Grid-Connected Photovoltaics Electric Vehicles Charging Stations on Existing Service-Areas on Motorway in Pakistan

By

Talha Hussain Shah

Reg. No. 00000317797

Session 2019-21

Supervised by

Dr. Sehar Shakir

U.S.-Pakistan Center for Advanced Studies in Energy (USPCASE)

National University of Sciences and Technology (NUST)

H-12, Islamabad 44000, Pakistan

August 2022

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A Thesis Submitted to the U.S.-Pakistan Center for Advanced Studies in Energy in partial fulfillment of the requirements for the degree of

MASTER of SCIENCE in

ENERGY SYSTEM ENGINEERING

U.S.-Pakistan Center for Advanced Studies in Energy (USPCASE)

National University of Sciences and Technology (NUST)

H-12, Islamabad 44000, Pakistan

November 2021

THESIS ACCEPTANCE CERTIFICATE

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Signature: ______________________________

Name of Supervisor: Dr. Sehar Shakir

Date: ______________________________

Signature (HoD): ______________________________

Date: ______________________________

Signature (Dean/Principal): ______________________________

Date: ______________________________

Certificate

This is to certify that work in this thesis has been carried out by Mr. Talha Hussain Shah and completed under my supervision in Solar Energy Research Laboratory, U.S.- Pakistan Center for Advanced Studies in Energy, National University of Sciencesand Technology, H-12, Islamabad, Pakistan.

Supervisor: __________________

Dr. Sehar Shakir
USPCAS-E
NUST, Islamabad

GEC member 1: __________________

Prof. Dr. Adeel Waqas
USPCAS-E
NUST, Islamabad

GEC member 2: __________________

Dr. Nadia Shahzad
USPCAS-E
NUST, Islamabad

GEC member 3: __________________

Engr. Abdul Kashif
National Skills University
Islamabad

HOD-ESE/TEE/EPE: __________________

Dr. Rabia Liaquat
USPCAS-E
NUST, Islamabad

Dean/Principal: __________________

Prof. Dr. Adeel Waqas
USPCAS-E
NUST, Islamabad

Dedication

The thesis is wholeheartedly dedicated to my beloved parents and my supervisor Dr. Sehar Shakir. A special thanks to Dr Adeel Waqas, Dr Nadia Shahzad and Sir Abdul Kashif Janjua for pushing me forward in times when I struggled. I am thankful for their love and measureless support. All of you have been a driving force throughout this process.

Abstract

The global automobile industry is evolving toward electric vehicles (EVs) in order to mitigate the environmental impact of fossil fuels emitting 23% of greenhouse gas (GHG) globally. The existing grid infrastructure is being strained. Adoption of EVs comes with its own set of difficulties. Currently, charging station infrastructure is extremely limited, and the majority of existing charging stations are powered by the utility grid. Photovoltaic charging infrastructure for electric vehicles may contribute to the reduction of GHG emissions. The optimal configuration of grid-connected photovoltaics (GCPV) for electric vehicle charging stations (EVCS) on the existing services along the Islamabad-Lahore motorway section of the China- Pakistan Economic Corridor (CPEC) eastern route is assessed technically and economically in this research, with a focus on cost-effective charging of EVs while taking environmental emissions into account, in accordance with Pakistan's energy economics. The estimated EV load model is designed using National Highway Authority (NHA) data. The findings reveal that 300 kW GCPV system for EVCS is the investment efficient based on highest net present value (NPV) among all GCPV's. The results demonstrate that the systems generate 461,802 kWh and 437,845 kWh of energy annually at a levelized cost of electricity (LCOE) of around 3.11 ¢/kWh and 3.28 ¢/kWh in Islamabad and Lahore, respectively. It has a payback time of 2.4 years, making the suggested GCPV system for EVCS economically viable. The research will assist in identifying comparable GCPV sites on South Asian highways. Moreover, the combination of GCPV electricity and EVCS may provide an opportunity for investment and long-term sustainability in the EV sector of developing countries.

Keywords: Electric Vehicles (EVs), Greenhouse gasses (GHGs), Grid-connected photovoltaics (GCPV), Electric vehicle charging stations (EVCS).

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Submitted in Journal of Renewable and Sustainable Energy Reviews.

"Techno-economic Appraisal of Electric Vehicle Charging Stations Integrated with On-Grid Photovoltaics on Existing Fuel Stations: A multicity study framework"

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Under Review in Journal of Renewable Energy.

List of Abbreviations

EV	Electric Vehicles
EVCS	Electric Vehicles Charging Station
FFV	Fossil Fuel Vehicles
GCPV	Grid Connected Photovoltaic
GHG	Greenhouse Gasses
LCOE	Levelized Cost of Energy
NEPRA	National Electric Power Regulatory Authority
NHA	National Highway Authority
NPV	Net Present Value
NREL	National Renewable Energy Laboratory
NUST	National University of Science and Technology
PV	Photovoltaic
PBP	Payback Period
SAM	System Advisor Model

Chapter 1: Introduction

1.1 Background

In today's era of technological and economic warfare, the energy sector is the backbone. In present world of science and technology where every country is struggling for its nation's sustainable development and to be a part of developed countries, world is heading towards globalization. Due to cultural exchanges as result of expanded urbanization and rise in transport industry, global primary energy demand is continuously increasing in an impressive way and has become almost double during last three decades [1]. Conventional fuels are being widely utilized to meet this rapidly expanding energy demand. Toxic environmental issues have developed from excessive use of fossil fuels in the production of energy in the industrial, residential, and commercial sectors, putting Earth's life at risk and hastening the extinction of fossil fuels [2]. These emerging threats forced the world to divert its focus from fossil fuel technologies towards renewable and clean energy systems and this was the main motivation quiescent behind selecting current research topic. Global warming is real, and it is proceeding at an alarming rate. Greenhouse gasses (GHG) emissions have caused the Earth's temperature to rise that has led the Globe to shift towards carbon free fuels [3]. In response to this challenge, researchers in the area of sustainable energy are encouraged to increase the utilization of green energy resources while simultaneously increasing energy production and minimizing environmental impact [4]. The major consumption of fossil fuels is in the transport sector as a substitute to fossil fuel vehicle (FFV) are Electric Vehicles (EV) which are the better options in-terms of environment friendly. EVs, unlike FFV, use an electric motor powered by a re-chargeable battery rather than a combustion engine [5]. Electric power is used as a fuel for EV's whereas electric power for charging of EV is required from utility grid. Charging of EV's is a major challenge to carter this challenge the charging of EV's various renewable energy source are utilized on their feasibility according to the location climate.

During COVID-19, investment in photovoltaics (PV) surged by 12%, bringing the total to $148.6 billion [6]. Photovoltaics industry was the best performing renewable technology in 2020–21, contributing 135 GW to the eventual expected total of 1 TW by 2022 [6]. The transportation industry has a vital role to play in this sustainable goal, and the penetration of electric vehicles (EV) has multiplied the opportunities to have a substantial influence on electric power grids and current distribution infrastructures. The range anxiety of EV's users is an important issue which can't be neglected. Limited availability to charging infrastructure and electric power generation from fossil fuels is the one of the major barriers in the adoption of EVs in the present system. These issues have brought the researcher attention towards the installing charging station of EV's in urban areas and at highways [7]. Grid Connected Photovoltaics (GCPV) system for Electric Vehicles Charging Station (EVCS) on highways would help to alleviate the discussed issues. Figure 1.1 shows the GCPV system for EVCS.

Figure 1.1: GCPV EV charging station [8]

A techno-economic analysis has been adopted by using System Advisor Model in which the techno-economic feasibility of GCPV systems for EVCS for motorways has been investigated. In the literature, System Advisor Model (SAM) has been used to compute and evaluate technical analyses for power outputs, as well as the calculation of EV charging tariff reductions when compared to utility grid and fossil fuel rates [9] [10].

1.2 Photovoltaics Technology

Solar energy is converted into electrical energy using PV systems. Semiconductor devices are utilized to produce the photoelectric effect for this purpose. PV systems are comprised of solar modules that are connected in parallel and series to obtain the required electric power output. On-ground systems, Rooftop systems, Wall Mounted Systems, and Floating PV systems are all options for PV installations. Monocrystalline silicon, polycrystalline silicon, and thin film are different technologies of PV systems which are been used as illustrated in Figure 1.2 Commercially accessible solar panels of all types of technology can be used in GCPV systems for EVCS.

Monocrystalline **Polycrystalline** **Thin Films**

Figure 1.2: Three major types of Photovoltaic Technologies used in EV charging globally [6]

1.3 System Advisor Model

The SAM is a software program developed by the National Renewable Energy

Laboratory (NREL) for designing and modelling renewable-energy systems (RES). It also offers a detailed economic evaluation of a RES based on the parameters on which the systems have been simulated. Engineers, policy analysts, researchers, and technology enthusiasts utilize it because it is open-source software and free to use. Modeling, designing, and techno-economic analysis can be done for photovoltaic, battery storage, fuel cells, concentrating solar panels, geothermal, solar water heating, marine energy, biomass combustion for power generation, wind power, high concentration PV systems, and industrial process heat from parabolic trough and linear Fresnel systems. On the other hand, financial models include commercial and residential projects, as well as power purchase agreement project (PPA) along with third-party ownership projects [11]. Photovoltaic project design, financial modelling, and performance analysis are all covered by this software program.

The SAM has the database that contains information about weather conditions, solar panels, irradiance values, inverter technology, and all other aspects of renewable energy technology. The SAM records 8760-value hourly data sets that display annual data against a selected parameter. For graphical depiction of data, the parametric tool in SAM would be utilized. It's also utilized for sensitivity analysis and comparison of results, like in this research. The system advisor model begins with the selection of weather files based on the project's installation location. Performance evaluation in the form of input set in SAM in the form of system requirements and system losses are the next steps. The PV system's power generation is determined by the weather file input, system details, and losses combined. Similarly, costs, incentives, compensation, and system finance are all inputs to the designed PV model's economic side. For the observed model, these inputs result in yearly, monthly, and hourly production, capacity factor, net present value (NPV), revenue, payback period (PBP), and levelized cost of energy (LCOE).

1.4 Problem Statement

Pakistan's energy crisis is a significant obstacle to EV adoption in the current system; the existing grid infrastructure would be unable to endorse vast numbers of EVs charging on a massive scale at economically efficient rates for electricity units; this is because the majority of Pakistan's energy generation comes from imported costly fossil fuels, a major source of GHG’s emissions.

1.5 Research Objectives

The overarching goal of this endeavor is to create and explore a grid-connected photovoltaic system for electric vehicle charging stations on highways. Specifically, the research is aimed at achieving the following goals:

- To acquire traffic information on the Islamabad Lahore motorway in order to estimate EV energy load demand.
- To design a system that may not strain the current power grid system while charging EVs on a large scale, while also being ecologically sound.
- To conduct a feasibility study of GCPV system for EVCS using LCOE, NPV and payback time.

1.6 Scope of Research

The research carried out is based on simulation results and can be practically implemented in the future. The load assessment for EVs was done using traffic data from the National Highway Authority (NHA) and Pakistan's policy transition toward EVs. The climate data of Islamabad and Lahore was utilized for the given service areas on the motorway which are nearer to these cities respectively. For simulation work, climatic data of Islamabad and Lahore cities of Pakistan, is taken having latitude= 33.6° N, longitude = 73.1° E latitude= 31.5° N, longitude= 74.4° E respectively, where summer season is almost dry and hot while winter season is very cold.

The simulation work has been conducted to determine the power potential of the GCPV system on the motorway for EV charging along with performing a technoeconomic analysis using System Advisor Model. Furthermore, economic analysis has been performed using sensitivity analysis in the Parametric tool in System Advisor Model. The economic analysis is conducted in terms of the cost per watt of electricity produced by GCPV systems. The NPV, PBP and LCOE are the main parameters on which the economic feasibility has been determined. This study can help to determine the cost-effective charging of EV’s and to alleviate EV range anxiety.

1.7 Limitations of Research

The economic and technological assumptions used are as realistic as feasible, but they may alter if the installation site and timing are changed. The estimated installation and maintenance expenses are estimates that will change over time. To further confirm the research findings, a real-time out-of-door experiment may be conducted. Furthermore, prior to the actual deployment of a GCPV system for EVCS, a site study including environmental impact assessment, as well as research into the environmental effects of deploying a GCPV on motorway, is required.

1.8 Dissertation Organization

This complete write-up is segregated into six main sections, as:

Chapter 1 answers the first pre-requisites for beginning research work, such as motivation, what to do in this task, work objectives, and methodology used in this study.

Chapter 2 begins with a review of the literature and then on to discuss various methods of electric vehicle charging stations, as well as the background of grid-connected photovoltaics systems and its optimization.

Chapter 3 is highlight about estimating the energy demand of electric vehicles, finding the ideal locations on motorway to install GCPV systems for EVCS, to analyze the techno-economic feasibility of various GCPV systems for EVCS and for system-based performance optimization, SAM software simulation is introduced.

Chapter 4 discusses all the results obtained during the modelling and simulation of various GCPV systems for EVCS, and a comparison is made to determine the optimal system.

Chapter 5 concludes the work outcomes and elaborates possible future perspectives of current work.

Summary

In this section, the depletion of fossil fuels and utilization of fossil fuels how it affects the environmental issues have been briefly examined. The basic pre-requisites for beginning research work, such as motivation, the objectives to be fulfilled, what to do in this work, and the work approach used in the present study. Furthermore, the research's benefits, scope, and limits are all addressed in the end. The next chapter is focused with a literature review of the EVCS and GCPV systems that will be constructed and investigated in the present project.

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Chapter 2: Literature Review

2.1 EV Adoption

One of the main barriers in the adoption of EV's are unavailability of charging stations [1]. Furthermore, increase in the number of charging facilities is comparable to a load on the grid, which is predicted to disrupt the existing power system [2].

External and internal variables influence the adoption of EV's: internal elements include charging time, ownership costs, and driving range, while external considerations include social norms/public visibility, gasoline prices, and charging networks [3] [4]. Range anxiety is described as the dread of running out of battery power before finishing a trip [5]. Range anxiety, as well as the long time it takes to recharge an electric vehicle's battery compared to filling a fuel tank, are significant deterrents to purchasing EV's [6] [7].

The researchers have researched on different types of residential and commercial PV modelling for EV's charging and feasibility analysis. The installation of EV charging stations may alleviate range anxiety and, as a result, lessen the barriers to EV ownership [8].

2.2 Electric Vehicle (EV) Charging through Utility Grid

Though it may appear to be a straightforward and quick operation, charging an electric vehicle through the utility grid is a complex process with multiple consequences for the existing grid infrastructure. During non-peak or peak hours, depending on the type of EVCS, the power consumption might range from 1kW to 50kW, causing increasing energy demand and straining utility grid infrastructure. Thus, according to [9], throughout the afternoon, when EV users arrive at their individual workplaces [61] and begin charging, there is a possibility for a spike in demand.

Furthermore, according to study published in [9], the maximum energy demand seen on the grid owing to EV contact occurred between 3 and 5 p.m. on a normal workday. The economics, emissions, and grid stability will all be influenced by the levels of EV adoption and their discharge or charging procedures [10]. The load of electric vehicles may also compromise utility grid reliability if charging EV batteries is not scheduled or planned properly [10].

- Distribution transformers are overloaded.
- As demand grows, so does the cost of energy production.
- Congestion on transmission lines.
- Transmission line losses have increased.
- Localized voltage variations in EV charging areas.
- There are likely to be blackouts.
- Grid infrastructure wear and tear.

The aforementioned consequences might be avoided to a considerable extent by establishing a coordinated charging plan with the use of distributed generation (DG) using renewable sources, making EV charging a rewarding and economic possibility [9]. Charging electric vehicles through the grid has no environmental benefits. People have a common misunderstanding that electric vehicles charging is not associated with GHG emission. However, generating power from other carbon-intensive sources produces significant GHG emissions, which are then used to charge these electric vehicles. According to [11], there hasn't been much progress in reducing GHG emissions in the United States' regions with high GHG intensity grids. Furthermore, [11] implies that the grid's GHG intensity has a far larger impact on overall EV emissions than the charging circumstance, making it a time-consuming and difficult exchange procedure.

However, in areas where the energy-mix is mostly comprised of GHG-free sources, such as hydro, nuclear or renewables, the penetration of EV charging stations may not have a significant influence on GHG emissions [12]. More charging stations, especially those powered by renewable energy sources, will have a good influence on the environment by lowering GHG emissions. This will be the emphasis of the thesis's subsequent parts.

2.3 Charging Electric Vehicles using Renewable Energy

Renewable energy sources (RES) have built a name for themselves as a viable alternative to traditional fossil fuels in recent years. Despite COVID-19, renewable energy capacity expanded by 265 gigawatts (GW), the biggest increase in history [13]. Furthermore, because these renewable-energy sources may be positioned close to the load center, system efficiency can be greatly enhanced by reducing losses, voltage variations, and power infrastructure costs [14] [52]. The combination of RES with EVs opens up a world of possibilities for sustainable growth with little environmental effect [53] [54]. By estimating the best degree of EV penetration, as well as the location, size, and installation year for RES units, Shaaban et al provide a multi-objective planning approach to reduce GHG emissions and system costs [15]. Furthermore, it has been demonstrated via various studies in [16-18] that the fluctuating nature of RES through power system networks may be minimized by intelligent coordination and use of EV storage capacity [55] [56]. Solar photovoltaics had the strongest year of all renewable technologies in 2020, increasing 139 GW to a total anticipated capacity of 760 GW. With the emergence of photovoltaic charging stations or solar-powered charging stations (SPCS), generally in parking lots to generate energy for EV charging as well as feedback to grid [19], an alternative and green charging station infrastructure has been developed. By covering 200 million parking spots with solar panel canopies, it is conceivable to generate 25% to 33% of the entire power produced in the United States [19]. Because of the usable life of currently functioning FFV and power plants, EV integration with SPCS infrastructure and smart grids is still a long way off.

However, because to the significant drop in the cost of solar panels and battery technology, this shift has been envisioned and idealized. Envision Solar International Inc, for example, created EV ARC, a standalone SPCS system with battery storage that is meant to be self-contained and independent of the grid [20].

The location of the SPCS system is mostly determined by the EVs' duty condition:

- Home charging stations for EVs.
- More than 1 hour of parking for EVs at workplace.

- EVs) throughout the route.

The majority of EV consumers have SPCS at home, which they get through rooftop solar panels or panels mounted on the carport. In other circumstances, EV manufacturers charge a premium to offer charging infrastructure to their consumers. Tesla Motors, for example, maintains a network of SPCS throughout the Europe and United States [20]. This is a famous example of electric vehicle charging throughout the route. SPCSs are also increasingly being installed in public places such as parks, gymnasiums, convention halls, and malls. The life cycle analysis (LCA) of SPCS is positive, according to [21]. SPCS appears to be a viable and acceptable approach for reducing GHG emissions, according to the LCA. The sustainability and operational economics of charging EVs from solar PV systems are two major advantages. Solar energy is now cheaper than traditional sources in many regions of the world, thanks to falling PV system prices throughout the world.

SPCS are also preferred for the following reasons:

- Both EV and PV work on DC power.
- The Vehicle to Grid protocol proposal will make DC charging easier.

Wind and solar will account for the bulk of global renewables investments, with solar accounting for over half (USD 148.6 billion, a 12 percent increase) of all renewable investments in 2020. Wind energy is another renewable energy source that might be used to charge electric vehicles.

However, the maintenance and mechanical stability issues of a wind energy system for EV charging pose a difficulty since it has so many mechanical components. Unlike solar-based systems, wind-based systems require a more complicated control mechanism since wind turbine speeds must be altered in real-time in response to changing wind speeds [22]. Wind-based systems, on the other hand, might enhance SPCSs with intelligent and precise integration. However, the scientific community has not been particularly interested in commercialization, maintenance, or large-scale adaption of this integration, and considerable motivation is not expected in the future.

Several previous studies [23-29] looked into the architecture of an EV charging station based on PV systems. The reciprocal advantage of charging electric vehicles with solar energy has been noted in [30] [31], where the ability to charge electric vehicles with solar energy enables for greater adoption of both technologies. The negative consequences of surplus solar energy from PV on a national scale were found to be alleviated by using it to electric vehicles charging in [32]. The economic incentive and Greenhouse gas offsets for PV system charging have been proven to be larger than charging the EV from the grid in [33] [34], for the instance of Los Angeles and Columbus, USA. The fluctuation in PV energy generation is a key drawback of EVs charging trough PV systems. Smart charging allows for electric vehicles charging flexibility to precisely match PV system energy generation. Smart charging paired with Vehicle to grid (V2G) has been proven to increase PV self-consumption while lowering peak demand on the grid [35]. [36] Shows how the EV's charging profile may be changed over time to utilize maximize PV energy. It is clear that as EV's penetration increases, the surplus PV energy decreases [37] [38]. Alternatively, as shown in [39], the maximum number of electric vehicles charging at a continuous power could be dynamically adjusted, causing the net charging energy to follow the PV energy generation. This form of sequential charging has a significant advantage over simultaneous EV's charging, as demonstrated by 9000 distinct scenarios in [40].

The electric vehicle battery serves as a solar energy storage system, reducing the detrimental effects of large-scale PV system implementation in the distribution network. V2G technology, in which the EV works as a controlled spinning reserve for the smart grid, can be implemented because to the long parking duration of EVs [62].

Including electric vehicles (EVs) in the home-grid loop can help achieve net zero energy status [57]. The PV-battery combo can offer an offset to utility grid-imposed peak demand rates and direct renewable to EV source electricity while also delivering peak power to utility grid [58]. Though this procedure appears straightforward, it is beset with a slew of implementation challenges that must be handled at numerous stakeholder levels. From a resale standpoint, having a net zero premise with an intelligent EV charging station will increase the retail value, enticing additional homeowners and business owners to invest [59]. Finally, from a sustainability standpoint, a completely net zero premise (commercial or residential) would generate equal or more power utilizing renewable energy sources than it consumes from the grid, putting a greater focus on clean energy generation and lowering GHG emissions.

2.4 Pakistan Energy Scenario

Pakistan is among one of those Countries in the world which has dependence on fossil fuels as major chunk of electric power generation. Pakistan's overall GHG emissions are roughly 167.2 tetragrams (Tg) of CO_2 equivalent, with the transportation sector alone accounting for nearly 23% of GHG emissions as shown in the figure 2.1 or 37.7 Tg of CO_2 [41]. Climate change has influenced both the precipitation and average annual temperature of Pakistan, making it the seventh most vulnerable country in the world. The GHG emissions have a negative influence on human health, and contaminated floodwaters have caused epidemics of different illnesses [42].

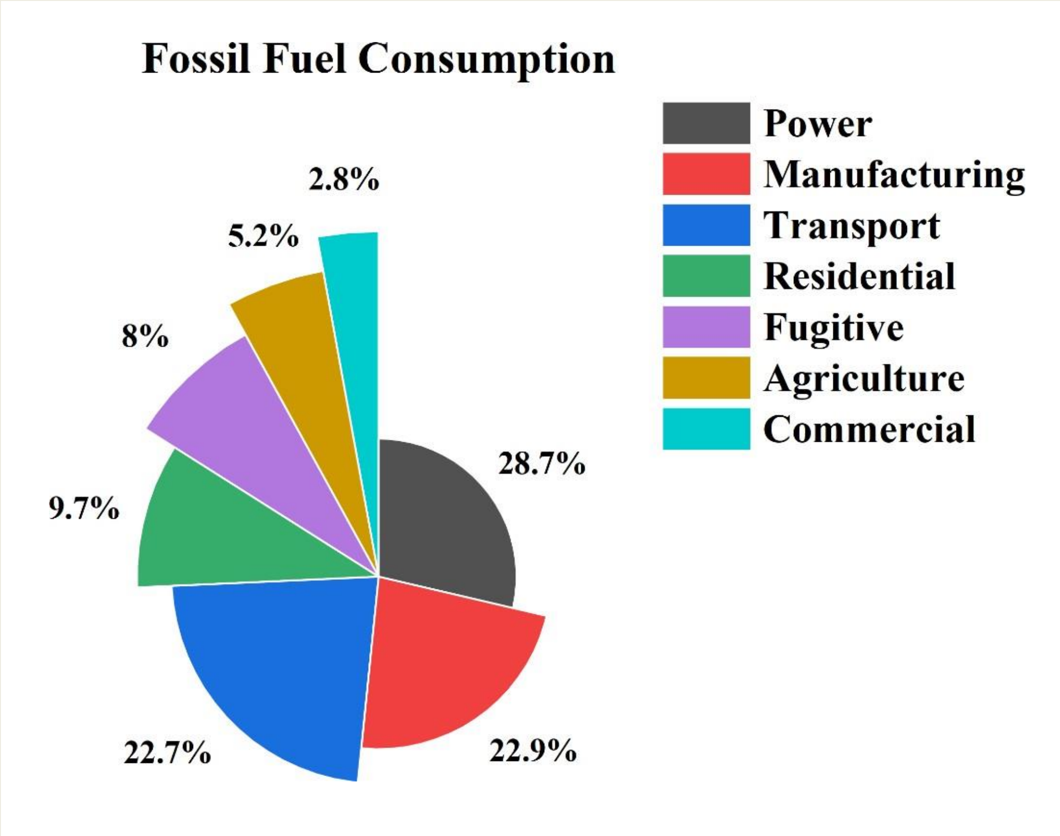

Figure 2.1: Emissions of greenhouse gases by various industries [41]

Energy crises is one the major issue of Pakistan which is resolved recently but Pakistan faces peak energy load crises up-till now. The adoption of EV's in the transport sector of Pakistan will increase in energy demand. Pakistan energy mix scenario is shown in the figure 2.2 almost 62% of its energy is produced by fossil fuels which are being imported [43]. Pakistan imports almost of 13.3 billion USD fuel which are expected to grow till 30.7 billion USD by the end of 2025 to meet its energy requirements. Pakistan produces most of its electricity on expensive fuels which can cause negative effect on EV's adoption by the consumer as they may not get the EV's fuel cheaper price. These imported fuels are not only causing damage to the environment but also have negative impact on the economy. Pakistan have installed capacity of 37261 MW with the demand of almost 20000 MW on average for this Government of Pakistan (GOP) had pay capacity charges of non-utilized energy which is also main concern for the economy [44].

The Government of Pakistan (GOP) have developed the policy to increase renewable energy resources including solar, biomass, wind and hydropower to reduce the GHG's emission under the Paris Agreement [45]. Pakistan has huge solar energy potential which can be used to generate emission free electricity which can be utilized for the charging of EV's and domestic sector.

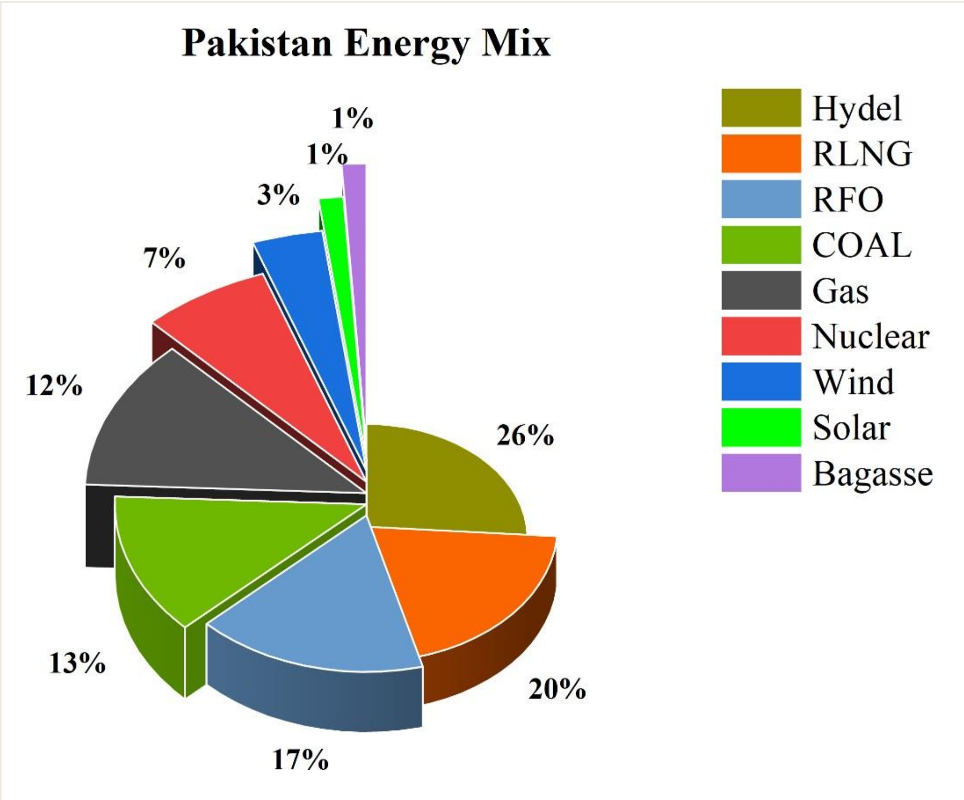

Figure 2.2: Pakistan energy generation by various sources [43]

2.5 Highways and EV Charging Infrastructure

However, to overcome the range anxiety issue of EV's which can be solved by building charging infrastructure on major cities highways [2] [46]. The electric vehicle charging stations along highways are designed to accommodate EVs' long-distance travel. The ideal siting of charging infrastructure, their influence on the power grid, and the accompanying energy management measures have all been the subject of much research.

Aside from a lack of charging infrastructure, another factor that deters consumers from acquiring EVs is that the energy replenishing period of EVs is significantly longer than that of regular fuel cars [46]. [47] proposes a multi objective EVCS design strategy. However, such design methodologies are focused on urban EVCS scenarios, whereas highway constraints are different. In the highway situation, for example, it may be assumed that EV drivers want to complete their energy supply as rapidly as feasible, therefore queue duration and charging period are the most essential elements. [48] proposes a charging infrastructure planning method for electric vehicles that takes into account energy portfolio optimization and cost demand, however this scheme is created from the standpoint of the charging station operator, and the requirements of EV customers are not completely considered [60].

Pakistan has two major highways which comes under China Pakistan Economic Corridor (CPEC). The adoption of EV's in the present system may not result in reduction in the GHG's emission rather it would increase the energy generation from fossil fuels. To electrify the infrastructure for the EV's most of its energy should be generated by green sources. The optimal grid connected photovoltaics for electric vehicles charging station are modelled on the Islamabad to Lahore motorway service area [63]. Because there are currently several service areas along this route where drivers are permitted to park their vehicles, building charging infrastructure on service areas is considerably more efficient [49].

2.6 Techno-economic Feasibility of PV Technology Using SAM

In a global context, previous GCPV and PV-battery research highlights studies that conducted a techno-economic feasibility study along the residential and commercials applications deployment. Several studies have utilized SAM, software that deals with the modelling and design of renewable-energy systems, to estimate energy gains. SAM was used to compute and compare observed and real electric power outputs from GCPV technology, as well as to assess the technology's technological potential. SAM can also help with a techno-economic study, which is what this work is all about.

he LCOE can be used to assess the viability of an GCPV system [50]. SAM is used to compare the GCPV's systems and develop a sensitivity analysis based on PV system power capacities. The NPV and PBP of the GCPV system were also analyzed in a financial comparison.

2.7 Selection of SAM Software

RET-Screen, developed by the Canadian government, PVGIS, developed by the Joint Research Center of the European Commission's in-house science services, PV-Watts, Homer, and System Advisor Model, all developed by the National Renewable Energy Laboratory in Washington, D.C., United States of America, are just a few examples of software packages that can be used for technical and financial analysis. The projects initiated by NREL have been compared briefly by Psomopoulos and Ionnidis in 2015 [51] along with Blair and Dobos in 2014 [50]. The System Advisor Model is a free tool that may be used to assess the future performance of renewable energy technologies and the financial viability of any renewable energy project. The availability of performing a techno economic analysis on a particular project is the reason why SAM has been chosen as the first choice of the project. The software has a number of benefits, including the ability to do sensitivity, parametric, statistical, and probability-based analyses on any renewable energy technology [50]. SAM has also been used to estimate energy gains in renewable energy systems through modelling and design. The system advisor model has been used to assess a wide range of photovoltaic technologies, including solar dish technology, solar thermal technology, grid connected photovoltaic systems, concentrated photovoltaic systems, and floating photovoltaic systems. Our research focuses on grid-connected photovoltaic technologies for electric vehicle charging, but first, let's have a look at how these technologies may be analyzed with the help of the System Advisor Model.

2.9 Utilization of SAM Software in Literature

SAM has been used in various different papers showing the scope in which it can be used. Economic study, technical analysis, battery storage capacity, sensitivity analysis, and life cycle analysis have all been done with SAM. The simulations were done using a variety of different models.

A technoeconomic analysis, designing, modelling, assessment of energy gains, calculation of electrical power output, and identification of technological potential for EVCS integrated with GCPV system is have all been done in this research by utilizing SAM software.

In Table below, a few research papers have been shown related to the thesis.
Table2.1: Literature Review.

Name of Research Paper	**Journal / Published on**	**Key Finding**
Feedbacks among electric vehicle adoption, charging, and the cost and installation of rooftop solar photovoltaics / Robert. K. Kaufmann. [52]	Nature Energy / Jan 2021	Policy that increases the installation of RPVs will reduce the cost of installing RPVs and increase the purchase of EVs.
Emission control strategies for automotive engines with scope for deployment of solar based e-vehicle charging infrastructure /C Kurien. [53]	Environmental Progress and Sustainable Energy / May 2019	Deployment of EVs in countries, which relies primarily on fossil fuels for electricity generation, will only shift the emission threat from vehicle operation phase to energy generation phase.
Economic Viability of Roof Leasing for Rooftop Photovoltaic Systems from a Leasing Company's Perspective / Muhammad Adnan Hayat. [54]	IEEE 7th World Conference on Photovoltaic Energy Conversion / 2018	Roof rental is one type of solar leasing in which the solar leasing company owns and operates an RPV on a rented roof and pays the household a portion of the revenue.
The role of existing infrastructure of fuel stations in deploying solar charging systems, electric vehicles and solar energy: A preliminary analysis / MA Alghoul. [55]	Technological Forecasting and Social Change / December 2018	Transportation sector by providing nationwide EV rapid charging infrastructure, boosting the efforts of EV deployment in the country
Integrating electric vehicles and residential solar PV / Makena Coffman. [3]	Transport Policy / January 2017	PV cuts fuel costs by about 50% for EVs.
Advances in consumer electric vehicle adoption research: A review and research agenda / Zeinab Rezvani. [4]	Transportation Research Part D: Transport and Environment / January 2015	Barriers against consumer adoption of EVs and develop the current understanding of consumer EVs adoption.

Technical Economic Analysis of Photovoltaic-Powered Electric Vehicle Charging Stations under Different Solar Irradiation Conditions in Vietnam / Phap Vu Minh. [56]	Sustainability / March 2021	The solar irradiation intensity and feed-in tariff pricing of rooftop solar power have a significant impact on the ideal arrangement and investment efficiency of PV system for EV charging stations in each metropolitan location.
Factors influencing the economics of public charging infrastructures for EV / Qi Zhang. [57]	Renewable and Sustainable Energy Reviews / 2018	The elements that can impact the economics of public charging infrastructure both directly and indirectly and knowledge gaps, constraints, and possibilities in the charging infrastructure development have been identified and evaluated.
Electric vehicles and key adaptation challenges and prospects in Pakistan / Rafiq Asghar. [58]	Journal of Cleaner Production / August 2020	This study presents a comprehensive assessment of the current state of EV maturity in Pakistan, as well as some of the most pressing adaption difficulties and possibilities.
Energy assessment and economic sensitivity analysis of a grid-connected photovoltaic system / Yuanlong Cui. [59]	Renewable Energy / December 2019	The findings of a techno- economic study of a grid- connected photovoltaic (PV) system for home building applications are presented in this research.
A planning strategy considering multiple factors for electric vehicle charging stations along German motorways / Jiayan Liu. [2]	Electrical Power and Energy Systems / 2021	EV charging station design technique that takes into account building costs and motorway existing service areas.
Multi-period planning for electric car charging station locations: A case of Korean Expressways / Sung Hoon Chung. [60]	European Journal of Operational Research / 2015	The absence of charging station infrastructure is one of the most significant hurdles to broad adoption of electric vehicles and case study based on the Korean Motorway network's real-time traffic flow information
System design for a solar powered electric vehicle charging station for workplaces / G.R. Chandra Mouli. [61]	Applied Energy / February 2016	This research looks into the feasibility of using solar energy to charge battery electric automobiles at workplace and the effective storage size for reducing

		grid reliance by 25% is determined.
Review of Renewable Energy-Based Charging Infrastructure for Electric Vehicles / Gamal Alkawsi. [62]	Applied Sciences / April 2021	With the growth of the electric vehicle industry, local electrical networks are being put under strain, necessitating the use of naturally plentiful and affordable alternative energy sources such as wind and solar.
Location optimisation method for fast charging stations along national roads / Csaba Csiszár. [63]	Journal of Transport Geography / August 2020	The service areas along highways and major routes, as well as to suggest deployment locations for fast charging stations.

Summary

EV adoption challenges in current exiting system were discussed in this chapter. The following are the fundamental EV charging interfaces that have been described in this chapter:

- Electric Vehicles charging via present grid infrastructure.
- Charging Electric Vehicles using Renewable Energy

Throughout the process, the hardship of current grid infrastructure was highlighted, emphasizing the implications of widespread EV charging. It was also discovered that continuing to utilize grid power has a detrimental influence on sustainability, as grid power in most emerging economies is predominantly supported by fossil fuels. PV systems and wind energy systems were offered as alternative solutions for EV charging. PV system was shown to be the most accessible, cost-effective, and practical solution for powering EV charging stations while simultaneously achieving sustainability with low GHG emissions. The growth of renewables despite COVID 19 has been seen. Pakistan energy scenario were discussed in detail with hefty capacity payments and energy crises issues of Pakistan. In the following chapters, the System Advisor model has been chosen as the main software, and the technoeconomic analysis performance has been hinted at by constructing and evaluating various GCPV systems for EVCS.

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Chapter 3: Methodology

3.1 Methodology Approach

The methodology adopted for this research work starts from a very initial step of topic selection. Following the selection of a work domain, reading on the topic is searched to gain a better understanding of the background of the work's constituent elements and to determine what and how I must produce something unique in the chosen domain. The estimated Electric Vehicles EV energy load demand and various GCPV systems were modelled in SAM tool. The SAM is an open-source performance and financial design software developed by the NREL. The techno economic. Feasibility of various SAM-modelled GCPV system for EVCS are investigated. After analytical study of various designed GCPV system for EVCS the optimal system configuration is adopted for charging stations. Finally, the work is concluded with dissertation write-up along with simulation and experimental results-based articles.

The system advisor model (SAM) is an open-source performance and financial design software developed by the National Renewable Energy Laboratory (NREL). SAM has been utilized in a different of renewable energy techno-economic feasibility assessments [1]. Moreover, Photovoltaics (PV) and the utility grid are combined modelled using SAM to assess the technical feasibility of GCPV system for EVCS and to calculate green electricity generation. Figure 3.1 illustrates the research methodology used in this study.

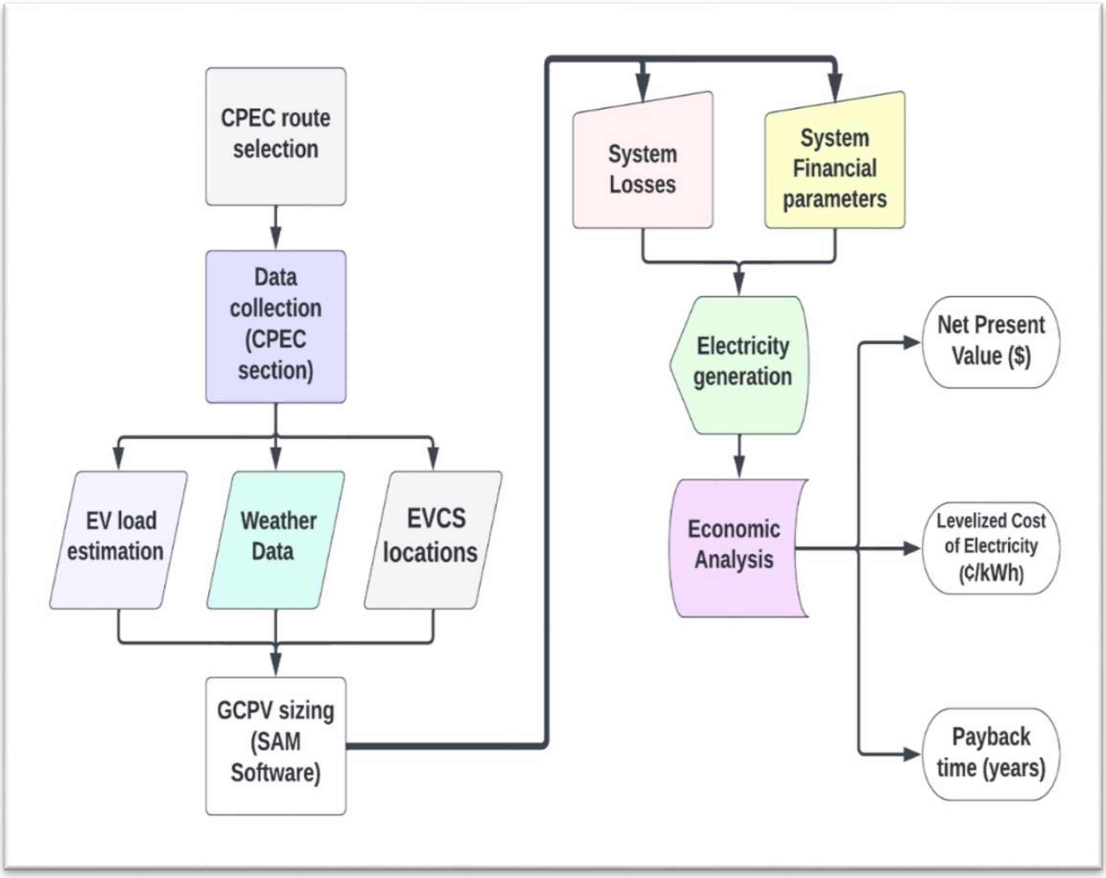

Figure 3.1: Flow diagram of Methodology

The optimal configuration of GCPV system is determine by the using high efficiency solar panels with high output power per module and which are available in market of Pakistan. The solar panels required the area to installed which can be rooftop or ground. The Seven different GCPV system capacities for EVCS on existing service areas along the motorway are consider for implementation. These GCPV's systems solar panels can't be mounted only on the available rooftop only as these are big power system required more area so, these solar panels are mounted on rooftop and ground. The land on lease is available at these service areas along the motorway which are considered for the ground mounted solar panels. The GCPV system is chosen optimally based on the maximum NPV as well as the lowest LCOE and good payback period. The GCPV systems economic viability is determined based on Pakistan's present energy and economic situation. Figure 3.2 depicts an overall view of the planned grid-connected photovoltaics system for electric vehicles charging station

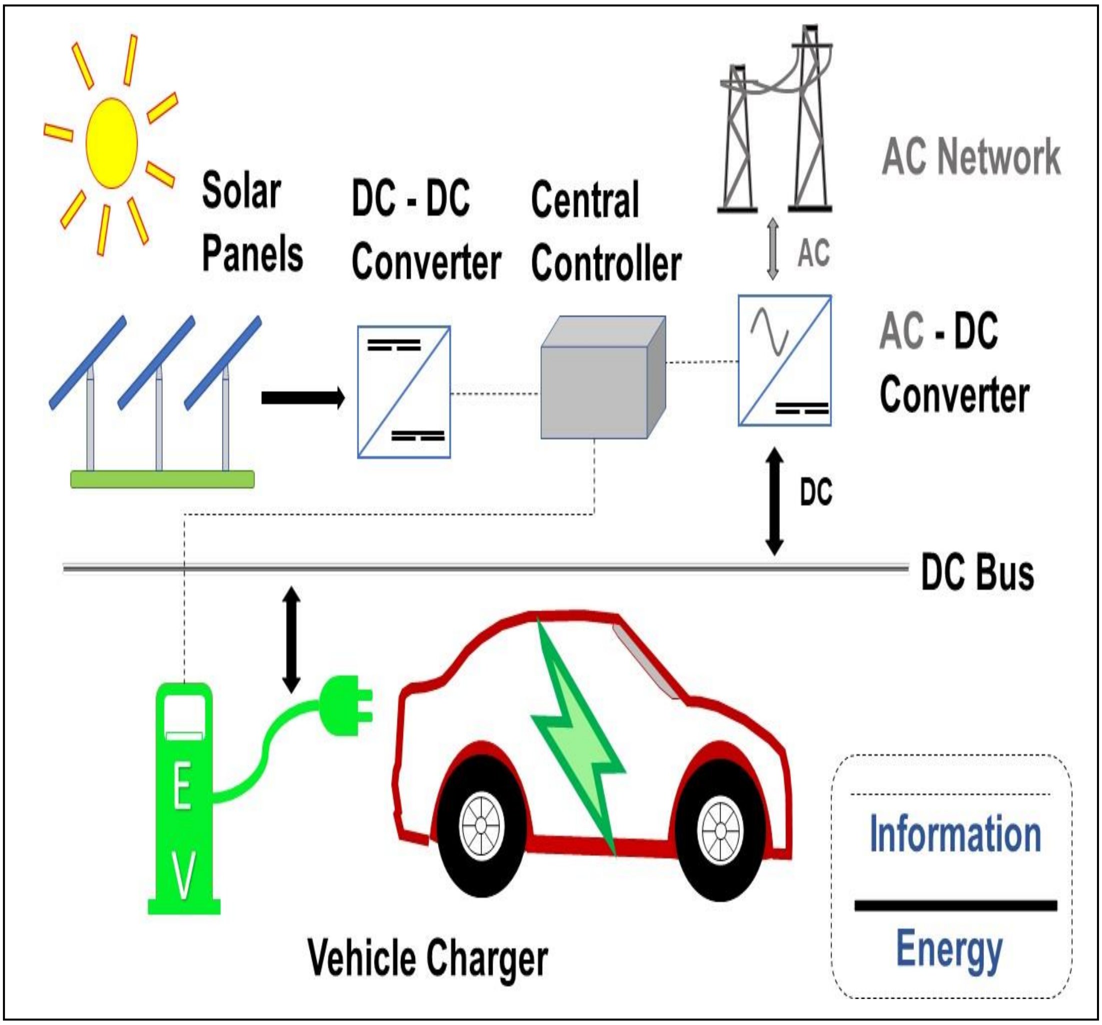

Figure 3.2: Grid-Connected Photovoltaics Electric Vehicle Charging Infrastructure.

3.2 China Pakistan Economic Corridor (CPEC) Route

There are 2 routes of China Pakistan Economic Corridor eastern and western route [2]. The western route of CPEC length around of 2463 km is under construction which is expected to be completed by 2030. The eastern route of CPEC length around of 2781 km which is almost completed that has number of sections which are called motorways. There is total 16 motorways planned under CPEC among which 12 motorways are completed and operational [3].

3.3 Data Acquisition and Site Details

Highways and motorways of Pakistan are maintained and operated by National

Highway Authority which is a department of Pakistan's Government. All 12 motorways are connected. The toll plazas are installed in this motorway network to collect the tolls through the tickets from which toll the vehicle is entered and to which the vehicle exits the motorway. NHA manages all traffic information like traffic volume the distance travelled by the vehicle. This is possible because all the motorways are connected by which NHA can calculate all traffic volume from any entering and exiting toll plazas. Motorway-2 (M-2) connects two major cities of Pakistan Islamabad and Lahore which is fully developed with modern facilities. This motorway has advanced system of collection of toll trough scanning of M-Tag which are installed on a vehicle is used to record information and calculate the distance travelled. We utilized the traffic volume information of 2021 year which was made available by NHA upon special request of our institution [4]. After analyzing this information, we discovered that the highest traffic flow among all these motorways is on the M-2 which connects Lahore to Islamabad. So, we select one busiest route of the CPEC section that is Islamabad to Lahore motorway. These two cities are major and developed cities of Pakistan with maximum traffic flow in between them. In between Islamabad to Lahore the motorway section has fixed number of entrance and exit points which are called interchanges, as shown in Figure 3.3.

The distance between all interchanges is measured and shown in Table 3.1. The allowed speed on this motorway is 120 km/h fix by NHA. The total length of this Islamabad to Lahore motorway section is 358 km.

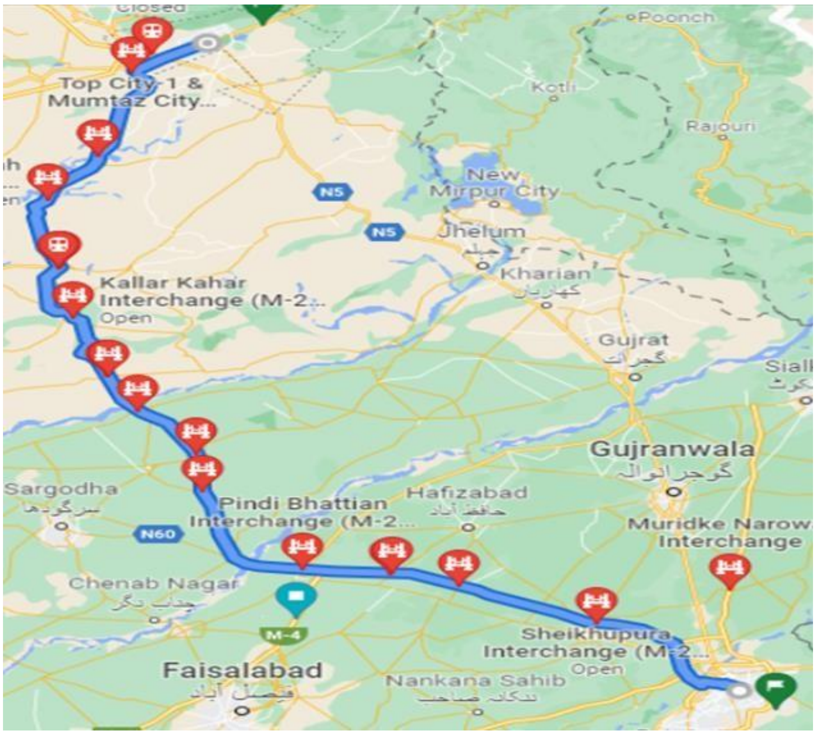

Figure 3.3: Interchanges on M-2 [8]

Table 3.1: Distance between the interchanges on M-2

No. of Interchanges	Distance (km)
1	27 km
2	32 km
3	52 km
4	88 km
5	105 km
6	120 km
7	125 km
8	144 km
9	198 km
10	204 km
11	219 km
12	247 km
13	271 km
14	320 km

3.3.1 Service Areas

However, we conclude that there are enough operational service areas within the Islamabad to Lahore motorway section and there are some new service areas being added on this route soon planned according to NHA [5]. To alleviate EV range anxiety, long-distance infrastructures required charging stations installed on roads and motorways with a practical length of no more than 100 km [6] [7]. The fully operational service areas that are already located on this section of motorway are located almost after every 40-55 km range on this route which means there are almost 2 service areas on the motorway within 100 km boundary. The distance between all fully operational service areas is measured and shown in Table 3.2. The Figure 3.4 shows the fully operational service areas located on the motorway. These fully operational service areas are equipped with all the modern facilities required along with utility grid power supply and have fuel station which can be upgraded by adding charging points for EV's. The rooftop area of the fuel station is not enough to install big PV systems, so these service areas have huge land area available for lease to installed big PV systems. So, we considered these fully operational service areas to installed GCPV for EV's charging on the motorway which can be accessible by EV's users to reduce range anxiety.

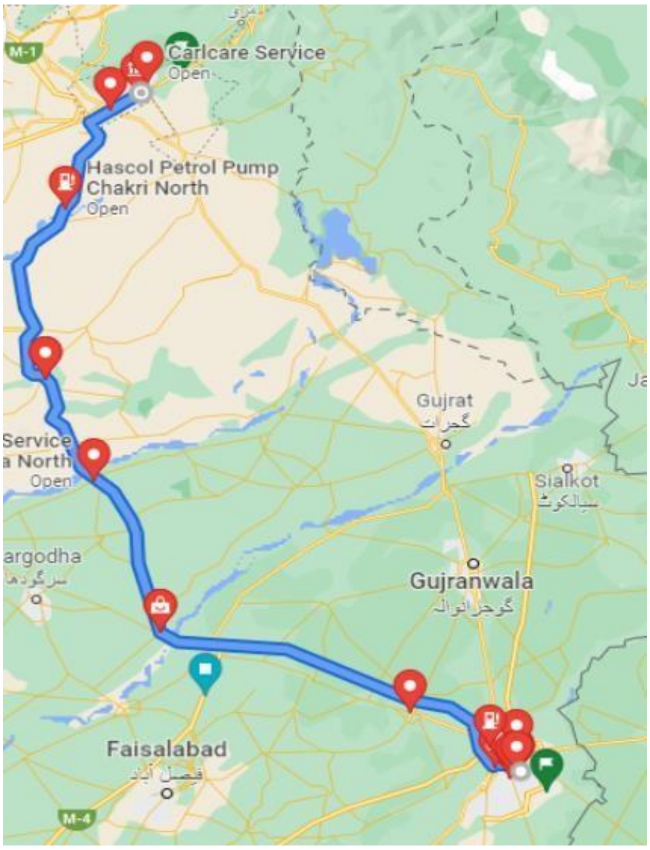

Figure 3.4: Service-areas on M-2 [8]

Table 3.2: Distance between Service-areas on M-2

Service Areas	Distance KM
1	47 km
2	87 km
3	130 km
4	185 km
5	225 km
6	265 km
7	310 km

3.4 Mathematical Modelling

Various parameters of mathematical models are developed form different methods and discussed below:

3.5 Estimation of Load of EV's on the motorway

Load assumptions are made on numbers of cars travel from Islamabad to Lahore and Lahore to Islamabad every day from motorway. The traffic information of 2021 year which is provided by National Highway Authority (NHA) of Pakistan [4]. The information contained different type of vehicles entering and exiting from motorway this data information was analyzed and separated in different categories to calculate the numbers of cars travel on motorway per day in the period of one year.

$$NvT = nvE - nve \qquad (1)$$

Where, NvT is Total number of vehicles travelled at least more than 100km on motorway per day, nvE is Total number of vehicles entered on motorway per day, and nve is Total number of vehicles exits from motorway within 100km interchanges per day.

$$NvT \cong NvL \cong NvI \qquad (2)$$

Where, NvL is Total number of vehicles entered to Lahore per day and NvI is Total number of vehicles entered to Islamabad per day.

$$NEV = NvT \times P\% \qquad (3)$$

Where, $P\%$ is Percentage of Shift FFV into EV's and NEV = Total number of Electric Vehicle available to travel on motorway [9].

$$EL = NEV \times E \qquad (4)$$

Where, E = Electric power consumed by an EV to charge and EL = Electric load per day on motorway.

Eq. (1) is used to calculate the total number of vehicles that travelled more than 100 km on motorway. The EV's that travelled more than 100km on motorway need to recharge at least one time.

In Eq. (2) it is obtained that the total number of vehicles from Eq. (1) we calculated both sides from Lahore to Islamabad and Islamabad to Lahore were approximately equal to the number of vehicles which entered to Islamabad toll and Lahore toll respectively. The Eq. (3) is used to estimate the shift of FFV to EV's according to the GOP planned till 2030 [10]. Electricity load is calculated using Eq. (4) where average charging units were considered form the NEPRA report [11].

3.6 Designing of GCPV system

The EVCS should have at least 3 charging points to charge at least 3 electric vehicles at the same time. The EVCS on the motorway should have rapid and ultra-rapid charging option to decrease the recharging time of electric vehicles. The rapid and ultra-rapid chargers have power range in between 50-150 kw. The available roof of existing fuel station and service areas building will be utilized along with the nearby land for roof and ground mounted PV system to be installed to meet the required power capacity of charging station. The motorway would not have the limitation of PV system is ground mounted such like metro cities. The Government of Pakistan (GOP) has planned to shift 30% of fossil fuel vehicles into EV's till 2030 [10]. The GOP plans to increase in renewable energy generation, in accordance with the Paris Agreement to reduce CO_2 emissions by 2030 [12]. According to National Electric Power Regulatory Authority (NEPRA) report on average EV consumes 40 units to charge and average distance covered per unit is 12 km. These assumptions are made by NEPRA based on 81 EV models of 2020-2021 mode of consumption data taken from Office of ENERGY EFFICIENCY & RENEWABLE ENERGY by NEPRA [11] [13]. We considered these parameters in designing of the GCPV system.

The Eq. (5) below is used to sizing the PV system for the EVCS located on the motorway.

$$Ppv = \frac{EL}{\eta ac \times \eta inv \times \eta dc \times \eta m \times \eta di \times \eta as} \qquad (5)$$

Where, Ppv is PV power sizing, kW, EL is estimated Electric load of EV's per day, kW, ηac is AC cable efficiency, ηinv is Inverter Efficiency, ηdc is DC cable efficiency, ηm is efficiency after module mismatch loss, ηdi is efficiency after diodes & connections loss, and ηas is efficiency after soling loss.

Solar energy is available for the greater number of hours in summers as compared to the winters. Solar energy is not available all day, like in night when sun is no present and there can be cloudy days as well. Meeting the total electrical energy demand from solar energy sources is challenging, the system has been connected to the electrical power grid so that any extra energy may be used. The PV system is designed so it may sell excess energy to the grid on net-metering which can be utilized at the time when there is no or less PV power production so the EV's can be recharged. The electricity rates sold to Grid and to the EV's costumer were used in SAM as NEPRA has decided.

3.7 Simulation of GCPV in SAM

SAM was used to simulate seven GCPV systems as well as compare them. The simulations are carried out in the software step by step. The simulation begins with the selection of a renewable technology of "Photovoltaic" and "Commercial Model". The SAM software is used to develop a 100 kW - 700 KW GCPV systems that changes depending on the weather file circumstances.

3.7.1 Input Weather Files

The data in a SAM weather file is organized in hourly and minutely time steps. The data perfectly describes the up-to-date solar and wind resource of a location under observation in SAM. A year's worth of weather data is contained in a weather file. The data collected is via ground weather stations, data from satellites or it can be a combination of both. The weather files may be simply modified, and the data can be updated to fit the circumstance.

The weather files utilized in this investigation have two primary changes: one to the temperature data and another to the humidity data. The Solar Resource for Islamabad and Lahore has been tweaked to provide the data as near to real-time weather as feasible.

3.7.2 Location and Resource Page

The city under observation is selected on the Location and Resource Page. In this case, Islamabad and Lahore were chosen, and the appropriate meteorological file was downloaded. SAM contains the most up-to-date meteorological data from various of locations. SAM will retrieve weather data from its library after a target area has been specified. Energy output models are generated using this up-to-date meteorological data. Figure depicts the location and resource page:

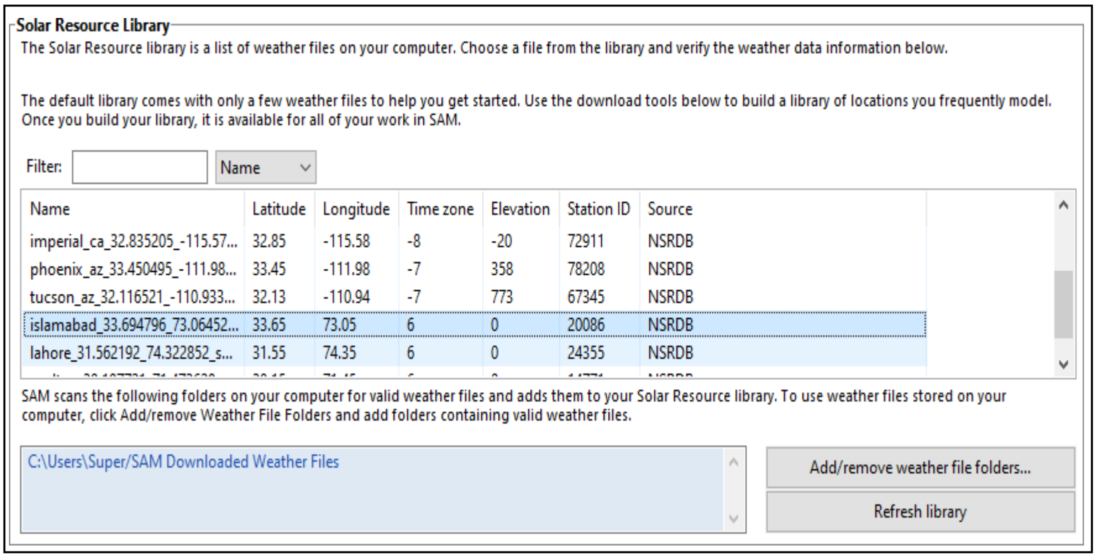

Figure 3.5: Location and Resource Interface of the System Advisor Model (SAM).

3.7.3 Selection of PV Module

The module selection is based on the most recent industry standards in use across the world. The availability of the selected module in the real-world scenario is also essential. As a result, the 500-Watt mono crystalline panel TSM-500DE18M(II) was employed, as indicated in Figure:

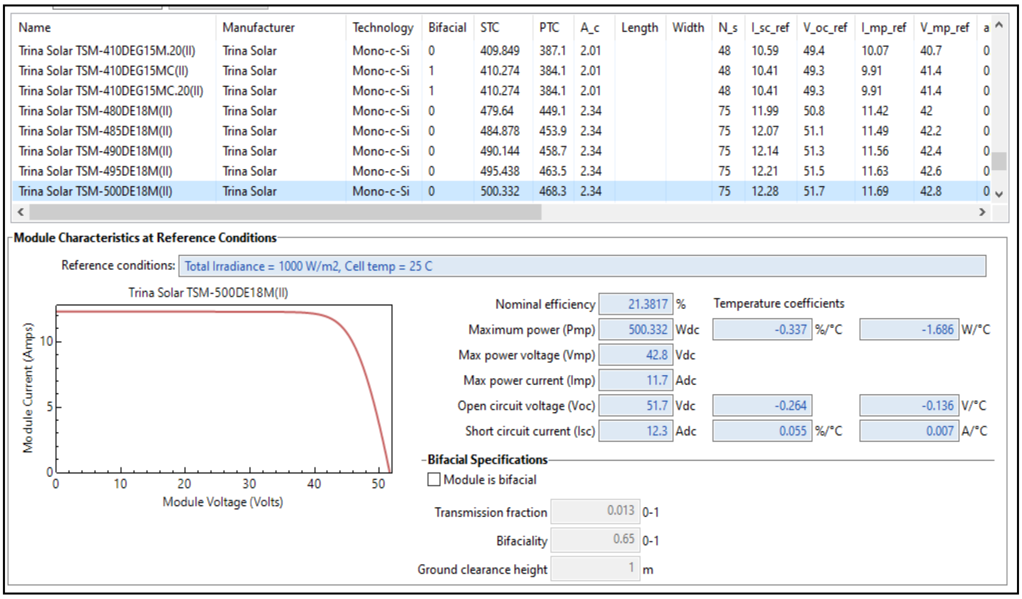

Figure 3.6: Module Characteristics of the System Advisor Model (SAM).

3.7.4 Selection of Inverter

The inverter is used PVI-CENTRAL-250-US 250Kwac and DC to AC ratio is kept on 1.20 generally this ratio lies in between 1.10 to 1.20 [14]. Figure shows the inverter page in SAM:

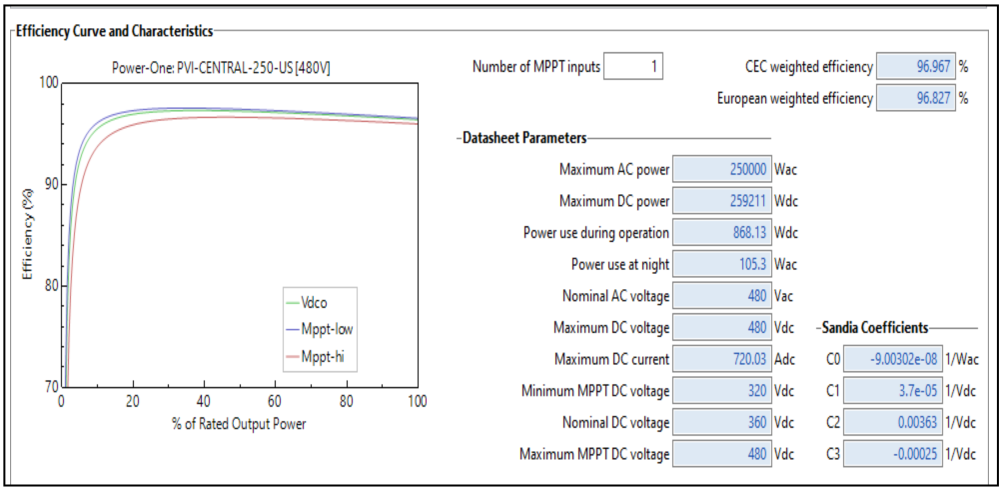

Figure 3.7: Inverter Characteristics of the System Advisor Model (SAM).

3.7.5 System Design Specifications

The various GCPV system has been designed for EVCS. The number of modules selected must be such that our system's DC to AC Ratio remains close to 1.20. Figure illustrates the 300 kw GCPV system design for EVCS page in SAM:

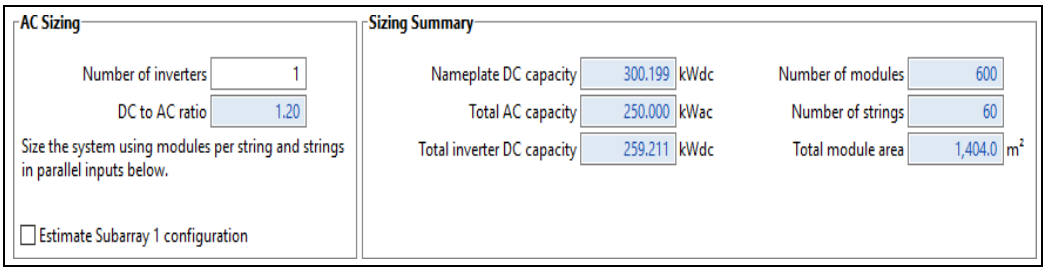

Figure 3.8: Sizing for System Advisors (SAM)

3.7.6 DC Losses Specifications

The Figure shows the DC losses of the system considering while designing in SAM.

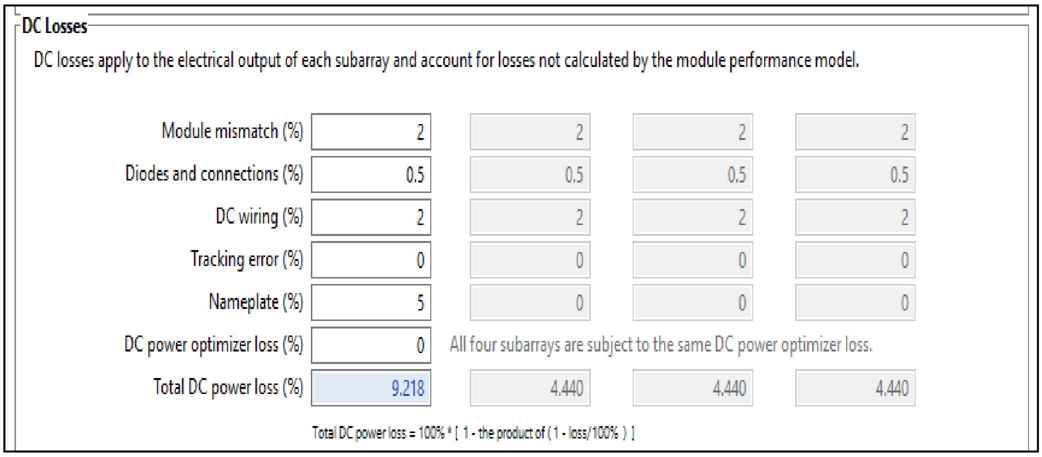

Figure 3.9: System Advisor Model (SAM) DC Loss Selection Interface.

3.8 SAM Electricity Load Profile

SAM requires every hour value of electricity load demand for 365 days of the year which are 8760 values. The Figures shows the electricity load profile for one year and monthly load summary respectively.

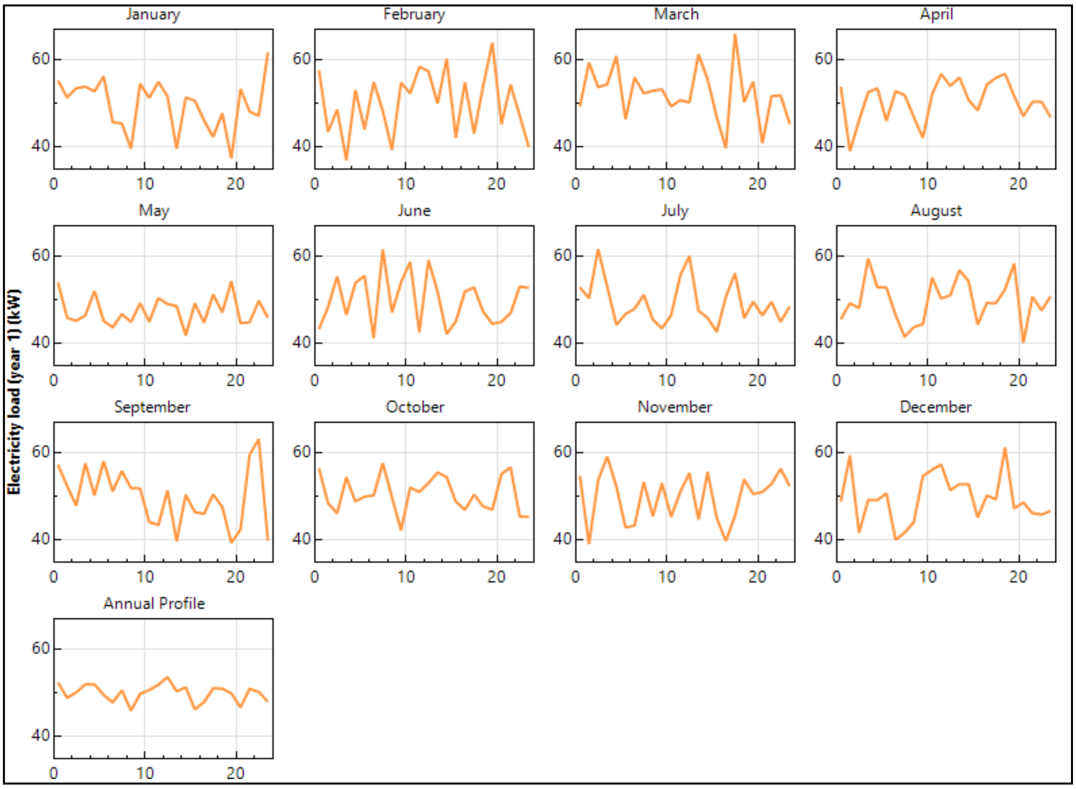

Figure 3.10: System Advisor Model (SAM) Electricity Load Profile.

Monthly Load Summary

	Energy (kWh)	Peak (kW)
Jan	36,907.00	100.00
Feb	33,689.00	100.00
Mar	38,845.00	100.00
Apr	36,391.00	100.00
May	35,366.00	100.00
Jun	36,040.00	100.00
Jul	36,757.00	100.00
Aug	37,001.00	100.00
Sep	35,858.00	100.00
Oct	37,658.00	100.00
Nov	35,830.00	100.00
Dec	36,873.00	100.00
Annual	437,215.00	100.00

Figure 3.11: System Advisor Model (SAM) Monthly Load Summary.

3.9 Modelling of GCPV System and Economic Parameters

The SAM tool developed by NREL generates the performance and financial models to analyze the location-specific energy generation of GCPV systems over the period of lifespan of the system. The PV system is designed by using modules of Trina Solar TSM-500DE18M(II) of mono crystalline and it is flat plate type PV panel. The PV module specification shown in Table 3.3. The inverter is used PVI-CENTRAL- 250-US 250Kwac and DC to AC ratio is kept on 1.20 generally this ratio lies in between 1.10 to 1.20 [14]. The inverter specification shown in Table 3.4. The electricity rates sold to Grid and to the EV's costumer were used in SAM as NEPRA has decided [11]. The price of Trina Solar 500w PV panel is 29000 PKR which is converted into $/kw. Land leased was also added in the financial parameters as the availability of the roof area was not enough for this PV system to be installed on it. The technical and financial parameters are listed below in the Table 3.5.

Table 3.3: PV Module Characteristics in System Advisor Model (SAM)

PV Module Specifications	
Nominal efficiency	21.38%
Maximum power (Pmp)	500.332 Wdc
Max power voltage (Vmp)	42.8 Vdc
Max power current (Imp)	11.7 Adc
Open circuit voltage (Vsc)	51.7 Vdc
Short circuit current (Isc)	12.3 Adc
Temperature Coefficient	-0.34%
Nominal efficiency	21.38%

Table 3.4: Inverter Characteristics in SAM.

Inverter Data Sheet	
Maximum AC power	250000 Wac
Maximum DC power	259211 Wdc
Power use during operation	868.13 Wdc
Power use at night	105.3 Wac

Nominal AC voltage	480 Vac
Maximum DC voltage	480 Vdc
Maximum DC current	720.03 Adc
Minimum MPPT DC voltage	320 Vdc
Nominal DC voltage	360 Vdc
Maximum MPPT DC voltage	480 Vdc

Table 3.5**:** Input Technical and financial parameters during Simulations

PV Modules Tracking & Orientation	
PV Tracking	Fixed
Tilt Angle	20°
Azimuth Angle	180°
Ground Coverage Ratio	0.3
Direct Capital Cost	
PV Module	0.33$/Wdc
Inverter	0.10$/Wdc
Contingency	5%
Indirect Capital Cost	
Land Lease for 25 years:	14705$/acre
Land preparation and transmission	1000$/acre
Discount Rate	
Real Discount Rate	6.4%
Inflation Rate	13% [23]
Annual Degradation	0.5%/year
Analysis period	25 years
Project Taxes and Insurance Rate	
Federal Income Tax and Sales Tax	Both kept zero [51]
Insurance Rate	0.5% installation cost
Depreciation Method	MACRS 5-year [49]
Note: The following losses are taken into account in SAM [52] [53]	
Annual-Soiling loss	5%
Module-Mismatch loss	2%

Connection and Diode losses	0.5%
DC-wiring loss	2%
AC-wiring loss	1%
Nameplate loss	5%

The motorway service areas near to particular city are consider with that weather station. The first three service areas are considered with Lahore weather data as these service areas are nearer to Lahore then Islamabad and the rest of 4 service areas are considered with the Islamabad weather data. The optimal PV system was design by varying PV system capacity so that there should be minimum load on utility grid, with maximum NPV, lowest LCOE and a viable payback period to boost the interest of investors to invest in the installation GCPV systems for EVCS to sustain infrastructure and EV market [18].

3.9.1 Net present value (NPV)

$$NPV = \sum_{n=0}^{N} \frac{En}{(1 + \text{Ɣ})^{n}} \quad (6)$$

The difference between the inflow and outflow of the sum of discounted cash flows is the net present value. Financially and economically viable investment must have positive net present value. NPV is calculated using eq.6 where En is net cashflow Ɣ is discount rate [19] [20].

3.9.2 Levelized cost of energy (LCOE)

Over the system lifespan, the cost of per unit energy (¢/kWh) is calculated by the levelized cost of energy (LCOE) of the system. LCOE is a metric that is used to compare various energy system technology based on the generation of unit energy cost (¢/kWh). The Eq.7 calculates the LCOE of the system [21].

$$LCOE = \frac{LCC}{TEP} \quad (7)$$

Where, LCC is Lifecycle cost of the system ($) and TEP is Total electricity production (kWh). LCC includes capital cost, operation, and maintenance (O&M) cost, replacement cost and subtracts salvage value which is the value of the system at the end of life. The Eq. 8 calculates the LCC of the system [21].

$$LCC = TCC + \sum C_{O\&M} + \sum C_r - C_s \qquad (8)$$

Where, TCC is Total capital cost ($), $C_{O\&M}$ is Total operation, and maintenance (O&M) cost ($), C_r is Total replacement cost ($) and C_s salvage value.

3.9.3 Payback period

The time it takes for an investment to pay for itself in terms of earnings or net cash flow is referred to as the payback period. A simple and discounted payback period are two types of payback periods. A simple payback period is one in which the revenue equals the investment cost, but a discounted payback period takes the time value of money into account. The Eq. 9 calculates the simple payback period of the system [22].

$$SP = \frac{C_i}{R - C_{O\&M}} \qquad (9)$$

Where, C_i is the total investment cost of the GCPV system, R is the annual revenue ($) generated by the GCPV system and $C_{O\&M}$ is annual operation, and maintenance (O&M) cost ($) of the GCPV system.

Summary

This chapter explains the parameters and methodology for modelling various GCPV system for EVCS at the Islamabad Lahore motorway in order to investigate the energy demand, generation, economic behavior, and feasibility of the modelled system using the system advisor model simulation software. The whole set of mathematical relations used for numerical modelling of EV energy consumption and included into the system advisor model software user interface for determining the optimum GCPV system for EVCS are provided. After that, a technoeconomic study was carried out using system advisor model software, which included financial parameters such as LCOE, NPV, and PBP. The output of various GCPV systems for EVCS at the Islamabad Lahore motorway, as simulated in the system advisor model, is discussed in the next chapter.

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Chapter 4: Results and Discussion

4.1 Results

The strategy of Pakistan in energy sector is to enhance its EV market, which may be accomplished by establishing GCPV system for EVCS, which is currently the best option for the deployment of EV charging infrastructure. The GCPV EVCS is installed at the services areas to reduce its construction cost, the availability of grid connection and it is more economical rather build new EVCS along the motorway. Service areas are already located at the distance constraint, these services areas are designed on the motorway so that the maximum vehicles can easily access the service area on the motorway even on an emergency basis hence it means that most of EV users can easily reach service area where they can access charging station [1]. Seven various GCPV systems range of 100-700 KW are modelled and investigated along the motorway with two meteorological stations data of Islamabad and Lahore. The net capital cost (NCC) of these GCPV is directly proportional to the system size which is represented in the Figure 4.1. The evaluation is performed on LCOE, investment cost, NPV, and payback period for each system to determine the optimal GCPV system. The GCPV system configurations, there LCOE and NPV for EVCS Islamabad Lahore motorway represented in Figure.4.2, which clearly demonstrates that given Islamabad weather conditions, the lowest LCOE of 3.11¢/kWh and the highest NPV of $407,602 are achieved with a GCPV system of 300 KW. After analyzing these results, the GCPV system of 300 KW is deemed the most optimal design due to the highest NPV and lowest LCOE.

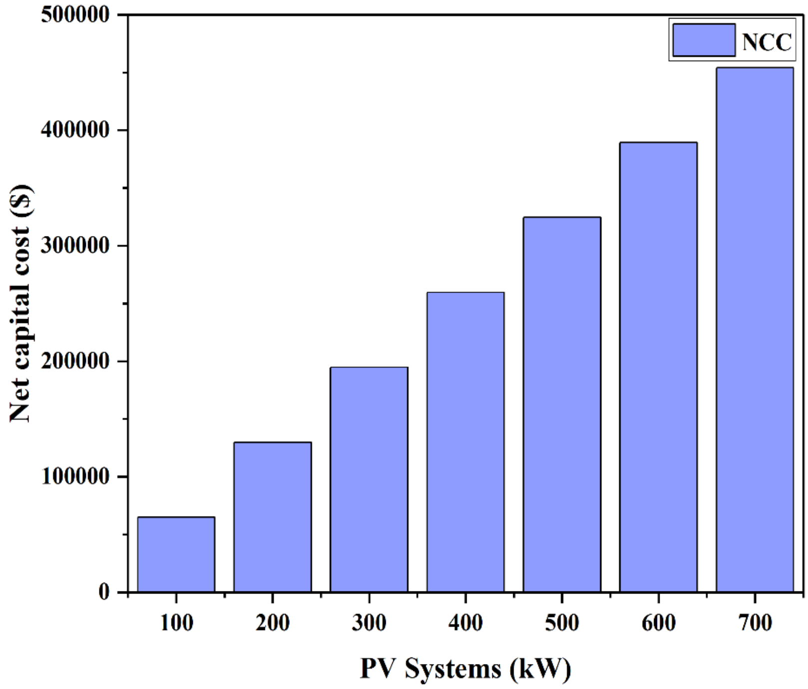

Figure 4.1: Effect of size of GCPV system on Net Capital Cost

Figure 4.2 represents the LCOE, NPV of these seven GCPV system for EVCS Islamabad Lahore motorway with meteorological stations data of Lahore. The results shows that the 300KW GCPV system has Lowest LCOE and highest NPV as compared to other GCPV systems. In case of Lahore weather conditions, the 300 KW GCPV system has achieved LCOE which is 3.28 ¢/kWh and highest NPV of $407,180. It is observed that the LCOE of GCPV systems under weather conditions of Lahore is slightly higher than the GCPV systems under weather conditions of Islamabad and the NPV of Lahore based GCPV systems are slightly lower than Islamabad ones. This is due to the change in weather condition of both cities.

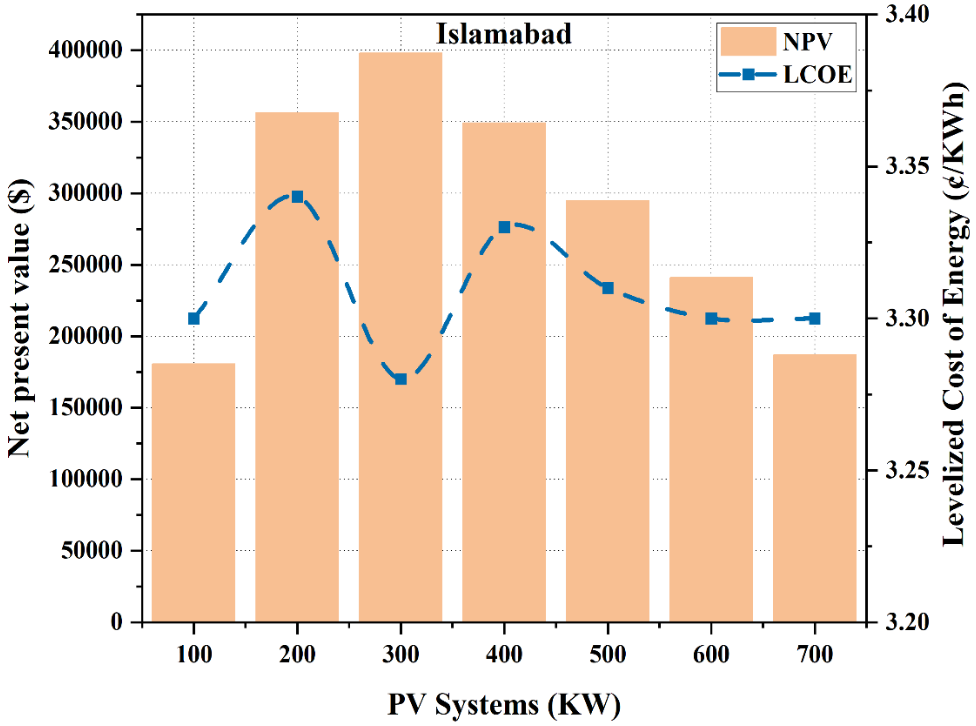

Figure 4.2: Effect of various GCPV system under Islamabad conditions comparison of LCOE and NPV.

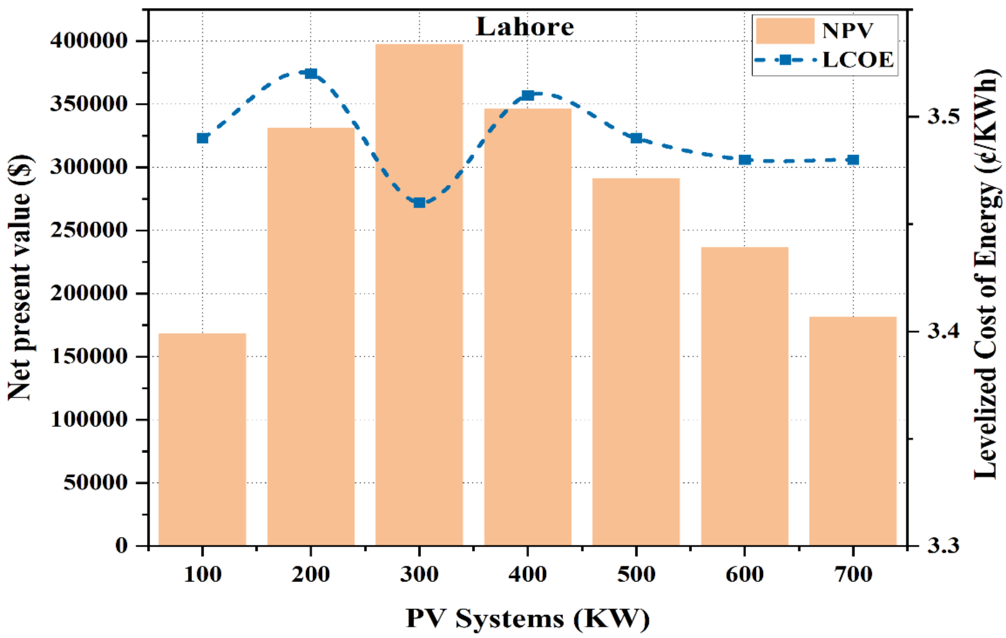

Figure 4.3: Effect of various GCPV system under Lahore conditions comparison of LCOE and NPV.

The optimal GCPV system of 300 KW of EVCS in both Islamabad and Lahore condition has the initial investment cost of $194679 which is higher than the 100kw and 200kw GCPV systems respectively. The Figure 4.4 shows the payback period of these GCPV systems under both Islamabad and Lahore conditions. It is obtained that there is only difference of 0.4 years in the payback period between these systems which is not a huge difference and makes this 300 KW system viable in both cases. Therefore, 300kw GCPV system is most suitable and optimal for initial installation at the motorway because the EV's users will required availability of rapid or ultra-rapid charging system to improve charging time efficiency. The rapid or ultra-rapid chargers required power range of 50-150 KW. This GCPV system can supply power to three charging points for EV's to charge at the same time EV's can be easily charged by the carbon free fuels with minimum impact on utility grid. The waiting time for EV's will be reduce and so the range anxiety issue of EV's user will be resolved [2].

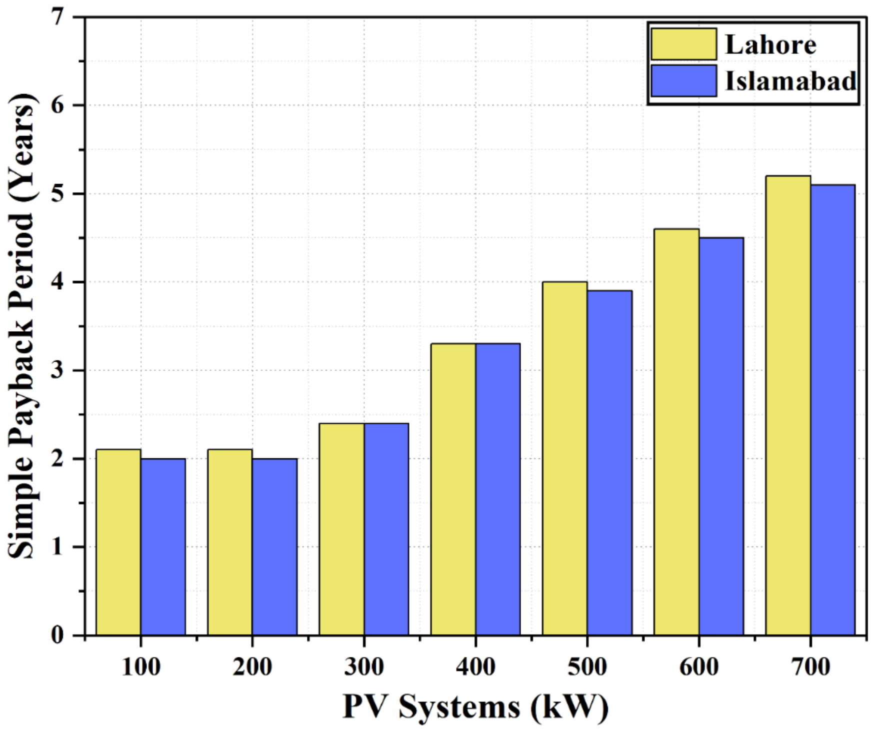

Figure 4.4: Effect of various GCPV system under Islamabad and Lahore conditions on Payback.

The electricity generated by 300 KW PV system and the share of utility grid electric power to meet the energy demand by EV's load estimation to maintain the EVCS operational shown in Figure 4.5 & 4.6. The GCPV charging station will utilize PV generated electricity when it is available in the day the surplus electricity will fed-back to utility grid and when there is shortage or no availability of PV electricity the charging station will draw electricity from utility grid. This is the net-metering phenomena of GCPV system [3].

The Figure 4.5 shows the 300 KW GCPV system under Islamabad condition its energy mix. It is obtained that there is surplus green energy is generated by PV system from the month of March to October that energy is exported to the utility grid and form November to February PV system generates less energy than the energy demands this energy gap is filled by the energy imported by utility grid. This energy gap will not be considered as the extra load on the utility grid because in winters Pakistan's domestic energy demand is almost half as compared to summers. Whereas Pakistan has an energy generation capacity of 40000 MW peak generation. Pakistan has a generation capacity of 42 TWh which is unutilized energy. Pakistan GOP had to pay hefty capacity payments for this unutilized energy. More than 490 billion PKR are paid in terms of capacity payments, which will be around 1500 billion PKR by the end of 2025. This has a huge impact on Pakistan’s economy. The utilization of utility grid energy in winters for EV’s charging will decrease the unutilized energy and reduce the hefty capacity payments [4] [5].

The Figure 4.6 shows the 300 KW GCPV system under Lahore condition its energy mix. It is obtained that there is surplus green energy is generated by PV system from the month of March to June and August to October that energy is exported to the utility grid and form November to February and July PV system generates less energy than the energy demands this energy gap is filled by the energy imported by utility grid. The in from June to July Lahore has monsoon rain season due to lower number of sun hours the solar irradiance decreases which reduce the PV energy generation.

It is obtained from Figure 4.5 & 4.6 that 300 KW GCPV system overall net-power added to utility grid per year is around 24586 KW in Islamabad case and 630 KW is in Lahore case. The overall PV energy generation Islamabad is more than the PV energy generation Lahore this is because the solar irradiance of Islamabad is higher than the Lahore as shown in the figure 4.7. In summers the solar irradiance is high because the greater number of sun hours are available in the day which help to generate more PV energy. Whereas in winters the solar irradiance is low because the smaller number of sun hours are available in the day which reduces PV energy.

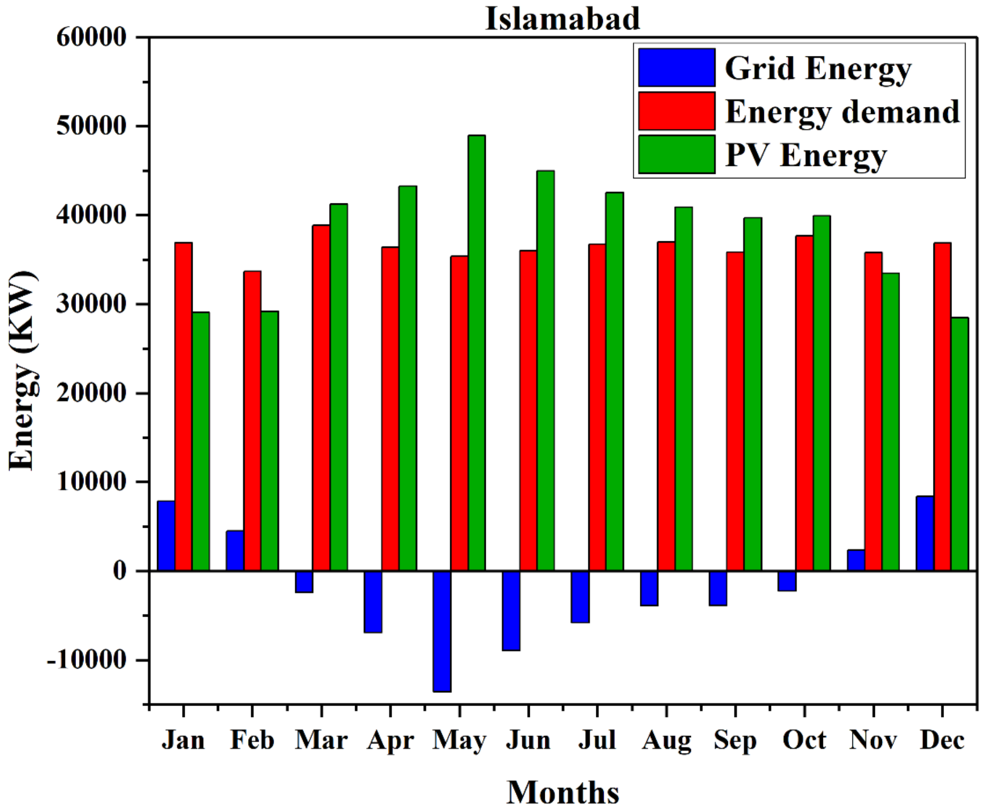

Figure 4.5: 300 kw GCPV system under Islamabad conditions on energy mix scenario.

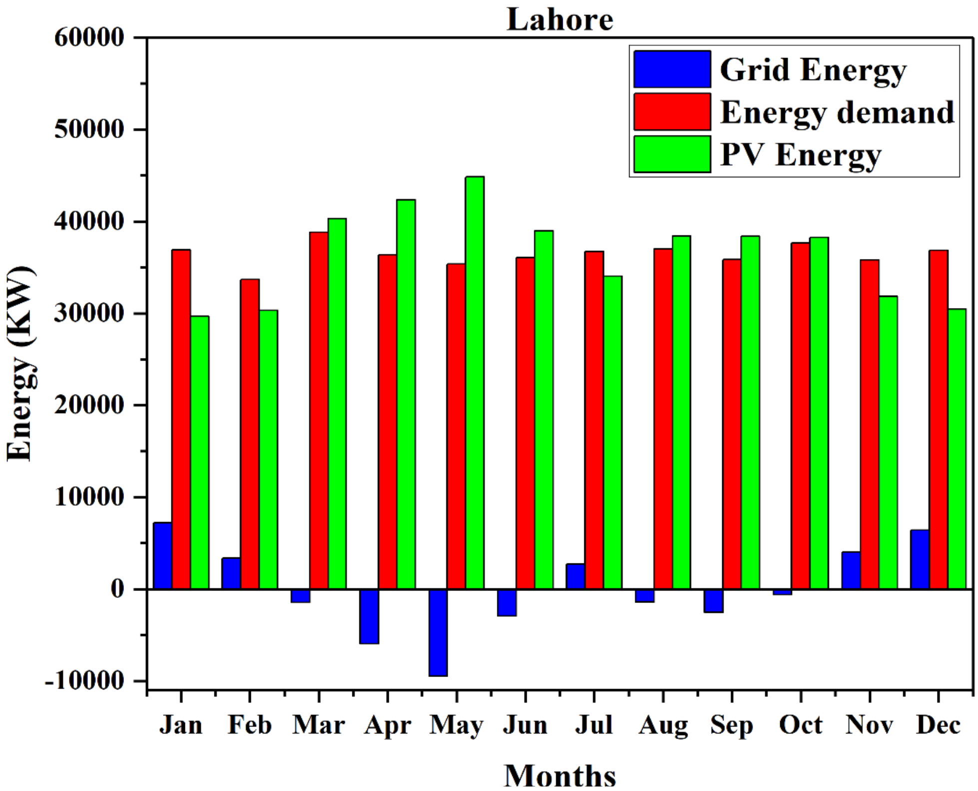

Figure 4.6: 300 kw GCPV system under Lahore conditions on energy mix scenario.

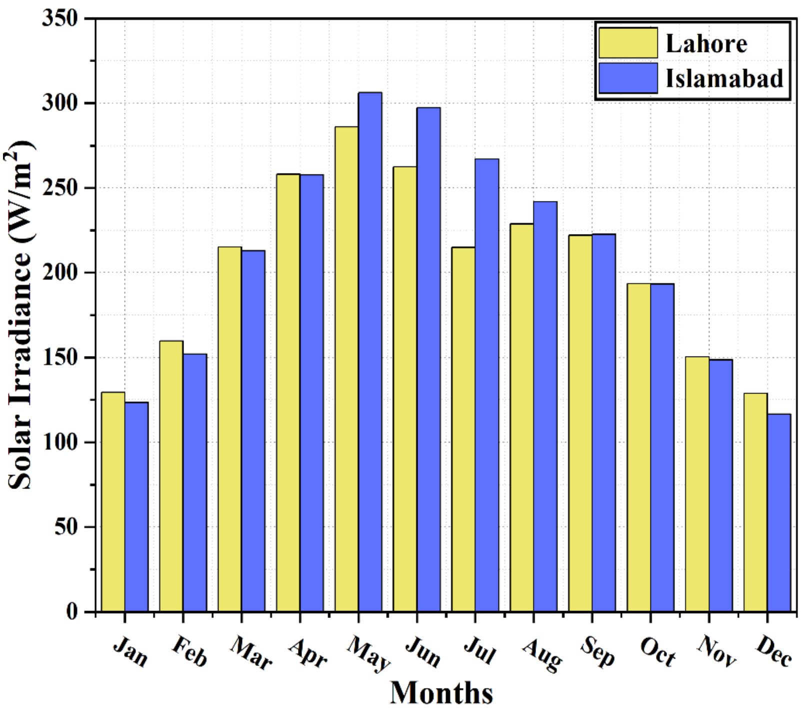

Figure 4.7: Monthly solar isolation of Islamabad and Lahore comparison.

4.2 Sensitivity Analysis

The sensitivity analysis is done by varying PV system capacities with constant grid connection under both weather condition of Islamabad and Lahore which would help in overcoming the energy demand as EV's market will grow. Various GCPV systems were analyzed to optimize the objective function NPV and LCOE. As the EV market will grow there would be a greater number of EV's on the road which will increase the EV energy load demand for these the various GCPV system capacities are modelled. In initial stage 300 KW GCPV system is feasible among all other systems in terms of NPV, LCOE and the energy load on the utility grid. The EV energy load demand increases from the GCPV system of 300KW than more than 300 KW systems will become more feasible and these 300KW systems can be upgraded to increase it PV energy so there may less energy load on utility grid. The number of charging points which are three at the time of 300 KW system can be upgraded to decrease the EV's waiting time to charge. In figure.10 & 11 it is obtain that at maximum GCPV system the LCOE is 3.3 ¢/kWh and 3.48 ¢/kWh Islamabad and Lahore respectively which are still less than the Pakistan's commercial electricity rate on average 10 ¢/kWh according to NEPRA [6]. The NPV $186912 and $181498 in both cases NPV is positive which indicates that these systems are feasible. This sensitivity analysis shows that the size of GCPV system can be increased as increase in EV's energy load demand in the future.

4.3 Discussion

Pakistan aimed to expand its renewable energy resources. Solar energy is one of the major renewable energy resources in Pakistan according to its climate conditions. Pakistan aims to achieve the target of 30% of its FFV users to shift towards EV users up till 2030 as stated in the Paris Accord. This can be achieved by the installation of GCPV for EVCS which will be the best option up till now for the charging infrastructure of EV's. Countries like Pakistan whose major chunk of utility electricity depends on non-renewables will get less affected by the EV's charging load demands due to this system.

This GCPV system will also have its benefits on the Pakistan energy crisis issue when there is surplus energy generated by the PV system that green energy will be fed into the utility grid which can be utilized by different sectors. The GCPV EVCS is installed in the services areas because it reduces the construction cost, the availability of grid connection and it is more economical rather build new EVCS along the motorway. Service areas are already located at the distance constraint, these services areas are designed on the motorway so that the maximum vehicles can easily access the service area on the motorway even on an emergency basis hence it means that most of EV users can easily reach service area where they can access charging station [12]. As EV market will grow it is obvious that the number of charging points will get occupied for this the charging points and capacity of GCPV can be increased to decrease the waiting time for EV users and the energy load on the utility grid this will be more feasible rather than building new EVCS on the motorway.

The owners of charging station can earn more profit while fully charged a single EV as compared to fuel station owners while fully refueling a FFV [7] [8]. The NEPRA has fix the selling price of electricity unit of EV charging 0.26$/KW (45PKR) as comparison to fossil fuel price is almost 0.74$/liter (125PKR) which is almost 3 times more than the EV fuel per unit [9] [10]. This measure will bring the attention of the investor from different markets to invest in the EVCS infrastructure where electricity unit price is very viable in case of GCPV systems for EVCS and the LCOE of the 300KW system is 3.11 ¢/kWh and. 3.28 ¢/kWh respectively. As compared to NEPRA Tariff for EV's charging per kWh the LCOE of GCPV systems is far less, there are huge profit margins in the deployment of this infrastructure [9] [10]. The interested investor will likely invest in the 300KW GCPV system in initial stage where the EV market is expanding, because of its feasibility where this system has payback period of only 2.4 years and make's it viable. The absence of public EV charging infrastructure is one of the most important barriers to the growth of the EV market [8]. The development of this infrastructure and rapid charging will reduce the range anxiety issue of EV users which will boost the interest of consumers in adoption of EV's [11] [2].

This research will spur new investment and expansion in the EV's charging infrastructure and will boost the interest of the consumers to shift towards EV's to expand the EV market.

The deployment of this infrastructure will reduce GHG's emissions and decarbonize the transport sector of Pakistan. The transport sector is one of the major production sources of GHG emissions, carbonization and EV's will play an important role to mitigate these environmental issues. The energy generated by PV system has negligible GHG's emission and carbonization. Global warming has affected Pakistan as it is among 10 countries on the list [12] [13]. The Air Quality Index (AQI) of major cities of Pakistan has been affected badly Lahore is at the top of the list [14] [15]. The GCPV for EVCS will reduce overall environmental costs.

Summary

All results on system advisor model software simulated are illustrated in this chapter. This chapter explains the selection of optimal size of GCPV system for EVCS is designed for the Pakistan CPEC route section Islamabad to Lahore motorway under the economic, social, and environmental challenges. Pakistan has significant Solar energy potential along this route which can be utilized in the charging of EV's, and surplus energy can be fed back to the utility grid. The techno-economic effects were investigated with different GCPV system capacities under different weather conditions of Islamabad and Lahore. The GCPV system for EVCS is installed on the existing fuel stations at the service areas of the motorway to reduce building new infrastructure cost, available utility grid connection and to resolve range anxiety of EV's users. The 300 KW GCPV system initial investment cost of $194679 can be recovered in just 2.4 years which is a good payback period, LCOE at 3.11 ¢/kWh, 3.28 ¢/kWh and NPV $407,602, $407,180 in Islamabad and Lahore cases, hence this system is feasible and to develop the interest of the investors in this technology. This system is designed to have minimum effect of EV's energy load on the national grid of Pakistan. The much cheaper fuel price for EV's is achieved as compared to fossil fuel which will develop the interest of consumers to shift toward EV's. The development in this EV charging infrastructure will kick start the EV's adoption in the transport sector of Pakistan. As EV market expands this system will have a positive impact on Pakistan's economy with respect to energy capacity payments. This will result in reduction of GHG's emissions to meet the target of Pakistan in Paris Accord agreement.

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Chapter 5: Conclusions and Recommendations

5.1 Conclusions

In this research one of the major barriers in electric vehicle adoption is taken into account with some energy challenges of the developing countries like strain on utility grid, energy dependence on fossil fuels, and environmental challenges, reduction in GHG's. The various sizes of GCPV system for EVCS is designed for the Pakistan CPEC route section Islamabad to Lahore motorway under the economic, social, and environmental challenges. The EV estimated load modelling was developed by the Pakistan EV shift policy and the traffic information by the NHA of Islamabad Lahore motorway which is converted to energy load demand. The techno-economic effects were investigated with different GCPV system capacities under different weather conditions of Islamabad and Lahore. The optimal GCPV system in the initial stages of EV market is selected on the basis of the financial, economic and energy demand requirements. The 300 KW GCPV system initial investment cost of $194679 can be recovered in just 2.4 years which is a good payback period, LCOE at 3.11 ¢/kWh, 3.28 ¢/kWh and NPV $407,602, $407,180 in Islamabad and Lahore cases, hence this system is feasible and to develop the interest of the investors in this technology. This system is designed to have minimum effect of EV's energy load on the national grid of Pakistan. The much cheaper fuel price for EV's is achieved as compared to fossil fuel to develop the interest of consumers to shift toward EV's. The development in this EV charging infrastructure will kick start the EV's adoption in the transport sector of Pakistan. As EV market expands this system will have a positive impact on Pakistan's economy with respect to energy capacity payments. GCPV technology is urgently needed for the entire world's energy future problems, particularly in nations where the energy field condition is currently dreadful, such as Pakistan. This technology will not only aid in the reduction of fossil fuel use, but also in the alleviation of natural gas fuel shortages, particularly during the winter months, and in the country's green growth and in summerswill reduce the peak energy crises. This will result in reduction of GHG's emissions to meet the target of Pakistan in Paris Accord agreement.

5.2 Recommendations

The outcomes of this study demonstrate that using a GCPV system for EVCS might be a watershed moment for the country's fossil fuel savings and green growth. The recommendations for future work could be suggested as:

- Using the SAM software technique, this work may be expanded to include a study of GCPV systems for EVCS use on additional Pakistani highways and motorways.

- Artificial intelligence can be used to develop the electric vehicles charging demand on the motorways and EV adoption by the consumer.

- The Government of Pakistan must enhance GCPV system installation for EVCS and execute coordinated charging at all motorways and highway stations.

- The GCPV system for EVCS can be designed for the metro cities which have almost same climate as these cities have.

- Rooftop GCPV system can be designed for metro cities whose existing fuel stations which are surrounded by the buildings that have leased roof availability which can be used for the PV system to install.

- To improve governance, intelligent metering should be installed at each EV charging station to effectively control and maintain the power level while also providing an efficient payment system.

- Policies for selling power and subsidizing electric vehicle infrastructure: Government of Pakistan have a critical role in several elements of EV charging infrastructure, from regulation to public investment on charging infrastructure to providing subsidies.

- The developed system might vary the price of electricity and the location of the site, as well as the performance comparison. This would assist to find the optimal PV module for certain regions as well as the ideal position for the proposed system.

- For the sake of this study, a particular PV module was chosen, however other varieties such as polycrystalline or thin film might be employed. This would allow for a comparison of the costs of various solar PV installations.

- Rather than using simplified load models, a real EV charging profile may be obtained and utilized to estimate more precise energy generation, energy demand, and payback period in this study.

Acknowledgement

I am thankful to Almighty Allah who gave me strength and approach to compete this work. All respects are for the holy prophet Muhammad (PBUM) whose teachings are true source of success in both worlds for the whole mankind.

I would like to express my gratitude to Asst. Prof. Dr. Sehar Shakir, my MS thesis advisor, for being so kind and helpful at every challenging stage of work. I would like to acknowledge my guidance and evaluation committee members too: Dr. Adeel Waqas (Principal of USPCAE NUST), Dr. Nadia Shahzad (HOD Research at USPCASE NUST) and Engr. Abdul Kashif (Lecturer EET National Skill University Islamabad).

In the end, I pay my earnest gratitude with sincere sense of respect to my parents, aunt, sister, friends and fellows.

Techno-Economic assessment and model development for the Grid-Connected Photovoltaics Electric Vehicles Charging Stations at Existing Service Areas on the motorways in Pakistan

Talha Hussain Shah [a], Altamash Shabbir [a], Abdul Kashif Janjua [b], Adeel Waqas [a], Sehar Shakir [a*]

[a] U.S -Pakistan Centre for Advanced Studies in Energy (USPCAS-E), National University of Sciences and Technology (NUST), Sector H-12, Islamabad, Pakistan

[b] Department of Electrical Engineering Technology National Skills University, Islamabad, Pakistan

***Corresponding author:** sehar@uspcase.nust.edu.pk

Abstract

Global automobile industry is shifting toward electric vehicles (EVs) to reduce the detrimental environmental impact of fossil fuels, which emits 23% of greenhouse gases (GHGs) globally. Photovoltaic (PV) electric vehicle charging stations (EVCS) may contribute to significantly reducing GHG emissions. In this work, a cost-effective and green energy charging of EVs along the Islamabad-Lahore motorway section of the China-Pakistan Economic Corridor (CPEC) eastern route has been assessed under Pakistan's energy economics to facilitate long-distance EVs travel. An estimated EV load model was fabricated by using National Highway Authority (NHA) data for vehicular transits along the route. Using System Advisory Model (SAM), PV and utility grid models were integrated to explore the techno-economic feasibility of grid-connected photovoltaics (GCPVs) systems EVCS. The findings reveal that the 300 kW GCPV system for EVCS has the highest net present value (NPV) and the lowest Levelized cost of electricity (LCOE). The systems in Islamabad and Lahore, generate 461,802 kWh and 437,845 kWh of annual energy respectively. It has a payback time of 2.4 years, making the proposed GCPV system for EVCS economically viable. The findings demonstrate that integrating GCPV power with EVCS may permit investment, and long-term sustainability in the EV industry of underdeveloped countries.

Keywords:
Electric Vehicles
Greenhouse gasses
Grid-connected photovoltaic
Electric vehicle charging stations
System Advisory Model

Techno-economic Appraisal of Electric Vehicle Charging Stations Integrated with On-Grid Photovoltaics on Existing Fuel Stations: A multicity study framework

Talha Hussain Shah[a] , Altamash Shabbir[a], Adeel Waqas[a], Nadia Shahzad[a], Sehar Shakir [a*]

[a] U.S.-Pakistan Centre for Advanced Studies in Energy (USPCAS-E), National University of Sciences and Technology (NUST), Sector H-12, Islamabad, Pakistan.
*Corresponding Author: sehar@uspcase.nust.edu.pk

Abstract

The affordable transportation industry has been severely compromised in 2022 as a consequence of the unexpected surge in the price of fossil fuels. By 2050, the transportation industry is forecasted to expand twice, leading to a variety of issues, such as fossil fuels depletion and environmental emission. As the result, worldwide trend toward electrifying transport, with energy production originating from both traditional and carbon-free sources. Therefore, consumers of electric vehicles require convenient access to the services of charging stations around the country. This research investigates existing fuel station rooftops for the deployment of the grid-connected photovoltaic (GCPV) system electric vehicle charging stations (EVCS), design and performance analysis of Pakistan's cities. A mathematical model of the GCPV EVCS under consideration has been described. At three cities in Pakistan: Multan, Lahore, and Islamabad-EVCS powered by photovoltaics and the utility grid have been designed and their comparison of the techno-economic performance indicators have been done through System Advisor Model (SAM) software. To comprehend the impact of uncertainty on the functionality of the GCPV EVCS, sensitivity analyses were conducted at all three designated cities in Pakistan. With this strategy, Pakistan will be able to reduce its greenhouse gas emissions to the level required by the Paris Agreement. Furthermore, the synergy between GCPV power and EVCS may provide a new avenue for economic reward and innovative sustainability in the EV market of a developing country.

Keywords:
Greenhous Gases
Grid Connected Photovoltaics
Electric Vehicle Charging Station
System Advisory Model
Techno-economic Analysis