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Optimal Model to Setup Charging Infrastructure for Commercial and Domestic Electric Vehicle Charging Station in Bengaluru Urban

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Abstract

Background: An accessible network of Electric Vehicles (EVs) and Electric Vehicle Charging Stations (EVCS) lead an ambitious transition in mobility sector of India. Moreover, India is not one among the frontier countries in EVs. *Methods*: The research is designed to adopt strategies by benchmarking from developed countries through Data Envelopment Analysis. An arrangement to find the optimal number of commercial CS based on the demand is obtained by forecasting the sales of EV through Exponential Triple Smoothening model. Further, the supply is validated through Sensitivity analysis by considering the utilization factor of EVs. For the Domestic CS, a gravity model is utilized to allocate facility points for EVCS by considering supply from substations of BESCOM and demand from estimated population in Apartment block areas of BBMP. *Results*: India is only 2% efficient when compared to Finland. The number of EVs to be registered in the next 4 years at Bengaluru Urban is 4,96,299 units. In May 2026 at 10% utilization of EV, the required number of CS shall be 492. At 70% utilization of Electric Vehicle, it will be 3440 charging stations. *Conclusions*: In summary, an optimal model to setup charging infrastructure for Commercial and Domestic EVCS is put forward.

Keywords: Utilization Factor; Exponential Triple Smoothening; Sensitivity Analysis; Data Envelopment Analysis; Gravity Model

1. Introduction

The study deals with the development of an optimal model to set up charging infrastructure for Commercial and Domestic EV Charging Station in Bengaluru Urban. The innovation in technology has led to a change of trend in the automobile sector [1], Electrification of automobiles is drastically increasing in both developed and developing countries. The EV sales projection for the next decade as the global leaders and automakers are willing to create a healthier environment for the future by opting to eco-friendly products which enhances the livelihood of the future generations [2].

Authors have provided a systematic review and framework of integration of charging behavior with infrastructure planning of electric vehicles [3]. The framework can capture intricate supply-demand dynamics and assist strategies for designing the infrastructure for EV charging, providing a road map for both developing and established EV markets. Further study evaluates the functionality of the charging system and there are lot more issues to focus on to develop a reliable Direct Current Fast Chargers and addresses the reliability of the DC fast charges [4].

Authors have expressed that automobiles contribute to a larger scale of pollution in nature [5]. For this purpose, the automotive industry is moving to alternate modes of transport over IC engines. EV presents a chance to displace fossil fuels and reduce its dependency to attain a sustainable transport system [6]. The transition to EVs in India is being driven by a need to reduce air pollution, lower the cost of oil import, and increasing the nation's energy security [7]. The deployment of EVCS is a key infrastructure to operate EVs envisaging evolution of EV industry in terms of EV sales [8]. Researchers demonstrated charging infrastructure and pricing of EV are the main factors which play a greater role for EV adoption by consumers. To maintain robust EV demand, automakers are making significant investments in EV innovation. India registered around 12 million EV sales by the end of 2021. To match international benchmark, the nation must install 46,000 public Electric Vehicle Charging Station by 2030 [9]. To set up charging stations, it is important to have a better strategy to allocate and install charging points. As the sales of EVs are increasing, people now want their EV to get charged in a limited time. Indians are particularly interested in the fast chargers [10]. Coming to slow chargers, it is like a charger we use at our home. Most EV users charge their vehicle in their home. Around 75% of the users charge in their home, which is now expected to decline to 40% by 2030 [11]. It takes more than 3 hours to charge a 40 KWh battery with an AC charger. In future, people may depend on public electric chargers. The question that arises is whether the EV ecosystem has enough Public Charging Stations (PCS) in India. Moreover, India is well-positioned for innovation and quick EV adoption in the future is inevitable due to significant pollution from automotive sector.

DEA approach provides opportunities for analysts and decision makers in addressing '*what-if*' questions. This extends to benchmark *what-if* actions of competitors as well. As a result, identifying the potential competitors to benchmark is required considering their performance in the EV segment [12]. Earlier researchers studied how to determine the efficiency of Decision-making units (DMUs) to understand the output behaviors [13]. The efficiency of DMUs with variable Return-To-Scale (v-RTS) was considered for the analysis. Other analysis of DEA with constant Return-To-Scale (c-RTS) with an output-oriented approach of model. C-RTS has a proportionate increase in outputs for output-oriented models and decrease in inputs for input-oriented approach. Here, specialists utilize steady re-visitation of scale to assess the effectiveness and presume that there ought to be an improvement in the EV charging networks to accomplish productivity in all the DMUs [14]. A two-stage DEA technique aimed at increasing the market share of Battery Electric vehicle (BEV). The model uses an output-oriented approach with a c-RTS considering the BEV adoption from annual date 2010 to 2018 of 20 European countries. Efficiency of 20 DMUs (Countries) is determined first, and the role of electric mobility is addressed utilizing fractional regression model [15]. Researchers concluded that the efficiency to be increased by using electricity from renewable sources in the Country.

To provide better guidance, Government of India along with Ministry of Power (MoP) released guidelines related to EV charging infrastructure, density of distance regarding placement of PCS to have at least a single PCS charger within 03 sq km grid in urban areas for commercial purpose. For residential purposes, guidelines were released for private charging at the building premise levels for individuals who are interested in installing. Standalone Battery Swapping guidelines were also released by GOI [16].

In this phase, the motivation for the projects is listed below:

Pollution: Considering the rate of air pollution in the prominent cities of the world, the regional Governments are promoting EVs to lower the rate of air pollution. India's capital Delhi citizens have witnessed the peaks of air pollution which created smog for days impacting visibility and the air quality was worsened as the air quality index had reached to 189 [17].

Energy Desirability: Demand for fossil fuels is increasing which in turn increases the prices of fossil fuel and that adds to the change in trends of the consumer buying behavior towards the EV. Further, EVs operational cost are less compared to the operational cost of the IC engines which are operated by fossil fuels like petrol and diesel. Chances of scarcity of non-renewables resources are high whereas it is not the same with renewable resources [18].

Futuristic View: The EV makers in India are considering setting up the charging infrastructure across the Country as both State and Central Governments are promoting Consumers as well as OEMs by providing subsidies and waivers in tax to encourage the EV sales [19].

The distribution of EV by 2030 shall be 30% for 4-wheeler classification, 70% for business vehicles and up to 80% for two and three-wheelers class. Author briefs on the interest factor with changing capacity to charging stations. With slow expansion in EVs, the requirement for the charging framework is expanding quickly. The absence of material and information accessibility involves a test for the States and the Merchants to estimate the proper expansion and demand for renewable energy [20]. The flood of EVs might require an improvement in framework fortifications. However, these can be decreased and streamlined by a blend of new devices, advances, and methodologies, for example, the organization of solar PV age coordinated with collected energy capacity frameworks [21]. Authors provide an understanding on decarbonizing street cargo transport. In European Association intends to construct a quick charging network for trucks. European roadways have charging stations at normal spans of each 50 or 100 km along the main highways [22].

An accessible network of EVs and EVCS leads to achieve an ambitious transition in India towards mobility. Whereas there is a lag in the EV market which is holding it back and affecting the growth of the EV market. Few of the challenges are as follows:

- Lack of coordination with the OEMs and Government
- Scarcity of the resources
- Lack of technology and innovation
- Inadequate infrastructure
- The buying behavior of consumers is unpredictable.
- Change in EV technology and fluctuation in global market is high.

The next section highlights commercial Charging Stations.

1.1 Commercial Charging Station Point of View

As of January 2022, the total number of EV's registered in India across all categories stood at 9.66 lakhs, stated by Parivahan Sewa and Vahan dashboard [23], an official website of the Ministry of Road Transport and Highways, India [24]. The key problem addressed was the sale of EVs which is drastically increasing year by year whereas the charging infrastructure was not in parallel. The problem statement addresses uncertainty in the supply end addressing what would be the requirement of charging stations with respect to the demand of the EV. Considering Bengaluru as the EV hub for its potential market, the study was to identify the demand and the sale of EVs were considered with respect to supply side. In addition, the utilization was considered to determine the optimal commercial charging stations for Bengaluru Urban.

1.2 Domestic Charging Station Point of View

The main challenge EV sector is facing is to place the charging stations based on demand of EVs in urban areas with good infrastructure planning. Previously researchers have proposed approaches to address the EV demand uncertainty to identify the required number of EVCS. The geographical areas with a high density of EVs or high charging demand benefits to a greater extent with level 3 DC charging in the transportation network [25]. 'Range anxiety' is one of the main problems caused in allocation of charging station location when considering the demand uncertainty [26]. In India to install a DC charging station, it requires space for the infrastructure and expensive compared to AC charger. Working EV owners in apartment buildings or detached homes are likely to depend on DC charging stations located in public & workplaces because it is expensive to install a DC charging station in homes and apartment buildings. When public charging stations are provided to these EV owners, there might be a shift in charging behaviors from home to public chargers [27]. Therefore, installation of 50 KW DC chargers near multi-family Units, Apartments, and Workplace areas in Bengaluru can solve the problem of range anxiety and encourages EV usage.

In summary, an optimal model to setup charging infrastructure for commercial and domestic EVCS is proposed for Bengaluru Urban. An optimal network for EV and Electric Vehicle Charging Station can lead to the transition of urban mobility in India. This study contributes to the existing literature by addressing the gaps in the EV market by benchmarking with developed and developing Countries. Results reveal that India is not one among the frontier countries and there is a huge scope to setup EVCS to boost EV sales.

2. Methods and Methodology

2.1 Data Envelopment Analysis

DEA approach provides opportunities for analysts and decision makers in addressing '*what-if*' questions. This extends to benchmark *what-if* actions of competitors. As a result, identifying the potential competitors to benchmark is required considering their performance [12]. The study evaluates the efficiency of Countries (DMUs) considered with the highest market share of EVs and who have publicly available EVCS considering the real time data as on 2021 [28]. The top countries with the highest market share of EVs are considered along with India as one among DMU. Further, DEA analysis makes an ideal approach for India to find an efficient frontier with a good operational plan related to EVCS.

DEA is a non-parametric technique which estimates technical efficiency to identify a frontier. The identified frontier is used as a standard benchmark for other observations representing the performance entities that are to be evaluated. DMUs are used as such entities for evaluating the efficiency utilizing similar inputs to produce similar outputs. The performance scores will have a range from 0 to 1 in the resulting evaluation which also represents the 'degree of efficiency' from the evaluated DMU entity. The amount of efficiency is determined from each input and output for every DMU. The common measure of efficiency is provided by input/output which is also used to obtain a single-output to single-input ratio. But when there are multiple outputs and multiple inputs, it becomes complicated to draw the efficiencies. For this reason, DEA approach uses basic CCR model for multiple outputs and multiple inputs [12]. The CCR model is named after its developer Charnes, Cooper and Rhodes. With the CCR model, the overall efficiency can be calculated for each DMU in need of n optimizations. A single value is obtained aggregated with both pure technical efficiency and scale efficiency. If DMUj is to be evaluated, DMUo is the trial designated where '0' ranges 1, 2,….n. The objective function is solved using fractional linear programming to obtain input (vi) and output (ur) weights. Linear function is obtained from the original objective function, because only in linear form, the DEA solver tool can determine the solution. In order to find the weights, ratio uses maximization linear programming, and it should not exceed 1 for any of the DMU.

$$\text{Virtual input} = v_1 x_{1_0} + \cdots + v_m x_{m_0} \quad (1a)$$

$$\text{Virtual output} = u_1 y_{1_0} + \cdots + u_s y_{s_0} \quad (1b)$$

$$(\text{FP}_0) \qquad \theta = \frac{u_1 y_{1_0} + u_2 y_{2_0} + \cdots + u_s y_{s_0}}{v_1 x_{1_0} + v_2 x_{2_0} + \cdots + v_m x_{m_0}} \quad (2)$$

$$\text{Subject to} \quad \frac{u_1 y_{1_j} + \cdots + u_s y_{s_j}}{v_1 x_{1_j} + \cdots + v_m x_{m_j}} \leq 1 \ (j = 1, \ldots .\text{n}) \quad (3)$$

$$v_1, v_2, \ldots, v_m \geq 0 \quad (4a)$$

$$u_1, u_2, \ldots, u_s \geq 0 \quad (4b)$$

The ratio of optimal weights (v*, u*) for the DMU$_0$ determines the optimal solution (5) and the ratio is given by,

(FP$_0$) $$\theta = \frac{\sum_{r=1}^{n} u_r y_{r_0}}{\sum_{i=1}^{n} v_i x_{i_0}} \quad (5)$$

Maximize $u_r y_o$

S T constraints

$$v_i x_o = 1 \quad (6)$$

$$-v_i X + u_r Y \leq 0 \quad (7)$$

Where $v_i \geq 0$ and $u_r \geq 0$ (8)

TABLE 1: Input and Output Decision Variables

Decision Variables	
Inputs	**Outputs**
Total Land Area (sq km)	Charging Stations for 3 Sq Km
Available Charging Stations	Number of Charging Stations for 1000 EVs
Total Number of EVs	

For multiple inputs and multiple outputs, efficiency and DEA frontier are found using DEA solver. DEA frontier drives Excel Solver as an engine to solve DEA models. Variables are chosen based on the total percentage share of EVs in that Country because the studies relating to EVCS show that the Country with maximum number of EVs can have a good number of charging stations installed to support EVs. The inputs and outputs considered for the study are shown in Table 1.

Total Land Area: Land Area measured in square kilometer (sq km) of each DMUs/Country (excludes other area of inland water bodies (major rivers and lakes)

Available Charging Station: Each country has an active network of public charging stations which are installed and available as on 31st December 2021 [28].

Total Number of EVs: Sale of EVs in each Country is one of the important DMU accounted for Inputs.

Charging Stations for 3 sq km: In 2018, the Ministry of Road Transport & Highways passed an amendment aiming to install one EV charging station for every 3 sq km in urban areas by 2030 [16].

Number of Charging Stations for 1000 EVs: To foster decent charging stations, it is essential to know the proportion of number of accessible charging stations to each 100 or 1000 EVs.

The considered decision variables compare information from many countries available online. To maintain consistency, data for each variable was collected from a single source of websites pertaining to that Country, Automotive Publications, and the Government Websites.

2.2 Commercial Charging Stations

2.2.1 Conceptual Framework

The research flow is formulated into a conceptual framework to arrive at an optimal number of charging stations by evaluating the constraints step by step to forecast the EV sales demand. Later, sensitivity analysis is conducted on the supply side with different variables to arrive at the final stage where the results from demand and supply side are validated. Figure 1 depicts the conceptual framework for attaining optimal number EV Charging Station.

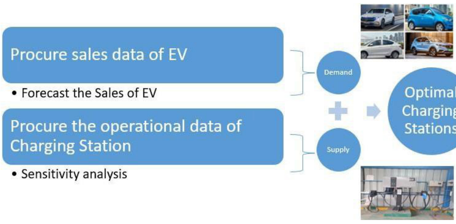

FIGURE 1 Conceptual framework for attaining optimal number of charging stations

2.2.2 *Empirical Study based on Demand and Supply of Electric Charging*

EV vehicles data were procured from Vahan Sewa Dashboard (Parivahan Sewa | Ministry of Road Transport & Highways, Government of India) [23]. The EV registration data of past 12 months (01-06-2021 to 01-05-2022) of Bengaluru Urban was obtained for 10 Regional Transport Office which consist of KA 01, 02, 03, 04, 05. 41, 50, 51, 53 and 59 registrations. The total sales of 2-wheelers from the year (01-06-2021 to 01-05-2022) is 30,129 units. The total sales of 3-wheelers from the year (01-06-2021 to 01-05-2022) is 2,006 units. The total sales of 4-wheelers from the year (01-06-2021 to 01-05-2022) is 1,742 units. The sales include from all the 10 Regional Transport Office at Bengaluru Urban.

2.2.3 *Review on Utilization of Existing Government EV Stations*

A qualitative spot check was conducted in the Corporate Office (Head Office), BESCOM, KR Circle areas of Bengaluru. The authors contacted Asst. Engineer from Department of (ELE) of Smart Grid and Electric Vehicle Cell and interviewed to obtain information on EV Charging Station.

EV Stations have 2 types of chargers - AC and DC chargers:

- AC chargers deliver 3.3 kW and 7.7 kW
- DC chargers are considered as fast chargers consisting of the power of 15 kW and 25-50 kW

EV connection for charging station is LT6T which can be used for commercial, and majority of the stations consist of 4 connectors

- Combined Charging System (CCS) connectors with capacity up to 50 kW costs INR 8.32/Unit
- Guobiao Standards (GB/T) connectors with capacity of 15 kW each costs INR 7.65/Unit

FIGURE 2 GB/T and CCS Chargers

Figure 2 consisting of Guobiao Standards (GB/T) and Combined Charging System (CCS) chargers were clicked in the premises of Mathikere, Bengaluru Electricity Supply Company Limited.

2.2.4 *Optimal Model to Setup Charging Infrastructure at Bengaluru*

Exponential Triple Smoothing technique was used to handle the time series data as it smoothens out minor deviations in past data trends by detecting seasonality patterns and confidence interval. Holt Winters Algorithm = FORECAST.ETS(A14,$B$2:$B$13,$A$2:$A$13,1,1) was used to forecast the sales of 2,3 and 4 wheelers from June 2022 to May 2026 where the demand is estimated. Figure 3 represents EV sales forecast for 2,3 and 4-wheeler.

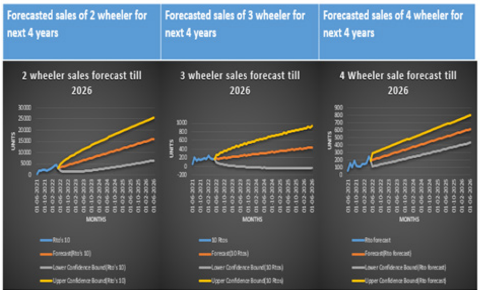

FIGURE 3 Forecasted EV sales of 2,3 and 4-wheeler from June 2022 to May 2026

Figure 3 illustrates that 2 and 4-wheeler sales have a strong positive trend and are likely to increase year by year tremendously, whereas 3-wheeler also have a positive trend, but the growth is gradual.

Sensitivity Analysis is a model that decides what target factors are affected based on changes in other variables known as input variables. Assumptions were made from reliable resources of the Bengaluru Electricity Supply Company Limited:

- Idle working hours of charging station is 16 hours / day for both AC and DC charging station.
- AC charging station have 4 connections of 1 phase AC 7.7 kW chargers and DC charging station have 2 connections of CCS DC 25-50kw.

Output of charging station with respect to AC charging station with 1 phase 4 connectors of AC 7.7 kW charger for 2 and 3-wheeler is 192 units and DC charging station with 2 Combined Charging System Chargers with 2 connectors for 4-wheeler is 1,280 units. Based on the assumptions, the supply side is estimated and the required optimal AC as well as DC charging station is calculated.

2 and 3-Wheeler:

Formula: Demand of 2-wheeler Units for May 2023 = Forecasted value of 2-wheeler (for May 2023) * 10% *3 Units = 58445*10%*3 = **17,534 Units** Formula: Demand of 3-wheeler Units for May 2023 = Forecasted value of 3-wheeler (for May 2023) * 10% *10 Units = 2459*10%*10 = **2,459 Units** where 3 and 10 Units represent the average battery capacity of 2 and 3-wheeler respectively. Later, both the 2 and 3-wheeler demand of Units are categorized under AC charging station i.e., 17,534+2,459 = 19,993 Units. Likewise, it is carried out on other variables as well. Here, table 2 displays the demand of 2 and 3-wheelers electric units from June 2022 to May 2026 with respect to the utilization factor of the electric vehicle with varying percentages.

TABLE 2: Demand of Units for 2 and 3-Wheeler based on Utilization Factor

Year vs Utilization Factor	10%	20%	30%	50%	70%
June 2022 - May 2023	19993	39985	64895	99962	139948
June 2023 - May 2024	32215	64432	96648	161080	225511
June 2024 - May 2025	44331	88663	132994	221656	310319
June 2025 - May 2026	56501	113001	169502	282503	395505

The yearly demand of units is measured with respect to the utilization factor of electric 2-3 wheelers.

4-wheeler:

Formula: Demand of 4-wheeler Units for May 2023 = Forecasted value of 4-wheeler (for May 2023) * 10% *3 Units = 2997*10%*40 = **11,988 Units.** Here, 40 Units is the average battery capacity of a 4-wheeler. Likewise, it is carried out on other variables as well. Here, the table 3 displays the demand of 4-wheelers electric units from June 2022 to May 2026 with respect to the utilization factor of the electric vehicle with varying percentages. The demand of units yearly is measured with respect to utilization factor of electric 4-wheelers. Tables 2 and 3 show the demand of the electric Units for 2, 3 and 4-wheeler.

With respect to the demand of units and output of the ideal AC as well as DC charging, the optimal AC and DC charging station is proposed.

2.3 Domestic Charging Stations

From the previous studies, it is concluded that installation of 50 kW DC chargers near multi-family Units, Apartments, and Workplace areas of Bengaluru can solve the problem of range anxiety and encourages EV usage. So, assuming to have at least one DC charging station of 50 kW charger in every Bruhat Bengaluru Mahanagaa Palike ward. Here a single charging station is to be installed, considering the supply from substations of Bengaluru Electricity Supply Company Limited and market/demand from estimated population in Apartment block areas of Bruhat Bengaluru Mahanagaa Palike and demand areas. Gravity model provides a better framework in understanding and determining the exact location between the supply and demand areas.

2.3.1 Gravity Model

Gravity location models are basically used in network design and planning of Supply Chain (SC) to reduce the cost. Around 80% of the SC costs pertain to facility location and demand flow between the facilities of supply & market. With the help of gravity location model, new geographic locations are determined by minimizing the SC cost of transportation cost between the supply / market facilities. The model assumes that both supply and market are located on a geometrical plane. The distance between the facilities is calculated as follows:

$$d_n = \sqrt{(x - x_n)^2 + (y - y_n)^2} \quad (9)$$

and the total Transportation Cost (TC) is arrived through TC $\sum_{n=1}^{k} d_n D_n F_n$ (10)

Here, () is the coordinate location of facility, (n:n) is the location of market / supply coordinates, Fn is cost occurred to ship one unit for a distance of one km, and Dn is the amount of quantity. The cost

TABLE 3: Demand of units for 4-wheeler

Year vs Utilization Factor	10%	20%	30%	50%	70%
June 2022 - May 2023	11988	23976	35964	59940	83916
June 2023 - May 2024	16920	33840	50760	84600	118440
June 2024 - May 2025	21852	43704	65556	109260	152964
June 2025 - May 2026	26784	53568	80352	133920	187488

minimization model is formulated using Solver. This determines the points by doing iterations to minimize the TC. When the TC reaches the minimum, the iteration shall be stopped. Figure 4 provides a framework of supply and demand consider for gravity model to determine a facility point (charging station).

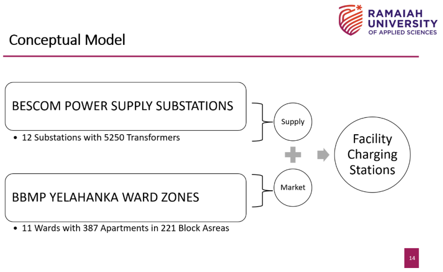

FIGURE 4 Framework of Supply and Market in Facility Allocation

Gravity model requires data from both supply and market region to determine facility point. The framework details are provided in the supply and demand section.

2.3.2 Supply Side:

Yelahanka BBMP zone obtains power supplied from 12 main subdivisions (C 6 Mathikere, C 4 Hebballa, C 5 Kavalbyrasandra, C 7 Yelahanka, C 8 Sahakara Nagar, C 3 Jalahalli, C 9 Vidyaranyapura, C 10 Nagavara, C 11 Chikkajala, C 12 Yelahanka Airforce, C 13 Jakkur, N 3 Byatarayanapura) which covers the entire ward. For each ward, there is a power supply from more than 2 substations which are deemed as supply points for the gravity model. The commercial charges in BESCOM are Rs. 7.8 per Unit, which has 10% of distribution charges including efficiency loss. i.e., 10% of Rs. 7.8 = Rs. 0.78 per unit to transfer from substations to facility [29}. The total available transformers in Yelahanka wards are around 5,250. As per BESCOM officials each substation is interconnected with transformers to supply power in each ward.

2.3.3 Market Side:

Allocation of charging point facility is carried out in Yelahanka BBMP zone which has a total of 11 wards (Kempegowda, Chowdeswari, Atturu, Yelahanka Satellite Town, Jakkuru, Thanisandra, Byatarayanapura, Kodigehalli, Vidyaranyapura, Dodda Bommasandra, Kuvempu Nagar). As assumed, an electric vehicle visiting a charging facility with 50 kW battery runs 461 km [30]. The commercial charges in BESCOM is Rs. 7.8 per unit. It means that the EV requires 0.1085 Units of charge to run 1 km. So, the cost to run 1 km is 0.1085 * 7.8 = 0.8463. Thus, the transportation cost for 1 km unit is Rs 0.8463. The total apartments in Yelahanka BBMP zone are around 387 situated in different area blocks of each ward. Coordinates of each substation are derived from google map as latitude and longitude points in decimal format.

3. Results and Discussion

3.1 Analysis using DEA

After solving in DEA Solver, it exhibits the efficiency scores for each DMUs. The efficient input target results for the considered outputs are also observed. Figure 5 shows the results for various scenarios with area and without area. It can be observed that India is not efficient, and it is suggested to benchmark with Finland to reach the frontier. If the Country is having a DEA score of 1.0, it is said to be efficient and the Country with the DEA score less than 1.00 is deemed to be inefficient. There is a decrease in average efficiency when compared to scenario 1 and 2. In the first scenario, the total area of DMUs / Countries was considered as the input. In the second scenario, the total area was neglected. The result shows that the area of individual Country is having an impact on the decision variables.

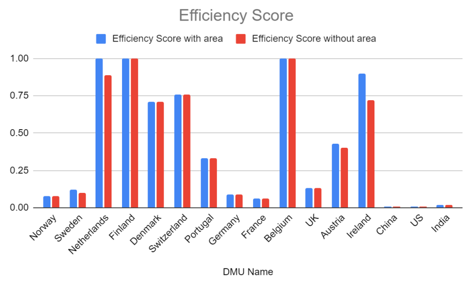

FIGURE 5 Efficiency of Countries

According to the ranking of the DMUs, Netherlands, Finland and Belgium are efficient, and all are top ranked. China has a less efficient score when compared to India. India has an efficiency score of 0.0235 that means it is only 2.3% efficient when compared to Finland.

3.2 Commercial Charging Stations

The key results of the empirical study are stated below:

In Table 4 the sales units of all the 2,3 and 4-wheeler categories are mentioned. Sales statistic record of entire network of BESCOM for the month of April and May 2022 is 48,000 and 52,600 units respectively. The lowest sales were witnessed in Covid times at 150 units during April 2020, which consists sales of the entire network.

Considering BESCOM's entire network of EV stations which has potential to deliver effective profits where the ROI is 0.50% for the month of MAY 2022. From the above analysis, it can be envisaged that BESCOM initiative can turn out to be fruitful for all Bengaluru EV owners in coming days. The charging station can be profitable considering the sales growth of the EVs. The optimal number of charging stations for 2, 3 and 4-wheelers of Bengaluru are represented graphically in Figure 6 and 7 with respect to variable percentage of utilization of electric 2,3 and 4-wheeler and year. Subsequently, the Augmented Dickey Fuller test results revealed that the procured data of 2,3 and 4-wheeler sales were not stationary. Based on the demand of units/output of the charging station i.e., demand of electric units of 2 and 3-wheelers and output of 4 connectors of 1 phase AC 7.7 kW charger, provides the optimal AC charging station for 2 and 3-wheelers. Similarly, demand of electric units of 4-wheeler / output of 2 Combine Charging System DC 25-50 kW charger is estimated.

The optimal number of charging stations can be measured to the known demand of units which is divided by output of the chargers. Formula: Combined units of demand for 2 and 3-wheeler for May 2023 @ 10% / Combined output of the

TABLE 4: Sales of 2,3 and 4-wheelers

Year	Vehicle Category	Sales in Units
01-06-2021 to 01-05-2022	2-Wheeler	30,120
01-06-2021 to 01-05-2022	3-Wheeler	2006
01-06-2021 to 01-05-2022	4-Wheeler	1742

chargers in units = 19,993/192 = **104 stations** Formula: Units of demand for 4-wheeler for May 2023 @ 10% / Combined output of the chargers in units = 11,988/1280 = **9 stations**.

Total optimal number of AC charging stations for 2 and 3-wheeler and DC charging station for 4-wheeler are listed in figure6 and 7:

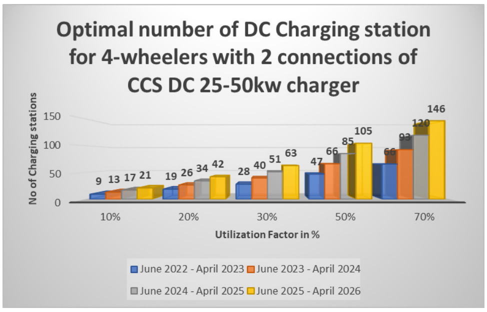

FIGURE 6 Optimal Number of AC Charging Station for 2 and 3-wheelers

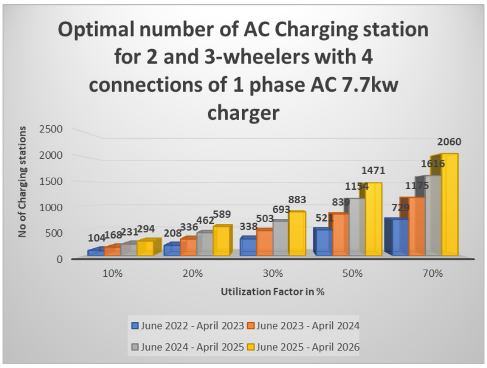

FIGURE 7 Optimal Number of DC Charging Station for 4-wheelers

The above figures show the required optimal commercial AC and DC charging stations for 2,3 and 4-wheelers for the region pertaining to Bengaluru Urban.

3.3 Domestic Charging Stations

The proposed approach addresses allocation of domestic EVCS based on the population density in the apartment areas. The gravity model addresses the allocation of EVCS based on apartments in each block area of a ward and substations covering the same ward with a certain number of transformers to supply electricity.

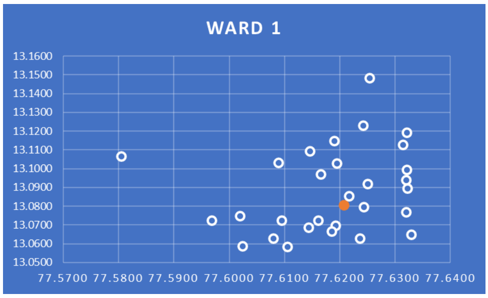

FIGURE 8 Optimal Point Coordinates for Ward 1 in Yelahanka

Optimal allocation of EV charging stations is determined with the help of Gravity location model. As the research was conducted only in Yelahanka BBMP zone wards. The power supply through transformers from each substation area and markets from each ward area blocks constitutes to allocate facility charging points. After solving, the solver uses cost minimization to find facility between supply and market points. It can be seen that the potential location for ward 1 is located in coordinates longitude and latitude respectively. Figure 8 shows coordinates of supply & market, orange dot is the optimal location determined for Ward 1 and the same method is carried out for the remaining 10 wards.

4. Verification and Validation

DEA: The DEA approach exhibits the efficiency score of each Country (DMU) and determines the frontier Country which has a good operational plan in EVCS infrastructure. Efficiencies of 16 Countries are found. Netherlands, Finland, and Belgium Countries stand as a frontier. India is having the least efficiency. Considering India, which has an output of 0.002 value of charging stations for 3 sq. km and 1.452 charging stations for 1000 EVs. For the attained output, the obtained efficient input targets a value of 5,683.3 of total land area in km2, 41 available charging stations, and 505.8 total number of EVs. Formulation of LPP through Solver minimizes the inputs while satisfying at least the given output levels. It means that India should have efficient input values to attain the outputs. Thus, India as a DMU is not efficient for the given output levels. If India needs to reach the frontier, it should benchmark operational plans from Finland to become efficient in setting up CS infrastructure. To increase the efficiency, the Country should focus on installing more CS for every 3 sq. km. Also, there should be charging stations for 1000 EVs.

Commercial Charging Station: Augmented Dickey Fuller test was conducted to check the stationarity of data. Based on stationarity, the forecasting technique can be varied whereas the results stated that data is not stationary, Thus, Exponential Triple Smoothening forecasting model was used in the statistical algorithm for the time-series forecasting and majorly focuses on trend and seasonality. Further, accuracy of the forecast is higher when compared to ARIMA modeling. The forecast statistics power was good and reasonable when the forecast statistics values were compared with the standard MAPE forecast power values. Hence, the forecasted data is reliable for future study. Based on the forecasted results, it can be stated that the sales of the 2 and 4-wheeler are likely to be outstanding whereas the 3-wheeler sales forecast are not geared up when compared to the other two categories. Considering this scenario, there is a scope to find the constraints and arrive at solutions to enhance the sales of the 3-wheelers.

Domestic Charging Station: Charging Stations solve the problems of range anxiety and in the development and sales of EVs. The research considered a demand of setting up one 50 kW fast charging station in each BBMP ward. The supply from substations connecting transformers and market from apartments present in each block area are considered for every BBMP ward to find out the best facility location to set up charging station. The result shows 11 facility point locations for each of the 11 wards in Yelahanka. Figure 9 shows the results of the gravity model. The optimal coordinate points of Yelahanka wards are verified and validated on google maps. Orange dot is the facility charging point, black is substation location and blue points are block areas. From the proposed gravity model, the optimal points to set up EVCS are identified in Yelahanka wards. There is a scope to develop a model considering the weightage of EV population in particular locations and determine the accurate number of charging connectors required. Develop an optimal route plan for the EV owners of Bengaluru considering all the EVCS

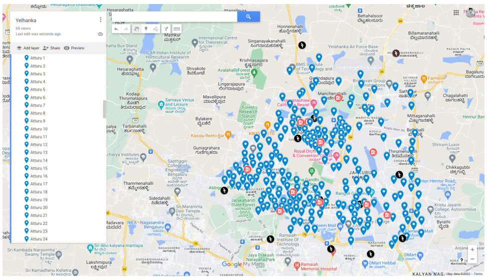

FIGURE 8 Optimal CS Mapping in 11 Yelahanka Wards

information. Gravity location models can be applied to all other BBMP zone wards in Bengaluru to allocate facility charging points.

The model can be applied to find optimal points in workstations considering the total population of companies present in each area. Optimal points can be determined for highway CS considering the demand of EV population in highways.

5. CONCLUSIONS

From the proposed results, it can be stated that the EV trend is going upwards, and EV has all the capabilities to acquire the IC engine market. Urban mobility is in the zone of transition already. As the demand increases, the supply needs to be increased in parallel. The study majorly focuses on arriving at the optimal CS required for EVs. The initiative from the Government is commendable. OEMs are also driving the transition of electrification and adding to the betterment of society.

India has an efficiency score of 0.0235 that means it is only 2.3% efficient compared to Finland. However, the scale of India warranted for further enquiry. Hence, India requires more CS as there is a greater opportunity for businesses to set up charging infrastructure as desirability for the EVCS are high. In May 2026, the required commercial optimal AC charging station for 2 and 3-wheelers at utilization factor of 10% and 70% will be at 294 and 2060 stations respectively. Likewise in May 2026, the required optimal DC charging station for 4-wheelers at utilization factor of 10% and 70% will be at 21 and 146 stations respectively. For domestic charging stations, the population density present in apartments of Bengaluru Urban areas is considered. The optimal allocation of EVCS is mapped in each ward of Yelahanka BBMP zone in Bengaluru Urban. This proposed method can also provide local Government departments with a preliminary idea about location scheme to construct EVCS. Overall, the study provides a holistic view of EV trends and the need of EVCS to match the demand of EV Owners in Bengaluru Urban.

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