Distributed Renewable Energy Network for Electric- Vehicle with Battery Ferry Supply Chain management, Battery Swapping

by

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CERTIFICATE OF APPROVAL

The thesis titled,"**Distributed Renewable Energy Network for Electric- Vehicle with Battery Ferry Supply Chain management, Battery Swapping**" accepted as partial fulfillment of the requirement for the Degree BACHELOR OF SCIENCE IN ELECTRICAL AND ELECTRONIC ENGINEERING of Islamic University of Technology (IUT)

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Declaration of Candidate

It is hereby declared that this thesis report is only submitted to The Electrical and Electronic Engineering Department any part of it has not been submitted elsewhere for the award of any Degree or Diploma.

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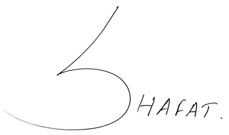

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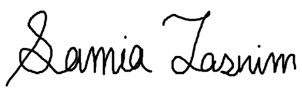

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We dedicate our thesis to our families, friends and everyone who has inspired and mentored us throughout this journey. We wish them health and prosperity.

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Abstract

This thesis presents a widespread adoption of renewable energy, e.g., solar farms, to charge electric vehicle (EV) batteries. A sustainable decentralized network of battery ferrying and swapping technique is proposed. Batteries are charged by solar power at the solar farm, transported to local distributors, and further distributed to consumers' EVs through delivery vans. The scenario focuses on building off-grid decentralized solar farms for communities (dependent on fossil fuel) overburdened with limited space not to use renewable energy. The model constructs a network that provides charged batteries at any time, at the doorstep to mitigate the range anxiety aligned with EVs. It is a cyber-physical framework (using the Internet of Things (IoT)) enabling machine-to-machine communication (i.e., battery-to-battery or battery-to-EV) in real-time information (inclusion of EV user). A simulated scenario assesses the successful battery deliveries/supplies considering driving locations, traveling paths, demand for charging requests, etc. The results use a 4-layer neural network to forecast/predict the battery demand with an explained variance of 0.99289 for 72 hours, enabling batteries to be delivered within the shortest time and adequate number of batteries to be stored at the solar farm for supply. Besides, a system with a first-come, first-served (FCFS) queuing strategy is simulated where local distributors are placed at an optimum position near consumers through k-means clustering which provides efficiency of 82.524%. This thesis focuses on battery ferrying and swapping techniques and considers a human-centered practical approach of a green decentralized battery network that adopts the vision of Society 5.0.

Chapter 1

Introduction

Road vehicles are highly responsible for global warming, greenhouse emission, health hazards, and also a significant source of pollutants. To combat the associated disadvantages, in the last decade many countries like China, the European Union, and the United States, drastically switched gears from conventional energy to renewable [1]. A reduction in greenhouse emission by making major alternations to the transport sector through the penetration of solar energy and deployment of the electric vehicle (EV) can have a widespread positive effect on the environment. Batteries are cost efficient and reliable medium to store energy. Countries with the vision of becoming fully renewable energy-based are replacing internal combustion engines with green transports like E-bikes, E-cars, Hybrid cars, Hyperloops, etc [2].

There are several technologies to charge EV and plug-in hybrid electric vehicle (PHEV) which include plug-in chargers and battery swaps. Plug-in chargers can be classified into three levels i.e., 1, 2, and 3. Among them, the fastest technology, level-3 chargers reduce charging times to about half an hour. These expensive chargers lead to unsustainable load spikes on the distribution, thus require complex electricity distribution infrastructure [3].

1.1 Problem Statement

Energy systems around the world are going through a rapid transformation that will bring important changes to the ways we fuel our cars, heat our houses, and power our industries. The energy crisis is the result of the limited utilization of alternative energy sources and fossil fuels. The planet earth is suffering from a disproportionate energy mix. Owing to intemperate dependence on fossil fuels even for the next two decades, fossil fuels are subjected to depletion [4] . Central issues in global energy are discussed through interdisciplinary dialogue between experts from both North America and Eu-

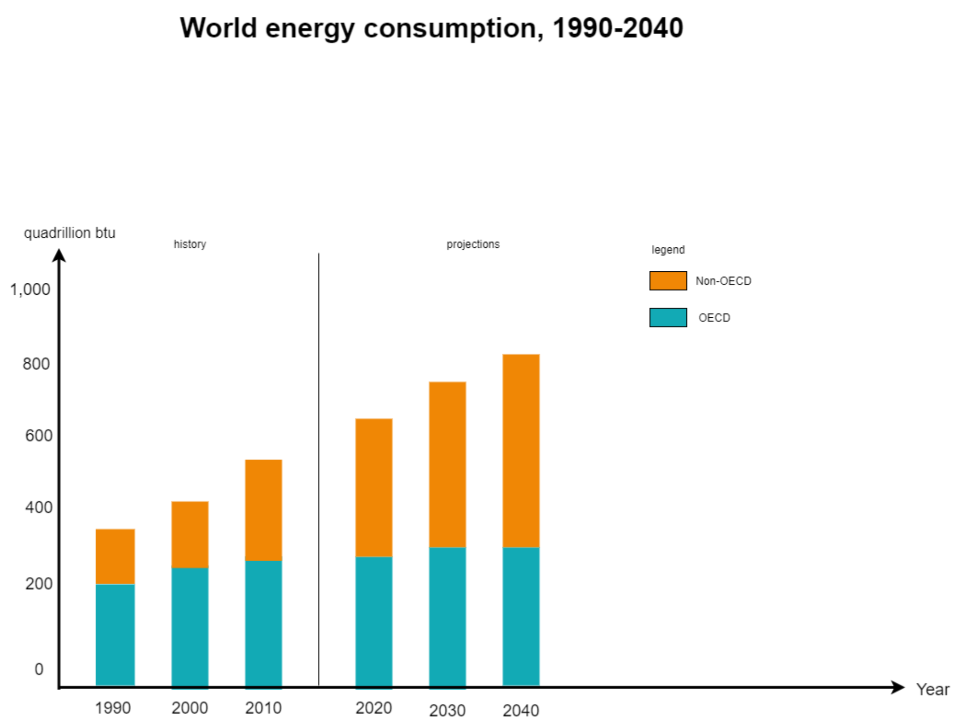

Figure 1.1: World energy consumption prediction from 1990-2040.

rope. They considered it from historical, political, and socio-cultural perspectives, outlining the technology and policy issues facing the development of major conventional and renewable energy sources. We are facing a global energy crisis caused by world population growth, an increase in demand, and dependence on fossil-based fuels for generation. It is widely accepted that increases in greenhouse gas concentration levels, if not decreased, will result in major changes to world climate with consequential effects on our society and economy [5] - [6].

Energy sources may broadly be classified into two major categories that are: conventional energy sources and renewable energy sources.For decades, conventional energy sources have been used for power generation and industrialization. These energy sources are mainly dependent on fossil fuels namely: coal, oil, and natural gas. Renewable energy sources are the ones that are inexhaustible, clean, pollution-free, and environmentally friendly. These sources of energy include water energy, wind energy, geothermal energy, solar power, and tidal energy. In the last decade, electricity generation has drastically switched gears from conventional to renewable concerning the associated advantages. China, European Union, and the United States are key stakeholders in this run chase [1].

The world's most polluting energy sources are clean alternate energy and nuclear power, both of which are growing at a rate of 2.5% per year [7]. As the cost of renew-

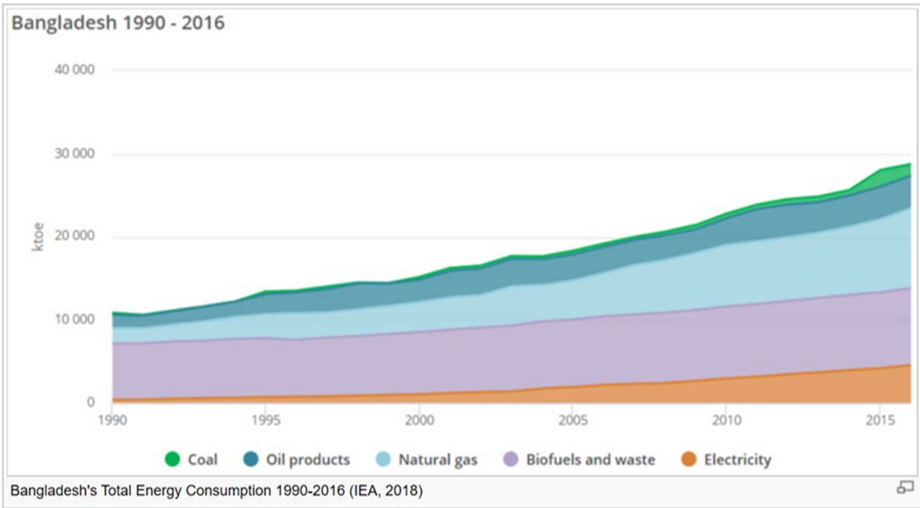

Figure 1.2: Bangladesh's total energy consumption prediction from 1990-2016.

able energy has come down further, many countries are going to adopt full renewable energy generation-based system within the coming four to five years. The cost of batteries is also decreasing, and many countries will opt for electric vehicles over internal combustion engines in the next four to five years.

With the ever-increasing demand for electricity, transport and industries' energy consumption plays a vital role. The government is focusing on the three targets of Sustainable Development Goal-7: access to energy and clean cooking, renewable energy, and energy efficiency. Building solar energy plants is a renewable and affordable solution. Due to obstacles such as overburdening centralized energy management, limited space, finances, and other factors, EV adoption in Bangladesh is extremely difficult. Besides, in such an overpopulated country, the government enforces policy not to establish solar farms in agricultural lands, which inspires decentralized solar farms in distant places.

Bangladesh has for some time been experiencing energy starvation with its increasing population of 160 million, of which 80% live in village. Bangladesh has a huge power request where just 67% individuals get power access. According to the BPDB, on June 30, 2018, there were 25,26,594 power consumers who had served a total of 10,958 MW of power [8]. The disparity between the most intense interest and the inventory triggers load shedding in Bangladesh's various areas. Similarly, about 9% of electricity is lost at power plants, transmission and distribution networks.Bangladesh faces and will look in not so distant future an emergency in energy area. In the village woods, straws and cow waste are as yet the principal energy source. Consequently, the market interest and demand cannot be satisfied and in this manner load shedding emerges.

Bangladesh predominantly relies on indigenous natural gas, which accounts for 89% of power generation. Other sources include coal (3.5%), furnace oil (3%), HSD (1.7%) and hydro (2.5%). Unfortunately, with gas consumption at this pace, resources are estimated to be depleted within a decade. Not that the country currently enjoys uninterrupted power: six to eight hours of power cuts are standard for people residing in rural areas.

As of 2008, power generation was 3200-3400 MW against a national demand of 5200MW. Load-shedding seems to be the only solution to curb these peaks, with the poorest being the worst sufferers. To allay these power cuts, the government turned to high-cost oil-based rental and public sector peaking power plants for emergencies. If this yawning power deficit is not addressed immediately, the energy situation will only exacerbate. Demand is expected to reach 19000 MW in 2021 and 34000 MW by 2030, according to the Ministry of Power, Energy, and Mineral Resources. This demand can certainly not be met with given resources,short of a miraculous gas discovery, leaving the country with no better choice than to opt for expensive alternative schemes. Lack of resources should not be taking the blame alone; a history of corrupt regimes and lack of transparency equally take the blame for the unreliable and intermittent gas supply.

After Bangladesh's independence in 1971, only 3% of the total population had access to electricity [9]. This ratio has gone up to 59.6% in 2012, and almost 76% by 2016 [9] - [10]. Load shedding affects 79% of grid-connected people, and 60% have low-voltage power [9].

Natural gas revelation does not make any assistance to the villagers. Expansion of gas is out of inquiry and LPG stays more a devout wish than a reality. Throughout the nation trees are being fallen arbitrarily in large numbers to consume block which increase rate of deforestation and cause biological irregularity in not-so-distant future.

With the goal of ending the use of traditional fossil fuel, the time has come to consider inexhaustible sources of energy as a primary source of support to the grid. Nature provides us with various sustainable sources of energy like daylight, wind and flowing force. Unlike limited sources of fossil fuel, energy from these assets can be used for a very long time. Modern technology has enabled us to capture the vast amount of energy from sunlight. Various gadgets have been invented for catching and putting away solar based energy.

Plausibility and utility of the sustainable sources of energy should be researched in depth to support the grid of Bangladesh which gets significant solar radiation each year. Shortage and increasing cost of fossil fuel can be assessed from the statistics of asset accessibility, utilization and reliance on import of fuel.

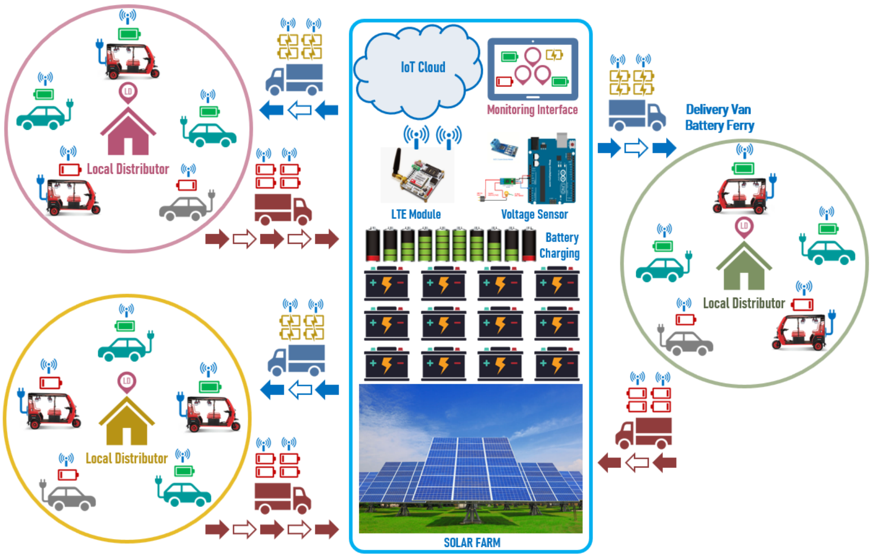

Figure 1.3: Overview of the Proposed Battery-Ferrying and Swapping Techniques for Charging of Electric-Vehicle using a Distributed Renewable Energy Network.

1.1.1 Research Gap

EV charging system can be categorized as follows: time-varying price [12],centralized control [13], [14], [15], and decentralized control [16],[17]. The study in [9] shows how the electricity charge per unit increases during peak hours on connecting EV load. As discussed in [15], and [18], a centralized infrastructure has to maintain a primary database to store information from all the EVs, optimizing their charging profiles, and minimizing power loss. Therefore, decentralized management is more acceptable when their population of EVs is high.

In recent years, decentralized control facilitated by innovations like energy management systems, home area networks, and advanced electric vehicle chargers has introduced new dimensions. Reference [11] proposes a decentralized control system, but do not guarantee optimality. [12] proposes another decentralized system, where all electric vehicles (EVs) plug in for charging at the same time, have the same charging period, need the same amount of electricity to charge, and have the same maximum charging rate.

Coming to battery swapping technology, it was introduced by a Better place and Tesla Motors where batteries were swapped in specialized stations, which is competitive with gas stations of internal combustion engines as discussed in [4]. The project failed due to huge capital investments for EV companies and consumer acceptance of not owning the battery.

1.1.2 Problem Identification

For EV charging some common problems are: i) Comparatively high charging cost and waiting time, ii) lack of efficient storage, charging stations, and supply management system for batteries (leads to range anxiety), iii) unauthorized means used for the charging of EV, and iv) fast charging mechanism diminishes battery life.
Besides, in developing country like Bangladesh, a huge demand for battery charging exists for EVs (e.g., Easy-Bike and Auto-Rickshaws) because of ease of movement and cheap fares [13]. However, due to obstacles such as overburdened centralized energy management, limited space, and finances, EV adoption in Bangladesh is extremely difficult. Besides, in such an overpopulated country, the government enforces policy not to establish solar farms in agricultural lands, which inspires decentralized solar farms in distant places. Therefore, the proposed model is also an encouraging idea because here utilization of decentralized solar energy network meets energy demand of EV through greener and cost-effective means helping to achieve sustainable development goal SDG-7 [14].

1.1.3 Research Motivation

Motivations towards our research are:

1) Comparatively high charging cost and waiting time of EVs which reduces the customer satisfaction level.

2) Lack of efficient storage system management, charging stations, and supply management system for batteries .

3) Unauthorized means used for the charging of EV in many countries.

4) Fast charging mechanism that diminishes battery life.

5) Lack of proper charging infrastructure in developing countries.

1.1.4 Scopes of the Research

In our research the problems mentioned above are subsided by proposing a complete supply chain management which starts with storage of energy into batteries and ends with ensuring efficient supply to the targeted group of users in conjunction with IoT. Many developed countries already have the infrastructure ready for solar farms .With our model they may have a more efficient supply chain management and abundant use of solar energy. Besides, decentralized battery ferrying and swapping is advantageous in overpopulated developing countries. Therefore, our model is suitable both in developed countries (have the infrastructure ready for solar farms) and in developing countries (lack of land beside communities) to increase penetration of renewable energy.

1.2 Research Objectives

The objectives of our research are :

1) To adopt renewable energy for EV charging.

2) To design a green off-grid decentralized battery network with an effective battery ferrying and swapping technique through efficient battery supply chain management with the vision of Society 5.0

3) To design an efficient battery supply chain management for supplying battery anytime anywhere.

For designing a decentralized system for EV charging, energy is produced on a decentralized basis at distant photovoltaic (PV) solar farms with allocation for optimized energy production and environmental safety. Batteries are stored at local distributors and further supplied to consumers' EVs by delivery vans using a first-come,first-served (FCFS) queuing strategy. Note here that delivery vans are also EVs.The real-time data is sent to the central cloud server which analyses battery information, e.g., charge status, health status, battery real-time location, EV driving speed, etc. As shown in Fig., battery information like charge status, health status is measured by voltage sensor. Each battery is connected with an LTE module which enables cellular communication with the central server and a monitoring interface assesses the parameters to direct actions for successful battery supply. This whole system is a cyber-physical framework (using the Internet of Things (IoT)) enabling machine-to-machine communication (i.e., battery-to-battery or battery-to-EV) in real-time information (inclusion of EV user). The internet of things (IoT) is a communication network in which all computing devices and people exchange data using unique identifiers (UIDs) rather than human-to-human or human-to-computer interaction [7]. The design of our model supports the notion of Society 5.0 [8], where cyberspace and physical space are merged with the help of IoT, to create a human-centered society where inclusion of renewable energy and attention to consumer satisfaction, hinders the shortcomings of mobility. An efficient battery supply chain is constructed, which develops a framework to supply the batteries from the local distributors to EV.

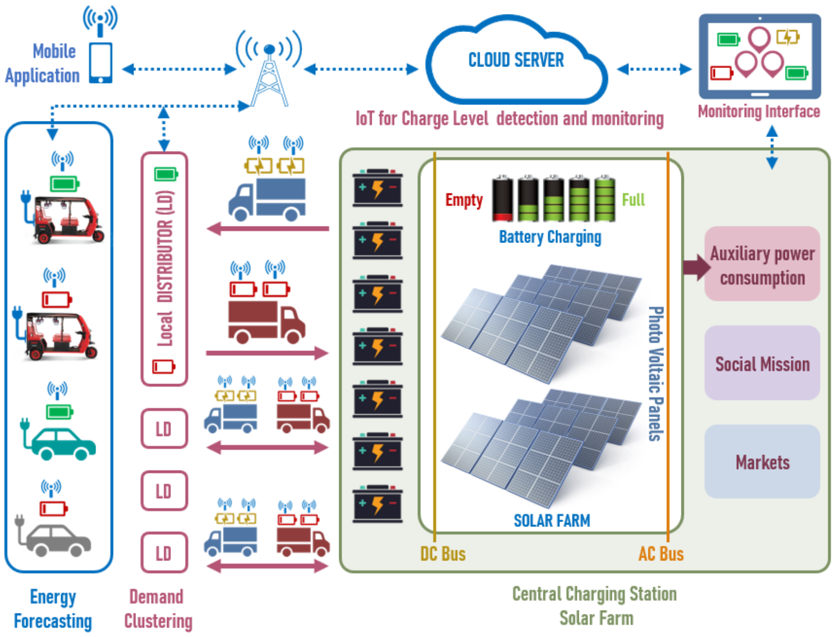

Figure 1.4: Holistic diagram of the battery ferry and swapping model.

1.3 Research Outcome

From the objectives our expected research outcomes are:

1) A simulated scenario assesses the successful battery deliveries.

2) Prediction of the battery demand from customer side

3) Placement of Local distributors at an optimum position near consumers

1.4 Novelty of the Research

This thesis newly models battery swapping technology and provides the following solutions:
1) Use of distributed renewable energy for battery charging is a comparatively cost effective means. Solar energy prediction is done using neural network, so that enough batteries can be stocked beforehand.
2) Allocation of charging station is done using data clustering analysis. This will be done according to users most likely used daily routes. That's why whenever the users will request for batteries, they get it within in close proximity and shortest time, reducing range anxiety.
3) The model includes solar farms, local distributors and delivery vans. Demand from customer side is forecasted using liner regression.So that the distributors can arrange enough batteries to supply. Optimum number of delivery vans will be there to ensure battery supply within shortest possible time.
4) Whole system will be under IoT and in sync with use of an Application,so that the owner get notification before their batteries get completely empty.
5) As opposed to those who experience the quick charging scheme (50 kW and more), the battery swapping strategy decreases consumer wait time and extends battery life (better battery chemistry) since the battery is charged at the desired voltage for a longer period of time.

1.5 Overview of the Methodology

The purpose of our model is to design a decentralized system for EV charging with an effective battery ferrying and swapping technique through an efficient battery supply chain management. Energy is produced on a decentralized basis at distant photo voltaic (PV) solar farms with allocation for optimized energy production and environmental safety. Batteries are stored at local distributors and further supplied to consumers' EVs by delivery vans using first-come, first-served (FCFS) queuing strategy. Note here that delivery vans are also EVs. The real-time data is sent to the central cloud server which analyses battery information, e.g., charge status, health status, battery real-time location, EV driving speed, etc. As shown in Fig. 1.4, battery information like charge status, health status is measured by voltage sensor. Each battery is connected with LTE module which enables cellular communication with the central server and a monitoring interface assesses the parameters to direct actions for successful battery supply.

This whole system is a cyber-physical framework (using the Internet of Things

(IoT)) enabling machine-to-machine communication (i.e., battery-to-battery or battery-to-EV) in real-time information (inclusion of EV user). The internet of things, or IoT, is a communication network in which all computing devices or people exchange data using unique identifiers (UIDs) without requiring human-to-human or human-to-computer interaction [15]. For an efficient battery supply chain, the placement of local distributors in a certain region, battery flow and forecasting of demand play a crucial role. The whole supply chain management system is simulated using a *Agent-based modeling* simulation software.

1.6 Organization of the Thesis

The design of our model supports the notion of Society 5.0 , where cyberspace and physical space is merged with the help of IoT, to create a human-centered society where inclusion of renewable energy and attention to consumer satisfaction, hinders the shortcomings of mobility. A efficient battery supply chain is constructed, which develops a framework to supply the batteries from the local distributors to EV.

This thesis focuses on the following goals to achieve the outcomes:

i) Utilizing distributed renewable energy for cost-effective battery charging mechanism,

ii) Customer specific allocation of charging station by analyzing users' daily routes through *Data Clustering Analysis* (delivery is made possible within proximity in shortest time, reducing range anxiety),

iii) Demand from the customer side is forecasted using a n-layered *Neural Network* enabling batteries to be delivered within the shortest time and adequate number of batteries to be stored at the solar farm for supply.

iv) Whole system will be under IoT and in sync with the use of an Application so that the owner gets notification before their batteries get empty.

Chapter 2

Literature Review

The study in [16], explains the unsynchronised EV charging procedure that may cause unacceptable voltage deviations. Many studies show that “smart” charging EV may lower the need to construct additional power plants. Besides, frequency adjustment is done by the charge stored in EVs [17], to provide constant aid for fault protection, and remunerate fluctuating renewable generation [11].

Reference [19] shows an optimal allocation of charging stations with a clustering algorithm to meet EV users’ needs and [20] exploits minimum total transportation distance. An optimized mathematical model in [21], takes approximate EV consumption in the urban area as an input.

Xu et al. [18]proposed a model for optimum charging station allocation with the shortest total transportation distance for EVs. Baouche et al. [19] provided an optimized model that used projected EV consumptions in urban cycles as an input to the mathematical procedure (integer linear model).

2.1 History of EVs

Electric vehicles were introduced over 100 years ago, and at one point a 3rd of the total car fleet consisted of electrical vehicles. the electrical vehicles were appreciated by users since it absolutely was silent and did not consume fuel. However, in 1935, the EVs disappeared from the market partly because of improved infrastructure, an increased number of gas stations, and fuel diminution. These improvements made it possible to travel longer distances, and at now, EVs could not compete with the fuel driven vehicles. At 1970, when the fuel price increased, the EVs appeared on the market again. Although, it absolutely was not until the start of 2000 when the EVs reached a turning point, and the development of EVs proceed. Until this time, the golf range for EVs was still limited. In 2006, the geographical area startup, Tesla Motors, announced the development of an EV with a practice range of 200 miles This, together with various other motives like the environmental advantages contributed to the event of EVs in already established vehicle manufacturing companies (Matulka, 2014).

2.2 Future of EVs

The EV3030 initiative presents the chance to simplify the transition to a totally renewable energy system through transport electrification. According to IAE 2018, a collective goal has been established that 30 percent of all global sales of cars must be electric vehicles by 2030 . In Sweden, a member of the EV30@30 initiative, proposed a goal for reduction of emissions within the domestic transport sector by a minimum of 70 percent by 2030 compared to the degree of 2010. To accomplish the presented goal, Fortum Charge & Drive along with Swedenergy, compiled The Almedalen Manifesto 2016. The Manifesto shows how electric vehicles and charging infrastructure should be promoted to succeed in the Cross-Party Committee on Environmental Objects proposed goal. The Manifesto states that electric vehicles and the charging infrastructures technical development have reached a degree where an introduction to the broader market is feasible. Therefore, the Manifesto proposes a goal of two million EVs in Sweden until 2030 to attain the proposed reduction.

2.3 Importance of Electric vehicles in future power systems

Road vehicles are highly responsible for global warming, greenhouse emission, health hazards, and also a significant source of pollutants. To combat the associated disadvantages, in the last decade many countries like China, the European Union, and the United States, drastically switched gears from conventional energy to renewable [1]. The dissolute energy sources are clean alternative energy (e.g., solar, wind, biomass, biofuel, etc.) and nuclear power, both of which are increasing at a rate of 2.5% per year [2]. A reduction in greenhouse emission by making major alternations to the transport sector through the penetration of solar energy and deployment of the electric vehicle (EV) can have a widespread positive effect on the environment.

Chapter 3

Background Study

3.1 Distribution network for storage

Distributed generation of energy has become a popular concept in the last few years. The construction and operation of electric power generation units connected directly to the distribution network or connected to the network on the customer side of the meter is referred to as distributed generation [20]. As a result of the distributed generation method, several countries have already adopted a micro-grid. It's also critical in the generation of electricity from renewable sources. The conservation of energy is done with batteries. Solar energy-generated electricity is also stored in batteries [**?**].These ideas have been implemented in many countries throughout the world. In our model, we are using solar farms or microgrids for the production of electricity using solar energy and batteries will be used as storage systems. We not only planning to use these batteries for household activities but also green transports like e-vehicles. we will also incorporate the concept of IoT (internet of things).so there will be efficient production and supply of batteries under the demand.

3.2 Equivalence of centralized and decentralized demand scheduling

Large-scale energy generation units (structures) that distribute energy across a vast distribution network (often) far from the point of use are referred to as **centralized energy systems**.

3.2.1 Environmental Impacts of Centralized Generation

Air pollutant emissions:
- Air pollution from burning fuel includes oxides of carbon, nitrogen and sulfur.

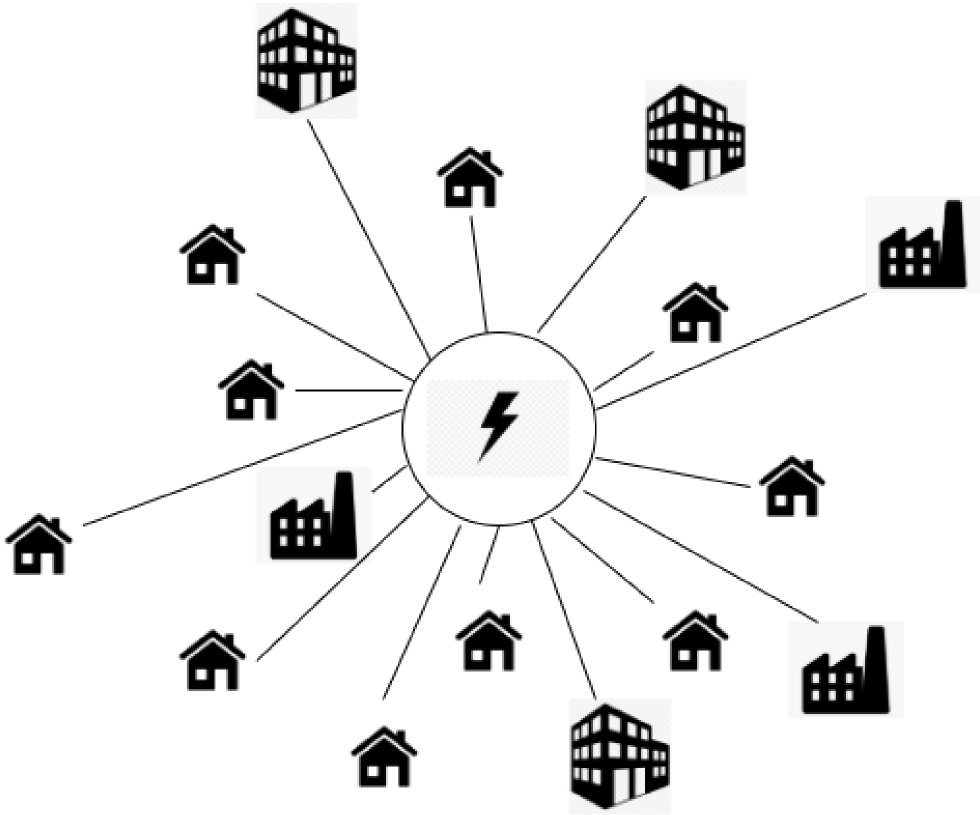

Figure 3.1: Centralized energy system structure

Water use and discharge:
- Evaporation can result in the loss of water used in steam production.

Waste generation:
- When certain fuels are burned, solid waste such as ash is produced, which must be properly stored and disposed of.

Land use:
- Large power plants need a lot of space to run.
- Transmission lines, which also use land, are needed for centralized generation.

Small-scale energy generation units (structures) that supply energy to local consumers are characterized by **decentralized energy systems**. These production units may be stand-alone or linked to others nearby through a network in order to share resources, i.e. the energy surplus.

3.3 Solar Farm

Types of solar panel:

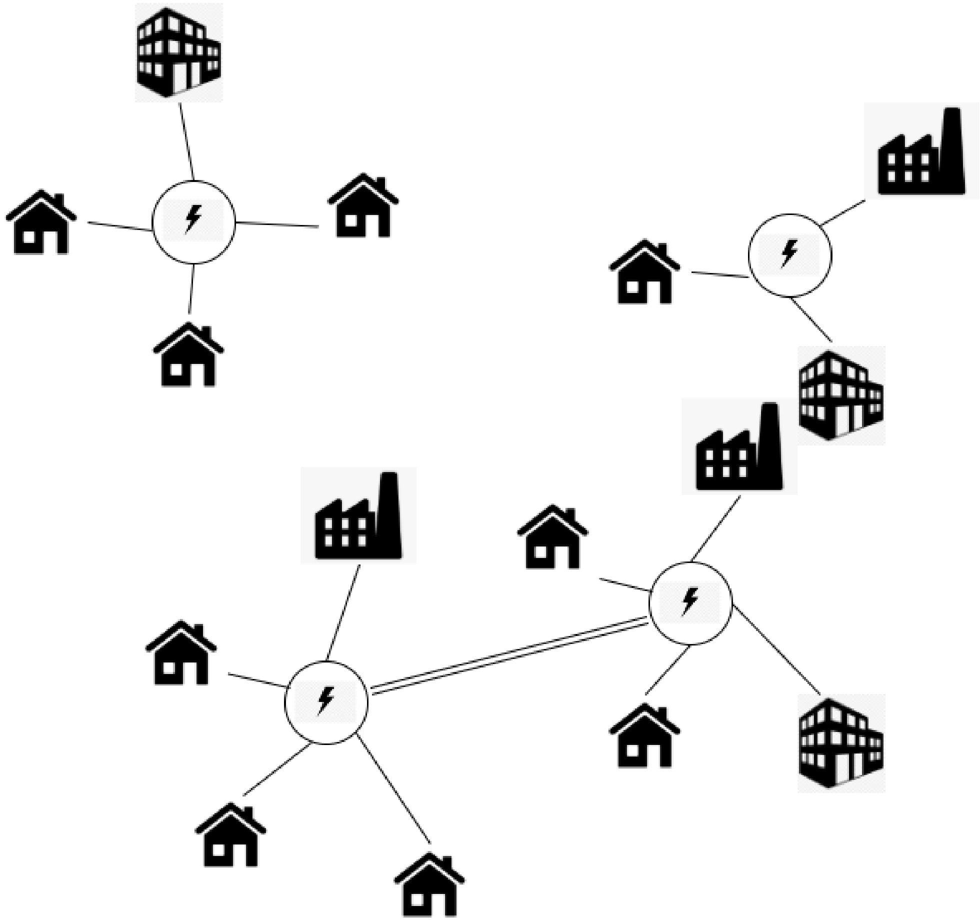

Figure 3.2: Decentralized energy system structure

3.3.1 Rooftop Solar Farm

A monocrystalline solar panel is a good choice in terms of efficiency for building solar farms at unused rooftops, though the higher costs set it back. Faster and efficient solar power concentration with permanent infrastructure makes it the most effective.

Advantages of Rooftop Solar Farm

1) The biggest advantage of installing rooftop solar panels is that they offer cost savings by cutting down electricity bills. The tariff rates for rooftop solar in comparison to industrial and commercial tariff rates are cheaper by 17% and 27% respectively.
2) It is a secure investment.
3) Low maintenance cost.
4) The chief factor that accentuates the importance of rooftop solar panels is that they require very little maintenance. They come with a service life of over 20 years if maintained properly.

Figure 3.3: Overview of roof top solar farm.

3.3.2 Floating Solar Farm

Advantages of Rooftop Solar Farm

1) No occupant on the land: The key benefit of floating PV plants is that they do not need any ground, except for the small areas needed for the electric cabinet and grid connections [21].

2) Installation and decommissioning: Floating PV plants are more compact than land-based PV plants, have a simpler management system, and are easier to install and decommission. The major point is that, unlike foundations for a land-based plant, no fixed structures exist, allowing for reversible installation [22].

3) Cooling: The floating framework allows for the introduction of a natural cooling system.

4) Tracking: A large floating platform can be easily turned and can monitor vertical axis without wasting energy or requiring a complex mechanical apparatus, as is the case with land-based PV plants [21].

5) Environment control: Another benefit is the prevention of algae blooms, which are a major problem in developing countries. This problem can be solved by partially covering basins and reducing light on biological fouling just below the surface, as well as active systems [21].

3.3.3 Solar Panel

Types of solar panel:

1) **Monocrystalline solar panel**

Advantages:

- This solar panel has high efficiency greater than 20%.
- It has good visual structure.

Disadvantages:

- It has high cost.

2) **Polycrystalline solar panel**
Advantages:

- It has low cost.
- It has efficiency of 15% - 17%.

Disadvantages:

- It has lower efficiency.

2) **Thin-film solar panel**
Advantages:

- It is portable and flexible.
- It is light weight.
- It has good visual structure.
- It has efficiency of about 11%.

Disadvantages:

- It has lowest efficiency.

3.3.4 Impact of PV on distribution grid

Installing photovoltaic panels on roofs could be a viable option for supplying electricity to residential buildings, developing a distributed power plant, and encouraging consumer self-sustainability. Solar energy, on the other hand, cannot be programmed because solar power is only available during daylight hours and output is dependent on the presence or absence of clouds, making it difficult to maintain a constant match between production and consumption [23]. Current infrastructures were usually not designed to accommodate bi-directional energy flows. As a result, new successful energy governance networks and processes must be established in order to efficiently access all available resources. The development of electricity from renewable sources can be optimized in terms of cost and environmental impact using a smart grid strategy, which also considers the use of energy storage systems [24] - [25].

Rising power rates and inadequate grid supply have resulted in a surge in PV installations in an increasingly dispersed network. PV installations on a distribution grid minimize power demand and relieve grid congestion, but they can have a number of other positive and negative grid effects.

Voltage rise and reverse power flow

When the PV power output exceeds the instantaneous load on a given line, this occurs. As PV power exceeds load, the voltage at the inverter and grid's Point of Common Coupling (PCC) increases. As a consequence, the voltage drop along the feeder would be minimized, resulting in power flow reversal (from load to the distribution grid). This is a situation that power grids do not usually expect, and it may pose significant safety concerns for workers. Aside from safety concerns, reverse power flow has an effect on distribution components such as transformers, switch gear, and other equipment located upstream of the distribution feeder.

Transformer Insulation

The temperature rise (or hot spots) within the distribution transformer has a significant impact on the transformer's insulation life. As the average power through the transformer downstream in a day is reduced, the peak load reduction due to PV is less. As a result, the load factor (average to peak load ratio) decreases. Aside from cases where PV installations are greater than the peak load, PV can lower daily top oil and hot spot temperatures, extending transformer life. The magnitude of the change is determined by the transformer's loading ratio and the degree of PV penetration [26].

Transformer Lifetime

PV penetration level, tap changes needed, load factor, PV power quality (dc bias, harmonics, etc.), phase imbalance, and other factors all influence the distribution transformer's effect. In general, the effect is positive at low penetration levels (under 40%), but the impact is greater at high penetration levels (over 40%).

Fault current

When compared to when no PV is installed, a high PV penetration level results in a higher fault current. This is due to the fact that when the PV inverter is malfunctioning, it continues to inject current into the feeder until the islanding condition is detected and the breakers are opened. As a result, grid equipment suffers more damage, as well as the risks that come with it (e.g. fire). Transformers can be damaged or disabled as a result of conductor injury [6].

Phase Imbalance

PV is also only linked to a single phase in many installations. As a consequence, there is a high risk of phase imbalance with respect to the other phases during reverse power flow. This could result in unbalanced voltage variations at each point, causing power quality issues for the connected appliances.

3.3.5 Inverter

An electronic device that converts direct current to alternating current is known as an inverter. The photovoltaic effect converts solar energy into electric current as sunlight is projected onto solar panels. This current is DC in nature and is converted into AC with the help of an inverter so that the home and utility grid can use it.

3.3.6 Charge Controller

This device regulates the flow of current/voltage from the solar panels to the batteries. It protects the batteries from overcharging.

3.3.7 Battery

Batteries are a cost-efficient and reliable medium to store energy. It has a dense energy capacity, rechargeable, portable, and environment friendly.
With zero emissions and no harmful gases, without the need for fuel storage, battery-powered emergency response units can be deployed indoors and underground with minimal risk. Delivering significant cost savings, lower maintenance, and reduced noise pollution than their diesel counterparts, they provide less disruption to residents, businesses, and the general public.
There are several types of batteries for different EVs. Two of them are discussed here.
Easy bike:

In Bangladesh,commonly used 3-wheeler easy bike is locally known as a tom-tom.
It has the following features:

- It requires lead-acid battery type.
- For a standard size easybike, it needs 5 batteries (standard 5 passengers).
- Battery size: height-20 inches, width-25 inches.
- Battery lifespan: 1-1.5years.
- Battery price: Tk 9000 - 10000 each (price varies with the season like in winter price get reduced to Tk 8500 and in summer increased up to Tk 11000. Price also varies with the price of lead).
  These batteries are sold as dry batteries. After buying, the vehicle owner uses a water-acid solution at a certain ratio. This solution ratio is to be maintained for the efficiency of the battery. After every 10/15 days, this solution has to be changed.
- Cost of changing acid water - approximately Tk 1000.
- Charging hour - At 15 amp, it requires 12 hrs to be charged and at 20 amp, it needs approximately 10 hrs.
- Charging cost - At the charging station cost of charging Tk 1200 to Tk 1500 approximately. Charging can also be done personally, for which the owner has to buy a charger.
- Cost of a charger - Starting from Tk 2500 up to Tk 6000.
- The daily average distance covered after being charged for 10-12 hrs is approximately 150km (with standard number of passenger and normal condition of the road).

Autorickshaw:

Two types of autorickshaws are commonly seen in Bangladesh.
E-rickshaw with skinny or thinner tires:

- Type of battery: Dry lead-acid (It does not use the acid water solution, so cost for solution changing is not included here but it has a shorter lifespan).

Figure 3.4: Battery for easy bike.

- Number of battery: 4 (Comparatively smaller in size and 4 batteries are packed together).
- Battery price: Tk 4000 each.
- Charging hour: 8-10 hours at 15 Amp.
- Lifespan: 6 month.

E-rickshaw with thicker or wide tires:

- Type of battery: lead-acid battery (known as Nishuk Battery).
- No of battery required : 4.
- Height:19 inches, Width:25 inches.
- Price: Tk 7000 - 7500.
- For a larger size of this category e-rickshaw number of batteries is 5 with all other features as before.

3.4 Solar energy in Bangladesh

Bangladesh is an South Asian country, a country of greenery and many waterways including Bay of Bengal. It is located between 23.6850° N, 90.3563° E [27]. Bangladesh with a total area of 147,570 square kilometres has a tropical season with dry weather from September to May and having monsoon weather from June to August. It has eight divisions named Dhaka, Chittagong, Khulna, Rajshahi, Barisal, Sylhet, Rangpur and Mymensingh. The electricity supply in all the divisions hardly meet the demand and in some regions electricity infrastructure is yet to be built. Due to the tropical weather, natural disasters often destroy the electricity infrastructure and building of new power plants is costly. To meet the energy demand, solar power plant can be a promising opportunity. The monthly normal sun radiation in Dhaka is discovered to be $4.24kWh/m^2$. Bangladesh is situated between 20.30 and 26.38 degrees north latitude and 88.04 and 92.44 degrees east latitude, making it an excellent location for solar energy harvesting. Daily average solar radiation differs between 4 to 6.5 kWh per square meter.

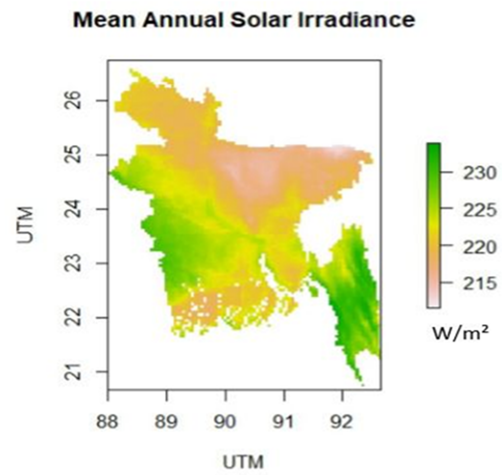

Figure 1 Mean Annual Solar Irradiance for Bangladesh | Data: PVGIS © European Communities, 2001-2017

Figure 3.5: Mean Annual Solar Irradiance in Bangladesh

3.5 Energy Scenario in Sweden

- **Issue 1** : Unclean forms of energy are being eliminated day by day to meet Sustainable Development Goals (SDG)
  Sweden has set lofty targets for energy and climate change adaptation. It has set a goal of using 50 percent less energy by 2030 and producing 100 percent renewable energy by 2040. It also aims to achieve net-zero greenhouse gas emissions by 2045.

  So distributed solar energy farms can support the national grid by creating new scopes for Government/ Private owned companies to generate green energy which ensures mobility, stability, increasing electrification, decentralization, and digitalization of the country's power generation.

- **Issue 2** : Green and clean energy are gaining momentum
  For a sustainable future, focus on renewable resources to generate green and clean energy is getting popularized. Government across the globe are supporting green energy by lower interest rates, tax credits, feed-in tariffs, and net feed metering to reduce pollution, support better health and ensure the stability of the power supply. Already in 2012, Sweden reached the government's 2020 target of 50 percent. For the power sector, the target is 100 percent renewable electricity production by 2040.

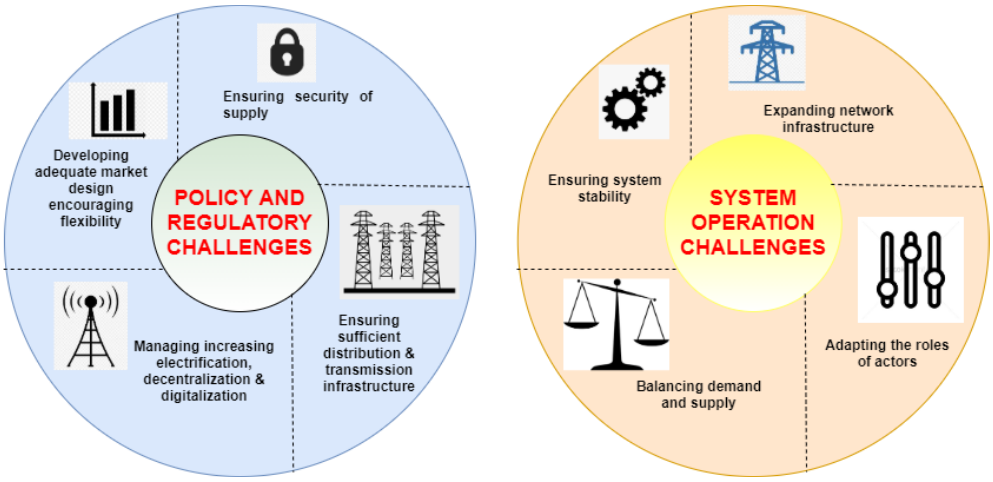

Figure 3.6: Challenges for 100% renewable power in Sweden.

3.6 Energy Scenario for different sectors

As of September 2019, Bangladesh's electricity sector had a single national grid with a capacity of 21,419 MW. The total capacity installed is 20,000 MW (including solar power). The total installed capacity is 20,000 MW (including solar power). According to a report of (PSMP–2016), the country has the potential to produce a combined 3.6 GW of electricity from renewable energy sources. Another research has estimated that the potential from wind generation alone at 20 GW. The electricity production in Sweden in 2016 was dominated by hydropower, 40.4% of total electricity generation, and nuclear power, 39.9%. Wind turbines have been built at an accelerated rate in recent years and electricity from wind power accounted for 10.2% of the total electricity generation. The rest is CHP, of which bio stands for approximately 7.3%. The total electricity generation in Sweden was 151,7 TWh in 2016, a decrease from the 158.6 TWh produced in 2015. The total amount of electricity used was 140 TWh. Sweden imported 14.3 TWh and exported 26.0 TWh in total [28].

Table 3.1: The top ten countries with the highest renewable energy percentage are[7]

Rank	Country	% of renewable energy used
1	Germany	12.74
2	UK	11.95
3	Sweden	10.96
4	Spain	10.17
5	Italy	8.8
6	Brazil	7.35
7	Japan	5.3
8	Turkey	5.25
9	Australia	4.75
10	USA	4.32

3.7 Green Energy Generation

Green energy comes from natural sources like sunlight, wind, rain, tides, etc. Solar power involves the conversion of radiant energy from the sun into electricity by using photovoltaics (PV) or concentrating devices. It is one of the cleanest forms of energy. That is why we have chosen solar energy in our model. The European Green Deal (COM(2019) 640 final), the most ambitious package of policies that should allow European citizens and businesses to benefit from the sustainable green transition, is primarily focused on Europe. The goal of becoming the world's first climate-neutral continent by 2050 is the goal behind the European Green Deal (COM(2019) 640 final) [29].

3.8 Global and local energy policies

The EU has built global leadership in renewable energy with its ambitious policies and pioneering businesses.In 2014, renewable energy accounted for about 15.5 percent of the EU's energy market, meeting the needs of 78 million Europeans. Renewable energy currently generates 27% of the EU's electricity, with that figure projected to rise to 50% by 2030. This unprecedented development of renewables in the EU has dramatically lowered renewable energy costs globally. We have seen an 80% reduction in PV module prices from 2008 to 2012 Renewable energy is now becoming cost-competitive, and sometimes even cheaper than some fossil fuels. The International Energy Agency has projected that renewable energy will become the world's number one source of electricity generation by 2035 [30].

The Energy 2020 set out the European Commission's energy strategy in the period

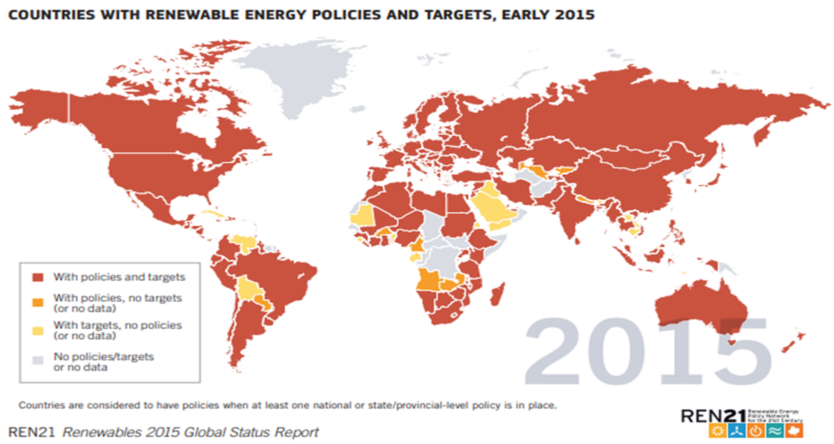

Figure 3.7: Countries with renewable energy targets and policies in 2015

to 2020. The new energy strategy mainly focuses on five points: gaining an energy efficient Europe; creating an integrated energy market; attaining safety and security; extending leadership in energy technology and development; spread the external dimension to any extent [29].

Chapter 4

Feasibility of EV Adoption and Location Priority

4.1 Dependency on fossil fuel

Starting from the 20th century, Industrial development has increased the mobility of passengers through the help of internal combustion engine. Energy consumption has a strong correlation with the level of development with transportation sector accounting for 20-25% of the total energy consumed. Transportation sector is mainly powered by petroleum and natural gas which are limited resources and becoming more environmentally damaging every day. From the sources of BPC, Bangladesh has an annual petroleum product usage of 2.03 million metric ton in the transport sector. Expect for natural gas, other forms of fuel used for transports in Bangladesh is mainly imported, which further adds to cost and green house emission. According to a recent report of International Renewable Energy Agency, the per megawatt establishment and running cost of solar energy has reduced from 35 crore (1 MW capacity) in 2010 to 11 crore in 2018. Therefore, instead of construction of high profile coal and nuclear power plant, Bangladesh should consider the socio-economic condition and possible transport scenario and move towards promoting renewable energy sources.

4.2 Monopoly of charging stations/ Inadequate EV Charging Model

Widespread adoption of EV needs proper allocation of abundant number of charging stations in Bangladesh. However, the charging stations are mostly private own, take high charges, have long waiting time and burdens the grid during peak hours. Our target customers focusing on parts of the country which have insufficient power supply and EV users. Public solar energy based EV charging station by BERB and DPDC are positive planning for this sector.

Issue 1: If the battery in the vehicle is not charged properly, the EV will not run for desired hours.

GLOBAL AVERAGE ELECTRICITY COST EXCLUDING GOVERNMENT INCENTIVES ($1 EQUALS TO Tk80)		
TECHNOLOGY	Average cost of electricity (BDT/kWh)	
	2010	2017
SOLAR PHOTOVOLTAIC	28.8	8
OFFSHORE WIND	13.6	11.2
ONSHORE WIND	6.4	4.8
BIOMASS	5.6	5.6
Reference: International Renewable Energy Agency (IRENA), 2017		

Figure 4.1: Global Average Electricity Cost Excluding Government Incentives.

The affected community :

1) The vehicle drivers (auto rickshaw + easy bike)
The vehicle drivers will not be able to fulfill their daily income, will try to crowd the vehicles with more customers or look for alternative sources of income.

2) The vehicle owners Their revenue will decrease, the capital cost to set up the charging station and EV will be a loss. They will look for illegal means for charging or invest in traditional transports.

3) The vehicle users The vehicle users will have to pay more for per km driven. Public transports like bus, train are not available in such short distances like EV, so their mobility will decrease.

Issue 2: A fixed station is needed where the electric vehicles will charge their battery.
A fixed station means a permanent infrastructure- total setup, maintenance, liability and land cost. As electric vehicle cannot run to long distances without recharging, these stations need to be placed densely. Most of the EV's are charged during the night, so overcrowding and difficult to give allotted time to each customer. Power outage or load shedding means total loss for the next day in terms of revenue from charging and income of vehicle owners.

Issue 3: The duration of battery charging defines the time the vehicle is off the

service. It should also be accounted that during traffic jams or natural disasters or load shedding, the vehicle cannot recharge its battery.
The battery needs to be charged at 120V for at least 8 hours a day. That means during this time the vehicle service is off and no income and complete reliability on charging station. Most of the owner prefer to recharge at night when there are less customers so have to suffer from monopoly of stations. The battery needs to be taken to a station, which inquires power loss and not utilizing the time during traffic jams to recharge.
Even though distributed stations are built, they fail to provide service during natural disasters and load shedding. Meaning that they have to forecast their service beforehand and is completely dependent on the circumstances and can lead to total shutdown of EV, fluctuations in fare price in a region for a day or till the stations are rebuilt. So the number of customers to be served is limited, revenue limited.
Issue 4: Not all owner garages have industrial electrical wiring so the charging is inefficient and there is illegal means of charging.
These makeshift charging stations are not designed and run by professionals. So inadequate electrical industrial wiring means the charging is slow, power loss in cables, shorter battery life and loss in revenue. Most of the stations take illegal connections from lamp post, industrial connection, so the Government suffers from theft of electricity.

4.3 Road condition/ Target customers/ EV speed/ EV road trips

The EVs operated in Bangladesh are mostly as easy bike and auto rickshaw have an average speed of 35km/h [31]. Battery operated autorickshaw is a recent addition to the metropolitan transportation system of Bangladesh. It is particularly famous among the lower and lower middle-income individuals as it provides short trips at lower cost. These vehicles having higher speed than a normal rickshaw and the structural faults in the design lead to road accidents. Besides, most of the EVs are operated in rural areas where poorly constructed roads hamper the mass penetration of EV.

4.4 High Charging Time and Low Range

The electric vehicles have been running on the roads despite having no permission in a country that faces power shortage. Most of the electric vehicle owner have contact with a charging station (which is mostly illegal) where they have to get a allotted time to charge the batteries, improper wiring and lower voltages at these stations leads to slow charging and affect their daily income. The average charging time of 4 sets of batteries required by each EV is 10-12 hours.

Status	Time of the day	Proportion of Vehicles
Plug-in EV's	7 pm - 8 pm	20%
	8 pm - 9 pm	20%
	9 pm - 10 pm	50%
All connected	10 pm - 6 am	100%
Plug-out EV's	6 am - 7 am	60%
	7 am - 8 am	30%
Not connected	8 am - 7 pm	100%

This high charging time gives a travel range of only 150km. Additionally the barriers of poor road condition and traffic jam reduce the range further. So, the drivers and passengers of EV are completely dependent on the central charging infrastructure and the uncertainty of travel.

4.5 Location priority for construction of solar farm: Maheshkhali and Sweden

4.5.1 Maheshkhali

Construction in respect to fixed area

The Chittagong division has the highest total radiation for one tilt angle device in $Kwh/m^2/year$, according to the geographical map of Bangladesh [32]. Maheshkahli a union situated in the Cox's Bazar district of Chittagong is chosen for the project. Maheshkhali is located at 21.5500°N 91.9500°E in the east region of Cox's Bazar.

This region is chosen because:

1) It is mostly surrounded by water and the majority of its land is salt bed Fig 4.2 which makes it difficult for cultivation, household, industries.
Floating solar panels can be set up in the surrounding water bodies and the huge barren land (salt bed) can be used for building solar farms.
2) Being located in Chittagong division it has long sun hours and has good transportation facility to the whole country.
A good transportation facility both through the waterway and by road. It is needed for maintaining the supply chain of batteries to and fro the solar farms and distributors.

Size of Solar Farm

From Fig 4.3, it can be seen that 3 unions of Maheskhali have the largest area of salt bed where our solar farm can be specifically situated.
Specifications of land size [33]:
1) Dhalgata (56% salt bed) – 494 acre 2) Kalarchhara (40% salt bed) – 7174 acre 3)

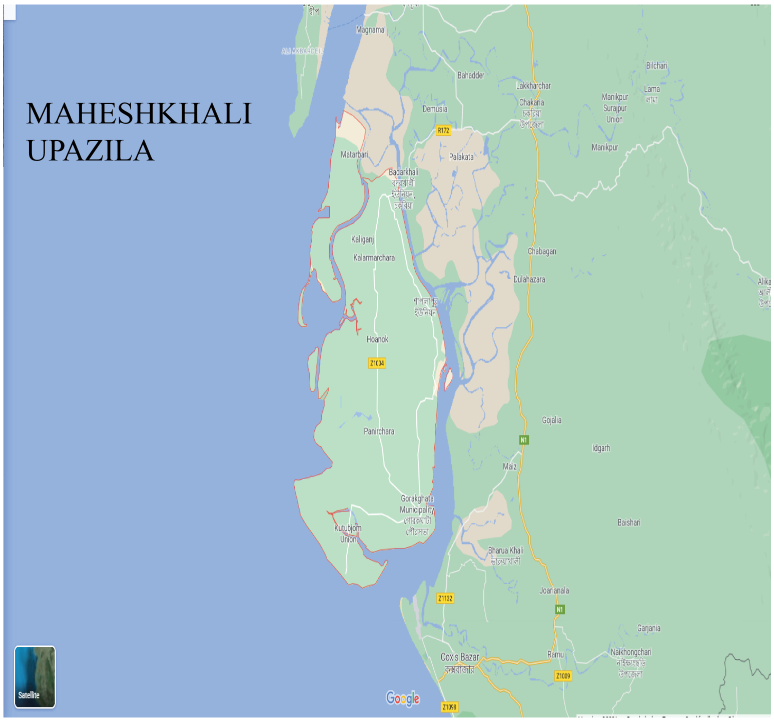

Figure 4.2: Map of Maheshkhali.

Malabari (48% salt bed) – 6682 acre

Area of the salt bed:

1) Dhalgata – 276.64 acre 2) Kalarchhara – 2869.6 acre 3) Malabari – 3207.36 If certain regions of the salt beds are only allotted as appropriate locations for the solar farm, then from these 3 unions, if we use 2% of the salt bed land to build the solar farm.

Total land size for the solar farm = $5.53 + 57.39 + 64.15 = 127.07acre$ Approximately, 2.5 acres of land is needed to built 1MW solar farm.

Total MW solar farm that can be built = $127.07/2.5 = 50.83MW$

Solar electricity production

Depending upon the location a 1MW system can generate between 1,300,000 -1,600,000kWh per annum. This equates to around 3,500-4300kWh/day on average [34].

Solar electricity production = $50.83MW \times 3900kWh/day = 198237kWh/day.$

Number of Solar panels The number of solar panels that are associated with this is entirely dependent upon the desired inverter/load ratio and the wattage of the panels themselves.

Assuming 200W monocrystalline solar panel is chosen, with an efficiency of 80%,

Number of solar panels required = $50.83MW/0.0002 = 254150$

Total Battery watt in the farm = 198237 kWh/day =$198237 \times 0.041667 = 8259.94kW$

Total number of empty battery that can be charged/day Considering a typical battery used for EV, Power plus 6-EV-12V JD 140A, Voltage=12V, Current= 140A

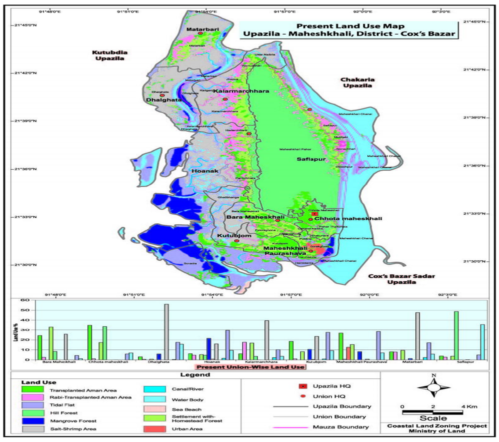

Figure 4.3: Land Use Map of Maheshkhali.

Division	**Total Radiation for One Tilt Angle System in Kwh/m^2/year**	**Total Radiation for Two Tilt Angles System in Kwh/m^2/year**	**Difference of Total Radiation Between Two System in Kwh/m^2/year**
Dhaka	3274.72	3382.21	107.49
Chittagong	3291.75	3400.23	108.48
Rajshahi	3267.82	3374.91	107.09
Khulna	3285.34	3393.45	108.11
Barisal	3286.53	3394.71	108.18
Sylhet	3261.80	3368.52	106.72
Mymensingh	3263.47	3370.29	106.82
Rangpur	3251.16	3357.25	106.09

Battery watt = $12 \times 140 = 1680W$

Total Number of Empty Battery that can be charged/day = $8259.94/1.68 = 4916$

Number of EV that can be served/day

A Standard size EV: 5 battery (standard 5 passengers) is needed. Number of EV that can be served/day = $4916/5 = 983$.

Construction in respect to fixed demand

Number of EV in community Easy bikes are dominating the Streets of Rajshahi, Rajshahi City Corporation (RCC) has issued licenses to 8,862 easy bikes [35].

Number of EV in community = 8862

Average speed of EV km/h = 35 km/h [31]

Number of hours/mins operated by per EV per day = (Total Battery watt/h load consumed (hour))

As referenced from [36], EVs are operated between 8 am to 7 pm, which is for 11 hours.

Number of KM traveled by per EV per day (hour/mins)
The average distance driven by an easy bike driver is assumed to be 150 km daily [37].
Consumed watt per Battery per hour/min = 1680/11 = $152.73W/h$
Time to fully empty of battery hour/mins
Time taken to discharge the batteries= distance travelled / Average speed = $150/35 = 4.2857h$
Total set charged battery needed/ EV/day = $11/4.2857 = 3$
Demand need to satisfy/day = 8862 easy bikes
Number of empty battery in farm = $8862 \times 3 = 26586$
Total Battery watt in the farm = $26586 \times 1680 \times 11 = 491309280 watt - hours/day$
Number of Solar panels
If 200Wp Monocrystalline solar panel with efficiency of 80% is chosen (assumed inverter/load ratio is 1),
Number of Solar panels = $491309280/160 = 3070683$ **Solar electricity production** = $491309280 watt - hours/day$
Size of Solar Farm
Total MW solar farm that has to be built = $491309/3900 = 125.98MW$
Size of Solar Farm = $125.98 \times 2.5 = 314.9 acres$

4.5.2 Sweden (Stockholm)

The most important factors for the exploitation of this renewable energy source are solar radiation, orientation and slope, population, transportation network, and electricity grid. According to the geographical map of Sweden, Stockholm being in the Southern part has high solar radiation of an average of 3.88-kilowatt hours per square meter per day ($kWh/m^2/day$). Stockholm is chosen for the project for the following reasons :
1) Insolation
For solar farms, satisfactory solar radiation is needed. Sweden possesses good conditions for solar energy with about 1000-2000 hours of sunshine each year. In Sweden, annual insolation is about $1000kWh/m^2$ in the south and around $800kWh/m^2$ in the north. Stockholm being in the South has high solar radiation.
2) Power price area
Stockholm is situated in a region where the production of electricity is less than the demand, so building a solar farm in this region will help to reduce the shortage.
3) Land conditions
Solar panels should be installed in areas unsuitable for building, agriculture and distanced from a sensitive ecosystem.Small-scale solar systems can be built in city areas such as parking lots, residential windows, rooftops, commercial buildings, and even

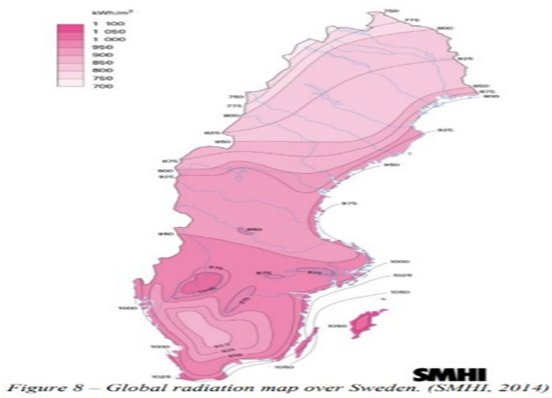

Figure 4.4: Global radiation map of Sweden

industrial buildings. Stockholm has plenty of vacant land that can be used for industrial buildings.

Size of Solar Farm

Stockholm has a size of 46,460 acres. If we choose 9 sectors from this region which take up to 0.2% of Stockholm's land size.

Total land size for the solar farm= $0.2\% \times 46460 = 92.92 acres$

Approximately, 2.5 acres of land is needed to build a 1MW solar farm.

Total MW solar farm that can be built = $92.92/2.5 = 37.168MW$

Solar electricity production

Depending upon the location a 1MW system can generate between 1,300,000 -1,600,000kWh per annum. This equates to around 3,500-4300kWh/day on average.

Solar electricity production = $37.168MW \times 3900kWh/day = 144955kWh/day = 144955 \times 0.04167 = 6040kW$

Number of Solar panels

The number of solar panels that are associated with this is entirely dependent upon the desired inverter/load ratio and the wattage of the panels themselves. If 340-375Wp Monocrystalline solar panel is chosen, which has an average of 357.5W output(assumed inverter/load ratio is

Number of solar panels = 6040 kW/ 357.5W = 16895

Total Number of Empty Battery that can be charged/day Considering batteries are supplied only for Nissan LEAF S PLUS 40 kWh battery, EV average daily driving distance in Sweden = 32 km [38].

Assuming average EV driving speed in Sweden = 50km/h

Average travelling time of an EV in Sweden = 32/50 = 0.64 h

Therefore, Power consumed by each EV = 40/0.64 = 62.5 kW

Number of EV that can be served/day = 6040/62.5 = 96

Chapter 5

Proposed Model

5.1 Overview of Model

This model considers solar farms with proper infrastructure placed at barren fields, rooftops of large industries or buildings, over water surfaces, etc., for production of electricity such that human and animals' habitation is not harmed. Batteries are used as storage system. The whole distributed network consists of solar farms, local distributor, delivery vans and end users from load point of view as shown in Fig. 5.1. An efficient supply chain starts from the generation of sufficient electricity, its storage and proper supply to fulfill the demand of various customers. So, here battery-ferrying and swapping method is considered which employs the concept of a ferry that conveys batteries like passengers over short distances as a regular service. The aim of our model is to decrease EV user battery charging time by supplying batteries anytime and anywhere. To accomplish the objectives, a large area is divided into multiple clusters such that each cluster consists of a local distributor and at least one delivery van. The demand for batteries will be estimated from customer side data, collected in a certain region over a week via a central server.

In each of the decentralized solar farm, a certain number of batteries are charged depending on its capacity. Each solar farm will assess orders that are placed at a certain time and supply batteries using delivering vans. The delivery vans are also electric vehicles integrating the use of solar energy in same manner. A queuing demand-based algorithm is followed, local distributor with the highest demand is served first and rest are supplied on a hierarchy FCFS basis. Each solar farm assesses orders and all batteries' charge status and health status are continuously being updated to the cloud, when a predetermined number of batteries are fully charged, a van comes to collect the batteries and supply them to respective local distributors.

When an EV user makes an order for a charged battery via the App, the real time lo-

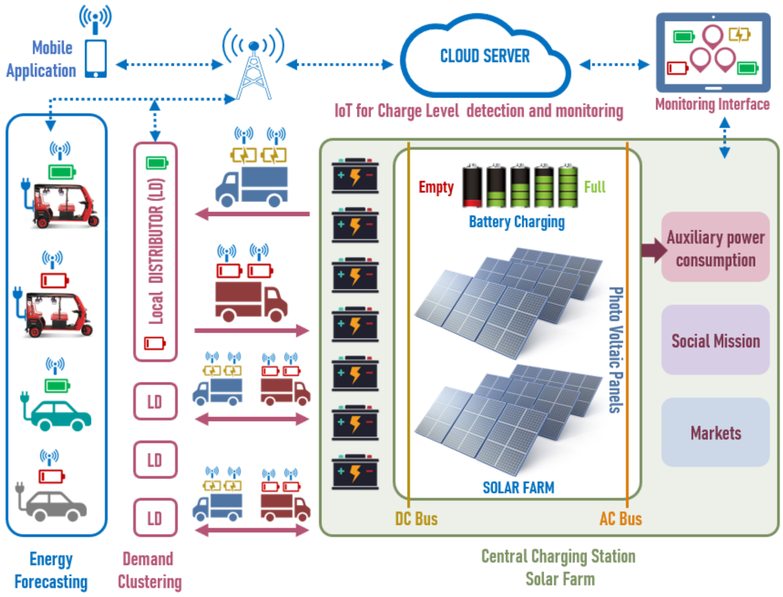

Figure 5.1: Holistic diagram of the battery ferry and swapping model.

cation of where the order is placed, time of order and remaining charge of user's battery is taken into the cloud. Each end user needs a swapping van consisting of skilled workers for minimum queuing delay (intelligently programmed swapping robots would make it more efficient). Most of the EV charging occurs at daytime which burdens the grid and increases user's waiting time at the charging station. So, if the user finds a mobile means of charging with small waiting time, it leads to major user adaption and wider range of travel. If the user' waiting time for battery delivery is matched, only then the charged battery is supplied.

The battery swapping van is provided with an automatic tracking and communication system that can communicate with the cloud and EV users via wireless telecommunication. This enables scheduling of delivery and the real time information of the battery swapping van, such as location, motion of travel and charge storage, are sent to the cloud. To reduce driving time of the swapping van and upgrade service experience, the van does not travel to large distances and the distributor is placed at optimum position. The number of vans depends on EV densities and road conditions of a given area. Once it reaches the user, it swaps the empty battery with the charged one. The empty battery is then sent to the solar farm to be charged and it is later returned to the distributor with full capacity. As the battery is charge by solar energy which is only abundant during the day, it is important that many EVs do not request for batteries before their SoC reaches below a significant value, this is penalized with higher prices. The number of EV users in a region is continuously noted, so that there is for smooth operation.

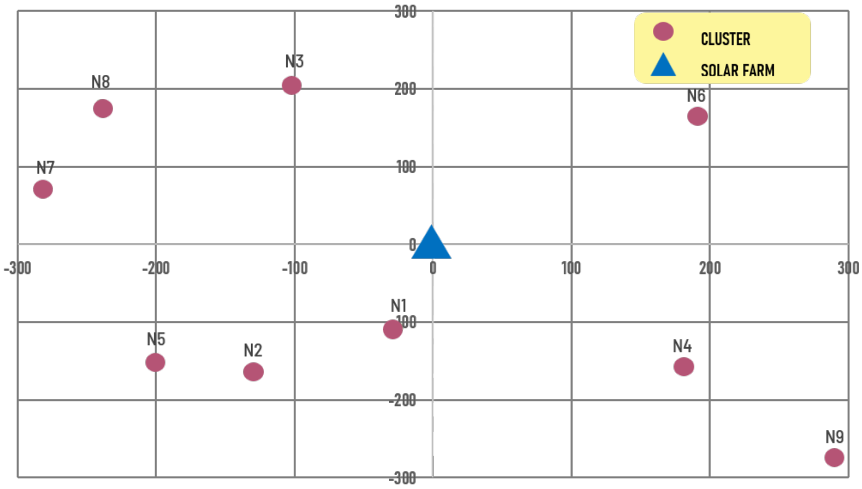

Figure 5.2: Simulation random layout model. The delivery vans travel from the solar farm to each cluster to deliver batteries.The cluster IDs, Ni are assigned in an ascending order to the distance, Si from the solar farm.

Further battery demand from these local distributors is forecasted for efficient supply of batteries using consumer side data driven approach. It is done by constructing a neural network. The placement of local distributors in a certain region plays a crucial role, as appropriate placement means: The delivery van from the local distributor has to travel shorter distance and minimized delivery time. Consumers demand for batteries in a convenient place. When they request for battery from local distributor, they are informed about the availability and time required to deliver the battery which includes traveling time and battery swapping time. If their requirement is fulfilled, they will confirm their order or else they will request to another local distributor at nearer places. So, customer satisfaction is given importance.

5.2 Simulation model

To accomplish our model's objectives, as shown in Fig. 5.2, a large area where the supply chain model will be implemented is divided into multiple clusters such that each cluster consists of a local distributor and at least one delivery van. N local distributors are considered labeled 1 to N at different regions of this area. The delivery van periodically visits clusters according to highest demand priority order and travels using the inter cluster distances. Other constraints include driving distance limit, and battery carrying capacity of each delivery van. Keeping in mind the time taken to charge the batteries, charge batteries are supplied 4 times a day with 6 hours gap. If sufficient number of charged batteries are not available at the solar farm, the batteries are distributed equally in every delivery van. A predetermined demand list is assigned to clusters, D = [100 20 150 50] and a weight list, W = [0.9 0.65 0.95 0.8 0.7 0.5 0.6 0.9 0.95] is used. The simulation is run for 24 hours with a 6 hours gap. In each hour Di multiplied by Wi, where i is varied from 1 to 24 hours. It gives different battery demand for each cluster in every hour relating to variations in load with time in real-life scenario. The demand for batteries, as well as each EV user's daily waiting time, is generated at random based on the number of EV users.

At the 1st period of the simulation, the charged batteries are loaded onto the delivery vans as per their carrying capacity = 100 batteries; considering the optimum sizing, weight of battery and the sizing of the delivery van. If number of charged batteries present at solar farm is less than (carrying capacity $\times$ number of delivery vans), the batteries are distributed equally among each delivery vans. A delivery van keeps on delivering batteries and collecting uncharged batteries, from one cluster to another until it has sufficient number of batteries to serve a cluster and the distance and carrying capacity constrain is maintained. When the number of charged batteries available in a delivery van reaches below than the demand of a cluster, it returns to solar farm to load off uncharged batteries and to collect charged batteries again, given there are sufficient batteries left in the solar farm. Each delivery van continues it's journey again to make sure the demand of all the clusters are met for that period.

The simulation of a certain period is stopped if the number charged batteries of the solar farm is less than the number of delivery vans. The speed of the delivery van and swapping time is assumed to be a constant value. The demand for batteries and the waiting time of each EV user per day depends on the EV users. The demand for batteries and the amount of time each EV user spends waiting each day is calculated by the number of EV users. This methodology is maintained, to run the simulation for different demands each day.

The simulation is done using an agent-based modeling software called Netlogo. The goal of the simulation is to see to relate it to real life scenario and check to what extent the user can be satisfied with our derived data.

The performance metrics of the simulation, the number of successful battery supplies is assessed using models where the following parameters are varied: i) The number of delivery vans available, ii) The speed of the delivery vans, iii) The distance a delivery van can travel each day, and iv) The number of solar panels at the solar farm.

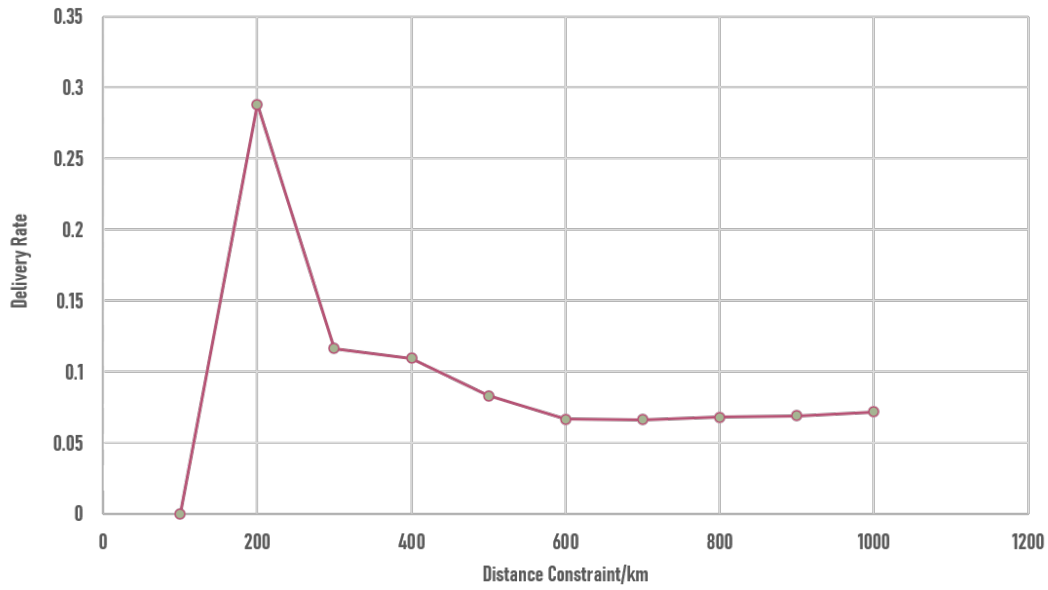

Figure 5.3: Relationship between Distance Constraint and Delivery Rate

Table 5.1 is created varying the distance constraint of delivery van, keeping the other two performance metrics constant. Table 5.2 is created varying the number of solar panels, keeping the other two performance metrics constant. Table 5.3 is created varying the number of delivery vans, keeping the other two performance metrics constant. To analyze the outcome and economic benefit of changing each performance metric, *Delivery Rate*, is calculated as follows:

$$DeliveryRate = \frac{Total\ Charged\ Battery\ Delivered}{Total\ Distance\ Traveled}$$

Observing Fig. 5.3 and Table 5.1, the overall distance traveled increases much more than the total battery deliveries in each day, making it an uneconomical solution. The total battery deliveries of all the cars in a certain day is limited by the distance constraint. Distance constraint = 200 km serves to be the optimum traveling limit for the simulation model, as maximum battery deliveries accomplished with minimum total distance traveled. With the given geographical arrangement in Fig. 5.2 and fixed number of delivery vans, in order to increase efficiency of battery delivery, the clusters have to be placed at a closer distance to the solar farm.

Observing Fig. 5.4, insufficient number of charged batteries at the solar farm hindered the delivery rate. Analyzing the output Table 5.2 and Fig. 5.4, it can be observed that increasing the number of solar panels at the farm increases the number of deliveries. This means that there is a positive relationship between the number of solar panels on the farm and the number of successfully charged batteries delivered.

Table 5.1: Total Distance Traveled, Total Charged Battery Delivery, Delivery Rate varying Distance Constraint.

No. of panels	No. of vans	Distance Constraint (km)	Total Distance Traveled (km)	Total Charged Battery Delivery	Delivery Rate
40	5	100	0	0	0.0000
40	5	200	1159	334	0.2882
40	5	300	4961	576	0.1161
40	5	400	5387.1	589	0.1093
40	5	500	8230.6	682	0.0829
40	5	600	12172.2	809	0.0665
40	5	700	12580.8	830	0.0660
40	5	800	13065.4	884	0.0677
40	5	900	13437.9	925	0.0688
40	5	1000	13885.2	994	0.0716

Table 5.2: Total Distance Traveled, Total Charged Battery Delivery, Delivery Rate varying Number of Panels.

No. of panels	No. of vans	Distance Constraint (km)	Total Distance Traveled(km)	Total Charged Battery Delivery	Delivery Rate
10	5	400	4332	274	0.0633
20	5	400	5307.1	368	0.0693
30	5	400	5387.1	489	0.0908
40	5	400	5387.1	589	0.1093
50	5	400	5694.2	789	0.1386
60	5	400	5694.2	819	0.1438
70	5	400	5694.2	825	0.1449
80	5	400	5694.2	844	0.1482
90	5	400	6131.3	1077	0.1757
100	5	400	6867.8	1215	0.1769

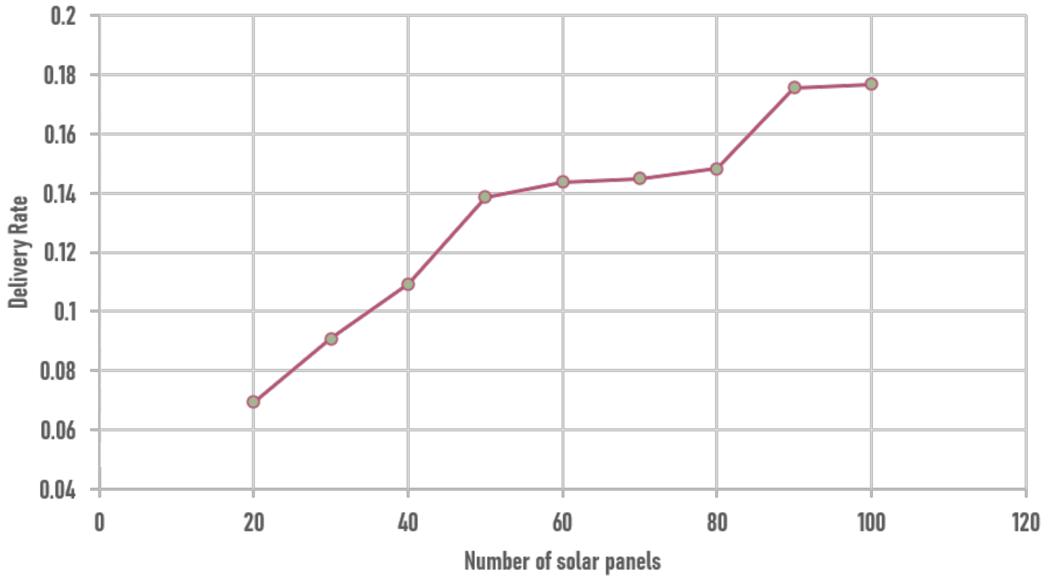

Figure 5.4: Relationship between Delivery Rate and Number of Panels.

Analyzing the output Table 5.3 and Fig. 5.5, the distance constraint of each car is limited by 400 km and limited number of charge batteries at the solar farm, increased number of delivery vans could not bring significant increase to the total battery deliveries.

The delivery van moves from the local distributor to EV user with a first-come, first-served (FCFS) queuing strategy. If the allowable waiting time for a certain EV user and traveling time of the delivery van to reach the user is matched, the delivery van travels to that user and swaps the batteries. In between travel, all the real-time demands are assessed by each van, the van which takes the lowest time to reach a user that van is directed towards that user. After supplying the batteries to a certain number of users, the van comes back to the local distributor to collect batteries and start supplying again. The simulation is stopped when no batteries remain in the local distributor.

To summarize our observations, the important parameters affecting the delivery of the batteries are: i) Distance constraint of the delivery van, ii) Number of solar panels, and iii) Number of delivery vans. Increasing the distance constraint of each delivery van and number of delivery vans decreases the number of successful battery delivery. Whereas increases the number of solar panels increases the number of charged batteries to increasing the rate of delivery showing delivery rate is mostly hindered due to insufficient number of charged batteries.

Table 5.3: Total Distance Traveled, Total Charged Battery Delivery, Delivery Rate varying Number of Delivery Vans.

No. of panels	No. of vans	Distance Constraint (km)	Total Distance Travelled(km)	Total Charged Battery Delivery	Delivery Rate
40	0	400	0	0	0
40	1	400	1220	302	0.2475
40	2	400	1860.6	328	0.1763
40	3	400	2980	497	0.1668
40	4	400	4664.2	651	0.1396
40	5	400	5387.1	589	0.1093
40	6	400	6237.1	609	0.0976
40	7	400	7126.5	612	0.0859
40	8	400	8325.5	621	0.0746
40	9	400	8917.1	628	0.0704
40	10	400	9902.8	689	0.0696

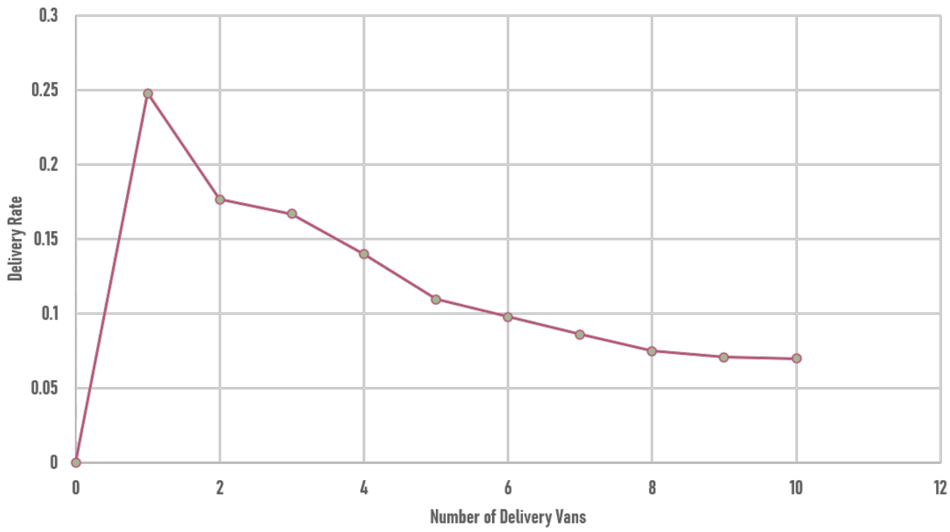

Figure 5.5: Relationship between Delivery Rate and Number of Delivery Vans.

Chapter 6

Result Analysis

For the optimum supply of batteries, it is important for the solar farm to know the approximate solar irradiance in the upcoming days. From this the number batteries able to be supplied in a particular period of time can be estimated. The number of batteries that a solar farm can charge depends on solar irradiance. Solar irradiance is the power per unit area received from the Sun in the form of electromagnetic radiation as reported in the wavelength range of the measuring instrument. In this paper, the meteorological data for solar radiation prediction was collected from the HI-SEAS weather station from four months (September through December 2016) between Mission IV and Mission V [39]. The framework for machine learning algorithm include i) Data preprocessing ii) Random forest algorithm iii) Neural network

6.1 Solar energy forecasting

1) **Data Preprocessing** : This consists of converting feature selection, Unixtime to Hawaiian local time, merging, cleaning and normalization of dataset to not include any incorrect values, sparse data.

Random forest is a Supervised Learning algorithm for classification and regression that employs an ensemble learning process. Here the least important feature of the regressor was repeatedly removed and the r2 scores were used to drop 'TimeSunRise','TimeSunSet', 'Data', 'Time', 'WindDirection (Degrees)' from the dataset.

2) **Building up neural network** : Now using the most important features- 'Radiation', 'Temperature',' Pressure' and 'Humidity', a 6 layer neural network is implemented to predict solar irradiance in the region. The neural network will be trained by running 5 times, so that initial random generator values are confined to give the same output each time. The error between the predicted values and actual values is calculated by Mean Absolute Error and Mean Squared Error.

Table 6.1: Preprocessed data for prediction of solar irradiance collected from the HI-SEAS weather station from four months (September through December 2016)

Attribute Name	Attribute Description
UNIXTime	Universal time seconds since Jan 1,1970
Time	Local time of day in hh:mm:ss (24-hour fomat)
Radiation	Solar radiation in W/m^2
Temperature	Degrees Fahrenheit
Humidity	Percentage
Wind Direction(Degrees)	Degrees
Speed	miles per hour
Time SunRise	Hawaii time
Time Sunset	Hawaii time

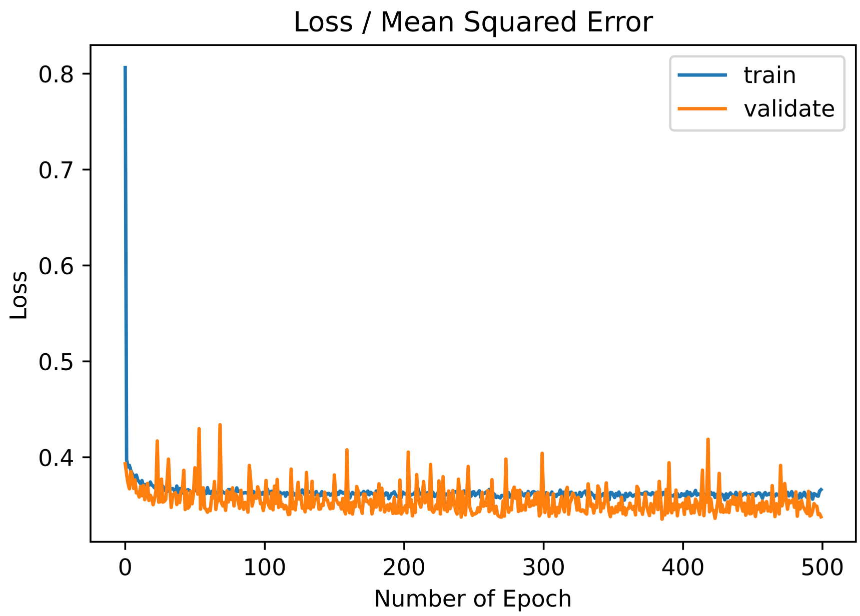

Figure 6.1: Loss(Mean Squared Error)of the predicted solar irradiance

Mean Absolute Error is the extent of the difference between the individual estimation and the genuine estimation of the amount. It is calculated to be 0.4753.

The averaged squared difference between the measure value and the real value is the mean squared error. It is calculated to be 0.4029.

The model is first fit on a training dataset, which is a subset of the dataset that contains 80% of the data. It was used to match the model's parameters (for example, the weights of connections between neurons in artificial neural networks). The fitted model is then used to predict responses for observations in a second dataset known as the validation dataset. The validation dataset contains 20% of the dataset's data

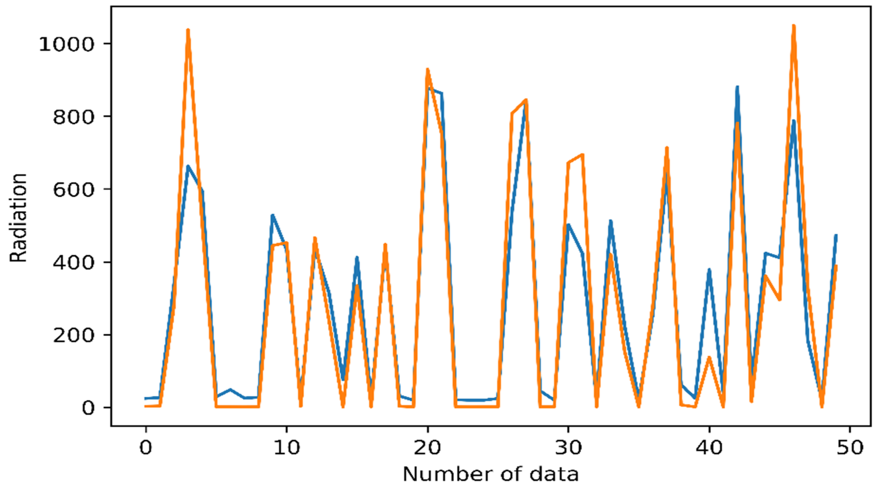

Figure 6.2: Graph showing comparison of predicted and actual solar irradiance

and allows for an unbiased assessment of a model's fit on the training dataset while tuning its hyperparameters.From the graph 6.1 it can be seen that the neural network implemented gives reasonable output. As the validation dataset gives fluctuation about the training dataset within a small range.

Using the first 50 data from the dataset:

The closer the data points fall to the fitted regression line, the more variance a regression model can achieve.It shows using the neural network implemented, data gives an variance of 0.87241 in predicted solar irradiance. That means the fitted values would equal the observed values for 87.24%,which is relatively high considering the small dataset used. The proportion of variance in the dependent variable that can be traced to the independent variable is measured by R-squared.R-squared value of 0.87086 means for 87.096% movement of the dependent variable can be explained by the movement of the independent variables. R-squared value of 0.87086 shows the points are close to the linear trend line.

To summarize our observations, solar energy forecasting is done to find the optimum supply of batteries in a day, which is calculated by finding the approximate solar irradiance in a certain location. From the neural network constructed to find the solar irradiance, it has been calculated with a variance of 0.87241.

For proper allocation of local distributors and forecasting of EV user side demand, real-life data is projected in our simulation model using a collected dataset of autonomous EVs of Columbus City, USA [40].

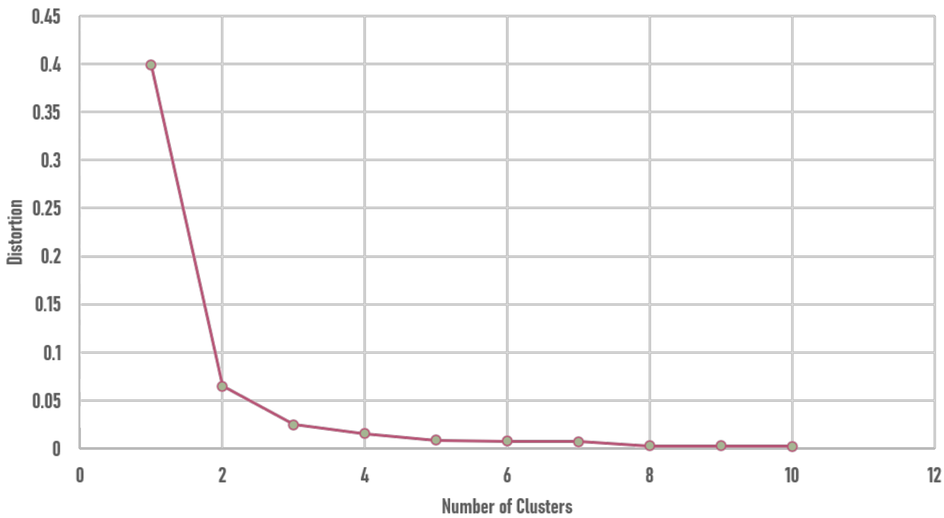

Figure 6.3: Optimum number of distributors in the given area.

6.2 Allocation of Local distributors

For proper allocation of local distributors, activity locations of EV users are taken. The details are discussed as follows.

1) Data Preprocessing: The locations (latitude, longitude), start time and end time of movement of a certain number of EVs in a certain region for a specific number of days are collected and processed. A mean value of the locations is calculated, the values that are too far away from the mean value of locations are excluded. This ensures the most likely positions of travel of EVs are taken into account to analyze their traveling pattern.

2) Finding region of interest: Using the locations data, a map is plotted to find the average area to be 28.1 ha within which the EVs tend to travel.

3) Clustering analysis: K-means clustering analysis aims to group data with similar data points by partitioning n data into k clusters in which each data is assigned to a cluster with the nearest mean, aiding to be the framework of the cluster. It is done to find the average locations (latitude, longitude) in which the activity of EV is maximum. Thus efficient placement of local distributors will be identified. The goal of this algorithm is to assign the cluster's centroids position as location of local distributor.

In our analysis, the activity region is partitioned into certain number of clusters. A local distributor is assigned to each cluster. We graph the relationship between the number of clusters and Within Cluster Sum of Squares (WCSS) as follows:

$$\sum_{k=1}^{K} \sum_{x \in S_k} d(x_{ij} - \bar{x}_{kj})^2$$

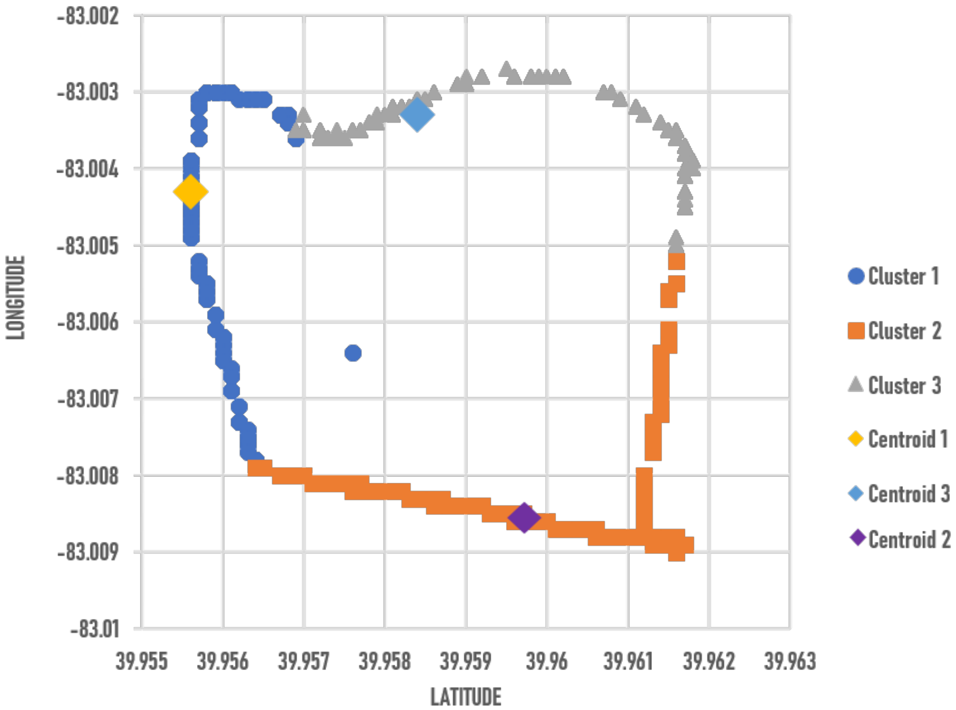

Figure 6.4: The centroids of the clusters identified as local distributors.

where S_k is the Cluster, K is the number of clusters, $x \in S_k$ is the Cluster Centroid, d is Distance and $\bar{x}$ is Sample mean.

The number of clusters is selected where the change in WCSS begins to reach an equilibrium (elbow method), to find the appropriate number of clusters in a certain area as shown in Fig. 6.3. From Fig. 6.3, we can observe that at the number of clusters = 3, distortion is minimum. So, the activity region can be divided into 3 clusters.

A comparison is done to show how clustering analysis for allocation of local distributors, increases the efficiency of battery supply chain management. Assuming 100 charged batteries in local distributor and battery carrying capacity of each delivery van is 10. The simulation output is taken from location of local distributors as shown in Fig. 6.4, along with (39.8906, -83.0120) and (39.9675, -82.9508) selected as random nearby locations for comparison. From the dataset, 50 random locations of battery demand is taken and the corresponding waiting time for this EV users is assumed a randomly generated value in the range of 0-100 minutes. This ensures that demand locations are chosen from a wide variety of locations and waiting time of the EV users logically vary, to make the system similar to real life scenario.

From Fig. 6.5, it can be seen that the locations in which the clustering analysis is applied, gives increased number of successful battery deliveries. The number of successful deliveries increases proportionally with the increase of number of delivery vans. As for the locations of (39.8906, -83.0120) and (39.9675, -82.9508), the number

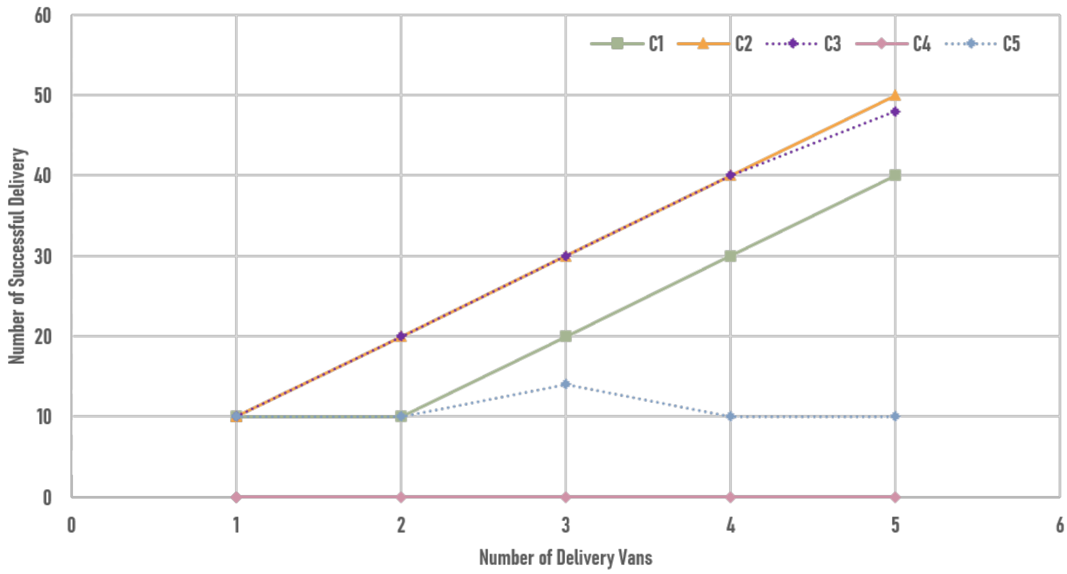

Figure 6.5: Relationship between successful number of battery supplies to EV users and Number of delivery vans. Cluster 1, 2, 3 is taken as C1, C2, and C3 respectively. Two random location for cluster is taken as C4, C5. Latitude, Longitude are: (C1= 39.9556,-83.0043; C2= 39.95999,-83.0085; C3= 39.9584,-83.0033; C4= 39.8906,-83.0109; C5= 39.9675,-82.9508).

of successful deliveries is significantly less with inconsistency as number of delivery vans are increased. From analysis, allocation of appropriate local distributors give an efficiency of 82.524% in successfully delivering batteries to EV user.

To summarize our observations, to increase the efficiency of battery delivery, optimum allocation of local distributors is done by K-means clustering analysis which increases the successful battery delivery by 82.524%.

6.3 Forecasting of battery demand

Efficiency of battery supply management will be further increased, if the demand from customer side is forecasted beforehand, so that the solar farms can generate adequate amount of charge. It is assumed that this model considers a scenario where batteries are supplied only for *Nissan LEAF S PLUS* [41], 40 kWh battery. The simulation model is run such that charged batteries are delivered for a time period of 6 months which utilises a demand list where demand of batteries for each cluster takes a *Guassion Distribution* (mean = 60, standard deviation= 20). The model is initially fitted to 80% of the data in the dataset using the dataset. The equipped model is then used to simulate responses for observations in a second dataset, which contains 20% of the data from the first. This allows for an impartial evaluation of fitting a model to a data set when tuning the hyperparameters of the model. This provides an unbiased assessment of

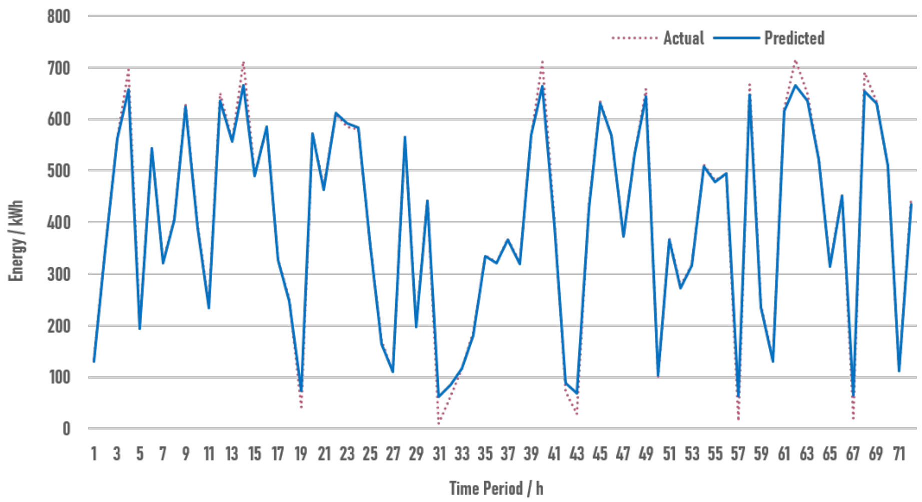

Figure 6.6: Comparison of Actual and Predicted values.

fitting a model on a data set while tuning the model's hyperparameters.

From Fig. 6.6, it can be seen that the neural network implemented has forecasted solar energy demand for 72 hours with reasonable accuracy. The error in the neural network model is calculated by *Explained variance*, a mathematical model which measures the amount by which a calculated value deviates from a certain value in the data set. Explained variance = 0.99289, concludes that our algorithm is working accurately to forecast demand of batteries.

To summarize our observations, the battery supply chain management is further made efficient, by forecasting the demand from the customer side. The neural network implemented has forecasted battery demand for 72 hours with Explained variance = 0.99289.

Chapter 7

Socio-economic Impacts of our model

7.1 Analysis of Challenges for EV Adoption by Different Methods

In this segment, the PORTER's Five Forces model and SWOT analysis are done in examining the difficulties for adoption of EVs in Bangladesh.

PORTER's five forces model

PORTER's five forces model is designed to take competitive decisions like factors affecting profitability, decision on expansion and crafting overall strategy of a business. This model structure had been created by Michael E. Porter. Five powers are utilized for this displaying where three powers (for example, entrants, substitutes, and established rivals etc.) are horizontal and two powers (for example provider force and purchaser power) are vertical. The Porter's five forces model for assessing for adoption of solar charged EV in shown below:

- **Threat of Entrants** : Entry of new participants in the business will not make the business very unprofitable, as solar energy EV vehicle and battery swapping is a new technology in Bangladesh. Instead, it will increase the widespread use of EV which is now a slow growing industry due to absence of charging framework and motivators for electric vehicle.
- **Threat of Rivalry** : There is no direct competitors aside from fossil fuel IC engine transports. The more businesses in the electric vehicle market make it competitive for market infiltration.
- **Threat of Substitutes** : Different vehicles run by wind power, biofuel, CNG, LPG etc. are the alternative vehicles that can threaten the market of EV.

- **Buyer Power** : Electric vehicle like easy bike, auto rickshaw is cheap in Bangladesh. However, these require frequent repairs and maintenance due to inadequate charging infrastructure and poor road conditions. For long range travel, traditional EV has to be used which are expensive but give performance alike traditional IC engines vehicles.
- **Supplier Power** : High technology cost and absence of assembling enterprises that manufacture solar panel and batteries are the obstacles for suppliers. Currently, number of industries have started to manufacture EV, fabricate solar panels and produce batteries. Due to absence of proper government strategy for EV ventures and subsidies to promote renewable energy, the supplier needs to deal with various issue in regards to EV manufacturing.

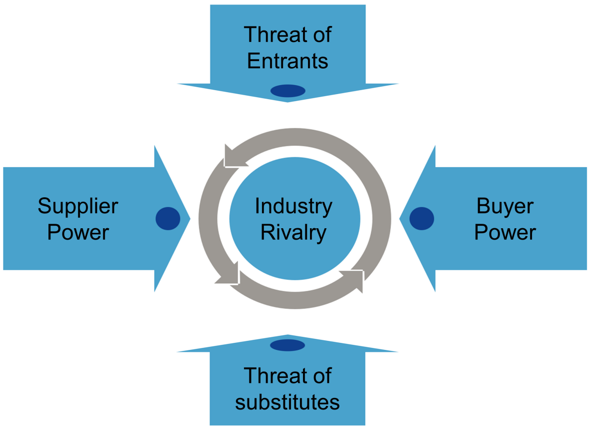

Figure 7.1: PORTER's five forces model for EV adoption.

SWOT Analysis

The SWOT (Strengths, Weaknesses, Opportunities, and Threats) analysis is an important planning tool for determining the strengths, weaknesses, opportunities, and threats of EV dispersion in Bangladesh.. In this proposition, the SWOT examination is executed to know the difficulties and afterward portray how these difficulties can be overpowered. The SWOT examination for the EV adoption is shown in Fig 7.2.

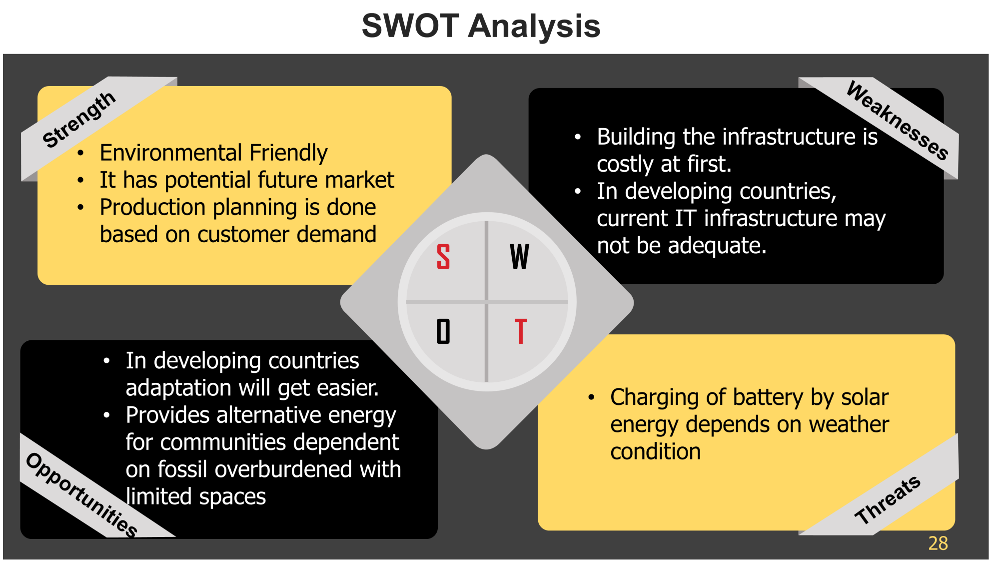

Figure 7.2: SWOT Analysis for EV Adoption.

Chapter 8

Discussion and Conclusion

In this thesis, a design model is proposed whereby the charging of EV is done using solar energy and battery swapping and battery ferrying technique is applied.So the given title has been justified .

8.1 Achieving Expected Outcomes from the Objectives

A simulated scenario helped to assess the successful battery deliveries where, the battery demand has been predicted through solar irradiation calculations, and the local distributors were placed at optimal positions through clustering analysis and data processing. The objectives and observations that justifies outcome of the thesis are given below:

1) To adopt renewable energy for EV charging.

A battery charging mechanism is constructed which utilizes solar energy to increase the penetration of renewable energy. A business model is designed for expansion of solar farms and battery charging stations which further exploits eco-friendly technology.

2) To design a green off-grid decentralized battery network with an effective battery ferrying and swapping technique through efficient battery supply chain management with the vision of Society 5.0.

For designing a decentralized system for EV charging, energy is produced on a decentralized basis at distant photovoltaic (PV) solar farms with allocation for optimized energy production and environmental safety. Here, the battery ferrying is justified by constructing a simulation where delivery vans are used to ferry the batteries from the charging station to the local distributor and further to the EV user. Battery is swapped between EV user and delivery van to mitigate the charging time and increasing mobility. This optimized battery supply chain management enables that batteries can be charged at a distant place and batteries can be supplied to EV user anywhere, enabling the inclusion of EV user at cities as well as well in the outskirts to align with vision of Society 5.0.

3) To design efficient battery supply chain management for supplying battery anytime anywhere.

From our observations, the important parameters affecting the delivery of the batteries are: i) Distance constraint of the delivery van, ii) Number of solar panels, and iii) Number of delivery vans. Further solar energy forecasting and optimum allocation of local distributors enable shortest time delivery of batteries, reducing range anxiety (customer specific allocation of charging station by analyzing users' daily routes through Data Clustering Analysis).

To complete the supply chain management, forecasting of battery demand from the customer side using a n-layered Neural Network enabled batteries to be delivered within the shortest time and adequate number of batteries to be stored at the solar farm for supply.

8.2 Future Works Recommendation

The proposed solar farm has also been seen as a business model for vendors and government in both developed and developing countries that support green energy. Our design model can be modified in future works to include the effect of weather conditions on solar energy production. When a solar farm fails to supply charged batteries, the App may notify the owner to connect to the grid and take the power supply from it, with the corresponding kWh price. As well, on a surplus of power at the solar farm, it may be supplied to the grid to gain extra profit by using Net metering. Additionally, electrification of public transport like bus and train should be considered in our model, and not concise our battery ferrying concept only to personal cars. Modeling and forecasting of battery charging and consumption for public transport will add value to the grid and minimize dependence of fossil fuel.

Chapter 9

List of Appendices

9.1 Appendix 1

9.1.1 Setting the local distributors in the geographical area chosen

```
to make-cluster
 random-seed 20
 create-clusters numcluster [
  set color blue
  set size 40
  set shape "circle"]
set xSET[ 150  -130  -180   -90    -140    -10    0    100    220  ]  ; x co-ordinates for each of the clusters
set ySET[ 300   250   110   -250    -100    -350   120    -130   -220  ] ; y co-ordinates for each of the clusters
 set xSET[ 140  -130  -190   -75    -140    -10    0    125    145   ]  ; x co-ordinates for each of the clusters
 set ySET[ 140   250   100   -75    -25    -90    120    -130   -220  ] ; y co-ordinates for each of the clusters[100 20 150 50 10 85 120 20 200]
set weight_list [ 0.9 0.65 0.95 0.8 0.7 0.5 0.6 0.9 0.95]
```

```
if (length xSET < numcluster) [
  user-message (word "Cannot perform. Stored values are for clusters = " length xSET ". But Number of clusters =" numcluster ". Check variables")
  stop ]
 let v 0
 while [v < numcluster][  ;this while loop will set the x and y co-ordinates of each cluster from the xSet and the ySet
  ask cluster v [set xcor item v xSET]
  ask cluster v [set ycor item v ySET]
  ask cluster v [set weight item v weight_list set label who + 1] ;; problem here
  ask cluster v [set label who + 1]
  set v v + 1]
end
```

9.1.2 Setting demand for each local distributor

```
to cluster_demand_set
 random-seed 20
  let j 0
  while [j < numcluster][
   ask cluster j [set cluster_demand weight * load set cluster_demand round cluster_demand]
   ask cluster j [set label cluster_demand]
   ask cluster j [set cluster_uncharged load]
   set j j + 1
  ]
end
```

9.1.3 Travelling pattern of delivery van to and fro solar farm to local distributors

```
to battery_from_centraldist_to_car
foreach sort centraldistributors[? ->
   set central_number ?
    ask central_number[
    if ( centraldist_battery >= 100 * numcar)
    [ ask cars [set car_battery 100  set label car_battery]
        print(word " car_battery: " car_battery)
        set centraldist_battery centraldist_battery - 100 * numcar
        print(word "centraldist;;;;;_battery " centraldist_battery)
    ]
    set label centraldist_battery]
ask central_number[;;
    if ( centraldist_battery < 100 * numcar)
    [ set central_battery centraldist_battery / numcar
      ask cars [set car_battery central_battery set car_battery floor car_battery
          print(word " car_battery: " car_battery)
      set label car_battery]
      set centraldist_battery 0
    print(word "centraldist;;;;;_battery " centraldist_battery)
  ] set label centraldist_battery
print(word " stop")
      if ( centraldist_battery <  numcar)[
        print(word "stop")
        stop]]]
end
```

9.1.4 Travelling pattern of delivery van to and fro solar farm to local distributors

```
to car_movement
  set available [car_battery] of number
  print(word " available: " available)
  set demand [cluster_demand] of cluster_chosen
  ask cluster-link now_at should_go [show-link]
  if available < demand [
    set distance1 0
    set distance2 0
    if (should_go != item 0 [who] of centraldistributors)[
      set distance1 ([link_distance] of cluster-link  should_go item 0 [who] of centraldistributors)]
    if (now_at != item 0 [who] of centraldistributors)[
     set distance2  ([link_distance] of cluster-link now_at item 0 [who] of centraldistributors)]
    if (([distance_] of number +  distance1 +  distance2) < numdistance) [do_extra_work]];;;;
if (available >= demand)[ask number
  [  set destination cluster_chosen
        if destination != nobody [ while [ distance destination > 1]
        [;ask cluster-link now_at should_go[show-link]
          face destination forward 0.001 ]
```

```
ask links[hide-link]
  set subtract [cluster_demand] of cluster_chosen
  set car_battery car_battery - subtract
  print( word " car_battery-subtract " car_battery)
  set caru_battery caru_battery + subtract
  print( word " caru_battery " caru_battery)
  set label car_battery
  set x_subtract subtract
ask number[set delivered delivered + subtract]
ask cluster_chosen[set cluster_demand 0 set label
cluster_demand]
 ask cluster_chosen[set cluster_uncharged 0 set label
cluster_uncharged]
 show [link_distance] of cluster-link  now_at should_go
  ask number[set distance_ distance_ +  [link_distance] of
cluster-link  now_at should_go]  ]]
end
```

9.2 Appendix 2

9.2.1 Customer side battery delivery success rate

```
while time!=end:
   for i in range(0,len(charbe)):
      if charbe[i]==0 or (charbe[i]==-1 and sum_time[i]<=time):
         sum_time[i] = time
   for i in range(0,len(charbe)):
      if order_nise[i]==0:
         #print('gotcha ' + str(i) + ' ' + str(remaining_battery))
         order_nise[i] = min(in_the_car, remaining_battery)
         remaining_battery -= order_nise[i]
         remaining_battery = max(0, remaining_battery)
         charbe[i] = -1
         dis_ = np.sqrt((current_pos[i][0]-0)**2+(current_pos[i][1]-0)**2)
         time_taken_ = dis_/50 ##########
         sum_time[i] += (time_taken_+((delay*2)*(time_taken_!=0)))
         current_pos[i] = (0,0)
```

```
for k in range(0,len(charbe)):
   sum_time[k] += (time_taken[k]+delay)
min_gari = argmin_replica(sum_time)
print(str(min_gari) + ' >>>>>>')
if min_gari == -1:
   yes_no.append('No Battery left')
   order_idx += 1
   time+=1
   continue
sum_time_least = sum_time[min_gari]
print(str(sum_time_least))
if sum_time_least-time > wait_time[order_idx]:
   yes_no.append('NO')
   for kk in range(0,len(charbe)):
      sum_time[kk] -= (time_taken[kk]+delay)
   order_idx+=1
   time+=1
   continue
```

```
for k in range(0,len(charbe)):
    sum_time[k] -= (time_taken[k]+(delay*order_nise[k]))
  sum_time[min_gari] += (time_taken[min_gari]+(delay*order_nise[min_gari]))
  if charbe[min_gari]==0 or charbe[min_gari]==-1:
    charbe[min_gari]=1
  order_nise[min_gari] -= 1
  current_pos[min_gari] = order_pos[order_idx]
  yes_no.append('YES')
  order_idx+=1
time+=1
```

9.3 Appendix 3

9.3.1 Demand based allocation of local distributor

```
km = KMeans(n_clusters=3, init='random',n_init=10, max_iter=300, tol=1e-04, random_state=0)
y_km = km.fit_predict(X)
obj_file= open("newlocationx.csv","w")
#obj_file.write("latitude","longitude","time","id")
obj_file.write("\n")
for i in X[y_km == 0, 0]:
   row_st="{}".format(i)
   obj_file.write(row_st)
   obj_file.write("\n")
obj_file.close()
```

9.4 Appendix 4

9.4.1 Solar energy prediction in a certain area

```
from keras.optimizers import Adam

model.compile(loss='mse', optimizer='adam', metrics=['mae'])

hist = model.fit(X_train, Y_train, batch_size=32, epochs=500,validation_data=(X_val, Y_val))
```

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