Electric Transportation in Pakistan Under CPEC Project: Technical Framework and Policy Implications

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ABSTRACT  Transportation sector in Pakistan has been rapidly growing, leading to an increase in diesel and petroleum consumption, heightened energy import bill, air pollution, and traffic congestion. The China–Pakistan economic corridor (CPEC) is a cluster of different multi-billion-dollar projects with a significant emphasis on enhancing regional connectivity, and the transportation sector is considered its backbone. Electric road transportation appears to be a game-changer to tackle energy, economy, and environmental issues of a country. This research paper is focused on a scheme and valuation of deploying electric transportation (e-trans) for mass transit under the CPEC umbrella in Pakistan. This paper identifies barriers and challenges and explores various technological options for adopting suitable electric vehicles (EVs) for mass transportation. The paper investigates technical infrastructural requirements, financial, and policy implications for the successful deployment of the proposed electric transportation. In particular, it proposes an EV charging infrastructure based on solar power generation to avoid any electricity burden to recharge EVs from the national power grid. In order to be comprehensive, it presents a case study to develop an EV charging station network with an estimation of the cost for accommodating charging requirements of one thousand electric trucks and hundred mobile charging trucks. Obtained results demonstrate that merely 0.29% of the CPEC’s energy sector approved budget will be incurred for deploying the proposed charging station network to support e-trans over the studies road segment, which appears to be a feasible initiative. Important factors which may influence the proposed scheme for implementation of e-trans under the CPEC is analyzed using SWOT analysis. The recommended set of policies for deploying electric transportation and its quantitative financial analysis will help the concerned stakeholders to discover and execute the necessary steps to ensure sustainable electric transportation under the CPEC in Pakistan.

INDEX TERMS  CPEC, electric transportation, solar power based EVs charging, SWOT analysis, policy.

I. INTRODUCTION

The road transport electrification is expanding worldwide as total EVs strength escalated to 5.1 million units in 2018 in comparison with 2 million in 2017 [1]. The world’s 64% EVs comprises of battery electric vehicles considering the involvement of countries in achieving global targets such as Vision 30@30 [2]. Pakistan is heavily dependent upon energy imports with gas and oil being the major source of energy contribution making 64% of the energy mix. It is followed by hydropower having a share of 30%, and the remaining little portion belongs to other renewable energies. According to world bank total of 342 million metric tons (MtCO\textsubscript{2}e) were emitted by Pakistan in 2012 [3]–[5]. The transportation sector is vital for the economy of Pakistan as it contributes 10% in GDP and around 17% in the Gross Capital Formation [6], [7]. The impact of Climate Change due to global warming has already brought many miseries to Pakistan in the
form of high floods, Glacial melting, Glacial Lakes Outburst Floods (GLOFs) and decrease in agricultural productivity. Hence, there is high need for reducing the GHG emission in Pakistan. Pakistan intends to curb GHG emissions by 20% as per Intended Nationally Determined Contribution (INDC) with the assistance of international grants. A developing nation like Pakistan would get benefit from the introduction of electric vehicles on its road networks as it decreases the transportation sector’s dependence on fossil fuels.

The economic and social growth of a country is heavily reliant upon the transportation sector. In this regard, Pakistan and China decided to enhance mutual connectivity through the China Pakistan Economic Corridor (CPEC) to strengthen the economy of Pakistan by improving trade amongst themselves and other countries of the region and beyond. The initiation of CPEC rejuvenated the infrastructural network expansion under the One Belt One Road (OBOR) initiative. CPEC is a conglomerate of infrastructural projects which comprises railway networks, roads, gas pipelines, economic zones, etc. having a link of 3000km from the western part of China, Xinjiang to Gwadar port in Balochistan, Pakistan [8]. With the completion of CPEC, heavy road transportation will be embarked for transit of goods from China to Pakistan and beyond. Hence, with traditional transports, fed with fossil fuels, the CO₂ emissions and subsequent air pollutions will become a major challenge besides heavy economic cost of the fuels. For an efficient and environment friendly transport system, an ample opportunity exists for Pakistan to implement e-trans on CPEC, which would help the country to achieve its INDC goal of a 20% reduction in GHG emissions. The current scenario of electric vehicles (EVs) in Pakistan does not look promising. The government of Pakistan revealed EV policies last year in November 2019 with a target on the conversion of 30% vehicle strength of cars and rickshaws (three-wheelers) into EVs by 2030 [2], [9].

Under the proposed scheme for e-trans realization under CPEC requires an in-depth research study of various aspects such as infrastructure requirements of e-trans deployment on CPEC, a renewable energy-based model of charging infrastructure to avoid burdening grid, the feasibility analysis of the proposed model, SWOT analysis for identification of internal and external factors contributing in positive and negative aspects, identification of challenges and barriers to familiarize relevant stakeholders about potential problems of e-trans on CPEC and suggestion of policies and recommendations to overcome mentioned challenges and barriers. The diverse topography of Pakistan demands a study of different vehicle types like hybrid vehicles, battery electric vehicles, and trolley vehicles due to their significant variations in performance. In general, requirements for e-trans implementation are classified into technical and financial factors that must be considered by stakeholders during the long-term and operational planning phases. Many authors have argued that renewable source of electricity is vital for supporting EVs charging infrastructure for any better well to wheel efficiency of vehicles in comparison with conventional vehicles [10]–[12]. Another important concern for utilities is the anticipated power quality problems due to increased penetration of EVs and renewable energy-based charging station in the power system [13]–[17].

Nonetheless, a research question that arises here is: Are renewable energy-based projects a feasible option for supporting e-trans in the developing countries? To ensure that all relevant stakeholders are on board with e-trans deployment on CPEC, SWOT analysis is conducted for highlighting potential positive and negative aspects arising from the ambitious goal of the e-trans proposition. Importantly, effective policies are prerequisite for the deployment of e-trans that encourages people to shift from conventional fossil fuel vehicles to hybrid or electric vehicles. A developing country like Pakistan can learn from China as a way forward towards e-trans implementation on CPEC [18], [19].

The major contribution of this research paper is given as follows:

1. Identification of barriers and challenges, including social, economic, environmental, political, and technical factors, are rigorously conducted to illustrate the critical areas where improvements are needed for seamless integration and function of e-trans under CPEC.

2. Infrastructural requirements of e-trans deployment under CPEC are identified and analyzed from the technical as well as financial perspectives. Savings in the annual cost incurred and GHG emissions using battery electric trucks and buses are also highlighted via aid of CPEC eastern route case study.

3. Key driving factors with the advantages and disadvantages of e-trans are brought to light through SWOT analysis. The intent here is to convey meaningful information to all relevant stakeholders.

4. A well-structured tool SWOT analysis is used to analyze the strengths, weaknesses, opportunities, and threats associated with the e-trans deployment under the CPEC. The presented SWOT analysis indicates the concerned stakeholders and private investors about the pros and cons of the proposed initiative so that they can be acclimatized.

5. A case study is proposed based on solar power to meet the supply requirements of 100 electric trucks, 100 electric buses and ten mobile charging trucks. To bolster the claim of its feasibility, economic analysis is also conducted and presented.

6. A set of policies is recommended to support the proposed model of e-trans implementation. It does not only ensure the effective functionality of e-trans but also addresses a research concern about suitable and pragmatic policies to ensure a smooth transition towards the electrification of heavy vehicles under CPEC. The suggested policies will certainly serve as guidelines and convincing argument for the relevant stakeholders to invest in and implement e-trans under CPEC in Pakistan.
The uniqueness of this research study lies in the fact that there are no such attempts in the literature with the proposition of the model for e-trans implementation under CPEC. The impact of the proposed scheme and realization of e-trans deployment in Pakistan will certainly have a huge impact on the socio-economic, transportation, energy, and environment of the developing country with a population of over 220 million. Though the study is focused on the multi-billion-dollar international project CPEC, the proposed model, financial and policy implications are researched and presented without loss of generality.

The manuscript consists of twelve sections. The first section gives an introduction. Existing situation of EVs in Pakistan is elaborated in the second section, and the third section elaborates on the transport and road networks under the CPEC. Section IV provides an overview of different electric vehicle technologies, and EVs infrastructural requirements are detailed in the fifth section. Section VI presents a case study of CPEC eastern route, and the detailed discussion and analysis of the results are given in section VIII. The strength, weaknesses, opportunities, and threats (SWOT) of the proposed e-trans on CPEC is highlighted in the 9th section. Section X explores potential barriers and challenges for realizing e-trans on CPEC, and the eleventh section suggests a set of policies and actions for the successful deployment of e-trans. Finally, the paper is concluded in Section XII.

II. TRANSPORTATION AND ROAD NETWORK SCENARIO IN PAKISTAN

The transportation sector in Pakistan comprises of 3.5 million employees and contributes 10% to its GDP and 17% to its Gross Capital Formation [20]. The transportation sector of Pakistan is growing within a range of double-digit percentages. The transportation sector contributes a share of 26% in total investment on CPEC, making it an astounding amount of USD 12 billion [21]. According to the Pakistan Bureau of Statistics, 17,715,428 vehicles are registered in the year 2015 within Pakistan. The composition of registered vehicles in 2015 is shown in Fig. 1. There has been a considerable change in the number of vehicles registered in Pakistan from 2000 to 2015. The change in the motorcycle is 439% being most amongst all vehicles, while the least change can be seen in buses, which increased by 48% in 15 years [22]. Overall, the total number of vehicles in Pakistan rocketed up by 248%, as shown in Fig. 2.

There has been a significant variation in the number of trucks within Pakistan over the past two decades. The number of trucks increased consistently throughout these years. The noticeable increase can be seen in Fig. 3 in the year 2018 in which trucks increased by 68.13%. The biggest fall was seen in 2019, with 37.5%. The number of buses has been considerably varying since 2000 and onwards. However, in 2003, the highest increase in the number of buses on road networks of Pakistan was witnessed. It indicates the highest buses sale within the same period. The anomaly can be seen in the year 2002, where a decrease of 4% can be seen in Fig. 4. Although, sales of heavy vehicles were declined in year 2019, it is expected that transportation sector in Pakistan will start growing in the near future. Deployment of e-trans would allow the increased penetration of renewable energy related projects as the charging infrastructure is proposed to be based on renewable energy. The Government of Pakistan has invested huge sums in the construction industry and various other businesses, which will help boost the sales of heavy vehicles in the near future. The Auto policy of 2016-2021 of Pakistan allows the foreign countries to set up their plants in Pakistan for trucks manufacturing, and Pakistan would be benefited by having the imports at better price. These measures have consistently led towards the growth of heavy vehicle industry in Pakistan. The only anomaly occurred in 2019 due to the factors mentioned above. Therefore, heavy EVs sales will increase in the future and with significant GHG emissions, and e-trans deployment on CPEC can considerably curtail it. The total road network of Pakistan is 264,401 km which comprises of expressways, motorways, strategic routes, and provincial highways [23]. The railways network in Pakistan spreads up to 7791 km throughout the country. It carries a total of 52 million passengers annually on average, and freight transport via rail recorded in the year 2015 was 5 million tons [24]. The Civil Aviation Authority has demonstrated...
the critical role in Pakistan as cargo transport across the country was recorded 338,467 tons in 2015.

The transportation sector of Pakistan consumed 57% of petroleum in 2017 [9]. According to [25], the net oil imports in Pakistan currently lies at USD 13 billion and is expected to hit a figure of 30 billion by 2030. Therefore, electrification of transportation is deemed necessary to curb oil imports for the reduction of the current account deficit. Increased dependence on fossil fuels led Pakistan to find ways of reducing GHG emissions. The escalating oil prices and increasing power demand are already stressing the weaker power grid of Pakistan [26], [27]. EVs are a viable option for Pakistan as it would certainly reduce dependence on petroleum products and curb GHG emissions. Government of Pakistan has approved EV policies in November 2019 with the motive of converting 100,000 cars and 500,000 bikes and rikshaws by 2030. The stakeholders and electric utilities have concerns over the drafted policies which are yet to be addressed.
FIGURE 4. Annual change in number of buses.

FIGURE 5. Highway network of CPEC [8].
Effective functioning would only be possible if these concerns are addressed. The Prime Minister of Pakistan instructed in May 2019 to achieve the target of 30% EVs by 2030, and the Ministry of Climate Change was handed over the responsibility of achieving the particular target. The Ministry of Climate Change mentioned that the sole purpose of the target is to reduce environmental pollution. The first phase is expected to be applied on two- and three-wheeler electrification in Islamabad and Sialkot.

### III. CHINA PAKISTAN ECONOMIC CORRIDOR

CPEC is an infrastructural network that provides regional connectivity. CPEC was launched in 2015 and it was made an integral part of Chinese One Belt One Road (OBOR) Initiative. China decided to invest USD 46 billion in it for the next 15 years [28]. The investment was split to be invested in two different sectors named transportation and energy. Not only Pakistan and China get benefitted by its objectives but also Iran, Afghanistan, India, and Central Asia have will have geographical linkage enhanced within the region. The geographical links are comprised of railway networks, roads, gas pipelines, economic zones, etc. As per the Pakistan Economic Survey 2018-19 [24], National Highway Authority (NHA) is involved in CPEC projects having worth of PKR 700 Billion by connecting Khunjarb to Gwadar. The highway network of CPEC is shown in Fig. 5. Almost 28% of the total investment was made in the development of infrastructural network. The investments are focused on upgrading and modernization of existing infrastructure. The breakdown of the allocated budget for CPEC is given in Fig. 6.

There are short, medium, and long term CPEC projects in progress that are being managed by NHA [24]. The primary objective here is to connect Gwadar port in Balochistan, Pakistan to Xinchang, China. The details of these on-going projects are given in Table 1, Table 2, and Table 3. The importance of CPEC’s transportation sector can easily be comprehended by its impact on the overall transportation infrastructure of Pakistan. It is because of this project that the geographical link between Pakistan and Africa, Europe, Asia, and all sub-regions within Asia would result in the removal of trade barriers [29]. The areas adjacent to corridors would be the beneficiaries, especially small and medium enterprises of Pakistan [30]. The astounding investment in transportation sector also stems from the fact that it has the potential to attract the world players and investors for availing trade assistance of CPEC [31]. Therefore, electrification of mass transit is necessary because of forecasted busy transportation on it as it will significantly curtail GHG emissions and oil imports in Pakistan. The total road network proposed for CPEC is 5430 km.

### IV. EV TECHNOLOGIES

With technological advancement, EVs are expected to receive preference in the future surpassing ICE vehicle demand. Vehicles having only batteries as a source of energy are known as battery electric vehicles (BEVs) [32]. However, hybrid electric vehicles (HEVs) use source of energy along with electricity. HEVs uses both electric and internal combustion engine [33], [34]. Ultra-capacitor-assisted electric vehicles have electric battery and capacitor in combination [35], [36]. Similarly, the combination of fuel cells and
TABLE 1. Short term eastern alignment projects.

| S. No. | Project description                  | Length (km) | Status          | Implementation period |
|--------|--------------------------------------|-------------|-----------------|-----------------------|
| 1      | Basima to Hoshab-Gwadar              | 400         | Completed       | -                     |
| 2      | Khuzdar to Basima (N -30)            | 110         | PC-I approved   | 2019 to 2022          |
| 3      | Wangu Hills to Khuzdar (M-8)         | 113         | Completed       | -                     |
| 4      | Quba Saeed Khan to Wangu Hills (M-8) | 42          | Completed       | -                     |
| 5      | Ratodero to Quba Saeed Khan (M-8)    | 59          | Completed       | -                     |
| 6      | Shikarpur to Ratodero (N-55)         | 49          | Under Construction | 2018 to 2023        |
| 7      | Sukkur to Shikarpur (N-65)           | 40          | Completed       | -                     |
| 8      | Hyderabad to Karachi (M-9)           | 136         | Completed       | -                     |
| 9      | Sukkur to Hyderabad (M-6)            | 296         | Under Procurement | 2018 to 2023        |
| 10     | Multan to Sukkur (M-5)               | 392         | Under Construction | 2013 to 2020       |
| 11     | Khanewal to Multan (M-4 Ext)         | 57          | Completed       | -                     |
| 12     | Gojra to Khanewal (M-4)              | 127         | Under Construction | 2018 to 2023        |
| 13     | MI to Gojra (M-1, M-2, M4)           | 402         | Completed       | -                     |
| 14     | Havelian to Burhan (E-35)            | 59          | Completed       | -                     |
| 15     | Thakot to Havelian (E-35)            | 118         | Under Construction | 2016 to 2020       |
| 16     | Raikot to Thakot (N-35)              | 270         | Planning Stage  | 2018 to 2023          |
| 17     | Khunjerab to Raikot including Atta Abad Lake | 335     | Completed       | -                     |

TABLE 2. Medium term western alignment projects.

| S. No. | Project Name                  | Length (km) | Status                              | Implementation period |
|--------|------------------------------|-------------|-------------------------------------|-----------------------|
| 1      | Hoshab to Gwadar (M-8)       | 193         | Completed                           | -                     |
| 2      | Surab to Hoshab (N-85)       | 449         | Completed                           | -                     |
| 3      | Quetta to Khuzdar (N-25)     | 306         | Detailed Design is in Progress      | 2018 to 2023          |
| 4      | Zhob to Quetta (N-50)        | 331         | PC-I approved                       | 2018 to 2023          |
| 5      | Yarik to Zhob (N-50)         | 235         | PC-I approved Detailed Design is in Process | 2018 to 2023        |
| 6      | Hakla (Islamabad) to Yarik (DI Khan) | 285     | Under Construction                  | 2013 to 2020          |

batteries are called fuel cell EVs (FCEVs). PHEVs are similar to HEVs which include internal combustion engine and electric battery engine. The only difference is that electric engine is primarily used, and internal combustion engine is mostly used for backup purpose [37]. BEVs have electric battery packs. BEV electric range depends directly on the
TABLE 3. Long term central alignment projects.

| S.No. | Project Name             | Length (km) | Status                        | Implementation period |
|-------|--------------------------|-------------|-------------------------------|-----------------------|
| 1     | Den Allahyar to Wangu Hills | 94          | Feasibility Study Plan in 2025 | 2025 to 2030          |
| 2     | D.G. Khan to Dera Allahyar  | 303         | Feasibility Study Plan in 2025 | 2025 to 2030          |
| 3     | DI Khan to D.G. Khan       | 229         | Feasibility Study Plan in 2025 | 2025 to 2030          |

The trolley vehicles operate via two overhead lines having a voltage in range of 600 to 750V are constantly in contact with two trolley poles on trolley vehicles [40]. The trolley poles have a length of 6m with swivel attached to the roof of vehicle. It provides the lateral movement of about 4.5 meters. The enhanced uphill performance and higher acceleration of trolley vehicles are attributed to excess power supply [41]. Therefore, these vehicles can survive overloading as well. The components of trolley vehicle are pointed out in detail in Fig. 7.

A. BATTERY TECHNOLOGIES

The energy storage system for vehicles are categorized into batteries, ultra-capacitors, and fuel cells. Batteries are most popular energy storage system for EVs [9]. Battery technologies can be further segregated into Lithium-Ion (li-ion), Nickel Metal Hydride (NiMH) and Lead Acid. The pros and cons associated with battery types are elaborated below with an intent to highlight factors contributing towards li-ion batteries widespread adoption in EVs. Later, the feasibility analysis for facilitating heavy electric vehicles and mobile charging trucks will be conducted using li-ion battery specifications.

1) LI-ION BATTERY

It's the most accepted battery technology in EVs due to its lower self-discharge rate, higher energy specific power of 300 Wh/kg and energy density of 90-140 Wh/kg. Its salient features are lower weight and its compatibility with emerging light weight vehicles. Due to its compatibility, auto manufacturers worldwide fulfilled their objective of producing light weight EVs to boost their performance. However, high flammability of lithium poses a major drawback for li-ion batteries. That is why a battery management system is mandatory for protection in case of accidents. Li-ion batteries sustain moderately higher temperature which makes it suitable for weather condition in some areas of Pakistan. Although, every year li-ion battery prices are declining, still they are expensive in comparison with other battery technologies.

2) NI-MH BATTERY

These batteries are designed to operate smoothly at higher voltages having an energy density in between a 40-50 Wh/kg. They have a life cycle of 2000 cycles, which is way more than li-ion batteries. Still, their significant drawbacks are reduction in storage capacity after 300 cycles and discharging at higher load currents. These factors combined makes it an unfavorable choice in comparison with the li-ion battery.

3) LEAD ACID BATTERY

These batteries have lowest energy density than other technologies with just a mere 20-30 Wh/kg. It can be seen that if lead-acid batteries need to store a similar amount of energy stored in the battery. BEVs have an average range of 100 to 250 km, whereas 300 to 500 km is the range for the latest models of BEVs [38]. This is dependent on various factors such as specifications of battery, usage of vehicle and the geographical location where it is used [39]. BEVs are environment friendly, simple in design and have reliable operation.
while compared to li-ion battery, it must be at least 3 times heavier than li-ion battery. However, it has a lower manufacturing cost in comparison with li-ion batteries. That’s why it does cover a wider battery market compared to other technologies.

V. INFRASTRUCTURAL REQUIREMENTS FOR ELECTRIC TRANSPORTATION

It is a visible fact that penetration of electric buses and trucks in the transportation system requires a particular infrastructure with a focus on charging stations, which must be convenient, accessible, and affordable. Importantly, it will be essential to determine the source of electricity to recharge electric trucks and buses. Pakistan is experiencing rapid growth in its energy sector with modern power generation plants being erected, transmission lines being installed, and distribution network being set up to safeguard access of energy for the ever-increasing population in the newly urbanized areas. Considering the scale of needed infrastructure development under the CPEC project, it opens up a golden opportunity for the deployment of e-trans in Pakistan. This section elaborates relevant technical and financial requirements for the seamless integration of e-trans under the flagship project of China’s initiative of One Belt and Road to abridge the distance between China and Eurasia-Pakistan.

A. TECHNICAL REQUIREMENTS

The technical requirements for deploying e-trans under CPEC are mentioned as follows:

1) ELECTRICITY REQUIREMENTS

It is essential to determine the source of electricity to recharge electric trucks and buses. The estimate can be made according to the expected number of vehicles, distance of routes covered, time of travel, number of charging stations and the battery size of the electric vehicles. Considering hybrid vehicles in mass transit makes the analysis a bit complicated as these vehicles consume 80% diesel and 20% electricity. In general, the trolley vehicles consume more electricity in comparison with battery electric vehicles as they are free from the constraint of battery size and the required energy over different landscapes to deliver desirable performance. Table 5 elaborates on the electricity consumption of different vehicles which would certainly aid to plan power requirements for e-trans deployment under CPEC.

2) ELECTRIC VEHICLE SUPPLY EQUIPMENT REQUIREMENTS

The electricity requirements of EVs are fulfilled by components like charging cords, charging stands, at, vehicle connectors, and protection equipment commonly known as electric vehicle supply equipment (EVSE). Yet, the Government of Pakistan has to install EV charging stations and for that effective planning is required to enable charging requirements and EVSE specifications to complement each other. To achieve EVSE compatibility with EV requirements, in depth understanding of various aspects of chargers is required. The vital specifications of EV charger includes mode, type and level. The Mode defines communication protocol between charging station and EV owners, type of chargers refers to charger’s socket and level of chargers defines the output power of EV chargers. The charger level alone cannot determine the charging period of battery instead the battery technology plays significant role in it. Pakistan can follow a case study of their neighboring country as the Government of India has installed two types of DC chargers and their detail is mentioned below [9]

- Level 1 DC charger providing output power in the range of 10 kW to 15 kW
- Level 2 DC charger providing output power in the range of 30 kW to 150 kW

Considering the humongous battery size and requirement of minimal charging time of trucks, level 2 DC chargers with 150 kW output power seems to be a feasible option to initiate e-trans on CPEC.

3) TYPES OF EV CHARGING STATIONS

Optimal utilization of electric vehicles can be achieved via planned charging infrastructure, which is also known as electric vehicle supply equipment (EVSE). Therefore, achieving standardization in EV chargers is of utmost importance. IEC (International Electro-technical Commission) defines a conventional plug charging standard of IEC 61851-1 for mode and IEC 62196-1 for its plug to ensure its standardization [42]. In order to meet these standards, it is mandatory for charging stations to comply with them to better recharge electric vehicles. The charging modes define the benchmark for setting up EVSE [43]. Energy requirements for electric and hybrid trucks can only be met via mode 3 and mode 4 as both of them can be installed at charging stations on highways. Mode 3 is economical if charging is performed overnight. Otherwise, mode 4 is preferred for quick charging.

4) SOURCE OF ELECTRICITY

The rapid growth of power system infrastructure in Pakistan with the installation of new generation units demands an effective strategy for the utilization of sources to sustain additional electrical load in the form of e-trans. There are possibly two options to address it; one is the exploitation of the abundant source for power generation while other is planned source utilization for increasing vehicle efficiency. It has been observed that electricity generated from renewable sources would result in the highest well-to-wheel (WTW) efficiency [10]. It has the potential to save 50% energy consumption of vehicles if compared to diesel engine vehicles [11]. The details for WTW efficiency of an electric bus are given in Table 4 to bolster the aforementioned fact. In Table 4, the diesel bus (DB) is used as a reference for planned source utilization for increasing vehicle efficiency. The charging modes define the benchmark for setting up EVSE [43]. Energy requirements for electric and hybrid trucks can only be met via mode 3 and mode 4 as both of them can be installed at charging stations on highways. Mode 3 is economical if charging is performed overnight. Otherwise, mode 4 is preferred for quick charging.

5) GRID EXPANSION

The penetration of e-trans under CPEC would create numerous problems for the ill-conditioned power grid of Pakistan at
TABLE 4. Well-to-wheel energy consumption.

| S.No. | Powertrains                                      | Source of Energy | WTW (MJ/km) | Average energy consumption reduction compared to DB |
|-------|--------------------------------------------------|------------------|-------------|---------------------------------------------------|
| 1     | Diesel Bus                                       | Diesel           | 20.66       | 26.14 %                                           |
| 2     | Diesel Hybrid Electric Bus in series configuration| Diesel           | 15.26       | 21.97 %                                           |
| 3     | Diesel Hybrid Electric Bus in parallel configuration| Diesel           | 16.12       | 9.68 %                                            |
| 4     | Battery Electric Bus                             | Renewable        | 10.33       | 50.00 %                                           |

6) POWER QUALITY ISSUES

Interface devices for EVs employ power electronic converters. These converters are highly non-linear based on their operating principle and involve switching power semiconductor devices. The input current fed to converter contains higher harmonics, and therefore, upon malfunctioning, they create power quality (PQ) problems [46]. Therefore, an effective strategy needs to be developed for suppressing these PQ problems before increased penetration of EVs load in the future. The PQ problems for the grid arising out of EV penetration are mentioned in Fig. 8. One of the major reasons behind PQ problems is the consumption of non-linear current by battery charging systems [47]. The major concerns as a result of PQ problems are listed below:

- Transformer overloading: EV penetration poses a risk of EVs being charged during peak hours which may cause an increase in the loading and rise in temperature of transformers. Consequently, voltage levels may fall below permissible range. To address this issue, there has to be hourly tariffs to avoid escalation of load during peak hours.

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- Voltage imbalance: The uncertainty in EV penetration level and connection points would cause voltage imbalance in three-phase networks alongside the use of single-phase chargers for charging EVs in residential networks.

- Harmonics: Frequent connection and disconnection of EVs will introduce current distortions and voltage harmonics in power system. Moreover, the randomness in EV charging pattern may overload the power lines, affect load curve, introduce harmonics, and increase system losses. It may also result in various other PQ problems like notches, flickers, voltage sag, voltage swell, interruptions, and transients.

B. FINANCIAL INVESTMENT REQUIREMENTS

The financial investment requirements for deploying e-trans under the CPEC is detailed in this section.

1) CAPITAL COSTS

Capital cost required for setting up e-trans infrastructure under the CPEC revolves around the costs mainly associated with the procurement of electric trucks and buses and charging infrastructure. The cost of electric vehicles would be dependent upon its manufacturer and the country from
which being imported. The cost of importing these vehicles is important to consider because Pakistan does not possess sufficient raw materials, skilled labors, technology, and industry to manufacture EVs. Similarly, charging stations deployment cost would also be primarily based upon the charger type installed in them. Also, to facilitate vehicles, it is not compulsory to confine infrastructure deployment to charging stations only as battery swapping stations (BSSs) can also fulfill EVs demands by exchanging depleted battery with a fully charged battery pack. The study conducted in [48] defines the composition of average investment on a single BSS which includes similar investment areas for charging stations. The investment details are given in Table 5.

2) OPERATIONAL COSTS

The operational cost comprises of fuel costs, salaries, permits, tax, and insurance. The cost associated with fuel consumption would make the largest portion of operational cost, and they can be reduced via shifting from diesel engine vehicles to electric vehicles [49]. The second major chunk of these costs is salaries of staff, administration, conductors etc. The Government of Pakistan has an immense responsibility here to manage the demand and supply of laborers in this sector. There can be considerable variations in the cost of permits, tax, and insurance. It’s a way for the government to provide an incentive for purchasing EVs or for the operation of these vehicles. In this manner, the state target of having reduced GHG emissions would be significantly fulfilled by the government. Total cost of ownership would be a sum of purchasing cost and operational cost incurred for the deployment of e-trans on CPEC. Since the goods movement under the CPEC is expected to be colossal, the ownership cost associated with trucks will be highlighted to estimate trucks’ cost with different powertrain technologies. The analysis conducted in [48] compares the ownership costs between diesel trucks (DTs), plug-in electric trucks (PETs), and battery swapping based electric trucks (SETs). All of these vehicles are compared in their two variants which are light and medium-duty trucks. Their ownership cost is given in Fig. 9. The results show the least total cost of light-duty PETs with USD 35,047 while the medium-duty SETs display the highest cost of amount USD 99,353.

3) MAINTENANCE COST

The maintenance cost comprises of spare parts, annual maintenance contract, and routine inspection. If vehicle inspector would proceed to outsource its maintenance cost, then they only have to bear its annual maintenance contract cost or else expenses of inspection and spare parts would also be incurred. The cost associated with spare parts makes a significant proportion of it due to its frequent wear and tear. However, it would be significantly reduced as EV has fewer moving parts. The regular inspection cost also possesses a

### TABLE 5. Investment composition of battery swapping station having daily serving capability of 120 vehicles.

| S. No. | Infrastructure                  | Cost (million USD) |
|-------|---------------------------------|--------------------|
| 1     | Installation                    | 0.40               |
| 2     | Distribution Facilities         | 0.24               |
| 3     | Building                        | 0.79               |
| 4     | Equipment for charging and swapping | 4.34             |
| 5     | Other Cost                      | 0.28               |
| Total Cost |                                | 6.04               |
TABLE 6. Electricity consumption of different trucks.

| S.No | Parameter                        | Battery Electric Truck | Hybrid Truck | Trolley Truck |
|------|----------------------------------|------------------------|--------------|--------------|
| 1    | No. of vehicles                  | 1                      | 1            | 1            |
| 2    | Annual distance covered          | 150,000 km             | 150,000 km (20% distance covered using electricity) | 150,000 km |
| 3    | Annual GHG emissions (CO2 kg)    | 0                      | 123,934      | 0            |
| 4    | Consumption (kWh/km)             | 2.67                   | 2.67         | 2.81         |
| 5    | Electricity tariff               | USD 0.06/ kWh          | USD 0.06/ kWh | USD 0.06/ kWh |
| 6    | Electricity consumed (MUs*)      | 0.40                   | 0.08         | 0.42         |
|      | Cost of electricity consumed per annum | USD 24,000           | USD 4,800    | USD 25,200   |

considerable budget to ensure the safety of drivers and goods being transported.

VI. CASE STUDY
CPEC being a multi-billion-dollar project and nexus between energy and transportation could pave the way for road transport electrification in Pakistan. The case study is divided into two cases A, and B. Case-A is about electrification of trucks for freight transportation and the Case-B is focused on electric buses for mass transportation (public transportation).

A. OPERATIONAL COST
1) CASE-A
To illustrate the difference in the operational cost of electric trucks and diesel trucks, different segments of CPEC eastern alignment route are selected. The route passes through major industrial cities of the country. The selected route starts from Karachi connecting Hyderabad, Sukkur, Multan, and Lahore. The total road network from Karachi to Lahore is 1694 km. Onwards, Lahore is connected to Islamabad via motorway M-2 and M-1 links to Peshawar. Total length of Lahore-Peshawar Motorway is 489 km. A branch known as Motorway M-4 originates from Pindi Bhattian junction on M-2 which connects Faisalabad. It has two termination points one at Abdul Hakeem junction on M-3 and other at Multan junction on M-5. The total road length of M-4 segment Pindi Bhattian-Abdul Hakeem interchange is 212 km. Thus, the total Motorways’ lengths is approximately 2,395 km.

Typical speed of heavy-duty trucks in Pakistan is in the range of 40-50 km/hr [50]. According to International Labor Organization (ILO) Road Transport Convention (A General Conference), the number of driving hours per day shall not exceed 9 hours for trucks [51]. If we consider an average truck speed of 46 km/hr and the driving time of 9 hours a day, then the maximum distance covered by truck would be 414 km. It makes an annual distance covered by trucks to be 150,000 km. It means that specified route would be covered 62 times a year. In Table 6, we will assess how much electricity is consumed by different vehicle technologies and their potential savings in GHG emissions. For a fair comparison, the parameters mentioned in Table 6 and 7 belong to a heavy-duty 22-wheeler electric, trolley, and diesel trucks.

It can be seen in Table 5 that based on 100% electric operation, the annual operational cost of battery electric truck is lowest. It must be noted here that electricity tariff price, fuel price and all other prices associated with PV based charging stations were originally taken in Pakistani rupee and are then converted into USD. Although, figures suggest that electricity consumption of hybrid trucks is the lowest as they consume 20% electricity for operation. However, it comes at the cost of higher GHG emissions in comparison with battery electric and trolley trucks. Moreover, the GHG emissions of battery electric truck is least in comparison with other vehicle technologies. The diesel trucks have highest GHG emissions and operational cost as mentioned in Table 7. The annual energy cost savings using battery electric truck is USD 34,560. The average annual reduction in GHG emissions using battery electric trucks is 168,584 kg CO2.

2) CASE-B
In this case, we will also use the same specified route (2,395 km) mentioned for operational cost analysis of...
The average speed of buses on highways in 50 mph (80 km/h) [24]. According to road transport workers ordinance, bus drivers can drive a maximum of 8 hours daily and 48 hours weekly [51]. The average speed and permissible driving hours of bus render daily distance to be 640 km. It means that on average, a bus can cover 233,600 km annually by making 97 one side trips on specified route. Table 8 compares the annual operational cost of different bus technologies and their contribution in GHG emissions.

It can be seen in Table 7 that based on 100% electric operation, the annual operational cost of battery electric bus is lowest. Although, figures suggest that electricity consumption of hybrid bus is lowest but they consume 20% electricity for operation. However, it comes at the stake of higher GHG emissions in comparison with battery electric buses and trolley buses. Moreover, battery electric buses have least GHG emissions in comparison with other bus technologies. The diesel buses have highest GHG emissions and operational cost as mentioned in Table 9. The annual energy cost savings using battery electric bus is USD 4,800. The average annual reduction in GHG emissions using battery electric buses is 94,710 kg CO₂.

TABLE 7. Fuel consumption of diesel truck.

| S.No. | Parameter               | Diesel Truck |
|-------|-------------------------|--------------|
| 1     | No. of trucks           | 1            |
| 2     | Annual distance covered | 150,000 km   |
| 3     | Annual GHG emissions (CO₂ kg) | 168,584 |
| 4     | Mileage (L/km)          | 0.64         |
| 5     | Fuel price              | USD 0.61/L   |
| 6     | Fuel consumed (Liters)  | 96,000       |
|       | Cost of fuel consumption (Annual) | USD 58,560 |

Moreover, it should be considered that capital and installation costs could significantly vary in Pakistan as it depends upon the country from where technical equipment has been imported and the strength of local workforce involved in its installation.

There is a huge difference in infrastructure deployment cost having a fast DC charger installation network almost 0.1% of trolley trucks infrastructure installation. Yet the right of the way requirement cost is not included which further scales up the trolley trucks infrastructure costs. Therefore, the eastern route case study yet alone proves that for total CPEC network deployment of charging stations would be a feasible option.

VII. PHOTOVOLTAIC POWERED CHARGING INFRASTRUCTURE

This section is focused on utilization of renewable sources of energy like solar for supplying charging stations on the CPEC road networks. Given the fact that major portions of the road network of CPEC are situated in the province of Punjab, Baluchistan, and Sindh, solar power appears to be a better choice for supplying power to charging stations. The choice of solar stems from a fact that every year, average solar irradiance in Pakistan is 1918 kWh/m² with ten hours of sunshine throughout a day on average [53]. Sindh and Baluchistan comprise more than half the area of the country, and they are amongst the regions with the highest global radiation levels of 19-20 MJ/day having sunshine of 10 hours throughout a day [54]. The aforementioned discussion hints towards the immense potential solar energy for powering EVs in the e-trans network on CPEC. Therefore, an appropriate PV charging station model is proposed in this paper for the sustainable deployment of e-trans infrastructure.

A. PROPOSED PV POWERED CHARGING STATIONS

Under the proposed PV based charging station scheme, the solar panels will be installed on the roof of BCS. The
charging station model is given in Fig. 10. It is shown in the model that power generated by PV panels can be utilized by electric trucks, mobile charging trucks, electric buses, and the grid. During a day, electric trucks and buses can be charged through solar energy as the power output of these panels is maximum at noon. However, there is a possibility that surplus power produced may be unutilized as there would be no EVs in BCS for getting the depleted battery charged. Therefore, when power is surplus, electric mobile charging trucks would be charged with the surplus power. It serves the same purpose as a battery energy storage system in the charging station, but this option will be more beneficial because of its mobility. If any vehicle loses energy entirely on its way to charging stations, then these mobile charging trucks will provide a vehicle to vehicle charging while ensuring reduced disruptions in their journeys. In addition, the extra power after fulfilling charging requests will be fed to the grid so that these

### TABLE 8. Electricity consumption of different buses.

| S.No | Parameter                  | Battery Electric Bus | Hybrid Bus | Trolley Bus |
|------|----------------------------|----------------------|------------|-------------|
| 1    | No. of vehicles            | 1                    | 1          | 1           |
| 2    | Annual distance covered    | 150,000 km           | 150,000 km (20% distance covered using electricity) | 150,000 km |
| 3    | Annual GHG emissions (CO2 kg) | 0                  | 69,626     | 0           |
| 4    | Consumption (kWh/km)       | 1.5                  | 1.5        | 1.92        |
| 5    | Electricity tariff         | USD 0.06/ kWh        | USD 0.06/ kWh | USD 0.06/ kWh |
| 6    | Electricity consumed (MUs*) | 0.225               | 0.045      | 0.288       |
|      | Cost of electricity consumed per annum | USD 13,500 | USD 2,700 | USD 17,280 |

### TABLE 9. Fuel consumption of diesel bus.

| S.No | Parameter                  | Diesel Bus |
|------|----------------------------|------------|
| 1    | No. of buses               | 1          |
| 2    | Annual distance covered    | 150,000 km |
| 3    | Annual GHG emissions (CO2 kg) | 94,710       |
| 4    | Mileage (L/km)             | 0.20       |
| 5    | Fuel price                 | USD 0.61/ L|
| 6    | Fuel consumed (Liters)     | 30,000     |
|      | Cost of fuel consumption (Annual) | USD 18,300 |
TABLE 10. Fast dc charging and trolley trucks infrastructure deployment comparison.

| S.No | Description                                         | Further Detail (if any)                      | Costs          |
|------|-----------------------------------------------------|----------------------------------------------|----------------|
| 1    | Fast dc charger hardware cost                       | EVSE equipment                               | USD 45,000     |
| 2    | Total cost after installation of fast dc charger    | Permits, project development, system upgrades, and design. | USD 375,000    |
| 3    | Overhead lines infrastructure cost per km          | Right of way (ROW) cost is not included as it can significantly vary. | USD 2.56 million |
| 4    | Total fast dc charger installation cost on a specified eastern route |                              | USD 6.72 million |
| 5    | Trolley trucks infrastructure installation cost on a specified eastern route |                              | USD 6.13 billion |

stations ease the burden on the grid during peak hours. EVS and mobile charging trucks can also pitch in to feed power into grid during peak hours. In the case of BSS, batteries would be charged using PV panels, and mobile charging trucks will carry fully charged batteries to replace them with depleted batteries of vehicles stuck on their way to BSS. For the effective functioning of the proposed scheme, there must be communication between BCS or BSS owner, grid, and EV owner. In case, if the grid demands more power, mobile charging trucks can also feed power to them under the concept of a vehicle to grid (V2G) as they act as a spinning reserve. The vehicles falling under an umbrella of V2G are usually encouraged to charge in low demand hours and discharge in peak hours [55].

1) VEHICLE TO GRID POWER EXCHANGE

According to authors in [56], power fetched from V2G cannot compete for lower power prices, but still, it provides an incentive for consumers to feed power back into the power grid. Research conducted in [56] also presented an in-depth analysis of its effectiveness during peak hours as it can provide a backup of 3 to 5 hours. In [57], it is mentioned that currently, frequency regulation and spinning reserve is the best market for V2G technology. As per a case study of Germany and Sweden, 5.5% and 4.3% EVs respectively are engaged in power regulation (V2G operation) for the fulfillment of power demands [58]. As per the proposed model in this paper, the V2G interaction could play a vital role as it will help alleviate the burden on BCS by availing power from consumers to fulfill either grid or customer’s power requirements. Nonetheless, they have to depend on a vehicle to vehicle charging via mobile electric trucks, or else they have to get their battery swapped from BSS. Therefore, a feasible approach would be a network of both charging and swapping stations for electric trucks. It is because BSS could be more helpful after the sunshine hours to meet power requirements than that of BCS. Amidst all the possible hurdles in meeting power requirements of e-tarms, V2G will ensure that power stored in any vehicle must not stay in an idle state. Rather it must be used for ancillary services or meeting the drivers’ power requirements.

VIII. DISCUSSION AND ANALYSIS

To model a PV based BCS, it is necessary to estimate the electricity demand of a single BCS through a rigorous case study. In this regard, we have performed a case study and assume that the total number of electric trucks, electric buses and mobile charging trucks in CPEC road networks are 100, 100, and 10, respectively. Each charging station must be capable of fulfilling the demand of either 3 electric trucks, 3 electric buses, and one mobile electric charging truck throughout a day. It is assumed that there must be at least four chargers of 150 kW installed in each PV based BCS. It makes a solar power charging station of rating 600 kW. If at an instant, a mobile electric truck is charging, then the available chargers for charging electric trucks reduces by one. During a day, each BCS cannot fulfill the power requirements of more than a single electric mobile charging truck.

As discussed in Table 12, a fully charged electric truck needs 435 kWh of electricity. The battery size of electric
TABLE 11. PV based battery charging station requirements.

| S. No. | Description                                      | Technical Parameter | Quantity |
|--------|--------------------------------------------------|---------------------|----------|
| 1      | PV Module (TTN-295-315W-M72 by Zhejiang TTN Electric Co., Ltd.) | 315 Wp              | 1        |
| 2      | Converter (SDP-200KW by Zhejiang Sandi Electric Co., Ltd.) | Up to 200 kW        |           |
| 3      | Average no. of Sunshine hours in a day           | 10 hours            |          |
| 4      | No. of PV Panels required per PV based BCS      | -                   | 2000     |
| 5      | No. of Converter required per BCS               | -                   | 3        |

.bus is assumed to be 300 kWh [9]. Mobile electric truck needs 500 kWh of electricity to provide service for trucks and buses. The total energy requirement with 3 electric trucks, 3 electric buses and mobile charging truck is 2705 kWh. Therefore, every BCS will be designed to accommodate a load of 2705 kWh. The summary of all the requirements by PV based BCS for meeting the desired load is given in Table 11. The steps involved in the computation of the PV charging stations requirements are given below.

Objective: The aim here is to calculate the requirements of a single PV based BCS, and then we multiply it with the total strength of BCS to be installed on CPEC to estimate the budget of solar-based e-trans realization on CPEC.

- **Step 1:** We define the EV strength that shall be facilitated throughout the day by each PV based BCS. In our case, it must be three electric trucks, three electric buses and one mobile charging truck.

- **Step 2:** Although the selected panel can provide a peak power of 315 W, it is still assumed that, on average, it provides 300W during sunshine hours.

- **Step 3:** Now, under the assumption that a maximum of four 150 kW chargers are deployed in charging station makes total station rating of 600 kW. The required PV panel strength is 2000, given a panel can produce 300 W on average.

- **Step 4:** The EV charging directly from DC output of PV panels have many layers of issues. Therefore, a converter is required for PV modules output conversion to AC which is then converted back to DC by converter installed inside DC charger. The DC to AC converter module needs to be selected in a manner to accommodate the charging requirements of vehicles.

As elaborated in step 3, total charging requirement at a particular instant can surge up to 600 kW, given that four heavy vehicles or 3 heavy vehicles with 1 mobile charging truck are charging at a particular instant. The selected converter delivers a maximum output power of 200 kW, so we need a total of three converters.

**A. FINANCIAL ANALYSIS FOR E-TRANS INFRASTRUCTURE**

To calculate the cost of installing EVSE, a certain assumption has to be made regarding technical parameters of freight transport on CPEC. Various approaches can be adopted, in this regard, which are either of these: setting up BSS, BCS, infrastructure for trolley trucks, the conglomeration of all of them throughout road networks on CPEC. An in-depth cost analysis is carried out to provide guidelines for the stakeholders in Pakistan that what would be the possible costs incurred by electric trucks and trolley trucks along with their charging infrastructure. The cost analysis would be carried out based on the assumption that road networks on CPEC would be dominated by heavy vehicles like electric trucks and buses. To generalize the specifications of trucks, we consider the BYD Auto class 8 electric truck because of its huge success in the market. The specifications of the truck are given in Table 12.

The total road network proposed for CPEC is 5430 km as per the completed and pending infrastructure projects information given in Tables 1, II, and III. The analysis conducted in [59] shows that if the temperature range is between 25 to 55 degrees Celsius, the battery storage capacity can be degraded by 4.22% at 25 degrees and 13.24% at 55 degrees after 250 charging cycles. Therefore, considering an average temperature of Pakistan and battery degradation percentage, li-ion batteries in electric trucks would maintain a state of health (SoH) above 80% for approximately two years. Once, SoH drops below 80%, and the battery needs to be replaced as it would not be suitable for a long-range. Charging infrastructure deployment analysis would be carried out considering the worst possible scenario of vehicles having SoH of 80%. The details of charging stations cost analysis on specified
route is given in Table 11. However, it does not include operational costs, grid connection cost, and installation cost as they vary in different countries, and it only considers EVSE costs for respective levels of charging stations. The complete deployment cost for a BSS is given in Table 10, which includes all the factors as given. The complete BSS deployment throughout CPEC would require an investment of approximately 217 million USD. Similarly, for trolley trucks, the required infrastructure installation cost is around USD 0.2 million for every 100 kilometers on which overhead lines are being installed [40]. Thus, it is an optimal approach for the national actors to opt for a plan which includes a mixture of different levels of BCS and BSS.

The solar map of Pakistan indicates a significant variation of solar irradiance throughout the country. The solar irradiance for different provinces of Pakistan are highlighted in Table 13. It states that Baluchistan has the highest solar irradiance while Islamabad receives the lowest irradiance. In quantitative analysis, we have used average solar irradiance throughout Pakistan to achieve precision in results. The average irradiance calculated from Table 13 is 1918 kWh/m². The selected PV panel TTN-295-315W-M72 has a panel efficiency of 16.28% at standard temperature and conditions. PV module temperature of coefficient for power is −0.42%/°C. The temperature average around 45°C in Sindh, Baluchistan, and South Punjab during summer season. The extreme temperature results in the decline of panel efficiency by 8.4%, making PV module to be 14.9% efficient. In such conditions, selected PV module can provide power of 300W on average. However, it is common for some areas in Sindh and Baluchistan to have temperature as high 55°C in summer. At 55°C, the average output power of panel drops to 271 W. The variation in PV panel output results in variation of charging station output power by 10% i.e 600 kW at 45°C and 542 kW at 55°C.

The cost of PV panels will make 50% of the total cost required for the installation of PV based BCS. As per the authors in [61], the installation cost, operation, and management (O&M) cost of PV battery charging station is USD 1800/kW and USD 20 per annum in 2014. Considering the currency deflation since 2014, the O&M cost in 2020 is USD 22 per annum. To ensure the profitability of PV based BCS, it is mandatory to implement time of use (TOU) tariff. Where TOU tariff also creates room for consumer’s participation in the V2G facility as they can recover a significant portion of charging cost by feeding power to the grid. For instance, Fig. 11 gives a TOU tariff of Shenzhen, China [62].

Such tariffs must be introduced in BCS under the CPEC networks to encourage consumers to sell excess energy to stations instead of storing them, which would not offer any financial benefits for the drivers.

Considering the technical equipment information given in Table 11, we aim to estimate the cost to be incurred for each PV based charging station and accordingly for a network of the proposed charging station. The details of costs associated with solar power based charging station deployment are given in Table 14. Nonetheless, this cost could significantly vary based on the level of EV charger deployed alongside the solar system. Considering the total budget of CPEC, which is USD 62 billion, USD 43.4 billion is supposed to be invested in the energy sector [24]. Approximately the budget of solar-based charging stations through the CPEC road network will make 0.29% of the approved energy sector budget if the PV based BCS are scaled up to accommodate 1000 electric trucks, 1000 electric buses and 100 mobile charging trucks. Where, the cost estimation is carried out for powering 100 electric trucks, 100 electric buses, and ten mobile charging trucks ensuring no loss of generality. A stepwise detail on the computation of the budget required for e-trans realization using solar power is given as follows:

**Objective:** The aim here is to calculate the investment required for deployment of solar energy based BCS network under CPEC, and its step-wise detail is given below:

- **Step 1:** Firstly, we need to find the number of charging stations required to be constructed on CPEC route to facilitate 100 electric trucks, 100 electric buses and ten mobile charging trucks. Assuming, the extreme conditions on the permissible state of electric vehicles, the BCS network strength will be decided. These extreme conditions are 80% SoH of the vehicle’s...
TABLE 14. PV based battery charging station requirements.

| S. No. | Description                                                                 | Quantity | Price  |
|--------|-----------------------------------------------------------------------------|----------|--------|
| 1      | PV Module (TTN-295-315W-M72 by Zhejiang TTN Electric Co., Ltd.)            | 1        | USD 8.22 |
| 2      | Total PV Modules in BCS                                                      | 2000     | USD 16,440 |
| 3      | Converter (SDP-200KW by Zhejiang Sandi Electric Co., Ltd.)                  | 1        | USD 50,000 |
| 4      | Total no. of Converters needed for BCS                                      | 3        | USD 150,000 |
| 5      | Installation Cost per BCS                                                   | -        | USD 420,000 |
| 6      | O&M Cost per BCS                                                           | -        | USD 22/year |
| 7      | Total PV Modules Cost for all BCS in CPEC                                   | -        | USD 263,040 |
| 8      | Total Converters Cost for all BCS in CPEC                                   | -        | USD 2.4 million |
| 9      | Total Installation Cost for all BCS in CPEC                                 | -        | USD 6.72 million |
| 10     | Total Annual O&M Cost for all BCS in CPEC                                   | -        | USD 792 |
| 11     | Semi-fixed Cost                                                             | -        | USD 3.10 million |
| 12     | Estimated Total Cost incurred for a for PV based BCS Network                | -        | USD 12.5 million |

Battery and fully loaded vehicle. The range of vehicles in such circumstances turns out to be 150 km. It implies a BCS has to be installed at an interval of 150 km throughout CPEC eastern route where the required number of BCS is 16.

- Step 2: Secondly, we find the cost of the selected PV panel associated with each BCS, and it turns out to be USD 16,440 for one charging station. The total cost for 16 BCS will be USD 263,040.
- Step 3: Next, we compute the total cost of power converters required for the charging stations, which is estimated to an amount of USD 2.4 million.
- Step 4: The average installation charges for a fast DC BCS including hardware are USD 420,000. Total BCS network installation charges on CPEC are estimated to be USD 6.0 million.
- Step 5: We have considered semi-fixed cost associated with the deployment of the BCS network, which accounts for annual interest and depreciation cost of the infrastructure and the equipment, salaries of executives, and applicable taxes.
- Step 6: Finally, all the costs estimated in the above steps are added, and the estimated total cost comes out to be USD 12.5 million.

It is observed that investment in solar energy based charging stations appears to be quite a feasible option. Importantly, Pakistan will be set forth on a path of clean energy utilization in the transportation sector. In addition, the benefits associated with it are long term if the concerned stakeholders plan its execution considering all the technical and economic aspects associated with it, as presented in this research paper. The scheduling of EVs charging is crucial to ensure that none of the charging stations gets overburdened with large number of charging requests by EV drivers. Optimal scheduling reduces EV queues for recharging their batteries. However, it is an optimization problem which goes out of the paper’s scope and it will be included in the future work to assess the profit margins for CPEC’s charging infrastructure owners with and without V2G operation.

B. BENEFITS FOR CUSTOMERS AND SYSTEM OPERATORS

Previous discussion underlined the reduction in GHG emissions and the lesser operational costs for the EV drivers. However, system operator can also reap benefits in the form of vehicle to grid integration in power system. EVs act as a spinning reserve by providing power during peak hours at cheaper price. To assess the financial benefits for system operator, we are using Shenzhen tariff given in Fig.14 as hourly TOU tariff does not exist in Pakistan. The peak hour electricity price is 17.8 cents/kWh and lowest cost in off peak hours is 5.7 cents/kWh. Assuming that EV owners would get 80% of electricity price being active at the time of arrival and system operator charges 30 cents/kWh to its consumers. The maximum and minimum profit of 25.44 cents/kWh and 15.76 cents/kWh can be earned in off-peak and peak hours, respectively. The EV benefits are not localized to reduced GHG emissions and operational cost of customers. They provide enhanced level of comfort in driving experience in comparison with conventional fossil fuel vehicles [63]. The
primary reasons contributing to the comfort in EVs are quick acceleration, higher energy efficiency due to instant torque, reduced vibration, less noise, better weight distribution and improved handling. Therefore, driving experience is another factor to attract customers towards EVs.

Electric bus offers considerable reduction in fares in comparison with diesel bus. We would try to demonstrate fare reduction by cost analysis on the route of Lahore-Multan with a length of 366 km. Currently, diesel price in Pakistan is 106.46 PKR/litre. The average mileage of buses in Pakistan is 5 km/litre [64]. The calculation with considered parameters delivers total fuel cost of diesel bus on a specified route to be PKR 7,793. Approximately each passenger bears PKR 200 fuel charges but after addition of other charges, total fare settles at PKR 1100. If electric bus replaces diesel bus on same route, its efficiency of 1.56 kWh/km and tariff of PKR 10/kWh results in the operational cost of PKR 5710. It is approximately 27% less than that of diesel bus. Similarly, it offers reduced fare of PKR 803 for one side trip.

GHG emissions and other toxic pollutants in air are generally treated as environmental pollution when it comes to analysis of EVs impact on the environment. However, very few researchers have discussed the potential of reduction in noise pollution by EV penetration. If heavy duty trucks and buses are electrified, then significant reduction in noise pollution can be achieved. As per authors in [63], the decreased noise levels have resulted in the improved health of bus drivers. The drivers used to exhaust after 7 hours of driving and have limited productivity throughout the rest of the day. However, after switching to electric bus, they now drive for 10 hours a day and rest of their day is quite productive as well. The V2G services are not restricted to provide financial benefits to system operators by acting as spinning reserve only. Instead, they provide ancillary services like frequency regulation and counter intermittency in the power grid operation. As mentioned earlier, V2G enables power transfer to grid during peak hours which means it contributes in peak shaving or valley filling.

IX. SWOT ANALYSIS
The SWOT analysis is a well-structured tool to analyze the strengths, weaknesses, opportunities, and threats associated with the e-trans deployment under the CPEC. The purpose of this analysis is to consider all the factors that affect the market and business of mass transit. It will clearly communicate the concerned stakeholders and private investors about the pros and cons of the proposed initiative so that they can acclimatize themselves with critical details about e-trans deployment on CPEC. Strengths and Opportunities are the positive aspects demonstrating the factors that provide an advantage over others and the possibility of capitalizing on factors that lead towards advantage, respectively. Weaknesses and Threats are somehow concerning aspects that highlight the areas requiring improvements that may hinder the success of the project. The summary of swot analysis is given in Table 15.
TABLE 15. Summary of swot analysis.

| Strengths | Weaknesses |
|-----------|------------|
| - No GHG and carcinogenic substance emissions | - Power system not robust to support EVs at massive scale |
| - Reduced dependence on oil imports | - Lack of charging infrastructure, and technologies |
| - Lower maintenance cost | - Limited range of EVs will make it difficult to compete the market |
| - Increasing gasoline prices would contribute in EVs success in market | - EV policy is in embryonic stage and is prone to changes |
| - Ongoing development of CPEC projects has ample margin for e-trans deployment | - Lack of research and development capacity |

| Opportunities | Threats |
|---------------|---------|
| - Deployment of electric mass transit across the country | - Varying landscape restrict BEV penetration in some areas of the country |
| - More job opportunities in transportation sector | - Lack of awareness amongst transportation sector personnel about EVs might lead to mishandling of vehicles |
| - The growth in awareness for the adoption of sustainable transport | - Low popularity of EVs due to high total cost of ownership compared to diesel engine vehicles |
| - e-trans development will put the country on a trajectory of Smart City Concept | - No raw materials available for manufacturing of EV batteries |
|               | - Lack of manufacturing facilities for EVs and its battery |

Using RES [65]. Countries like Canada, China etc. are strictly adhering to an idea of smart city and e-trans deployment under the CPEC will put Pakistan on the map of the smart world.

D. THREATS
The varying landscape of the country makes it difficult for extensive BEV implementation throughout CPEC the latter may underperform in hilly areas in comparison with trolley vehicles and PHEV. There is almost no awareness amongst personnel involved in transportation sector about technologies of BEV, PHEV, and trolley vehicles. It might lead to mishandling of e-vehicles in real-life. The total cost of ownership for diesel engine vehicles is quite less than BEV and PHEV which will hinder electric trucks acceptance amongst private vehicles in transportation sector. The increasing electricity prices will also make consumers hesitant to opt for electric mass transit vehicles. The raw materials for the manufacturing of lithium-ion batteries are not available in Pakistan so it has to rely on importing batteries from neighboring countries. Moreover, there are no plants for EV and batteries manufacturing which cause the increased EV cost and make it a tough choice for the consumers to opt for.

X. CHALLENGES AND IMPLICATIONS OF SOCIO-ECONOMIC, TECHNICAL AND ENVIRONMENTAL FACTORS
A number of factors such as lack of interest in EV manufacturing, sales, investment in its development, and infrastructure can be resistive for the launch of transport electrification. All the possible aspects are analyzed in this section that could hinder the e-trans implementation on CPEC. Broadly, these factors are categorized as economic, social, political, technical, and environmental barriers. Graphical abstract of the paper is shown in Fig. 12.

A. SOCIAL
Safety of infrastructure and foreign personnel is one of the major concerns for the investors of CPEC and it will apply to the proposed e-trans project. Pakistan has a deep history of public protests turning into ultimate chaos which eventually leads to heavy financial losses. In this wake, the provision of security and safety for deployed infrastructure is necessary for investors and EVs. Lack of familiarity for the technology amongst personnel involved in the transportation sector would take much efforts in convincing them to opt for electric vehicles. It applies equally to both investors and truck drivers. If this issue is not tackled properly, it will result in misuse of charging stations infrastructure and EVs leading the reduced useful lifespan. Besides, the language barrier would also make it difficult for professionals in Pakistan to seek advice directly from Chinese experts in this domain. Therefore, the government of Pakistan has to be directly involved in devising a scheme to educate local people for seamless transitioning towards new technology. Importantly, a widespread misconception of safety hazards is associated with EVs. Some locals who are aware of the technology still believe that chances of catching fire in EVs are more than that
of conventional ICE vehicles. Generally, cells of lithium-ion battery get short and may cause overheating and initiate ignition of the chemicals inside the battery. Such incidents usually occur due to overheating of battery if inappropriate charging method or equipment is used in charging a battery [66]. Though, considering the severe climatic conditions in some areas of Pakistan, the battery can still get overheated. However, again the probability of such incidents is extremely low if vehicle’s battery is properly managed. Thus, e-tans may have less social acceptability. In this regard, the government must educate EV users about safety aspects associated with it. The societal forces have always been very vital factor in deciding the fate of a project in Pakistan. If project benefits them, then it may be smoothly implemented; otherwise, huge investment goes in vain. KalaBagh Dam is a prime example of it as all societal forces are not on the same page. However, the Dam project is feasible and can eradicate power deficiency in Pakistan [67]. Therefore, timely realization of e-trans on CPEC demands no interference of societal forces. These forces can also affect the sustainability of project in the long term. In case of installation of overhead lines for trolley trucks, the right of the way (ROW) requirement is another humongous task. It involves securing ROW permissions as it involves the acquisition of land, environmental, and regulatory clearances. It will be extremely difficult to acquire permissions in densely populated areas and consequently, e-trans under the CPEC may become prone to unwanted delays.

B. ECONOMICAL

An important factor for hindering the interest of customers in shifting towards EVs is the cost of an electric vehicle. As the battery cost contributes significantly to it, the cost can be avoided by adopting BSS deployment in which batteries
are leased to customers by BSS owners. However, if BCS are deployed then customers need to pay for the batteries while purchasing vehicles. Even if we compare the total cost of ownership for EVs with conventional fossil fuel vehicles, the EVs cost is uncompetitive for the mainstream market. To ensure EV progress in the market, this barrier needs to be eradicated [68]. As considerable infrastructural projects of CPEC are still under development stage, there is a possibility that investors of BCS, BSS, and overhead lines infrastructure may not yield the profits as per their expectations which makes them hesitant to invest in this sector. They would rather prefer to wait for the completion of all CPEC infrastructural projects to make their investment safe by ensuring certainty in the payback period of their investment.

Contribution of financial investment by Pakistan in CPEC projects is below par. It is attributed to weak economic growth in the country for a few years. The relevant CPEC projects are reliant upon financial support from autonomous regions. Although CPEC projects recently have been developing rapidly still, Pakistan lags, considering a huge demand for funds [69]. The country is more dependent on Chinese investment as the state has limited financial resources. Still, in terms of infrastructure sustainability in the long term, Pakistan needs to invest more in CPEC infrastructure projects. Similarly, it poses an equal threat to e-trans projects on CPEC as Pakistan struggles to achieve financial stability, and it would simply result in the delayed implementation of the projects. The depreciation of Pakistan’s currency can be another hurdle in e-trans implementation in CPEC. Authors in [70] elaborated that Pakistan had an artificially inflated exchange rate to PKR 100/USD as a result of currency depreciation which would be unsustainable for the long term. Even in 2019, the funds of CPEC have been reduced by 60% in comparison with 2018 to sustain the economy of the country. Therefore, it is the need of the hour for Pakistan to address this barrier, or they might be under a huge financial debt of China.

C. POLITICAL
The political instability in Pakistan is linked directly with the pace of any project including e-trans implementation under the CPEC. The successive governments rarely stand on the same page when it comes to supporting the projects. The project of such massive scales requires persistent financial support and efforts from governments for a longer period. In a past, few examples can be witnessed in which a new government effectively carried forward the pending projects of previous governments. Although terrorism is eradicated from Pakistan still internal regional disputes amongst locals are common. The huge sum invested by investors must be secured to build their confidence. Unlike other infrastructural projects, any chaotic situation leading towards infrastructure destruction would upset the e-trans operation and trade would be severely affected. Importantly, Pakistan has a limited set of policy guidelines related to medium-duty electric trucks, heavy-duty electric trucks, and charging stations in place.

It would certainly cause diversity in installed infrastructure, and therefore standardization may not be achieved. The EV owners would be suffered from it and the potential customers may be discouraged from switching to EVs. In addition, inadequate coordination and coherence between the federal and provincial governments of the country have a history of impeding projects in the past. Such disputes always threaten investors and, to avoid any complications, they would disassociate themselves. To ensure flawless execution, every aspect of e-trans project has to be unanimously agreed by federal and provincial Governments.

D. TECHNICAL
Successful e-trans implementation is reliant upon both investors and electric vehicle owners. If any of them are not willing to adopt the latest technologies, it will directly affect the sustainability of transport electrification. Anxiety on the limited travel range of electric trucks could prove to be detrimental for e-trans as it may cause some typical users to not opt for the appropriate technology. Electric power grid of Pakistan is not robust enough to fulfill the electricity requirements of consumers and some areas still face load-shedding for many hours in a day. It poses a huge challenge to handle e-trans load requirements. In this regard, the proposed model presented in the paper argues for developing renewable energy-based charging stations to meet the EVs’ load demand. The critical component for smooth functionality of EVs is its battery, and majority of EVs around the world use lithium-ion batteries. To ensure long term sustainability of EVs, deployment of batteries manufacturing facility is a prerequisite as importing them through a proper channel causes unusual delays. Thus, it will create problems for BCS and BSS owners to possess permissible batteries (SoH greater than 80). It may result in some electric truck owners using batteries with dropped state of health, and the expected range of EVs would be significantly reduced.

E. ENVIRONMENTAL
Pakistan is comprised of diverse topography ranging from plain to hilly areas. The hilly areas are quite frequently faced with an issue of land sliding and the stakeholders may not afford to risk the deployed e-trans infrastructure due to such natural hazards. In this regard, extra planning and investment need to be involved in the installation of BCS or BSS in hilly areas which would take more time than that of expected installation time on plain areas. The scorching heat in the provinces of Sindh, Baluchistan, and Southern Punjab can significantly affect the efficiency of electric trucks as the optimal temperature for the best battery performance is close to 25°C. Authors in [71] measured the effect of temperature on SoH of a li-ion battery within the range of −10 °C to 70°C. They concluded that if temperature approached 50°C on the higher end and −10°C on lower end, a sudden drop in batteries SoH can be witnessed which is a great concern for the owners as well as users with increased anxiety of reduced EV travel range. Thus, it is important to employ a battery
thermal management system according to the environmental conditions to ensure the safety of vehicle users, improved battery life, and enhanced EV travel range.

**XI. POLICY RECOMMENDATIONS**

Effective regulations and policy guidelines are needed to be formulated for successful e-trans. The policies need to ascertain proper charging infrastructure deployment goals, identification, and obligation for the financing and implementation process. A sophisticated policy outline enables the government to attain an efficient balance between socio-economic, political, technical, and environmental challenges. Following is the suggested set of policies with a focus on multi-dimensional aspects.

**A. ENVIRONMENTAL POLLUTION**

One of the major goals of e-trans deployment is to eradicate GHG emissions for restricting environmental pollution in Pakistan. Therefore, to achieve promising results, it is mandatory to generate power using renewable sources of energy for charging vehicle batteries. Authors in [72] argued that electricity generated from a blend of fossil fuels and wind had reduced GHG emissions by 42% in US while powering all EVs using only wind energy resulted in a 99.97% reduction in GHG emissions. Thus, it must be mandatory for all BCS and BSS owners to meet their power demand using renewable energies only.

**B. BATTERY THERMAL MANAGEMENT SYSTEM**

Average temperature in the summer season in the regions of South Punjab, Sindh, and Baluchistan goes as high as 50°C and even goes beyond in some areas. It may result in a drop of li-ion battery SoH and this leads to unexpected interruptions and delays in goods transportation leading to huge financial losses. Thus, BSS and BCS must deploy a battery thermal management system inside their premises while charging/discharging a battery.

**C. PRIVATE SECTOR**

Although the government caters a project of such magnitude, the private sector can play a crucial role in the proposed model of the project. Humongous initial capital cost and power requirements for meeting demands of overhead lines and charging infrastructure can certainly exert financial pressure on the government. In this regard, attracting private sector investments or securing funding from reliable sources will provide huge relief to the government. The state should announce the policies for the facilitation of the potential investors in the form of subsidy, tax exemption, etc. in procuring technical equipment for charging infrastructure. For overhead lines deployment, the government should bear significant ROW requirement costs.

**D. RESEARCH AND DEVELOPMENT**

In the short- and medium-term plans, it may sound feasible to import electric vehicles and batteries for e-trans project. However, eventually, the overall cost will go up considering the inflation of Pakistan rupee over the past few years. In this regard, government should invest in research and development in the e-transportation sector. It will attract native specialists for EV manufacturing and li-ion battery design, development, and manufacturing. Collectively, it brings the overall cost to a low value. Reduced prices will directly attract more investment, development of infrastructure, and increased conversion of diesel trucks and buses into electric vehicles.

**E. INCENTIVES FOR CUSTOMERS**

To attract customers for switching from IC engine vehicles to EVs, it demands incentives from the concerned authorities. These incentives could be in the form of purchase cost or operational cost exemptions. Author in [73] concluded that out of all the possible incentives, value-added tax (VAT) exemption and purchase tax exemptions would seem to attract way more customers towards EVs, which they concluded from the case study of Norway, France, and Netherlands. In this regard, the Government of Pakistan may be assisted by China to come up with an effective scheme of attracting potential customers of electric vehicles. Also, the incentives for customers should not be restricted to the financial domain as non-financial incentives may equally play a role in attracting potential customers. Such incentives are highlighted in [74], where it was proposed to provide toll tax exemptions to EVs only and priority be given to EVs for accessing special lanes. Such incentives need to be considered and implemented by the concerned authorities to promote EVs penetration in the country.

**F. SAFETY STANDARDS**

Under any circumstances, the safety of customers and charging system infrastructure owners shall not be compromised. There are numerous causes for failure of li-ion batteries leading to vehicles catching fire. Thermal runaway is one of them, i.e. either charging voltage or temperature limits are violated. In this regard, strict policies about charging voltage standards and optimal temperature for using these batteries need to be drafted. Similarly, manufacturing faults and mechanical abuse may lead these batteries to internal short-circuit causing catastrophic damage. The policies for design standards of batteries considering the safety of consumers must be in place, and the authorized testing laboratories must verify all batteries. The batteries discharging below the minimum voltage would also lead to failure. Therefore, precise policies must be drafted for charging infrastructure owners about voltage standards for discharging while feeding power into a grid during peak hours under V2G concept. The government may take help of countries having developed charging infrastructure like China, Canada, etc. in drafting the safety guidelines.

**G. PUBLIC AND PRIVATE PARTNERSHIPS**

Although public private partnership (PPP) has been rarely considered for the deployment of any projects in Pakistan.
However, it does prove to be an effective option for deployment of charging infrastructure for e-trans as the financial position of the country is not strong enough to bear all the associated costs incurred. The case study of PPP in China, Anhui province is highlighted in [75] under a project named “Anqing Charging Infrastructure PPP Project”. The study analyzed that if public and private sectors coordinate with each other, the delays in project due to finances may be eradicated and even any risks associated will be shared between them. In this regard, the government of Pakistan should draft protocols for partnering with private firms and sort out the financial details in a manner that would appeal to private businesses.

H. ELECTRIC TRANSPORTATION AUTHORITY

The government can make a separate body under the name of e-trans authority for ensuring smooth operations of the network of charging stations and e-vehicles under the CPEC. The e-trans authority will be in coordination with the Ministry of Planning, Development, and Reform in Pakistan and the National Development and Reform Commission in China. The proposed authority will ensure strict implementation of policies through the deployed e-trans network. It will also help maintain check and balance of functionality, maintenance of routine schedules of charging infrastructure network, etc. In addition, an e-trans council may be established to facilitate EVs and batteries manufacturers in Pakistan for getting necessary approvals from the government. It will be a medium of coordination between the government and public/private charging infrastructure stakeholders.

I. AWARENESS AND EDUCATION

The success of e-trans on CPEC also relies upon the awareness of road transport electrification amongst consumers, power utilities and vehicle manufacturers. The public support for the Government’s massive investment in e-trans could only be achieved if they are well aware of the potential benefits of e-trans. The Government of Pakistan should initiate online campaigns and advertisements to embed the value of reduced GHG emissions by linking it with health benefits for citizens. Moreover, the following activities can also be used for the promotion of e-trans throughout the country.

- Newspaper, television and social media advertisements
- Organizing roadshows with highlighting potential e-trans benefits
- Hosting e-trans launching events in cities

Moreover, the government can also target the education sector, especially schools and colleges, for awareness of e-trans. One of the ways to effectively realize awareness goals in institutes is their curriculum revamping in the light of United Nations Sustainable Development Goals. Moreover, awareness events like ‘Electric Vehicle Day’ must be conducted in these institutes to enhance the value of a clean mode of transportation amongst students. Out of 17 goals proposed by the United Nations, the 13th goal is about climate change which encourages to adopt such practices that curtails the environmental pollution [76]. The Government also needs to take power utilities and vehicle manufacturers on board via discussion forums about the potential revenues generated by e-trans and devise such policies resulting in increased participation for e-trans throughout Pakistan.

XII. CONCLUSION

This research study assessed the potential deployment of e-trans deployment under the CPEC. To validate the proposed solar powered EVs charging unfactored on CPEC, a case study is presented with a detailed discussion on all the relevant aspects to facilitate charging of 100 electric trucks, 100 electric buses and ten mobile charging trucks. The results suggest that even if the model is scaled up to facilitate 1000 heavy EVs and 100 mobile charging trucks, only 0.29% funds of CPEC’s energy sector budget will be incurred. The infrastructure requirements for the realization of e-trans are classified into technical and financial requirements along with policy implications to familiarize stakeholders with the required resources of project. The SWOT analysis tool is applied to unfold the contribution of positive and negative aspects in e-trans segment of CPEC. The challenges and barriers are categorized into social, economic, political, technical, and environmental factors with an intent to familiarize stakeholders about risks involved in a project. Importantly, to ensure deployment of e-trans on CPEC, the refined policy recommendations have been prescribed that could pave the way for road transport electrification in the country. Although solar power is selected as a better choice for powering EVs, future research demands a comparison of financial investment for powering charging infrastructure network on CPEC using other RES like wind and biogas.

The future work should also focus on the optimal siting of charging infrastructure on CPEC. Moreover, it could also figure out that what particular mixture of RESs is appropriate for powering a network of charging infrastructure. In addition, scheduling of EVs charging to avoid overburdening of the charging stations is crucial, which we intend to perform in our future work.

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