Does Pakistan have enough electricity generation to support massive penetration of electric vehicles?

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***Abstract*—Pakistan experienced a grave power shortfall between 2006 and 2017. The government responded to the situation through fast track development of power plants. However, the energy planners were unable to accurately forecast the electricity demand, resulting in a situation where more generation is available than needed. The power plants are backed by take-or-pay contracts. Thus, even if the power plants are not operating, a substantial capacity payment is still paid. To utilize this surplus available capacity year around electricity loads are needed. On the other hand, Northeastern Pakistan has one of the worst air quality in the world. Over 45% of the emissions are attributed to the transport sector. Therefore, electric vehicles (EVs) are an ideal load that utilizes the excess generation capacity and at the same time, improves air quality in the region. In this paper, we analyse the impact of various penetration levels of EVs on the utilization of excess generation capacity. This analysis will help us to determine EV penetration goals such that the capacity is optimally utilized. The impact of EVs is analysed using three optimistic scenarios of 30%, 50% and 70% new vehicle sales for two, three and four wheelers starting from 2020. This showed that by 2024, EVs will add 1250 MW at 70% new vehicle sales and only with peak demand, it is expected to reach available generation capacity.**

***Index Terms*—electric vehicle (EV), generation demand gap, forecasting**

I. Introduction

Globally, with the advent of new technologies, the electricity generation and consumption patterns are shifting. Generation technologies such as solar photovoltaics and wind turbines are cheap but intermittent inherently. However, due to a global movement of shifting towards clean renewable resources, nations are encouraging the installation of such renewable energy resources [1]. On the other hand, new technologies such as electric vehicles (EVs) are causing an increase in the electricity consumption and as a result, the load patterns are changing. Although these new technologies increase profits and revenue for the utility companies, they also create a more tedious job for the system operator.

The electricity supply and demand scenarios in Pakistan have been hovering between over-supply and under-supply for the last many decades. From 2010 up till 2016 there has been a deficit of power as the supply was unable to meet the growing demand [2]. Pakistan embarked on a rigorous generation capacity expansion program starting in 2013 and since 2016, the country has surplus generation capacity which is increasing every year. As per the recent indicative generation capacity expansion plan developed by the National Transmission and Despatch Company (NTDC), sufficient generation capacity will be available till 2047 to cater to all potential loads in the future [3].

This surplus generation capacity comes at a very critical cost. In Pakistan the Power Purchase Agreements (PPAs) with the private power generation companies, commonly known as Independent Power Producers (IPPs), have been signed mostly on a 'take-or-pay' basis [4]. A hefty sum, commonly known as capacity payment, has to be paid to the IPPs to account for the fixed cost as well as for maintenance and other associated costs. Presently, the circular debt of the power sector stands at Rs 2 trillion (USD 12 billion), while the capacity payments are expected to reach Rs 1.5 trillion (USD 9 billion) in the next few years [5]. Henceforth, Pakistan direly needs to find a suitable load to utilize the surplus generation capacity.

Similarly, the internal combustion engine (ICE) based transportation sector in Pakistan also faces momentous challenges. The transportation sector in Pakistan is responsible for almost 44% of the total carbon emissions in the country [6]. As a consequence, Pakistan has been declared as the 7th most vulnerable country due to climate change, while it has been estimated that an amount equal to almost 0.6% of the country's GDP is annually lost due to environmental challenges [7]. Import of petroleum has the largest share amongst all import commodities. Presently, the annual bill for the import of petroleum stands over USD 13 billion, which is almost equivalent to half of the country's total trade deficit [8]. The transportation sector is the largest consumer of imported petroleum. Henceforth, Pakistan needs to curb dependence on hydrocarbons to support its fragile economy.

To cater to the aforementioned challenges, an ideal solution is the introduction of EVs into Pakistan's transport sector. On average, EVs result in the lesser release of harmful pollutants such as greenhouse gases into the atmosphere [9]. Also, relatively lower running and maintenance costs have significantly encouraged commuters to transition towards electric means of mobility. However, in Pakistan, the importance of EVs extends beyond environmental concerns and affordability. Over the years, EVs have proved to be an ideal flexible load which is also non-seasonal. Taking advantage of the surplus generation capacity, EVs can be used in the long term to increase the

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base-load and in the short term, EVs can be charged during the off-peak hours to prevent any potential increase in the peak demand [10]. The battery in an EV is a vast virtual store of energy. During the peak hours, energy stored in the battery of the vehicle can be supplied back to the grid to allow peak-shaving [11]. Such an approach is fundamental for the stability of the grid, especially during times when seasonal load like air conditioners causes spikes in the load demand curve. Also, vehicle-to-grid (V2G) energy transfer can reduce growing dependence on fossil fuel-based generation sources which generally act as peaker plants to cater to the peak load requirements.

There have been a significant number of studies carried out on different aspects of EVs. Many studies have made predictions on the overall effect that EVs have on consumption patterns [12], [13]. [12] established that widespread adoption of EVs will have a significant affect on countrywide electric power generation and on housing distribution systems. The effect of EVs on the installed distribution system has been studied in many different places such as Denver, CO, USA [14], Melbourne, Australia [15], Gothenburg, Sweden [16], Winnipeg, MB, Canada [17], and some residential networks in Malaysia [18] and Italy [19]. Introduction of EVs in the transportation sector is likely to disrupt existing electricity supply and demand patterns, which can adversely impact the stability of the grid. In [20] V2G energy transfer has been proposed to overcome the mismatch between load and generation. Similarly, in [21] V2G energy transfer has been proposed as an approach to address issues due to intermittent nature of renewable sources. EVs can help reduce the bill for oil import in Pakistan. It has been projected in [22] that EVs are likely to experience exponential growth across the world due to which peak oil demand will occur sooner than that projected by major oil companies. It has been estimated by [23] that a complete transition towards EVs in Pakistan can reduce the bill for oil import by almost 25-40%.

Through these studies, some establish that 20% EV penetration will not result in overloading while some systems experience overloading even at 10% EV penetration. Thus, it can be seen that each country's distribution network is a unique case, which requires standalone studies to fully understand the issues surrounding EV penetration and its additional load.

To the best of our knowledge, until now no such study has investigated the impact of EVs on the base-load and consequently, curbing the power sector capacity trap in Pakistan. For this reason, our paper presents a study based in Pakistan to examine the effect of EV penetration on Pakistan's capacity trap.

The main contributions of this paper are highlighted as follows:

- Pathway to reducing Pakistan's capacity trap - to reduce the gap between Pakistan's generation capacity and demand, it is proposed that we incorporate EVs into Pakistan's base-load. This will increase the overall electricity demand in Pakistan and reduce the capacity trap, which consequently will reduce the hefty amounts summed up as capacity payments that eventually add up to circular debt.
- Analysis on multiple vehicle types - we have also divided the EVs into two, three and four wheeler types. By adding this variety of EV types, we can more deeply understand and model consumer demand patterns for EV charging schedules.
- Based on our findings, we have also made policy recommendations for a fast-paced and immediate impact on the adoption of EVs.

The rest of this paper is organized as follows. Section II highlights Pakistan's energy crisis over the years. Section III then details the solution methodology employed as a pathway to curb the existing energy crisis. Section IV discusses the results of the paper and Section V concludes the paper.

II. Pakistan's Energy Crisis Timeline

Pakistan experienced a severe energy crisis in 2006 when the power deficit exceeded about one-third of peak demand. However, the roots of the crisis can be traced back to the policy decisions made in the 1990s. In late 1990, the consequent generation addition rate was much lower than the growth of demand. This pushed the system into a shortfall phase that started to appear in the same year. With this shortfall, the government reacted and added a massive 4.8 GW in just four years (1994-1997) by attracting Independent Power Producers (IPPs) for the first time in Pakistan's history to invest in Furnace Oil (FO) and Gas-based power plants for their quick-build early-return feature [24]. As most of these power plants were fossil fuel-based, therefore increasing prices of oil made electricity generation more expensive and financially complicated for the government.

At that time, the ruling governments initiated some policies to increase the demand through the promotion of consumerism, industrialization, rural electrification, and other economic pursuits. This promotion resulted in the robust growth of more than 5% in demand but did not appeal a similar response in supply that increased only at 3% per annum from 1998 onward. Since then, the power sector of Pakistan has started to plunge into a vicious financial crisis.

Figure 1 shows the peak demand for electricity of Pakistan and maximum generation capacity for the last two decades. As shown in the graph, during the late 1990s and early 2000s, Pakistan had a surplus of generation capacity as compared to electricity demand. During the same time in the early 2000s, there was a rapid increase in electricity demand as the per capita electricity consumption increased. However, the generation did not increase to cater to this rising demand due to a shortfall in government planning. Due to this, Pakistan experienced a severe electricity deficit in the coming years up to 2013. The government responded to this deficit by rapidly installing new power plants and this resulted in Pakistan having an overabundance of generation capacity starting from 2016. This excess gap between generation and demand is only expected to increase in the coming years.

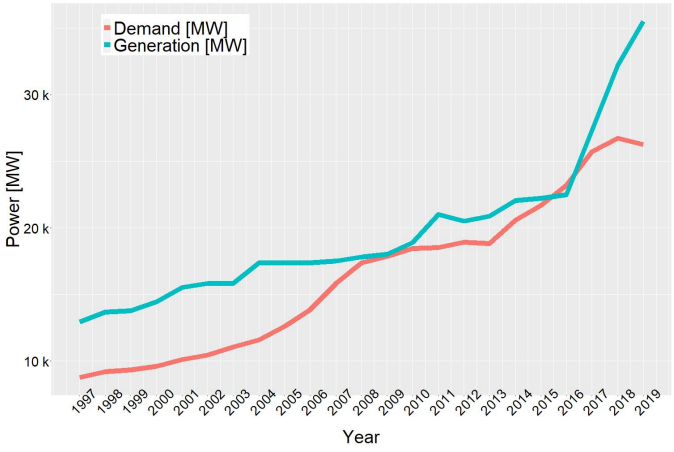

Fig. 1. Historical demand and generation trend.

III. Methodology

The procedure followed in this paper to calculate a realistic impact of EVs on the power grid of Pakistan can be represented through the flowchart shown in figure 2. The following sub-sections explain the data used and the procedure followed in each step.

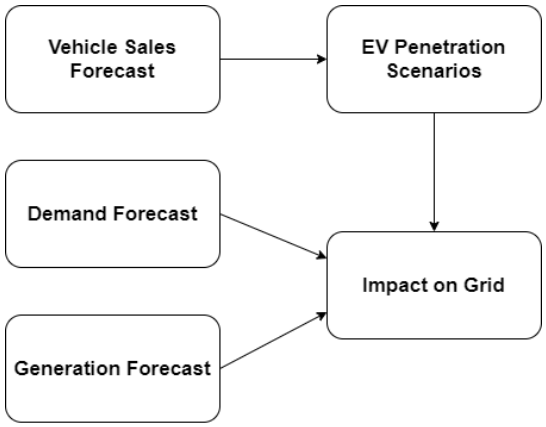

Fig. 2. Procedure Flowchart

A. Electricity Demand and Generation Forecast

To facilitate a sizeable transition to electric mobility, the crucial step is to forecast electricity demand for the coming years, from 2020 to 2024. Using the forecasted electricity demand data and its corresponding available generation capacity, we will be able to calculate surplus generation capacity for EV mapping.

Figure 3 illustrates the actual demand from 2007 to 2019 and forecasted electricity average demand from 2020 to 2024 [25]. The figure also shows the peak generation in Pakistan from 2007 to 2024. For our analysis, we have assumed the peak generation to be a constant from 2020 to 2024, assuming the government will not plan any new power plant installations. This demand and generation visualization solidifies that for the coming years Pakistan will have a lower demand as compared to its supply.

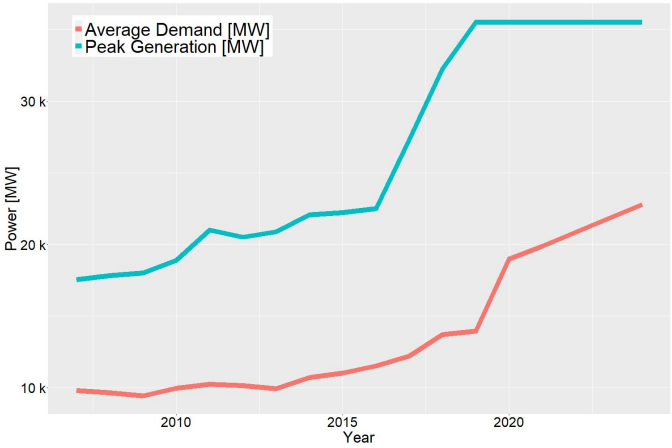

Fig. 3. Existing and forecasted average demand (excluding EVs) and peak generation (Assumption: constant generation).

B. Vehicle Sales Forecast

To identify the percentage of total ICE based transportation sector that can be converted to electric means of mobility, we need to first calculate the growth of all three types of vehicles (two, three and four wheelers) up to 2024. Pakistan Economic Survey [26] has provided data on registered vehicles. By examining the historical trend, in this paper, three linear models are applied to extrapolate future sales forecast of two, three and four-wheelers in Pakistan. This has been done using linear trend as the predictor variable which changes from 1 to 18 for data from 2007 to 2024. The linear regression equation used is as follows, where i is the vehicle type i.e. two, three or four.

$$\hat{VehicleSale_i} = \hat{\beta}_0 + \hat{\beta}_1 Trend\ predictor + \hat{\epsilon}_i \quad (1)$$

Figure 4 shows the overall sales forecast numbers for all three types of vehicles. The black dots in the graph show the actual sale values for the corresponding vehicle and the colored lines show the predicted value from the linear model. The gradient or $\hat{\beta}_1$ for two-wheelers shows that on average 0.15 million new vehicles are sold every year. On the other hand, three and four-wheelers show a similar trend i.e. approximately on-average 7,000 more vehicles are sold each year for each category. The model calculated that in 2024 there will be 2.9 million two-wheeler sales, 0.13 million three-wheeler sales, and 0.2 million four-wheeler sales. This information can also be seen in the table I.

To assess the reliability and robustness of our prediction model, we have examined the R^2. In linear regression, R^2 showcases the squared correlation between the observed known outcome values and the predicted values by the model [27]. In our linear model, R^2 for the two-wheeler and three-wheeler is 0.6, which shows that our predictor variable is a strong metric to assess our predicted variable. In the case

TABLE I
TWO, THREE AND FOUR WHEELER SALES 2020-24

Year	Two-Wheelers	Three-Wheelers	Four-Wheelers
2020	2,357,460	101,649	195,570
2021	2,508,365	108,253	202,387
2022	2,659,270	114,857	209,204
2023	2,810,176	121,460	216,023
2024	2,961,081	128,063	222,840

of four-wheeler, the R^2 sits at 0.25. This explains that sales of four-wheeler vehicles are less predictable as compared to our two and three wheeler vehicle sales.

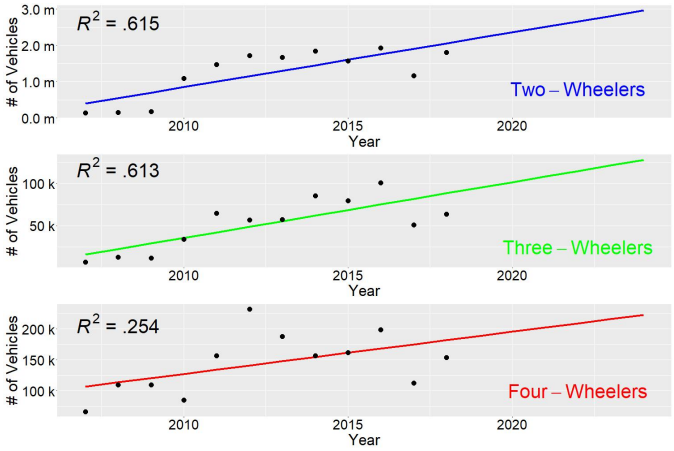

Fig. 4. Actual and predicted vehicles sales forecast till 2024 for two, three and four wheelers.

C. Impact of EV Sales on Grid

After calculating the vehicle sales numbers by vehicle type, we need to calculate the impact of potential EV growth scenarios on the grid. The Prime Minister Committee on Climate Change has set a target that 30% of all passenger vehicles should be EV's by 2030 [28]. Based on this target, we have created three growth scenarios for EV adoption to plug in the two, three and four wheeler growth numbers in 2020 and subsequently, extract the EV load based on these wheeler numbers. The scenarios considered are 30%, 50% and 70% of all vehicle sales as EVs. These scenarios are considered to be quite optimistic. However, the purpose of considering these scenarios is to show that even with a high EV penetration, power system of Pakistan can fulfill this increase in demand.

To calculate the average power demand of EVs that will be introduced in the country the table II is used. These assumptions are taken from public surveys and reports by the Government of Pakistan's sponsored and USAID's funded project known as sustainable Energy for Pakistan (SEP) on developing the Global Change Analysis (GCAM) model for EV adoption in Pakistan [29].

Figure 5 shows the average power required by all three type of EVs in the coming years for a low adoption rate. It can be observed that two-wheelers will have an average

TABLE II
ASSUMPTIONS FOR CALCULATING LOAD ON THE GRID

Category	Average Distance (km/year)	km/KWh
Two-wheelers	15,000	20
Three-wheelers	38,400	10
Four-wheelers	19,200	7.14

demand of 341 MW by 2024. On the other hand, three and four-wheelers will have an average demand of 75 MW and 96 MW respectively. Figure 6 and Figure 7 showcase a similar trend of average power required by EV's for a base and high adoption rate, respectively.

It is interesting to note that the highest average demand is forecasted for two-wheeler and the lowest average demand is recorded for three-wheelers in all three scenarios. For four-wheelers the average power demand ranges from 96 MW (low scenario) to 224 MW (high scenario) for the year 2024. These observations serve as crucial insights for policy recommendations on the adoption of EV's.

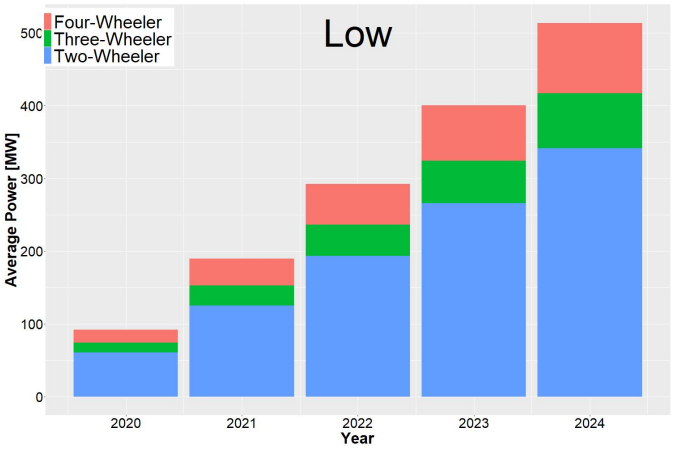

Fig. 5. Average EV Power for two, three and four wheeler for 30% (Low) Adoption Rate.

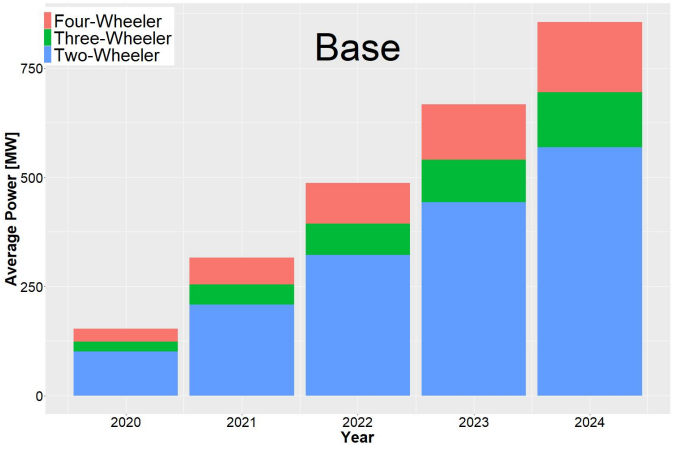

Fig. 6. Average EV Power for two, three and four wheeler for 50% (Base) Adoption Rate.

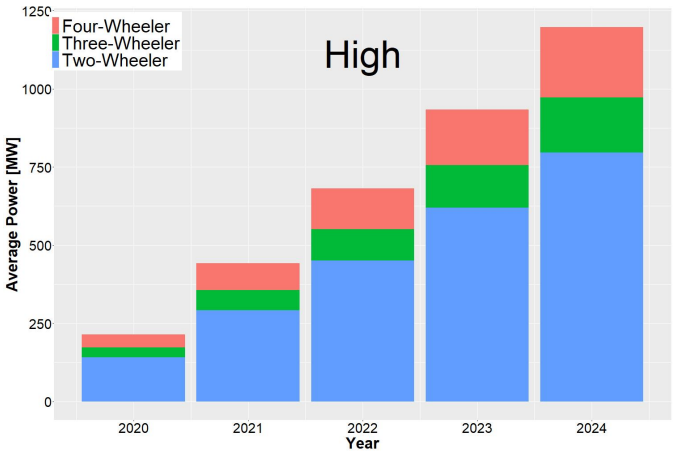

Fig. 7. Average EV Power for two, three and four wheeler for 70% (High) Adoption Rate.

Furthermore, by using peak demand data from [24], it can be observed from figure 8 that assuming the government will not install any new power plants and generation remains constant, introduction of EVs at very optimistic penetration scenarios, will still be feasible for Pakistan. The peak demand on which the load of EVs is added is the expected peak electricity demand of Pakistan in the coming years upto 2024. Given these optimistic scenarios, only in the case of high scenario (70% EV penetration) the peak demand will manage to reach the available generation capacity.

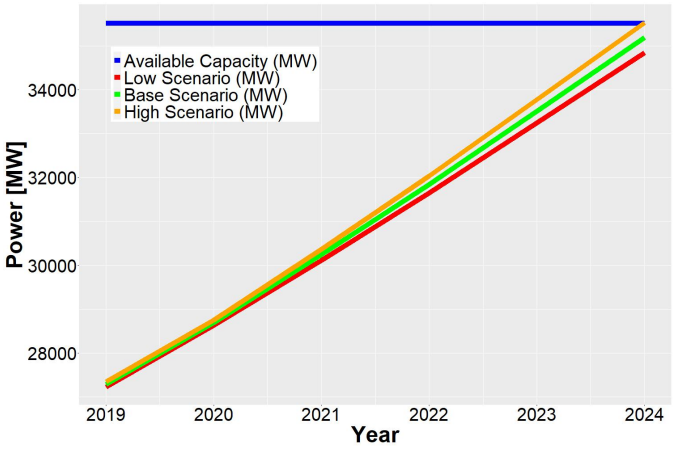

Fig. 8. Impact of EVs on peak demand with constant generation.

D. EV Charging Schedule

Despite having sufficient electricity to shift a sizeable percentage of ICE based vehicles to electric means of mobility, the capacity of the transmission and distribution network can limit the utilization of surplus generation capacity. The capacity of the existing transmission and distribution network is almost 22,000 MW, while the annual peak demand is close to 25,000 MW [30]. However, by March 21, 2021 a 660 KV HVDC Matiari-Lahore transmission line will be installed which will increase the transmission and distribution capacity by 4,000 MW [31]. Without an integrated scheduling system, the power grid will not be stable. Hence, optimization techniques are required to schedule charging of EVs which will lead to efficient energy management and subsequent reduction in power quality losses.

The Monte Carlo method is a stochastic simulation method, which is often used to simulate the uncoordinated charging load as explained in [32]. Similarly, for off-peak EV charging along with household appliance, a Mixed Integer Linear Programming (MILP) based optimization technique is proposed in [33] which minimize the peak hourly load by scheduling the optimal power and operation time. In [34], the author explains smart charging with a fuzzy controller. The method only needs basic communication to receive the energy prices by the electric utility instead of sophisticated real-time communication. The electricity price is assumed to vary during the day. According to this technique, EVs can be charged on an instance when there is maximum power but low electricity price. This also helps the electric utility to manage the tariff structure according to the peak time. Moreover, EV owners can also be motivated to charge at off-peak hours to get cheap electricity.

IV. Discussion

In this paper, it is shown that Pakistan has sufficient generation capacity to shift its major portion of the new fleet of vehicles to electric means of transportation till 2024. The introduction of EVs into the transportation network will bring many associated benefits for the energy and power sector in Pakistan as well as for the entire economy. The existing gap between demand and the generation capacity is widening with time. If this situation continues, the per-unit price of electricity for the end-users is going to further increase due to rise in the share of capacity payments in the overall price of electricity [35]. EVs can help bring the price of electricity down through the utilization of surplus generation capacity for which hefty sums of capacity payments are being paid.

The benefits of EVs are not limited to reduction in capacity payments. Pakistan has a fragile electricity grid that is susceptible to destabilization from rapid fluctuations in demand. A lot of techniques for EV scheduling can be found in the literature that are mentioned in this study [36]. Collectively, EVs are a vast store of energy. During the time of peak demand energy from the battery of the vehicle can be transferred to the grid to reduce the stress on the grid from rapid fluctuations. Over the years, EVs have proved immense compatibility with renewable sources of generation, especially distributed rooftop solar PV. Integration of renewable sources of generation with EVs can further reduce the emissions from the energy and transport sector in Pakistan.

V. Conclusion

Load from electric mobility has become indispensable for the power sector in Pakistan owing to grave challenges it faces due to overcapacity and fragile grid network. The most

fundamental requisite for EVs is the presence of sufficient surplus generation capacity. By forecasting electricity demand and generation, this paper shows that Pakistan has sufficient generation capacity to electrify a prospective electric vehicle fleet. This paper also analyses multiple scenarios of two, three, and four-wheeler type EVs penetration upto 2024. This shows that EVs at 70% of total vehicle sales starting from 2020 will only fill 10% of the forecasted 12700 MW gap between generation and demand in 2024. Henceforth, Pakistan enjoys ideal conditions for a transition towards electric means of transportation.

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