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Propelling the Penetration of Electric Vehicles in Pakistan by Optimal Placement of Charging Stations †

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Abstract: The world is rapidly advancing towards the electrification of mobility owing to the substantial benefits of emission reduction. Adhering to international trends and environmental obligations, the Government of Pakistan (GOP) also intended to adopt 30@30 plug-in-electric vehicles (PEVs) across the country, which implies 30 percent of new sales will be of PEVs until 2030. Despite the policy guidelines introduced by the GOP as well as incentives for vehicle fleet electrification and indigenization, the foremost challenge is the lack of a PEV charging infrastructure placement plan for the country. In this regard, an optimal locality map for level-3 or direct current fast charging (DCFC) stations' installation is proposed, considering traffic volume, service area, and local grid facility while ensuring the availability of charging stations across all major networks of the country. The area of focus for this is National Highway 5, known as N5, and the Motorway-2 (M2) Network. The paper also provides insights into the techno-economic analysis of the proposed charging station installation spots. The results are extremely encouraging and reveal the proposed PEV charging stations under observation on the highways from Lahore to Islamabad consumed an electricity share of 3 MW–0.13 MW based on minimum to maximum traffic volume scenarios, respectively. The study is impactful and ultimately paves a way forward for the aggravation of the EV market share by considering the initial investment and a payback period of 7 months. With the help of this study, better planning in terms of EV penetration size and its requirement for public DCFC stations can be implemented, and the exact recipe for the growth of the supportive industry with the pace of PEVs' perforation can be executed.

Keywords: charging stations; PEVs; optimal location; DCFC; route node coverage; techno-economic analysis

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1. Introduction

Fossil-fuel-based internal combustion engines (ICEs) are one of the key factors which account for 50% of environmental pollution [1]. Developing countries suffer more because of old and inefficient engines used in their transportation network which are the cause of transport-generated pollution, particularly in Asia, Africa, and the Middle East, ranging from 12 to 70% [2,3]. The challenge of transportation pollution can only be overcome by changing the transport fleet from ICE to plug-in electric vehicles (PEVs) [3]. To encourage maximum PEV penetration, there must be a coordinated network of fast charging stations available publicly with private parties involved to also enable the rapid market penetration of PEVs. In recent years, many researchers have focused on the optimal placement of charging stations by continuing to study areas such as the environment, commerce, self-sustainability, etc. [4–7].

Presently, Pakistan lacks a PEV charging infrastructure plan to facilitate the adoption of PEVs on a wide scale in the country. To solve this problem robustly, a similar approach as discussed in [7] is adopted with slight improvements in a model for the optimal placement of direct current fast charging (DCFC) stations based on the flow calculation by using the dataset provided by the National Highways and Motorways authority. The considered networks for this contextual analysis are the Motorway 2 (M2) and National Highway 5 (N5) networks from Lahore to Islamabad. These routes are more active traffic routes than the rest of the road networks in the country, and also, the region covering these routes is among the most densely populated areas of the country. Moreover, the study is focused on proposing an optimal PEV charging station plan for intercity routes to ensure long-range, anxiety-free traveling in the future.

2. Electrical Charging Stations Locality Deployment Model

To maximize PEVs' market share, a coordinated charging station (CS) network along highways and motorways is suggested. In this study, all vehicles were considered as cars, and heavy-duty traffic was not considered. Charging time was assumed to be 30 min for standardization, and the charger electricity consumption was 50 KW. The PEV charging port and CS charging port adopted the same type of standardization for the convenience of installation purposes. The tariff was assumed to be 35 rupees for dedicated load EV charging by the distribution companies and an annual 10% rupee devaluation. As the charging process interrupts the journey, only DCFC chargers were considered. To determine CS sites, we only considered rest-places with basic rest-place facilities as candidate sites. These facilities are available on the candidate site and also no farther than 250 m from it and are categorized as: (i) *basic facility location:* parking, small shops, and prayer provision (ii) *medium facility location:* supermarket, dining court, and minimum rest-place facility (iii) *superior facility location:* High-end rest and accommodation facility, food courts, and additional facilities such as a pharmacy, etc. By considering these facilities, the potential location of CSs could be selected based on the re-defined equation detailed in [7] for each nominated site, and the process is illustrated in Figure 1.

$$PL_i = a_1 x_{1,i} + a_2 x_{2,i} + a_3 x_{3,i} + a_4 x_{4,i} + a_5 x_{5,i} \quad (1)$$

where PL_i = potential location of candidate site, 'i', $x_{1,i}$ = security level on nearby roads at the candidate site, 'i', $x_{2,i}$ = evaluation value of traffic volume on nearby roads at the candidate site, 'i', $x_{3,i}$ = evaluation value of service level of the candidate site, 'i', $x_{4,i}$ = evaluation value of the distance between two candidate sites, 'i', $x_{5,i}$ = electricity availability at the candidate site 'i', while a_1, a_2, a_3, a_4, and a_5 are the weights of variables.

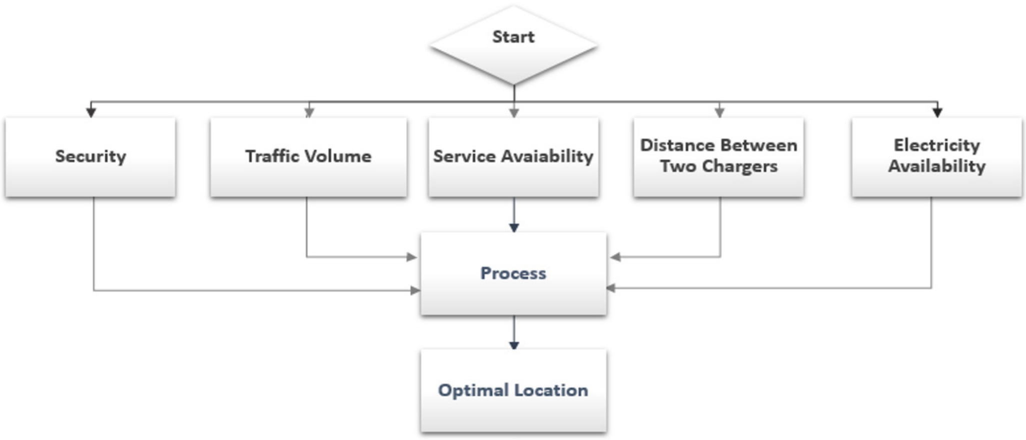

Figure 1. Algorithm for optimal location determination for installation of PEV charging stations.

The parameters in (1) require exploration for the precise determination of optimal CS spots. In (1) $x_{1,i}$ is the security factor for the CSs as well as for the nearby roads. The value of '$x_{2,i}$' is the sum of average daily traffic volume that passes through national highways and motorways within the range of 20–100 km (Km) from the CS (N_i) (vehicle/day) location. We considered the traffic volume of the directions from where the rest-place is accessible. The value of x_1 is calculated according to the equation below [7]:

$$x_{1,i} = \begin{cases} 0, & if\ N_i \leq fmin \\ \frac{N_i - fmin}{fmax} 0.5, & if\ fmin < N_i < fmax \\ 1, & if\ N_i \geq fmax \end{cases} \quad (2)$$

where N_i = number of vehicle flow, and $fmax$ = maximum vehicle flow $fmin$ = minimum vehicle flow. We defined the limit values according to the calculations by using the dataset. In terms of service level, $x_{3,i}$, a basic service facility is ranked as 1, medium is ranked as 2, while a superior service level at CS locations is given a rank of 3. $a_4x_{4,i}$ is assumed to be constant as the distance between two candidate sites on the motorway network is fixed (service areas also have a fixed location), while on the N5 network, a supposition is made that there must be a charging station after every 40 km. Additionally, $x_{5,i}$ factor ensures the availability of national power grids, transmission, and distribution networks for PEV CS integration at each candidate site.

3. Results and Discussions

To determine the optimal charging station locations based on the dataset, vehicle flow was calculated at N5 north, from Lahore to Islamabad, and at motorway M2 from Islamabad to Lahore. The dataset consisted of data of vehicle flow for April 2019 as depicted in Figure 2a,b, and for March 11 to the April 14 of the year 2020, respectively, as shown in Figure 2c. This particular dataset is important because it covered the pre-COVID-19 (2019) as well as the post-COVID-19 (2020) period. So, in this way, we gained the regular maximum vehicle flow data as well as the minimum vehicle flow data. Due to the availability of minimum vehicle flow data, different case scenarios could be developed, and we also learned the minimum amount of the traffic that would flow in any bad scenario.

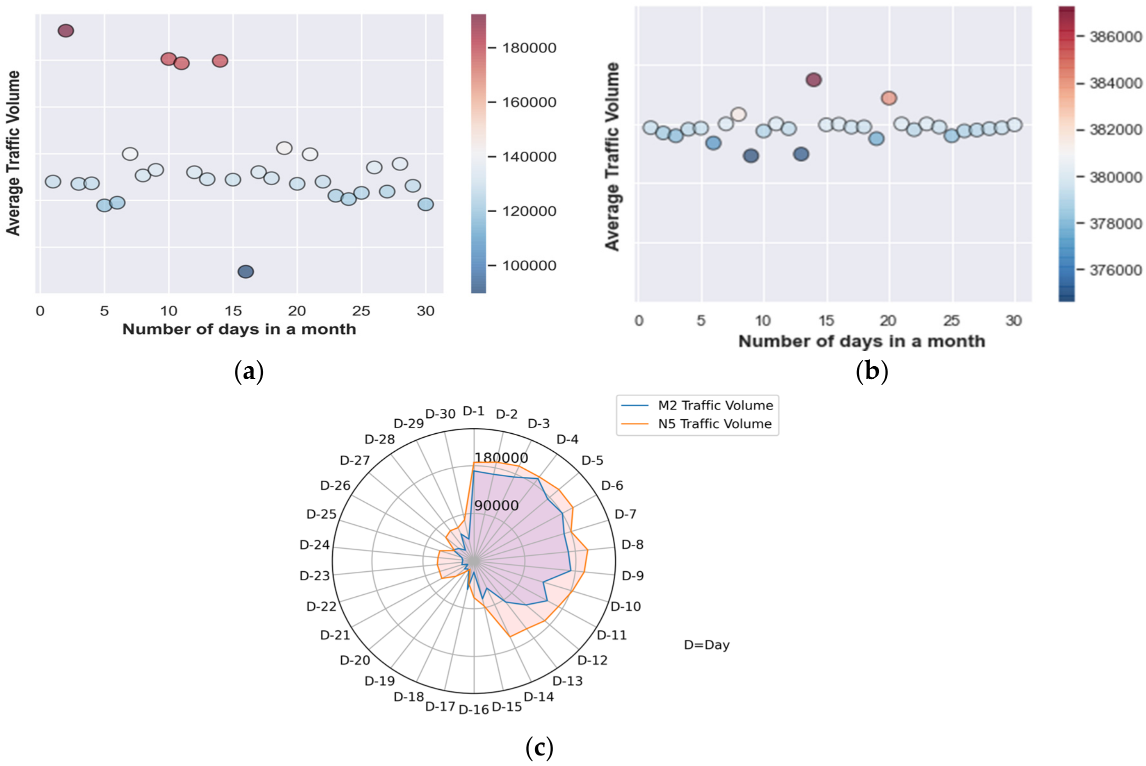

Figure 2. Vehicle flow data pre-COVID scenario on (**a**) M2; (**b**) N5; and (**c**) post-COVID scenario of M2 and N5.

Considering the provision of facilities, the study area was divided into different zones on M2 and N5, as shown in Figure 3. The zones were divided according to the traffic data and the nature of the facilities available. The PEV population was distributed between these zones. Considering the zones, proposed locations with distances in-between the two CSs are enlisted in Table 1. Further, battery size and the mileage range of different models of cars were also considered for this investigation (see Table 2 [8]). From the dataset, the average vehicle flow was calculated in the normal period as well as during the COVID-19 period (see Tables 3 and 4) by adopting approach detailed in [9,10]. By assuming the differences ranged from 1% to 10%, we developed the scenarios as listed in Tables 5 and 6 for the N5 and M2 highways, respectively. In this way, the goal of the research effort to establish a certain number of priority CSs was accomplished by maximizing the service of charging stations. It is to be noted that when calculating the distance from the demand point to the candidate point, the mathematical model mentioned in (1) and (2) and the after-mentioned principles were adhered to for the optimal placement of PEV CSs. The finalized scenario including transmission network infrastructure and the proposed potential charging station candidates for the M2 and N5 routes are depicted in Figure 4.

Table 1. Proposed Charging Station Locations and Distance.

Sr. No.	City	Longitude, Latitude	Distance
A	**N5 network**		
1.	Rawat	32.4805288, 72.687214	15.7
2.	Mandra toll plaza	32.4277489, 72.40935	59
3.	Deena	33.0285967, 73.598110	20
4.	Sarae Alamgir	32.907611040865, 73.730340115134	8
5.	Kharian	32.8830768, 73.7785187	46
6.	Gujrat exit	32.5959182, 74.0378919	9
7.	Gujrat	32.4797136, 74.091663	10.3
8.	WazirAbad	32.4026824, 74.1224383,	13.5
9.	Gakhar	32.317067, 74.143303	13.6
10.	Gujranwala		17
11.	MoreAimanAbad	32.0488448, 74.2085573	11.4
12.	Kamoke	31.995427755973, 74.218015463522	11
13.	Sadhoke	31.862328, 74.24472	12.7
12.	Muridke	31.6420817, 74.2032471	11.4
15.	Kala Shah Kaku	31.7338073, 74.2655666	46.2
B	**M2 network**		
16.	Chakri	33.3203856, 72.7829902	45
17.	KalarKahar	32.869405, 72.65204	73.5
28.	Bhera	32.453259538502, 72.886018340599	46.5
19.	Sial Mor	31.9680162, 73.1120396	77.5
20.	Sukheki	31.906767165001, 73.56816594500	48.6

Table 2. Travelling Range of Different Electrical Vehicle Cars [8].

Manufacturer	Range (Km)	Battery Size (KWh)
Tesla	483	60–100
Xpeng (China)	706	60–100
Chevrolet	355	60–100
Nissan	270	22–40
BMW	246	22–40
Kia	160	22–40
Volkswagen	130	12–20
TopSun	**300**	50

Table 3. Percentage of Electric Vehicle Flow in Normal Days.

Percentage of EVs from Total Vehicle	Number of EVs	Percentage of Different Models (50%, 30, 20%)	Number of Charger at Each Location
10%	100	50, 30, 20	100
5%	50	25, 15, 10	50
2.5%	25	13, 7, 5	25
1%	10	5, 3, 2	10

Table 4. Percentage of Electric Vehicle Flow in COVID-19.

Percentage of EVs from total Vehicle	Number of EVs	Percentage of Different Models (50%, 30, 20%)	Number of Charger at Each Location
10%	6	3, 2, 1	6
5%	3	2, 1, 0	3
2.5%	3	1, 1, 1	3
1%	3	1, 1, 1	3

Table 5. Power consumption at 15 Stations of N5.

Period	Demand	Power Usage (MW)
Normal period	Maximum	3
Normal period	Minimum	0.3
COVID-19	Maximum	1.98
COVID-19	Minimum	0.18

Table 6. Power consumption at 5 stations of M2.

Period	Demand	Power Usage (MW)
Normal period	Maximum	1.6
Normal period	Minimum	0.16
COVID-19	Maximum	1.36
COVID-19	Minimum	0.13

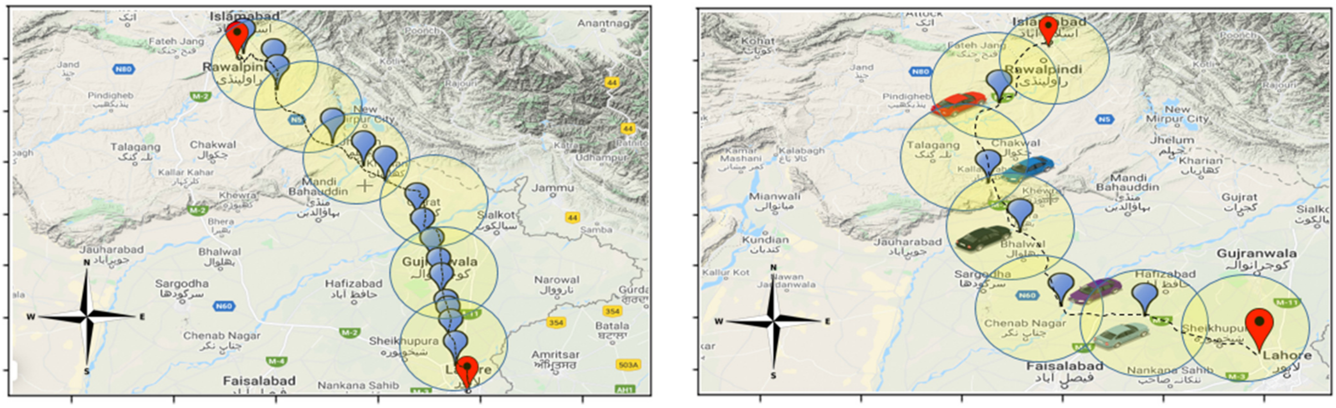

Figure 3. Zones to be covered for proposed PEV charging installation on (**left**) N5 north; and (**right**) M2 from Lahore to Islamabad. It is to be noted that figures are not according to the scale and only indicate the approximate zone areas.

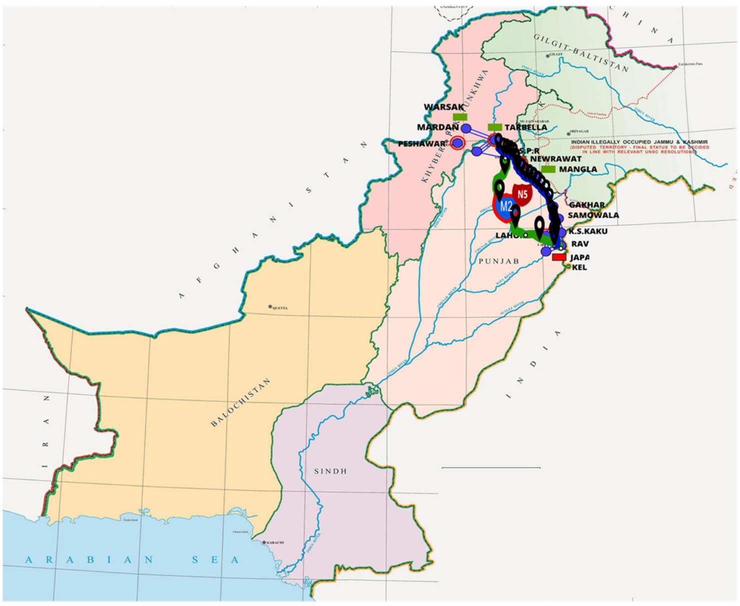

Figure 4. Proposed candidate sites for PEV charging stations on M2 motorway and N5 with transmission network.

Further, economic analysis about the investment and payback period was also taken into account for a feasibility analysis of the proposed model. For this, we considered the initial cost of investment, variable cost, operational cost, etc., as listed in Table 7.

Table 7. Economic analysis parameters for the installation of PEV CSs.

Parameters	Cost (USD)
Charger	20,000
Installation	1000
New Connection	2500
Operation and Maintenance	10% of overall
Electricity Tariff per kWh	0.142
Electricity Taxes per kWh	0.11
Rupee Devaluation	10% annually
Miscellaneous	1000
Total cost (excluding electric cost and taxes)	29,400

The charger mentioned above is the DCFC, with two ports for charging at one time. The installation cost included the labor cost, material cost, and other such parameters; the new connection cost was the cost of the regulator, and in the case of the transformer, there was a minimum cost both for the regulator and transformer. The operational and maintenance cost was taken as the 10% annual cost. The electricity and taxes costs were obtained from the provider, while we had to consider the rupee devaluation for investment and some miscellaneous charges, as this is the new technology, and there will inevitably be some unknown annual charges. Even during the period of strict lockdown during the COVID-19 pandemic, the minimum EV flow was 3 at each point in 1 h. So, at least two chargers are needed at one optimal location point. If the charging cost is assumed to be 0.31 USD/KWh and the installed charger worked for 24 h, then:

Total 1 day selling cost = 0.31 * (24 * 2) * 50 KW = 744 USD/KWh; Total 30 days selling cost = 22,320 USD/KWh, while:

Total 30 days actual electric cost is = 18,144 USD/KWh. Profit for 30 days = 4176 USDKWh.

Total investment recovery time = 29,400/4176 = 7 months.

So, in almost 7 months, the total investment will be recovered, even when the devaluation (or, if we remain in dollars, considering the interest rate at 10%) is also considered.

4. Conclusions

In the implementation process, a N5 road and motorway map was derived, and the results are presented in the above section. To address the problem of location selection during electric vehicle charging station planning, this paper proposed a location method based on regional information and future predicted demand. According to the battery life of an electric vehicle, we determined the service range of a charging station. Based on the cost constraints, we determined the number of CSs to determine the optimal location for a PEV CSs. The method proposed in this paper can obtain an ideal charging station planning scheme that meets requirements and provides a guiding significance and application value for the location and constant volume of an electric vehicle charging station.

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