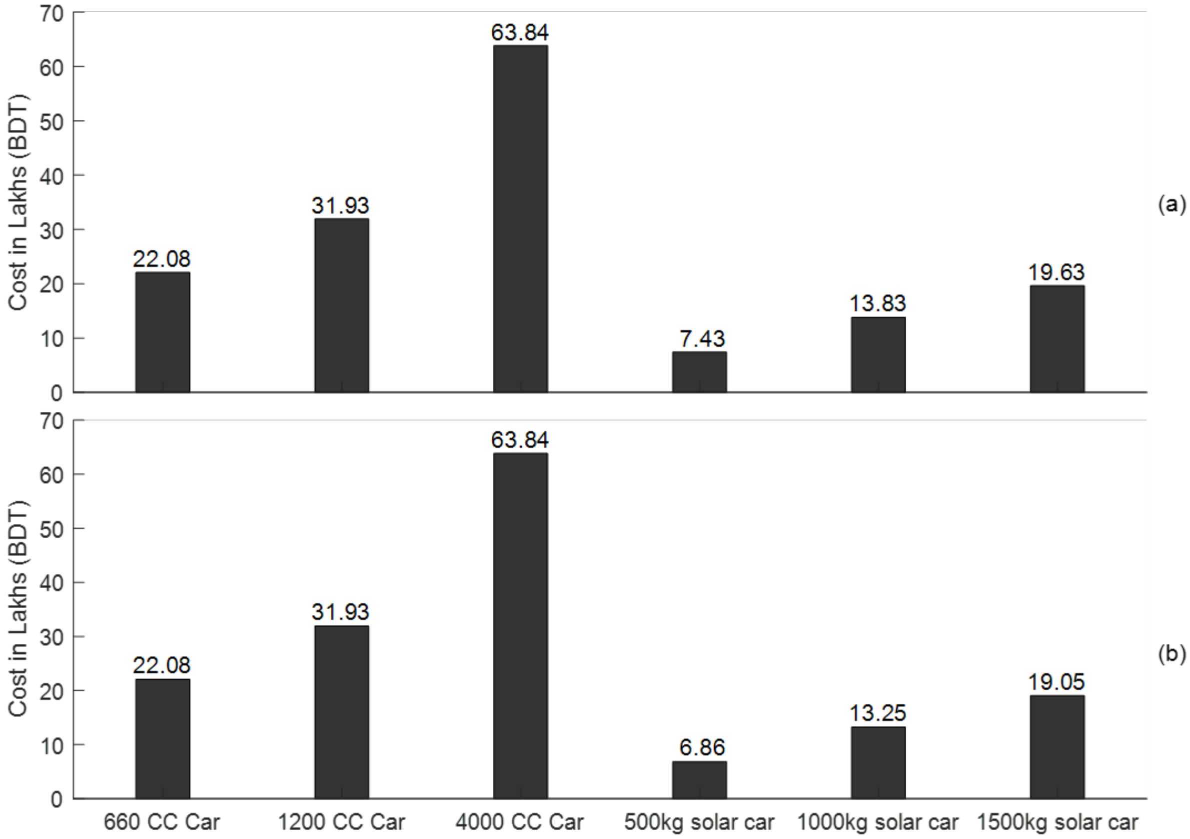

Figure 4.12 : Comparison of total LCC for 20 years between Fuel based car and Solar powered car (a)solar car fully dependent on grid(b)solar car partially dependent on the grid.

From the above **Figure 4.12** we have observed that the total life cycle cost for solar car is much less than fuel-based car. Even if we consider the solar car that weights the highest (1500kg) has the lowest life cycle cost compare to the 660cc which is the lowest among the consideration of all the other fuel-based car and that is even true if we consider that our solar car (1500 kg) is in its worst condition which is fully depended on the grid, the total LCC is even lesser than fuel-based car of 600cc. For the rest of the part of the bar chart we get the pretty much same idea as we have got before.

Chapter 5

Conclusion

In conclusion, the solar car bears a great importance in present era as everyone is looking for an alternative to the combustion engine-based cars for their high negative impact on the environment. The performance, environmental and life cycle cost analysis done on this study reflects the necessity of using the solar car for a Dhaka city dweller.

The journey started with the performance analysis where we have observed that for our test model, the battery gets drained by around 8%, for a single trip of 17.5 km, which is undoubtedly a good indication. However, when we moved for the input analysis for the battery, we have seen that our car can almost be independent of grid during summer. Except that during all other seasons, the car shows a far dependency on grid. As we came up with this situation, we then tried to understand how being fully dependent on grid makes the solar car a contributor for the CO_2 emission as it causes the grid to go for more power generation which results in more CO2 emission. Not only the emission related with the solar car is significantly less but also, we have found that it emits almost 6 times less CO2 emission while being fully dependent on grid and almost 4 times less CO2 emission while being partially dependent on grid compared to the traditional passenger cars. Also, we tried to mark the hotspots over Dhaka city and tried to get a ratio of passenger cars within 100. When we thought about replacing those cars with Solar Car, our result shows almost zero emission and almost 60% reduction in CO_2 emission in Dhaka city. Moreover, as the solar car reduces CO_2 emission, the environment of Dhaka city becomes habitable and reduces health risk for its dwellers. As we are done with the necessary analysis, one most important aspect which is economic analysis has also been done to see the economic effectiveness of solar car over traditional fuel-based car for city dwellers usage. Considering all the cost and expense for 20 years, our solar car of three different masses outperformed the three different fuel-based cars. It has been found that the life cycle cost of our most weighted solar car (1500 kg) is much cheaper than all the considered fuel-based cars.

After examining the mentioned outcomes, finally we have reached to a conclusion that Solar car be a revolutionary substitution for an efficient, energy saving, ecofriendly and a low-cost medium of transportation.

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