Renewable Energy for Electric Mobility: Assessing Energy Sources for Charging Infrastructure using Multi-Criteria Decision-Making Approach

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Abstract

Governments worldwide are aiming for 100% electric mobility as fossil fuel resources run out. Almost every country has announced its deadline to go 100% electric mobility as the existing fossil fuel resources get exhausted and leave our planet dry and void of traditional petrol and diesel. Manufacturers are developing new electric vehicles with long-term goals to become carbon neutral. However, achieving these goals requires addressing various obstacles, including the current capacity of existing grids and the availability of alternate energy sources. Several parts of the world still don't receive 24-hour electricity, let alone meeting the demands of upcoming EVs. Alternate energy sources must be recognized to supplement the excess energy requirement imposed by the newer EVs. However, no such single source of energy can be implemented to all regions of the world, as some parts of the world receive no sun fall to the contrary some parts receive abundant sun fall, while some regions may receive a high wind speed whereas some do not receive a good wind speed. Hence, we need to account for every condition to select the optimum technology for a particular location.   This paper uses real-life analytics to suggest which energy sources make sense economically, environmentally, socially, and feasibly in different regions. It also provides a framework for deploying charging stations with alternate fuels, addressing implementation challenges and economic considerations. The study presents case studies of successful RES-integrated EV charging stations and outlines future research directions for optimization and scalability.

Keywords: Renewable Energy Source, Electric Vehicle Charging Stations, MCDM, Green mobility

1. Introduction

In the coming years, our fossil fuels' existing reserves will be depleted, and many efforts have been put down to relax the usage of natural resources. A major innovation that aids this effort is the advent of electric vehicles. Electric vehicle has been around since 1832, but that was merely any good, however EVs became good in the recent years, but the question is the source of energy on which they run is electricity and do we enough of it to support the rising demands due to the shift from ICEs to EVs? Even if there is enough electricity, we would be getting it from coal. Which is again increasing our reliance on fossil fuels. Here we will discuss and suggest various sources of energy to complement the rising demands of

electricity due to the increase in EVs. The European Union has set a goal of reducing emissions by 55% from 2021 levels. Such a feat will be accomplished by switching from standard ICE-powered automobiles to electric ones. It is estimated that over 220 million EVs (Electric Vehicles) will be on the road by the end of this decade. By 2030, it will be 10 times as many as the 26 million EVs sold in 2022. [1]
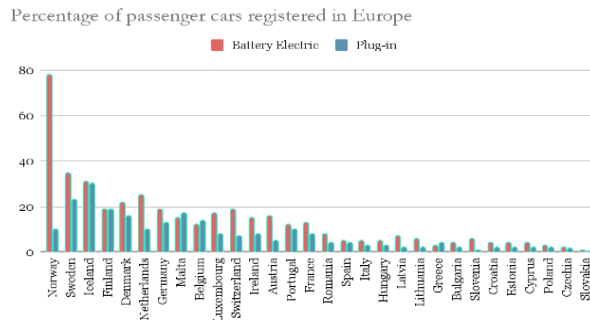
Fig.1. Percentage of cars registered in Europe

In 2022, the proportion of electric vehicles in new car registrations increased in all countries (EU-27, Iceland, and Norway) compared to 2021. The highest percentages were observed in Norway (89%), Sweden (58%), and Iceland (56%). Germany, France, and Norway accounted for around 64% of new BEV (Battery Electric Vehicle) registrations in the EU-27 and non-EU EEA countries. Norway had the newest BEV registrations in 2022, accounting for 79% of total new car sales. The highest percentage of PHEV sales happened in Iceland, Sweden (both 23%), and Finland (20%). In four European countries (Cyprus, Poland, Czechia, and Slovakia), EV registrations accounted for less than 5% of the total fleet [1]
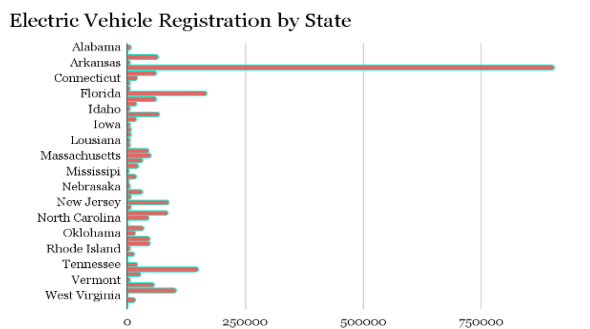
Fig. 2. Number of registrations of electric vehicles statewise

America's Federal government has set a goal to make half of the new vehicle sales in 2030 to have zero emissions vehicles. The American government also aims to develop a simple and fair network of 500,000 chargers to make EVs more accessible to Americans for both local and long-distance travel. [2]

When we talk about shifting towards Electric Vehicles, we must consider a case study to understand the trend in depth. For it we take India, an exponentially fast-growing country as our subject.

India aims to transition to electric vehicles such as buses to 40%, private automobiles to 30%, commercial vehicles to 70%, and two-wheelers to 80% by 2030, or 30% of the country's fleet to be electric [Niti Ayog]. The targets, however, may appear to be highly environmentally beneficial, but they may be overly

ambitious, because we do not know whether India's existing electrical infrastructure can satisfy the increased demand caused by newer EVs. This is especially true given that certain parts of the country still lack 24-hour access to energy. However, other fuel sources appear to help with such a situation. India, as a tropical nation, receives around 250-300 days of sunshine each year and has immense potential for solar power. Along with that, India's limits are surrounded by water on three sides, giving it a lot of wind power. Integrating these renewable sources of energy can serve as a support framework for our current thermal power plants, allowing them to fulfil increased energy demands in the next year. This article is to provide a clear picture in terms of Capex and OpEx of the suggested alternative energy sources, dispatchability, Levelized cost of energy (LCOE), efficiency, and viability of various proposals for integrating renewable energy sources.

A new analysis from Vahan Dashboard provides a quick comparison of several types of electric cars. These figures are the total number of electric cars on Indian roads, the amount of km they drive every day, and the consumption of each of these vehicles in terms of KWh/day.

Table 1 shows the data from the Vahan Dashboard, displaying the number of Electric powered vehicles of all categories on Indian roads as of December 2023.

Table. 1. Energy consumption per day of different types of EVs

Type of Vehicle (EV's)	Number of Units in market	Energy consumption (kWh/km)	Average usage of Vehicles	Energy consumed per day (kWh/day)
2-Wheeler	16,51,268	0.03 - 0.07	27-33 kms/day	1651268x0.03x30 = **14,86,141.2**
3-Wheeler	15,09,879	0.059 - 0.089	105 kms/day	1509879x0.07x105 = **1,10,97,610.65**
4-Wheeler	1,34,616	0.19 - 0.3	35 kms/day	134616x0.2x35 = **9,42,312**
Buses	5,926	1.15 - 1.66	160 kms/day	5926x1.45x160 = **13,74,832**

Total energy consumed by Electric Vehicles every day is **1,49,00,895.85** kWh. This energy is provided using charging stations. Each vehicle utilizes distinct types of chargers and the efficiency of it varies accordingly. Below provided table helps in identifying which type of electric vehicle uses which charger.

Table. 2. Types of chargers

Type of Vehicle	Type of Chargers used	Efficiency of Chargers
2-Wheeler	Level 2 AC	83-91%
3-Wheeler	Level 2 AC	83-91%
4-Wheeler	Level 2 AC/ Level 3 DC	83-91% / 86-92.6%
Buses	Level 3 DC	86-92.6%

So, since practically every car uses either a Level 2 AC charger or a Level 3 DC charger, charger efficiency may be 89%. To provide 14.9 GWh of electricity, the chargers must require 16.74 GWh from the grid. From the data obtained on The India Climate and Energy Dashboard (ICED), we obtain that the below provided losses takes place while transmitting power from the source to demand.

Table. 3. Types of losses due to transmission

Type of Losses	Amount (in%)
1. DC to AC Conversion	5
2. Step Up transformer for easy transmission	1-2
3. Transmission line	2-2.8
4. Step down transformer for distribution	1-2
5. Distribution line	2.5-5

Hence to obtain 16.74GWh of energy we will need to consider the above-mentioned losses, to obtain energy generation requirement using Solar or Wind.

So, 16.74/ (0.95*0.98*0.98*0.97*0.95) = 19.91GWh

After accounting for these losses, we arrive at a total energy need of 19.91GWh from the source. That indicates that charging 3.3 million automobiles per day would take around 19.91GWh of energy from any source.

2. Literature Survey:

For this research we have majorly scoured the government websites for the data. It is believed that the data available on these websites are not just random information but a comprehensive evaluated and authorized one, and hence being the most accurate that can be available to the general population.

The Literature survey is divided into 4 parts – 1) Information of Electric Vehicles, 2) Information of Energy Sources, 3) Information of EV Charging infrastructure, and 4) Site Selection Criteria

2.1. Information of Electric Vehicles:

Initially we began reviewing information regarding the sales and registration of Electric Vehicles across the USA and various countries in Europe. We observed that most countries across the globe have embarked on following the trend to shift towards a more sustainable future. This means the people of these countries opt for more electric vehicles instead of its counterpart IC Engine.

The EU saw a notable surge in the use of electric vehicles in 2022, particularly vans. Electric vehicles accounted for an astounding 21.6% of newly registered cars, over two million more than the 1.74 million registered the year before. Another notable increase in popularity was seen in electric vans, which made up 5.5% of all new registrations in 2022. In addition, the number of newly registered battery electric cars increased by 25%, while the number of plug-in hybrid vehicles stayed the same. It is interesting to note that in 2022, the bulk of electric van registrations were battery electric cars. [1] Yet, notwithstanding the remarkable strides witnessed in recent years, BEVs (Battery Electric Vehicles) constitute a mere 1.2% slice of the European automotive fleet. Thus, a concerted impetus toward further expansion of Europe's electric vehicle contingent stands imperative, not only to align with the EU's emissions reduction objectives but also to advance steadily toward the overarching aspiration of attaining climate neutrality by the year 2050.

The vehicle registration counts of all-electric vehicles by states are provided in a chart form, which clearly indicates that California has the greatest number of vehicles, approximately 37% of vehicles nationwide. Florida has the second highest count, followed by Texas. The federal government of the United States of America has set a lofty goal: by 2030, half of all new car sales must be zero-emission automobiles. To further improve American residents' access to electric vehicles and ease long-distance and local commutes, the government is working to develop a fair and simple infrastructure consisting of 500,000 chargers. [2]

In recent years, India has witnessed a notable surge in electric vehicle (EV) adoption, driven by increasing environmental awareness and rapid technological advancements. Government policies have also played a crucial role in facilitating this transition. With 2023 marking the second consecutive year of surpassing one million units sold, EV penetration has risen from 4.75% to 6.34% in just one year, with three-wheelers leading the segment at 53.75% penetration. Uttar Pradesh saw remarkable growth in EV sales, while Chandigarh emerged as a leader in penetration. Looking forward, forecasts indicate exponential growth in electric two-wheelers, but challenges remain for three and four-wheelers due to high upfront costs and inadequate charging infrastructure. Targeted interventions are essential to address these barriers and further accelerate EV adoption nationwide

2.2. Information of Energy Sources:

For this topic, we reviewed literature as well as websites for collecting information regarding energy sources like thermal, solar, wind and hydrogen fuel-cells. The information regarding efficiency, losses, classifications, economics, etc. was collected using websites and pre-existing literature.

Thermal power plants are vital for India's electricity generation, primarily using coal, natural gas, or oil as fuel to produce steam for turbines. Despite increasing focus on renewables, they remain essential for meeting energy demands. Concerns persist over environmental impact and air pollution, driving efforts to adopt cleaner technologies. Advancements like supercritical boilers enhance efficiency and reduce emissions. Government policies, such as the National Action Plan on Climate Change, promote sustainable practices (Government of India, 2008). Challenges remain in environmental compliance and transitioning to cleaner fuels.

The Indian solar power business has grown significantly in recent years, thanks to good geographic circumstances and government incentives. With plentiful sunshine around the year, India has the world's fifth largest solar deployment, with over 40 solar energy projects totaling at least 10 megawatts. In 2023 alone, the sector installed more than 10 GW of solar power, with 40 GW bids planned for the following year. Government incentives for solar rooftops have boosted adoption, with around 8877 MW of solar rooftops deployed across the nation. However, problems like PV conversion losses and soiling limits reduce total efficiency, which is currently approximately 20%. [2, 3]

India's wind energy sector has developed as a viable renewable energy source, owing to its extensive coastline and ideal wind conditions. By the end of 2023, the country's wind power capacity had reached 71.84 TWH, with substantial installations in Gujarat and Karnataka. Government efforts like the National Solar Mission and subsidies have boosted the industry's competitiveness and economic viability. However, aerodynamic losses and wake effects provide problems to increasing efficiency, affecting overall system efficiency, which ranges between 24.1% and 54%.

Hydrogen fuel cell technology became known as a cleaner and more efficient alternative to existing energy sources in India. Fuel cell power plants use hydrogen as their major fuel source, producing water as a byproduct, making them ecologically beneficial. Despite its benefits, activation losses and hydrogen crossing have a 60% to 82% influence on total efficiency. A thorough cost study demonstrates that, while

hydrogen fuel cells need more initial capital expenditure than solar and wind energy systems, operational expense stays comparatively cheap, making it a feasible long-term investment alternative. India's shift to renewable energy sources holds enormous promise for ensuring energy security and combating climate change, but overcoming technical obstacles is critical to realize the full potential of these technologies.

2.3. Information of EV Charging infrastructure

Charging infrastructure is the centroid of this research and hence it becomes more important to understand the basics of EV Charging Infrastructure. For this, we surveyed websites of organizations that work in setting up these systems. Also, we reviewed Government guidelines to plan and propose potential locations for EV Charging Stations in Indian states.

Types and levels of EV Chargers can be classified into 3 types: [4]

Table. 4. Input and output parameters for different types of chargers

Charger Type	Input Parameters			Output Parameters		
	Voltage	Current	Power	Voltage	Current	Power
Level 2 (J1772)	220-240 V	80-100 Amps	2.4 kW	240 V	10-30 amps	3-22 kW
Level 1 (J1772)	110-120 V	8-10 Amps	1.2 kW	100 V	10-30 Amps	1-1.8 kW
DC Charger (CCS)	480 - 1000	100-500 Amps	48 - 100 kW	110–900V	32-40 Amps	30-360kW

The Indian government regulates the EV industry through initiatives like the National Electric Mobility Mission Plan (NEMMP) and FAME India scheme. Bharat EV Standards set technical specifications for EVs and Charging infrastructure development is crucial for EV adoption in India, with public and private companies investing in it. Key players in the EV charging infrastructure market include Energy Efficiency Services Limited (EESL), Tata Power, and Bharat Heavy Electricals Limited (BHEL). Interoperability of public charging stations are mandated in India for seamless EV operation. [5]

The agreement includes terms related to the installation work, operating costs, system components, and the agreement's duration. The agreement emphasizes safety measures, compliance with laws, and customization options for EVSEs. It also mentions the projected adoption of EVs in the country and the need for urban development guidelines to align with the increasing EV market share. By emphasizing safety measures and compliance with laws, the agreement ensures a secure and regulated environment for the installation and operation of charging stations. Customization options for EVSEs, such as authentication and integrated payment gateways, enhance user experience and technological advancements in the charging infrastructure. [6]

3. Methodology

3.1. Stage 1: Realizing Energy Sources

When we perform research, we try to prepare models that would last at minimum 20 years, which means we need to look for a more sustainable future. This implies that we must consider alternative sources of energy that can be fruitful in the longer run.

There are several types of alternate energy sources like biomass, solar, wind, nuclear, hydro, etc. As for this research we have opted for 3 sources – solar, wind and hydrogen fuel-cell. We have briefly explained these sources and the reason for their selection.

3.1.1. Solar Energy Technology:

India, a tropical country, has over 40 solar power plants installed to produce at least 10 MW. The sector has seen significant growth, adding over 10 GW in 2023 alone. With ambitious targets of 40 GW tenders planned for 2023-24, India's solar power journey is far from over. With ambitious targets, supportive policies, and a thriving ecosystem of stakeholders, the sector is expected to play a crucial role in achieving India's energy security goals, mitigating climate change, and powering a sustainable future.

This being the reason, makes it crucial to select Solar as a major competitor among energy sources.

First, we need to understand what type of solar technology is available in the market. Only after that can we know the best technology that can be selected for optimized output. For this, we believe a flowchart would be a great way. Hence the below provided image is the flowchart of the same. [7]
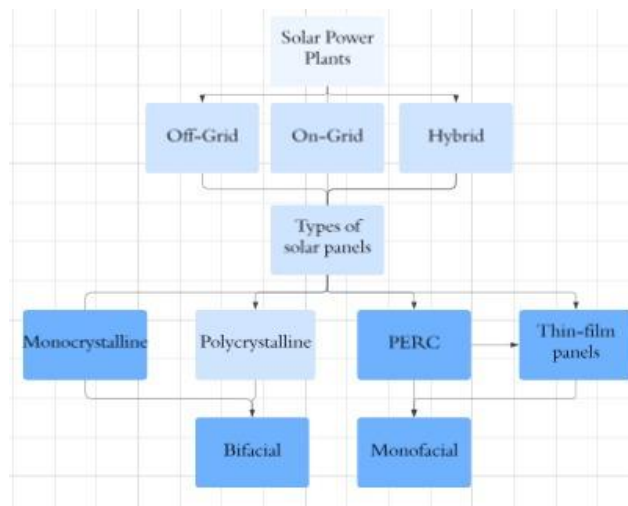

Fig. 3. Type of Solar power plants and panels

For this research we have proposed the following data for monocrystalline bi-facial technology. This technology is the most efficient one that is available in Indian market for commercial as well as consumer applications.

3.1.2. Wind Energy Technology:

India, with its water-covered borders, has significant wind power potential, with a wind power capacity of 71.84 TWH by the end of 2023. Major wind farms are in Gujarat and Karnataka, with plans for a 252 MW plant in Dwarka and a 2 GW plant in Gujarat's Khambhat. The Indian government has boosted wind power through programs like the National Solar Mission, subsidies, and simplified laws. Wind power has become a more competitive and economical energy source, providing a clean substitute for conventional fossil fuels, and reducing climate change and air pollution.

Now we need to understand what type of wind technology is available in the market. Only after that can we know the best technology that can be selected for optimized output. For this, we believe a flowchart would be a great way. Hence the below provided image is the flowchart of the same.
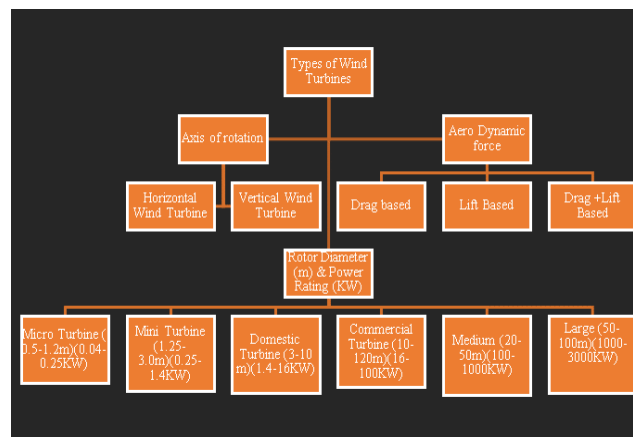
Fig. 4. Types of Wind Turbines

However, Horizontal axis wind turbines are more efficient than vertical wind turbines, therefore all utility scale wind power plants have horizontal axis wind turbines. Vertical wind turbines are also useful in some scenarios. [8]

3.1.3. Hydrogen Fuel Cell Energy Technology:

Hydrogen fuel cell power plants are a clean energy alternative to traditional sources, converting about 70% of input into useful energy. These fuel cells are highly efficient, reducing noise pollution and discomfort for nearby residents. They offer flexibility in fluctuating load demand and eliminate harmful pollutants like nitrogen oxides and particulate matter. However, proper storage and maintenance are crucial for their sustainability. Overall, hydrogen fuel cells are a promising alternative to traditional energy sources.

Table. 5. Types of hydrogen fuel cell

Fuel cell type	Temperature	Electrolyte	Efficiency (%)
PEMFC	60-140	Polymer	55
DMFC	30-80	Polymer	30
AFC	150-200	Potassium hydroxide	60
PAFC	150-200	Phosphoric acid	>40
MCFC	600-700	Li/K/Na carbonate	45
SOFC (+)	200-700	Barium cerate	40
Direct ammonia	400-700	Barium cerate	40

A hydrogen fuel cell plant has water as its major by product, which can be used by nearby civilians for household or even industrial purposes. The world's largest Hydrogen fuel cell plant located in South Korea touts a similar setup, where in, about 44,000 households use the hot water produced by the plant [9]

3.2. Stage 2: A comparison of diverse sources

Table. 6. Comparison of solar, wind and hydrogen energy

Sources	Criteria Efficiency (%)	Space Needed to make 19.91 GWh (in km²)	Generation (MWh/MW/year)	Capex ($)	OpEx ($)	Amortization of OpEx ($)
Wind (3MW on land *644 turbines)	24.1-54	4366.23	3775	3 Bil	81 Mil	200 Mil
Solar (100MW* 40 plants)	15-20	238.92	1460	8.4 Bil	204 Mil	506 Mil
Fuel-Cell (78MW*11)	75	4.5	8757.2	2.9 Bil	688 Mil	1.7 Bil

The above table is derived using data from [10, 11, 12]It is then changed according to Indian Standards for better understanding and ease of application.

As our planet strives for a sustainable future, the significance of renewable energy sources continues to grow. The leading contenders in this endeavor are hydrogen fuel cells, solar power, and wind energy, each boasting distinct advantages and disadvantages. Yet, how do they measure up in terms of performance and functionality when compared to one another.

Footprints and Amicability:

Land Utilization: Solar energy necessitates moderate spatial requirements, while wind farms encompass extensive regions. Hydrogen fuel cells manifest a comparably diminutive footprint when juxtaposed with the expanse of large-scale renewable installations.

Emissions: The triumvirate champions of clean energy all share the attribute of yielding zero emissions at the juncture of utilization. Nevertheless, the environmental ramifications of hydrogen hinge upon the specific method employed for its production. [13]

Within the Domain of Option:

The choice of the best technology depends on certain requirements. Solar shines when considering dispersed power generation and smooth grid integration. In the meanwhile, wind continues to reign supreme in the vast generation of power in windy locations. On a variety of dimensions, hydrogen fuel cells advertise themselves as suppliers of clean, flexible energy; but, to achieve wider adoption, infrastructural development and the relentless quest of cost reduction are crucial.

3.3. Stage 3: Site Selection Criteria

Table. 7. Criteria for site selection

Criteria	Sub Criteria
Environmental Factors	Air Quality: [14] Compliance with Air Quality Standards Waste Discharge:

	Proper Drainage Systems
	Waste Water Treatment Facilities
	Compliance with Environmental Regulations [15]
	Fine particles emission reduction
	Destruction Degree on Water Resources: [16]
	Impact on Aquatic Ecosystems
	Groundwater Contamination Risk
	Water Resource Sustainability
Technical Factors	Reliability and Redundancy of Power Supply: [15]
	Frequency of Power Outages
	Availability of Backup Power Sources
	Infrastructure Compatibility: [17]
	Compatibility with Smart Grid Systems
	Grid Capacity for EV Load
	Charging Technology: [18]
	Battery capacity and range of current EV Models
	Charging Speeds (Fast, Standard, Slow)
Economic Factors	Return on Investment (ROI):
	Construction cost
	Operation and maintenance cost
	Investment payoff period
	Operational Efficiency:
	Remote Monitoring and Maintenance [14]
	Financial Incentives and Subsidies:
	Availability of Government Subsidies [19]
	Tax Benefits for EV charging Infrastructure
Social Factors	Public Perception and Acceptance
	Measurement of population density
	Traffic convenience
	Service level [14]) in future
	Attitude of residents
	Local authorities support
Engineering Feasibility	Distance from the Substation
	Influence on the Power System of surrounding areas [16]
	Availability of Resources
	Grid connection feasibility [18]
	Topography

India's vast and varied landscape presents a unique challenge when it comes to choosing a single, reliable energy source. The solution lies in a multi-pronged approach, utilizing different options in different regions. Solar power might be ideal for sunny deserts, while wind farms could thrive in coastal areas. For densely populated cities with growing electric vehicle (EV) demand, strategically placed power plants could be the answer. The good news is that researchers are making strides in creating a robust

infrastructure for EV charging stations (EVCS). This involves cleverly combining renewable energy sources with well-placed charging points. The goal is an eco-friendly and self-sustaining EV network that not only benefits the environment, but also strengthens the power grid and reduces overall pollution. To make informed decisions about EVCS placement, it is vital to establish clear selection criteria. These criteria should guide resource allocation, adaptation to changing circumstances, and risk management. Analysts can then use these factors, along with different models, to optimize results and ensure the system can grow and adapt as needed.

3.4. Stage 4: Understanding geographical situation

The classification of cities must be done to understand the power needs and set up the stations accordingly. The classification will be based on the population density so the power requirement could be carefully assessed, the cities are classified into three categories as described: [20]

Tier 1 city (Metropolitan cities): These are cities with a population of 1,000,000. These cities also have a higher income rate, due to which more people prefer to commute with private vehicles which tend to have higher congestion on roads. So, a plan that encompasses building parking spaces integrated with charging stations and solar or hydrogen fuel cell-based infrastructure may prove to be an especially useful prospect for the future.

Tier 2 city (Urban centers): Tier 2 cities have less population than tier 1 cities, typically less than 1,000,000. These cities have fewer high-rise buildings due to which the dispatchability of wind turbine proposition might be higher as fewer buildings would be slowing down winds. Solar and hydrogen fuel cell propositions can also be considered as larger areas of land would be available since population density in such cities is lower.

Tier 3 city (Semi urban and rural centers): These cities are known for the least population density when compared to others, this is due to lack of opportunities. This results in the availability of large land areas particularly used for agricultural purposes. These land patches can be used in multiple ways (either by placing solar farms or wind farms or even by building hydrogen fuel cell plants) to provide energy to the cities as well as the charging stations to other nearby areas.

3.5. Stage 5: Site Selection Process

In this stage, the methods that can be used for best site determination are considered. Many studies have shown the use of Multiple Criteria Determination Method (MCDM) with either Hexagonal Fuzzy or use of Geographical Information System (GIS) and Analytical Hierarchy Process (AHP). For this study, we have opted to use GIS, MCDM and Stochastic Multi-Criteria Acceptability Analysis (SMAA). This will provide a detailed study as well as a robust MCDM model. The steps to achieve this is given below:

1. Criteria Selection
a. Population Density
b. Geographical Situation
2. Method Selection
a. MCDM, GIS
3. Tier Division
a. Using GIS and data from Geographical situation
4. Data Collection
a. Data of solar irradiance, wind potential and fuel cell availability
5. Data Normalization
6. Pairwise Comparison

a. Use of weighted scoring to compare data
7. Data Aggregation
8. Robustness check
a. Use of SMAA to check the robustness and ensure the sensitivity
9. Communication and Implementation
a. Communicate the results to relevant stakeholders, such as local governments, utilities, and EV manufacturers.
b. Implement the site selection recommendations to improve the EV charging infrastructure in India.
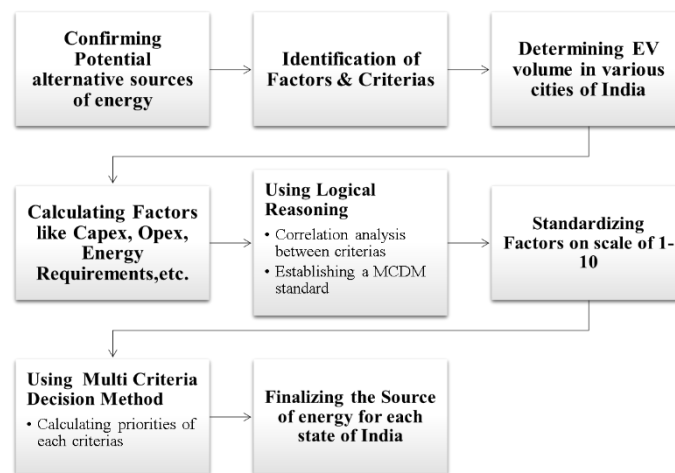

Fig. 5. Site selection procedure

3.6. Stage 6: Rules for EVCS

When we talk about planning and selecting sites for Electric Vehicle Charging stations, we need to first prepare some rules and regulation guidelines, which need to be followed by anyone interested in setting up one.

Now, as for India, the Ministry of Power (a government body) through Bureau of Energy Efficiency (BEE), has initiated a few energy efficiency initiatives and acts to regulate the EVCS demand. A specific document consisting of guidelines and specifications for charging station infrastructure, helps us lay the foundation work for optimistically selecting sites for charging stations.

For basic Public Charging Stations (PCS) the guidelines that are supposed to be complied with are: [6]

- At least one charging station shall be available in a grid of 3 kms x 3 kms.
- At least one charging station on each side of highways/roads at a distance of 25 kms.
- At least two charging stations (Fast/ Super-Fast) for heavy duty EV's on each side of highways at a distance of 100 kms.
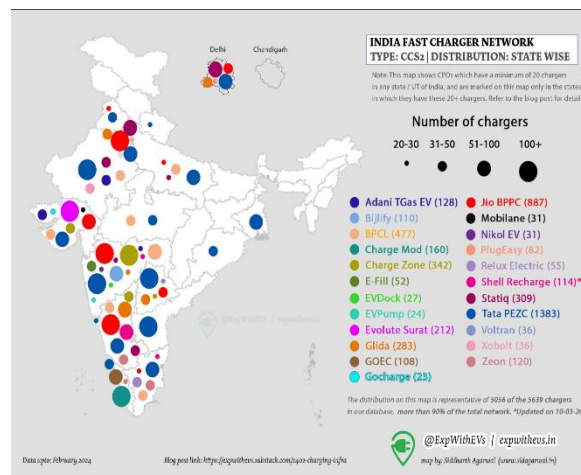
Fig. 6. India's charging network

The above image represents the EV Charging stations across India. It typically represents the volume, or the number of charging stations (inform of distinct size circles) provided by various companies across India.

Now, once we know the guidelines by the government and major charging station providers, we must select locations for the placement of new ones. As the data related to cities is not available, hence we must layout general idea for the location of the stations. The objective entails establishing a comprehensive network of EV charging stations that provides convenient and dependable access for electric vehicle proprietors, thus fostering the embrace and utilization of electric vehicles. Here are some key considerations:

- Accessibility and Visibility
- Proximity to High-Traffic Areas
- Parking Convenience
- Safety and Security
- Amenities and Services
- Strategic Infrastructure
- Collaboration with Local Stakeholders

Now as for location, keeping the above-mentioned considerations in mind and suggesting some open for all easily accessible location, these below mentioned ones can be considered:

- Shopping Malls
- Grocery shops and Marketplaces
- Airports
- Hotels and Restaurant Parking
- Public Parks and Gardens
- Parking Garages and parking lots
- Gaps under Flyovers
- Vacant Government lands

Incorporating readily accessible charging hubs, individuals owning electric vehicles (EVs) can confidently navigate through their daily routines, embark on extensive voyages, or luxuriate in recreational pursuits, all while being assured of dependable charging amenities.

The accessibility and availability of such charging infrastructure assume a pivotal role in the burgeoning acceptance of electric vehicles, emblematic of a change in basic assumptions towards eco-conscious transportation alternatives. Enlarging the grid of EV charging hubs in these strategic locales empowers us to fortify and incentivize the transition towards sustainable mobility, concurrently addressing the evolving needs of EV operators.

3.7. Stage 7: Example of the procedure

Multi Criteria Decision Making (MCDM) has been applied to determine the best alternate source of energy in this study. As considering charging station in Indian cities becomes impossible due to lack of information regarding geographical data. Hence a general standardization and scaling based on factors like Capex, OpEx, Environmental, Efficiency, etc. is provided below.

Table. 8. Demonstration of MCDM

Factors	Wind	Solar	Fuel Cell	Hybrid
Capex	7	2	7	5
OpEx	9	6	2	6
Efficiency	5	3	10	6
Losses	4	2	8	5
Environmental	8	9	7	8
Social	9	9	6	8

There are several other factors required to conduct MCDM, these factors are harnessed by processing data related to land requirement, land availability, grid penetration factors etc. These data are more reliable in case of a county in United States like San Francisco, California. California shares, a lot of cultural diversity and environmental resemblance, with India. Hence, we will provide an MCDM example focusing on the above-mentioned location.

Table. 9. Weightage for different criterion and MCDM for the California

State :-		California							
	Weights	Wind	Solar	Hydrogen	Hybrid (35% Solar, 45% Wind and 20% Fuel Cell)	Weighted Wind	Weighted Solar	Weighted Fuelcell	Weighted Hybrid
Capex	0.15	1	1	1	1	0.15	0.15	0.15	0.15
Opex	0.15	1	1	1	1	0.15	0.15	0.15	0.15
Area required	0.05	1	1	1	2	0.05	0.05	0.05	0.1
Ev Density	0.1	10	10	10	10	1	1	1	1
Environmental	0.3	8	9	7	10	2.4	2.7	2.1	3
Social	0.05	9	9	6	9	0.45	0.45	0.3	0.45
Grid Penetration	0.1	8	6	2	7	0.8	0.6	0.2	0.7
Land Available	0.1	8	8	8	8	0.8	0.8	0.8	0.8
Output	1	5.428571	5.285714	4	5.714286	0.714286	0.728571	0.564286	**0.792857**

4. Results and Discussion:

The MCDM approach has yielded a set of results that suggest specific alternate sources of energy for specific states of India. We considered numerous factors as a part of analyzing the prospect and compiled them in an excel sheet as shown in the figure below.

Table. 10. MCDM for the state of Gujarat state

State: -	Gujarat		
	Wind	Solar	Hydrogen
Capex	3	2	3
Opex	4	4	2
Area required	3	3	2
Ev Density	9	9	9
Environmental	8	9	6
Social	7	9	6
Grid Penetration	8	8	1
Output	6	6.285714286	4.142857143

These factors have been analyzed for every state of India, and for California. The output is basically the average of all values that has been allotted to each factor for every source of energy. The values have been allotted such that if a certain source of energy involves an extremely high capital expenditure, then the value allotted to it will be 1 and if it is extremely low it will be allotted 10. These values are allotted according to the scale that we created which compares all the states for the sources of energy and each factor associated.

Table. 11. Scaling for a few states in India

The scaling has been done based on detailed data of how many EVs have been registered, how much it would cost to run, and set up the plants, what would be the environmental impacts, how well it will be received among the civilians and grid penetration. All these factors do not hold equal weightage so a brief sheet displaying the weights was created.

As far as the weights that have been allotted are concerned, these are purely personal interpretations of the necessity according to the region. This may vary from country to country, state to state. For this example, we chose the weights as Capital Expenditure and Operational Expenses as 15% each. While we chose Environmental factor holding 30% weightage because these technologies have high impact on environment in the above-mentioned location.

For California, capital expenditure and operational expenditure are the highest. Hence, they are allotted the value of '1'. The EV density is lower; hence a number 10 is allotted. The amount of land needed to set up such power plants is massive because the electricity demand is high, as a result a higher capacity plant will be needed. On the opposite side the area available to set up plants is ample in the Saint Bruno region. The results can be shown by the last row, in which the energy source with the highest value is considered the most optimum solution. From the above table, hybrid technology is better in terms of all factors combined. Therefore, for the state of California hybrid technology with 35% solar supply, 45% wind supply and 20% hydrogen fuel cell supply is suggested.

Similarly, a state of India is considered, for example Uttar Pradesh,

Table. 12. MCDM for Uttar Pradesh state

State: -	Uttar Pradesh		
	Wind	Solar	Hydrogen
Capex	1	1	1
Opex	2	1	1
Area required	1	1	1
Ev Density	10	10	10
Environmental	7	9	6
Social	8	9	6
Grid Penetration	6	7	1
Output	5	5.428571429	3.714285714

Since, some data for hybrid technologies have not been available, it is not possible to conduct a study in that area for Indian states, however three main energy sources wind, solar and hydrogen are considered. Data for land available in the most recent year is not available and hence, it has not been considered.

Uttar Pradesh shows similar characteristics to California, but if we do not consider hybrid technology as a choice for California, we have wind energy as the next best solution, while for Uttar Pradesh it tends to be Solar energy. The major reason for this difference is because of the higher values for environmental, social, and most importantly grid penetration factors.

5. Conclusion:

The study focuses on real-life analytics to determine economically, environmentally, socially, and feasibly suitable energy sources for EV charging stations in India. It emphasizes the importance of considering factors like capital expenditure, operational expenditure, social factors, grid penetration, EV Density, and environmental factors in decision-making. The research provides a comprehensive framework for deploying charging stations integrated with Renewable Energy Sources (RES) while optimizing their location for maximum efficacy and environmental impact reduction. The paper discusses the challenges, regulatory frameworks, and economic considerations for the widespread adoption of RES-integrated EV

charging stations. Case studies of successfully implemented RES-integrated EV charging stations are presented, along with future research directions for optimization and scalability.

Different geographical conditions in India require planning for various sources of energy generation, such as solar power, wind power, and hydrogen fuel cell plants. Power plants can be developed in metropolitan cities to cater to the higher population density and increased energy demand for EVs. Transmission losses may occur when developing energy power plants in regions farther from urban regions. Stage-1 discusses dissimilar sources of energy that can be utilized to meet the rising demands of energy due to EVs. Solar, wind, and hydrogen fuel cells are the propositions that can be followed to avoid higher loads on our existing power supply grids. The current potential of all such sources is different, along with varying qualities like efficiency, output, and cost derivatives like Capex and OpEx. Based on these factors, a detailed comparison is provided in Stage-2 which helped determine the best alternate energy source. These sources of energy can be installed anywhere across the country and the energy can transmitted to any corner of the country, however careful considerations in stage-3 determine the factors like social, economic, environmental, technical, & engineering feasibility that will aid to fix the locations. Along with these factors come several geographical considerations that need to be addressed. The government of India has classified the cities into 3 categories: Tier-1, Tier-2, and Tier-3. These cities are classified by population and thus would help us determine the frequency of charging stations to be planted in a certain region. The certain locations on which these charging stations need to be planted must be determined by incorporating the use of certain methods and algorithms, after gathering data related to the source of energy. These methods, algorithms and models are very crucial for the project, which have been noted down under Stage-5. With the basic rules and guidelines from the government of India, the general location for Public EV Charging Stations is proposed under Stage-6. The final stage of MCDM/MCDA to select the best energy source for each state of India and an example of California, US to provide fundamental knowledge of the functioning of the method is bestowed in Stage-7. For every state in India Solar power comes out to be the best source of energy because of the geographic location of India.

6. Future Scope:

Even after concluding this research, we still believe that there is a scope for more research on this topic. The future in respect to the site selection of EV Charging Stations in India holds a vast pool of relatable research. The following list provides options for future research.

- **Optimizing the "Energy Efficiency" of the energy generating technologies as well as energy consuming technologies.** - There are several technologies involved in the energy sector which may need more research to be optimized for higher efficiency and lesser losses. Like preparing new types of solar panels or even highly efficient wind turbines. Energy efficiency can help to reduce greenhouse gas emissions and promote the transition to a low-carbon economy, while also providing economic benefits such as cost savings, etc.

- **Capacity determination of Charging Stations considering dynamic nature as well as uncertainty of consumer usage**. - This could involve developing models that incorporate road network topology, actual traffic conditions, and capacity constraints of the distribution network, as well as simulating users' travel processes to obtain the spatiotemporal distribution of EV charging load. This could involve using techniques such as adaptive simulated annealing particle swarm optimization algorithms to solve complex optimization problems.

- **Development of data and analytics tools to support EV charging stations. -** This could involve developing models and algorithms that analyze large datasets to identify trends, patterns, and opportunities for optimization, as well as developing visualization tools that help stakeholders understand and interpret the data.

- **Technological Integration and System Inter-Operability. -** This could involve analyzing existing policies and regulations, identifying gaps and challenges, and proposing new policy and regulatory measures to support the integration of renewable energy sources into the EV charging station infrastructure as well as exploring ways to ensure compatibility and interoperability across different systems and technologies.

- **Financial Model and Investment Analysis. -** Investigating various income sources, such as pay-per-use, subscription-based, and advertising-based models, as well as the possibility of indirect revenue generating, might be part of this. It can also include analyzing the initial capital costs, operating costs, and potential revenue streams, as well as the potential savings in energy costs and grid reinforcement costs.

- **Site Selection for EV charging stations in cities, villages, and towns with less or no grid connection using GIS. -** This could include more comprehensive research and model formation for the deployment of EV charging stations in small cities, villages, and towns. This might involve selecting stand-alone energy generation systems with proper infrastructure for regular operations.

- **Customizable and Sustainable Charging Solutions -** Future research can explore the development of customizable and sustainable EV charging solutions like Tata Steel Nest-In's Charge Nest, which offers robust, durable, and environmentally friendly charging stations that can integrate renewable energy sources like solar panels. This aligns with the growing need for sustainable infrastructure in Indian cities

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