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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 electrification of mobility owing to the substantial emission reduction benefits. Ensuing International trends and environmental obligations, the Government of Pakistan (GOP) also intended to adopt 30@30 plug-in-Electric vehicles (PEVs) penetration across the country, which implies 30 percent of the new sale is of the PEVs till 2030. Despite the GOP introduced policy guidelines as well as incentives for vehicle fleet electrification and indigenization, the foremost challenge is the lack of PEVs charging infrastructure placement plan for a country. In this regard, an optimal locality map for Level-3 or direct current fast charging (DCFC) stations installation is proposed considering the traffic volume, service area, and local grid facility while ensuring the availability of charging stations across all major networks of the country. The focused area for this is National Highway 5, known as N5, and the Motorway-2 (M2) Network. The paper also provides insights on the techno-economic analysis of the proposed charging stations installation spots. The results are extremely encouraging which reveals proposed PEVs charging stations under observation on the highways from Lahore to Islamabad consumed electricity share of 3MW-0.13 MW based on minimum to maximum traffic volume scenario respectively. The study is impactful which is ultimately a way forward for aggravation of the EV market share by considering the initial investment and a payback period of 7 months. By the help of this study, better planning in terms of EV penetration size and its requirement for public DCFC stations is 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 engine (ICE) is one of the key factors which contribute 50% in environmental pollution [1]. While the developing countries suffer more, because of old and inefficient engines for their transportation network and caused the transport-generated pollution particularly in Asia, Africa, and the Middle East ranging from 12-70% [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]. For the encouragement of maximum PEVs penetration, there must be a coordinated network of Fast charging stations available publicly with the private parties involved and for rapid market penetration of PEVs. In recent years, many researchers focus on the optimal placement of charging stations by keep focusing on the areas such as the environment, commercial, self-sustainable, etc. [4–7].

Presently Pakistan lacks PEVs charging infrastructure plan to facilitate the adoption of PEVS on a wide scale in a 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. The focused routes are the most active traffic routes than the rest of the road networks in a country as well the region covering these routes is among the densely populated areas of the country.

2. Electrical Charging Stations Locality Deployment Model

To maximize PEVs market share, a coordinated charging stations (CSs) network along the highways and motorways is suggested. In this study, all vehicles were considered as cars and heavy-duty traffic was not considered. An assumption about charging time was considered as 30 min for standardization and the charger electricity consumption is 50 KW. The PEVs charging port and CSs charging port adopted the same type of standardization for the convenience of installation purposes. The tariff is assumed of rupees 35 for the dedicated load EV charging by the distribution companies and annual 10% rupee devaluation. As the charging process interrupts the journey, only DCFC chargers are considered. For determining CSs sites, we consider only the rest-places with the basic rest-place facilities as candidate sites. These facilities are available on the candidate site and also not 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 pharmacy etc For considering the provision of facilities. By considering these facilities the potential location of CSs can be selected based on the re-defined equation detailbed 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 near roads at candidate site 'i', $x_{2,i}$ = evaluation value of traffic volume on near roads at candidate site 'i', $x_{3,i}$ = evaluation value of service level of candidate site 'i', $x_{4,i}$ = evaluation value of the distance between two candidate site 'i', $x_{5,i}$ = electricity availability at the candidate site 'i' while a_1, a_2, a_3, a_4, a_5 are the weights of variables.

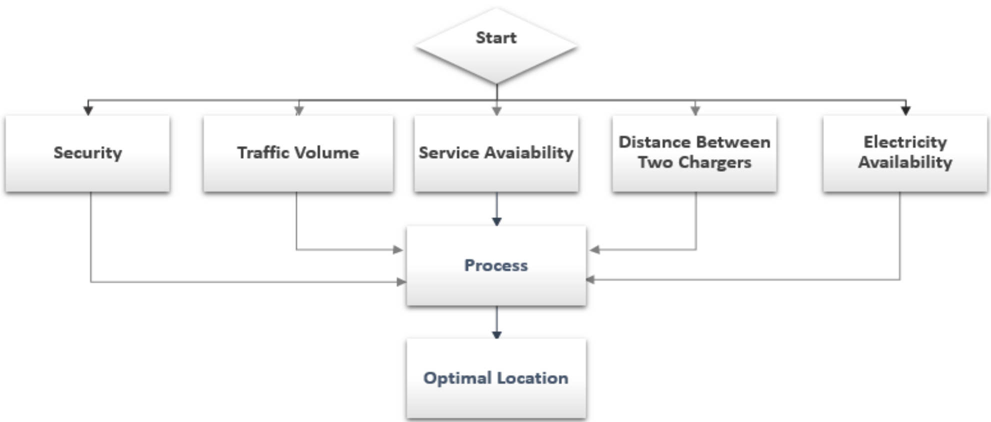

Figure 1. Algorithm for Optimal location determination for installation of PEVs charging stations.

The parameters in (1) need exploration for precise determination of optimal CSs spots. In (1) $x_{1,i}$ is the security factor for the CSs as well as for the personals. The value of '$x_{2,i}$' is the sum of average daily traffic volume that passes through national highway and motorway within the range of 20–100 km (Km) [20] from the CS (Ni) [vehicle/day] location. We consider the traffic volume of the directions from where the rest-place is accessible. The value of x1 is calculated according to the equation below [7]:

$$x_{1,i} = \begin{cases} 0, & if\ \ N_i \le fmin \\ \dfrac{N_i - fmin}{fmax}.5, & if fmin < N_i < fmax \\ 1, & if\ \ N_i \ge fmax \end{cases} \quad (2)$$

where N_i = Number of Vehicle flow $fmax$ = maximum vehicle flow $fmin$ = minimum vehicle flow. We defined the limit values according to the calculations by using the dataset. The service level, $x_{3,i}$is ranked as 1, medium as 2 while superior service level at CSs locations is given a rank of 3. $a_4 x_{4,i}$ is assumed to be constant as the distance between two candidate site on the motorway network is fixed (service areas also have fixed location) while on N5 network a supposition is made that there must be a charging station after every 40 km. And $x_{5,i}$ factor ensures the availability of national power grids, transmission, and distribution networks for PEVs CSs integration at each candidate site.

3. Results and Discussions

To determine the optimal charging station locations based on the dataset, vehicle flow is calculated at N5 north, from Lahore to Islamabad, and at motorway M2 from Islamabad to Lahore. The dataset consists 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 consists of the pre-Covid-19 (2019) as well as the post-Covid-19 (2020) period. So, by this way, we have the regular maximum vehicle flow data as well as the minimum vehicle flow data. By the availability of minimum vehicle flow data, different case scenarios can be developed and we also come to know that in any bad scenario minimum this amount of the traffic will flow.

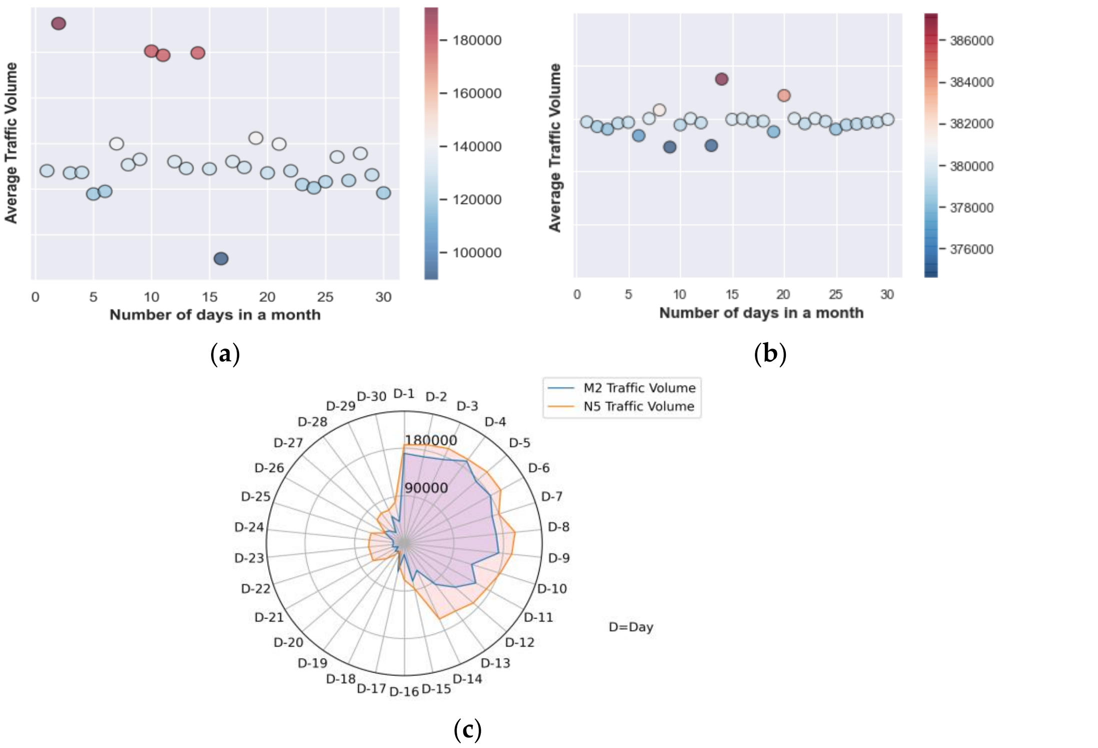

Figure 2. Vehicle flow data pre- COVID scenario on (**a**) M-2; (**b**) N-5; and (**c**) Post COVID Scenario of M-2 and N-5.

For considering the provision of facilities, the study area is divided into different zones on M-2 and N-5, as shown in Figure 3. The divide zones were according to the traffic data and the nature of facilities available. PEV population is distributed between these zones. Considering the zones, proposed locations with distance in-between the two CSs are depicted in Figure 4-Table A. Further battery size and a mileage range of different models of cars were also considered for this investigation (see Figure 4-Table B). From the dataset, the average vehicle flow is calculated in normal as well as during the Covid19 period. If we assumed its different ranges from 1% to 10% then we have scenarios as enlisted in Table C and Table D for N5 and M2 highways respectively. In this way goal of the research effort to establish a certain number of priority CSs was accomplished for maximizing the service of charging stations. It is 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 adhered for optimal placement of PEVs CSs. The finalized scenario including transmission network infrastructure and the proposed potential charging stations candidates for M-2 and N-5 routes are depicted in the Figure 5.

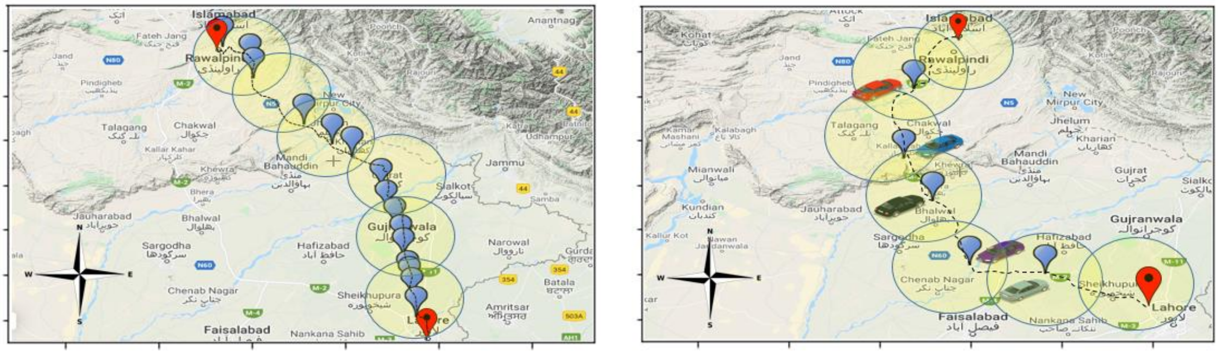

Figure 3. Zones to be covered for Proposed PEVS charging installation on (**left**) N5 north; and (**right**) M-2 from Lahore to Islamabad. It is to be noted that Figures are not according to the scale and is only to indicate the approximate zone areas.

Table | A. Proposed Charging Stations 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 | B. Travelling Range of Different Electric Vehicle Cars

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 | C. 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%	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 | D. Percentage of Electric Vehicle flow in COVID-19 scenario

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

Figure 4. Proposed charging stations (**Table|A**) Mutual Distance (**Table|B**) Travelling range of different PEV cars (**Table|C**) Percentage of EVs flow in normal days (**Table|D**) Percentage of EVs flow in COVID-19 specific duration.

Table 1. Power Consumption at 15 Stations of N-5.

Period	Demand	Power Usage (MW)
Normal period	Maximum	3
Normal period	Minimum	0.3
Covid19	Maximum	1.98
Covid19	Minimum	0.18

Table 2. Power Consumption at 5 Stations of M-2.

Period	Demand	Power Usage (MW)
Normal period	Maximum	1.6
Normal period	Minimum	0.16
Covid19	Maximum	1.36
Covid19	Minimum	0.13

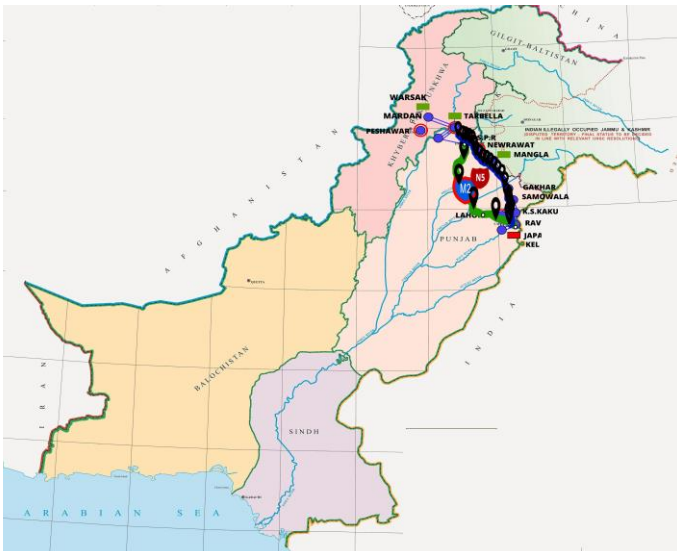

Figure 5. Proposed candidate sites for PEVs charging stations on M2 motorway and N5 with transmission network.

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 consider the initial cost of investment, variable cost, operational cost etc., as enlisted in Table 3.

Table 3. Economic Analysis Parameters for the Installation of PEV CSs.

Parameters	Cost ($)
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 having two-port for charging at a time. The installation cost includes the labor cost, material cost, and other such parameters, the new connection cost is the cost of the regulator and in the case of the transformer the minimum cost for regulator and transformer both. The Operational and maintenance cost is taken as the 10% annual cost. The electricity and taxes cost obtained from the, while we must consider the rupee devaluation for investment and some miscellaneous charges as this is the new technology and there must be some unknown charges beard by it annually. Even during the period, strict lockdown, of Covid19 the minimum EV flow is 3 at each point in 1 h. So at least need 2 chargers are needed at one optimal location point. If charging cost is assumed to be 0.31 $/KWh and the installed charger worked for 24 h, then;

Total 1 day selling cost = 0.31*(24*2)*50 KW = 744 $/KWh Total 30 days selling cost = 22,320 $/KWh, While

Total 30 days actual electric cost is = 18,144 $/KWh Profit For 30 days = 4176 $/KWh

Total investment recovery time = 29,400/4,176 = 7 months.

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

4. Conclusions

In the implementation process, a N5 road and motorway map is derived and results are presented in the above section. To address the problem of location selection during electric vehicle charging station planning, this paper proposes 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 an PEV CSs. The method proposed in this paper can obtain the ideal charging station planning scheme that meets requirements and provides a guiding significance and application value for the location and constant volume of the electric vehicle charging station.

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Conflicts of Interest: The authors declare no conflict of interest.

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