ELSEVIER

Challenges in the penetration of electric vehicles in developing countries with a focus on Nepal

RESEARCH REVIEW

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With growing concerns of climate change and unreliable fuel market, the world is moving towards an electric-based transportation system, one that entails a country to overhaul major infrastructures, establish high monetary funded research, change government regulations, and adapt available resources to transform its gasoline-based transportation system to an electric one. In this paper, various completed projects, challenges, proven policies, and infrastructure development corresponding to EVs in developed countries are meticulously studied to develop a five-factor-dependent plan to efficiently expedite the EV sector in developing countries in general. The findings and suggestions relating to the EV sector's development are presented in the general case of a developing country as well as in the specific case of Nepal to better understand the developed five-factor-dependent-plan.

Introduction

The transportation industry is transforming, one that entails overhauling of present transportation and electrical infrastructures. Construction of infrastructures has already started in various developed countries, with most of these countries focusing on the development of various forms of efficient electric transport, the building of new electric transmission systems (one that is capable of handling short periods of high electric vehicle charging loads), parking lots with low footprint area and efficient charging mechanisms [1–3]. With the growing concern of climate change, global warming and conservation of energy, the pace of evolution of EV technologies has accelerated since the 2010s to tackle these challenges. EVs provide emission-free urban transportation concerning the environment. From the energy aspect, EVs can offer a secure, comprehensive, and balanced energy option that is efficient and environmentally friendly. More so, with the utilization of renewable energies.

Furthermore, EVs are progressing and becoming more intelligent, thereby improving traffic safety and road utilization. This ultimately has the potential to uplift the energy scenario and environment significantly, further, it is leading to the creation of a new EV sector aiding in the overall economic development [4,5]. The world is progressively looking at alternatives to the traditional petroleum-based transport technologies, as concerns of oil exhaustion and reliability of supply remain as severe as ever. Faced with the consequences of climate change due to greenhouse gas emissions, EVs are seen as promising and favorable technology. EVs can lead to decarbonization by reducing transportation-related emissions [6].

More than a century of innovation in EVs first began with the simultaneous invention of battery-driven EVs in Hungary, the Netherlands, and the United States in the early 1800s [7]. Thomas Parker and Floken Elektrowagen were responsible for developing some of the early versions of practical electric cars in 1884 and 1888 respectively. Ferdinand Porsche and Henry Ford, the

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two titans of the transport industry, also began developing their versions of EVs, P1 and Model T1 in the late 1800s and early 1900s [8]. EVs were so popular in the early 1900s that one-third of the vehicles running on the road in the United States were EVs [7]. However, the inventions of highly efficient petroleum-based vehicles and low gas prices resulted in the general consumers opting for gas running vehicles. One area where the EV came second to none, however, was outer space. With no other feasible forms of energy, solar energy was used to form space rovers to explore the Moon and Mars. With rovers like Lunar Roving Vehicle on the Moon [9], and Curiosity and Opportunity on Mars [10,11], we have successfully implemented the use of electricity as the primary fuel source in outer space. Back on earth though, the EV sector has seen numerous companies pop up from 1897 to the present day; most of these entities had a rough lifespan, all resulting in enclosures. However, with Tesla leading the EV market, this has led to like-minded individuals banding together, forming numerous startups companies like Canoo and Enevate [12,13]. Car manufacturing giants have also ramped up their effort in developing and introducing their takes on what EV can be with the models like 2019 Audi e-tron, 2019 BMW i3 and Nissan Leaf to compete in the booming EV markets [14–17]. Adding to the advantages of EV over petroleum-based vehicles, recent findings have shown that several EV features can improve driving safety too. EVs tend to have a lower center of gravity that makes them less likely to roll over. They can also have a lower risk for major fires or explosions, and the body construction and durability of EVs may make them safer in a collision, leading to a safer EV product [18].

All the while, the government bodies have been forming various EV regulatory bodies, regulations, and infrastructures. Various companies have also been busy developing new forms of infrastructures and technologies to support EVs and capitalize on the growing market. However, the case of the EV sector is different in developing countries. For India in particular, five different barriers: technological, infrastructural, financial, behavioral and external, have been identified that have contributed to the slow EV adoption [19]. Not only in India, but these barriers also seem to apply to most of the developing countries. Further, developing countries like Nepal, with their limited small budgets, have been lacking in this sector. They have not taken any significant steps towards the integration of EVs in the transportation infrastructure of the country. EV penetrated the transportation sector of Nepal on 28 December 1975. Chinese government aided Nepal in the construction of an Electric Trolley Bus, spanning a total of 13kilometers distance in Kathmandu valley. At its peak, this trolley service provided transportation between 80% of the people from Kathmandu to Bhaktapur and vice versa. However, with the various setbacks, it limited its service to Tripureshwor and Koteshor areas inside Kathmandu [20–22]. With the introduction of Safa Tempo (a battery-operated three-wheeled tempo) in the early 1990s, the Nepalese government stepped in its effort to tackle the growing air pollution in its capital, Kathmandu. This involved the conversion of the six regular three-wheelers to EVs with the backing of USAID. A few cable cars are also present in operation in Nepal (e.g. Manakamana Cable Cars and Chandragiri Cable Cars, which are in operation from 24 November 1998 and 08 August 2016 respectively [23,24]). However, with all these progressions, there have been drawbacks too. The trolley bus closed its operation in 2009 due to maintenance, political and financial issues [21]. Except for Value Added Tax exemption on the EVs and a few other policies [22], no significant steps have been taken by the Nepalese government to develop the EV sector significantly in Nepal. That is to say that the government is yet to introduce an EV-focused development plan and regulations. Also, with the forecast of a high rise in EVs, even in the coming ten years, overhauling of the infrastructure and policies are required [25].

In this study, the authors aim to present the existing and relevant technologies, regulations, and challenges in the development of the EV sector in a developing country while taking into consideration the successful projects and successful examples of EV integration in the transportation sectors of some developed countries. With matriculate studies of past articles and relevant experiences of the authors, the study provides an overview of the EV sector of developing countries with a particular focus on Nepal. Section 1 presents the overview of the history and trend of EVs of the world and Nepal. In Section 2, the fundamental technologies on EVs are discussed. Section 3 presents the detailed EV scenario in a typical developing country by taking the example of Nepal. Section 4 presents five critical factors to be considered for a developing country to develop its EV sector by dissecting relevant examples and successfully implementing projects. Section 5 draws all the information from the previous sections of the study to develop a specific direction that Nepal needs to take for developing its EV sector. Finally, the conclusions are presented based on well-defined constraints regarding the study.

EV technologies and adaptation in different nations

EVs and charging stations

Vehicles can be classified based on the drive train and fuel type like conventional Internal Combustion Engine (ICE) vehicle, alternative fuel ICE vehicle and EV. Focusing on the EV, it uses an electric drive-train for propulsion. Also, it can be classified based on their energy sources, their propulsion devices, and how their propulsion devices are hybridized. The detailed classification of EVs is discussed, compared and presented in Table 1.

Currently, the number of EVs is on the rise. However, the majority of these vehicles are inefficient, carry heavy batteries, and at best have a minimal capacity range of 99.78 to 498.90 kilometers in a single charge [26]. Significant research is being carried throughout the world to develop new batteries, which can provide more power per unit weight, and have an overall higher capacity. This will ultimately allow for the development of long-range capable vehicles. Moreover, with the mileage of the EVs getting better every year, the need for better facilities to recharge them is also increasing [27–29]. Of course, such charging stations must be capable of delivering charging power to the batteries safely, quickly and economically [30]. Such charging stations must be capable of being controlled in such a manner that different batteries having diverse capacities and even diverse terminal voltages must be accommodated at the charging stations [27,31]. The EV charging stations can be categorized into the following sub-headings:

TABLE 1

Comparison of the types of EVs

Vehicle Type	Gasoline vehicle	Hybrid electric vehicle (HEV)	Plug-in hybrid electric vehicle (PHEV)	Battery electric vehicle (BEV)	Fuel cell electric vehicle (FCEV)
Energy source	Gasoline/ Diesel	Gasoline/Diesel and internal chargeable battery	Gasoline and plug-in chargeable battery	Plug-in chargeable battery	Hydrogen fuel
Propulsion	ICE	ICE and electric motor	ICE and electric motor	Electric motor	Electric motor
Emission	Max. (CO2)	Less (CO2)	Minimum (CO2)	Not any	H2O
Models	Ford EcoSport	Honda Civic	Toyota Prius	BMW i3	Toyota Mirai

A. Home charging station: As the name suggests, the home charging stations have a charging point at home/residence. It enables the user to charge their vehicle in the vicinity of their own home. This simply requires charging a vehicle by connecting it to a source of electricity via cable, and a certified electrician can make the required connections. However, some specific criteria and standards need to be fulfilled to have an EV charging point at home. Some vital matter to look into is location, safety and permission. The charging cables are usually short (5 to 10m) but are weather and waterproof. And so, can be located inside or outside the house but it must be near to the place of parking. The use of an EV charging point at home increases the household's energy demand. It must be ensured that electric cable, sockets and the main household supply can carry additional current drawn by EV while charging. The protection devices like main circuit breakers, moulded case circuit breakers, and fuses must be installed to ensure safety. Also, all of the permission from the local power utility (if required) must be fulfilled to install the charging point [32]. The home-based charging station makes use of two charging levels: Level 1 and Level 2. Level 1 uses a normal 220V connection using any standard household connection, and the charging time is slow, but no extra cost for a high-power connection is required. Whereas Level 2 uses a higher output of 400V power source with fast charging time. Generally, the Level 1 type charging is not favorable for the users who drive long-distance and have minimal time to charge their EVs. For example, a Mercedes B Class 250e takes up to 20 hours to be fully charged (140 kilometers of range) via a level 1 charger, while the same model can be charged in 3 hours via a level 2 charger [33]. Recently, England has made it mandatory for every new home to have an EV charging point installed [34].

B. Public charging station: Public charging stations are the stations that are available publicly and serve multiple vehicles simultaneously with a given infrastructure. These are the on-street facility provided by the electric utility or located at retail shopping centers, restaurants, or parking places operated by private or governmental bodies. As EVs on the road increase, charging stations in both parking structures and garages are becoming more important for longer-distance commuters. Charging stations available is a critical requirement to ensure the ability to complete a trip and make it home [35]. Public charging stations make the adoption of EVs as a daily driver more convenient. Public charging stations must be operated and assembled with consideration for the driving routes and driving habits of the user [36]. Also, the stations need to share the circuit by rationing the availability in such a way that it does not cause any overloads. Many governments have incentive policies, such as offering purchase subsidies and deploying charging infrastructure at convenient locations of urban areas. A public charging station mostly uses Level 2 charging and is located in the area having a highly concentrated number of EVs and on parking places. For a public charging station to be set up, various topics must be considered such as infrastructure type, networking (for utilization data, payment, customer service, and maintenance), accessibility, permission and flexibility [37]. Some of the institutions and hubs offer free charging to the customer or visitor, whereas various stations require payment by the hour. Similarly, some stations offer a monthly or annual subscription fee, following an all-you-can-eat model [38].

C. Fast charging station: Fast charging stations enables the quickest means of EV charging (other than battery swapping). It is also available at a public charging station and available for commercial applications. Mostly, it supplies high power by using 3-phase circuits and is termed as the Level 3 charger. In general practice, the equipment size varies from 50 to 150 kW, and the battery can achieve 50% charge in just 10 to 15 minutes [39]. The fast-charging station directly supplies current in DC for charging due to which there are no thermal and other losses in the conversion circuit. It is also termed DC fast charging. It bypasses all of the limitations of the onboard charger and no conversions are required. There are different variants of DC fast charging like CHArge de MOve (CHAdeMO), Combined Charging System and Tesla Supercharger; each having its own standards [40]. However, the chargers are extremely expensive, even costing tens of thousands of dollars. The cost of electricity plays a major role in determining the operation cost. It consumes relatively high power, and a fast-charging station can be considered as a medium voltage client, who may buy electricity in the regulated market, through the tariff [41]. With higher power capability, the power conversion and the control stage become bulkier and more expensive. This is one of the main reasons why DC fast chargers are implemented off-board. The other reason is that of safety concerns. With the high power-rated converters and components, the

safety of the passengers as well as the vehicle becomes a key issue [42]. A variant of DC fast charger, Tesla Supercharger is rated at 480V and is built by Tesla Inc. for their BEVs. Tesla Superchargers enable long-distance travel and convenient charging facilities in urban areas using precise energy modeling and convenient locations near amenities, such as hotels, restaurants and shopping areas. The supercharging takes place by bypassing the onboard converters inside the vehicles and delivers high-voltage/ high-ampere DC power directly to the battery. The conversion from AC to DC power is handled by the large power converters on the site, and it allows to recharge a vehicle in a short period. The V3 is a completely new architecture for supercharging concept, where a 1MW power cabinet with the same design as that of utility-scale, supports the peak values up to 250kW per car. At this rate, an EV can charge to cover up to 120 kilometers within just 5 minutes and charge at the rates of 1,600 kilometers per hour [43].

D. Battery swap station: As the name defines, a battery swap station is a station where the battery bank of EV can be swapped (discharged battery can be exchanged with a charged one). It is the fastest way to refuel a discharged EV. As time is not spent on recharging the EV but rather on swapping the battery, it is faster and convenient for EV owners. As charging EVs via an electric plug, method takes far longer than re-fueling a petroleum-based vehicle, most drivers are off-put by the concept of owning an EV. Also, the cost of building charging facilities and the required infrastructure is very high. For a typical plug-in-charge, EVs need enough space to be parked for several hours. Besides, deploying a charging station is costly, especially in densely populated urban areas due to high real estate prices [44]. Hence, to resolve these drawbacks, the battery swap concept comes into play with significant importance. To make the whole process optimum, the batteries should be located at the position inside the car where it is easily replaceable and accessible. Further, the use of standard batteries in all the EVs will ensure cross-brand support and will decrease the operation cost. However, stocking of batteries and standardization of battery use in EV is a major hurdle for the application of this process.

With these charging infrastructures being adopted all around the world, the advantages and disadvantages of each of the aforementioned EV types and EV charging station types should be tallied with one another to figure out the best route of the EV adoption in the developing markets. This will ensure that efficient spending of the limited budget these countries will have for the EV infrastructure development.

EVs adaptation

Table 2 goes into detail about the global scenario of EV market share, adopted charging schemes and EV-related topologies. With the look into both the developing and developed countries, various conclusions can be drawn regarding how developing countries can learn from the developed countries' method/ approach towards achieving EV-based transportation sector. After a detailed discussion, practical applications and selections of the charging scheme and types of EV are demonstrated.

Furthermore, briefly looking at the EV markets in developing countries, most of the developing countries have a long way to go if they are to successfully implement the EV market but this is not to day that progress has not been made. Indonesia plans 20% EV sales by 2025 and has introduced multiple tax cuts on EVs, with full luxury tax exemption on BEVs. They have also introduced financial breaks on custom duties and taxes to aid in automotive and battery manufacturing. Malaysia has plans to establish 125,000 charging stations by 2030, while Thailand has introduced a long-term EV policy with aim of 1.2 million operational EVs by 2036 and 690 charging stations [66]. Zambia aims to capitalize on the growing EV market by increasing its Cobalt production and refinery industries, thereby aiding the overall EV battery production [67]. Though EVs accounted for 0.04% of the total vehicle sales in South Africa, it is estimated that by 2050, half of all the vehicles in Cape Town will be EVs. South Africa already has a strong EV manufacturing market and to further it, the South African Master Plan (2021-2035) aims to produce 1% of the global EVs in South Africa [68]. These developing countries have introduced some form of EV-related targets or EV-centric laws to aid in the EV market development.

Globally, the sale of EVs is on the rise. Most of the developed countries (like Canada, USA, and Norway) have begun to introduce policies to increase the market share of EV with some even aiming to halt the production of petroleum-based automobiles in the next 15 years. However, most of the developing countries (like India and Bangladesh) have not presented any plans to set a ceiling in terms of percentage regarding the sale of fossil fuel-based cars soon. Even though research is being conducted on new and exciting EV technologies, the sales data show that majority of EVs being sold are BEVs followed by PEVs. The applications of Fuel Cell EV and Solar EV are in the testing phase. As such, it will be in the best interest of the developing countries to invest in introducing and developing the EV market based on BEVs and PEVs. As most of the EVs are sold in the company with some form of a charger, the electric distribution system should be upgraded in anticipation of the new loads in the form of EVs. While developing countries like Nepal and India have made plans to install public charging stations in major cities, other countries like Bangladesh have yet to introduce any such plans.

Further, developing countries should follow the footsteps of countries like China, Canada and Norway to establish fast charging in the major highways. This will ensure that the EVs will be capable of long travel. However, due to budget constraints, countries should first conduct detailed research on key demographics, areas, citizens' financial capability, etc., and only then decide on key areas where infrastructure development should be conducted. With the global scenarios now explained, the dissection of the EV market in Nepal is presented in Section 3 to better understand the EV scenario in a developing country.

EVs in Nepalese Market

Like other developing countries, the priority of the Nepalese government is not fixated on EV adoption but rather on the development of basic needs. However, this should not be the case.

TABLE 2

Comparison of EV market share, adopted charging topology and policy in the global scenarios.

Country	EV's market share	Adopted Charging Schemes	Production and sale policies	References
India	0.9%, 14.1%, 0.12% and 0.08% of total sales of two-wheelers, three-wheelers, passenger vehicles and commercial vehicles respectively were EVs. i.e., EVs hold <1% of the total automobile market as of 2020. Currently, available EV models are Tata Tigor EV, Mahindra eVerito, Tata Nexon EV, MG ZS EV, Hyundai Kona Electric and Mercedes-Benz EQC, all of which are BEV type.	Combination of Public Charging Stations and Fast charging stations. 1633 fast-charging stations and 1,003 slow charging stations to be installed in 62 cities with combinations of Bharat AC 001 10 kW (3.3kw*3), CCS2 & ChAdeMO of >=50kw and Bharat DC 001 (15kw) type II AC chargers	No plans to halt production or sales of fossil fuels-based auto-mobiles but an aspirational target to gain 30% market share by PEVs within 2030 as per nationally determined contribution to United Nations Framework Convention on Climate Change.	[45–49]
Bangladesh	With an 89.7% tax on imported EVs, the EVs are more prevalent in rural populations due to low fare charges. 3 wheeled EVs have the majority share of the market. However, the number of BEVs is about 1,500,000 as of 2019. As per the Automobile Industry Development Policy - 2020, Bangladesh intends to provide special importance on the assembly and manufacture of environment-friendly electricity-run vehicles.	No public EV charging infrastructures in place		[50–52]
China	Sales of BEV, FCV and PHEV are on the rise in China. Over 500,000 units of EVs were sold in 2017 alone, while 1,250,000 were sold in 2018. BAIC, BYD, Geely and SAIC hold more than 50% of the EV market share. 984,000 of the 1,250,000 units sold in 2018 were the all-electric type.	As of 2019, 330,000 public charges and 480,000 home chargers were reported. Most provinces have more than 2,000 public chargers. Chargers in highway corridors have been installed between Beijing and Shanghai and between other major cities too. It has 50% of the global public slow charging station while 75% of the public DC fast-charging stations.	Plans to sell only 'new energy-based' vehicles by 2035. Half of them should be an electric, fuel cell or plug-in hybrid.	[53–56]
United States of America	190,000 new EVs were sold in 2017, while 361,000 units were sold in 2018. Tesla, Chevrolet and Toyota hold more than 50% of the EV market, 235,700 of the 361,000 units sold were all-electric. 2% of the total automobile sales were EVs in 2019.	A survey has suggested that more than 80% of EV charging takes place at home. As of 2019, 67,000 non-residential charging stations were available. 11%, 91% and 6% of the non-residential charging stations offer DC fast charging, Level 2 charging and Level 1 charging respectively.	Plans for California to ban fossil fuel-based passenger cars and trucks by 2035.	[53,54,56,57]
Norway	There are 346,822 BEVs and 142,847 PEVs currently in operation in Norway. As of December 2020, EVs hold 66.7% of the total automobile market share.	There were 648 CHAdeMO points, 595 CCS points, 47 AC Type 2 43 kW points and 246 Tesla Superchargers in Norway in 2017. As of 2020, there are 16,111 publicly accessible charging points.	Plans to halt the sale of gasoline-powered cars by 2025.	[57–60]
Canada	8,412 BEVs and 3,586 PEVs were sold between January 2020 to March 2020. BMW i3, Chevrolet BOLT, Ford Focus Electric and Tesla Model x are a few of the EVs available. Only 3% of the total EV sales were EVs in 2019.	Companies like Petro-Canada and electrify Canada have been providing charging facilities through modernized apps and payment systems. There are 5,316 public charging stations out of which 2,200 are DC fast charging. Combined, it is estimated that they have 12,558 plug-ins.	Plans to halt sale of gasoline-powered passenger cars by 2035 in Quebec.	[56,57,61–64]
Nepal	Presence of a few EV brands such as Nui, BYD, Mahindra, and theeGO.	Plans to install around 50 charging stations in the major cities of Nepal by the Nepalese government in the coming year. Most EV charging conduction personal though in house charging.	Had plans to increase the share of EVs to 20% as of 2020 (as per the Paris Agreement 2015) but failed to meet the target.	[65]

Though not prominent in the present context, a developing country should gear up to adopt EVs. However, there are major hurdles that should be addressed first.

The use of EVs in Nepal began in 1975 as an alternative mode of transportation and towards the mitigation of growing air pollution. With the implementation of electric transportation, it led

to considerable success in South Asian countries to mitigate the environmental problem and transportation problems at that period time. Though it took a great initiative at the beginning, EV failed to meet its expectations as per the planning later. The critical events in the EV sector of Nepal are listed in Figure 1. Initially, the development of EVs in Kathmandu started in the form of a Trolley bus, and later in the form of SAFA Tempo. It was one of the significant initiatives in entire South Asia at that time, but the concept could not last long, and soon these initiatives were discontinued [69,70]. The SAFA Tempo could not exist in the market because of some technical, operational and policy issues. Later, various brands started to import and sell the EV in the Nepalese market with modern technologies, and this led to aggressive EV penetration in the market. Until 2018, there were more than 41,000 EVs (including two, three and four-wheelers) across the country [71]. However, the Nepalese market must do much more to maintain this rapid pace of growth and even move toward a clean transportation mode in the entire nation by a few decades to ensure a better electrical transportation sector.

In 2018, the vehicles with usual fuel systems like diesel and petrol amounted to almost all of the new vehicle sales. However, in the current market, EVs sales are slowly increasing, and consumers are still comfortable with their petroleum-based vehicles. As of 2019, there have been multiple published pieces of literature about EV planning, but all these pieces of published literature seem to contradict the actual amount of EV charging stations installed in Nepal. Nepal Electricity Authority (NEA) is also conducting surveys to increase the number of EV charging stations throughout the road network of the nation. This is a part of NEA's promotional activities towards encouraging people to use environment-friendly vehicles in the future. This study aims to identify potential locations to install more charging stations. Besides that, some of the significant challenges of EVs in the Nepalese market (may be similar to other developing countries) are discussed below [71–75].

a. Cost: Owning vehicles in Nepal (like other developing countries) is very expensive in comparison to developed countries because of various reasons such as high taxes, high custom charges, high import costs from other countries, high operation and maintenance charges and high fuel costs. A medium-class family cannot afford these high costs attached to owning a vehicle. It is the same case when we talk about EVs. The average cost of cheap electric cars in Nepal is around USD 17,000, which is not affordable to common people with an average income. Similarly, the operation and maintenances of these EVs are not so easy, since there are no EV manufacturers within the country, and all parts are to be imported. Maintenance and availability of some popular brands are easier due to the presence of brand-specific service centers run by the EV brands themselves, but this is not the case for all brands of EVs. The primary source of these problems is a small EV market and has contributed towards the monopoly of the EV market by selected few brands.
b. Policy and Finance: There are no clear and fixed policies to import and operate EVs within Nepal. The government has exempted the road tax and is providing some special discount on custom duty charges for EVs. However, 13% of the tax applies to all types of imported products. Besides, there is no official standard tariff structure in practice for EV charging purposes. There is a severe need for a lower electricity tariff for EV charging in Nepal. The government should focus on special schemes like lower EV charging rates during off-peak hours to encourage more people into buying EVs.
c. Power availability: For today's existing EV charging station, EV charging requires somewhere between 6 kW to 22 kW of electrical power. The charging time for these charging stations varies from 1 hour to 12 hours (approximately) in Nepal. With the increasing number of EVs, the national energy demand will increase significantly, resulting in problems in the electricity sector. Also, the tariff rate of power/ energy is also high. The electricity distribution systems in the city area are currently congested. Further, stable and reliable connections are in scarce amount all over Nepal. A dedicated distribution system is also lacking.
d. Charging station: Because of the expensive technology and installation cost, there are only a few charging stations situated in major cities under the ownership of private parties. However, the NEA is in the process of installing 50 charging stations in main cities all over the nation. In the current situation, the vehicle owners are forced to charge their vehicle with the traditional approach at their home or office with low ratings (i.e., single-phase power supply with 16 A or 32 A current limit). With a limited number of charging stations along the highway, the possibility of long-distance EV travel is very limited.
e. Target group: EVs seem to be feasible for city drive, not for a rural and long drive. The current EV market is completely focused on urban roads and city bounded areas. Also, the imported EVs have limited features with some conventional design and low specifications such as torque, rpm and range, resulting in less appeal towards the youths. The high cost of operation and maintenance also has limited EV users to high-income families. This is furthered by the increase in tax for EVs in Nepal. The Nepalese government is also lacking in nudging its citizen towards using EVs.

With the global EV scenarios as well as EV scenarios in a developing country (by taking an example of Nepal) now explained, discussions on the required infrastructures and challenges to ensure EV's success in developing countries are explained in Sections 4 and 5.

Required Infrastructure and Challenges for Successful EV's Adoption in Developing Countries

With the EV sector finally finding its stride in the market of developed countries and gaining market share in the automotive industry; the same cannot be said for the developing countries. As of 2018, EV holds 2% of the total vehicle market in Europe amounting to 294,352 new EVs in 2018 alone. The registration of BEV alone increased by 50% in 2018 when compared to 2017. Meanwhile, half of the vehicles sold in Norway in 2018

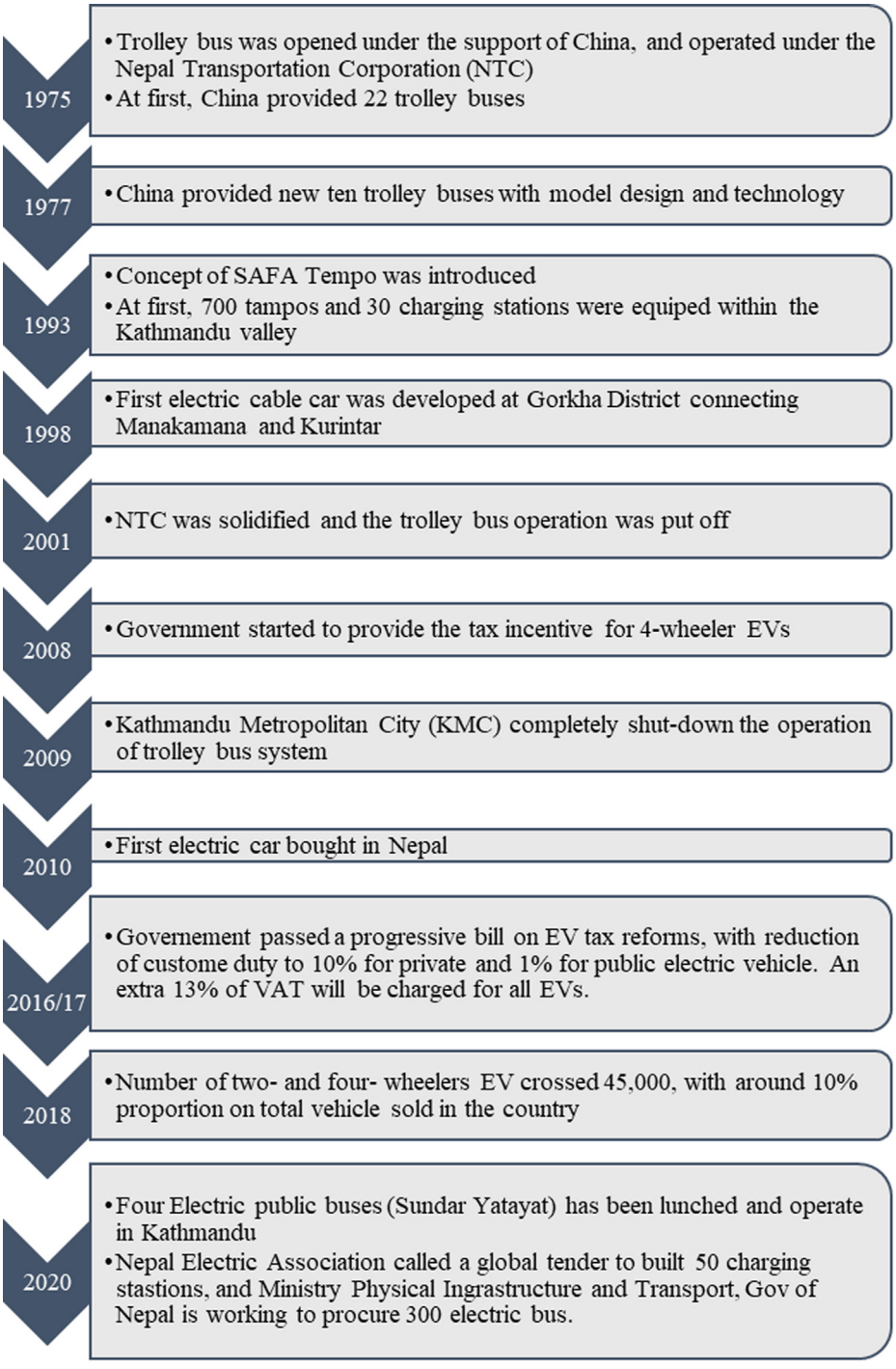

FIGURE 1

Important Date for Historic Movement in Nepalese EV Sector [69,70].

were EVs [76]. In 2019 alone, around 337,000 EVs were sold in the United States. Tesla made up 80% of this total sale. Tough a 6% decrease when compared to the total sales of 2018, this still puts the total market of EV sales in the US at about 2%, California having the highest number of EV sales; 153,442 (in 2018) [77,78]. 132,000 EVs were sold in Q1 2018 in China alone, which is more than the total EVs sold in Q1 2018 in the whole of Europe [79]. These staggering recent sales statistics can be duplicated in the developing countries by improving on various factors as follow:

Governing Body's Initiatives and Laws

With the ongoing global warming and the petroleum product's contribution towards it, governing bodies all over the world are fixated on finding an alternative transportation fuel. European Union Parliament's Environment Committee has approved the proposal to enforce car manufactures to have a total of 20% sales made of full-electric vehicles or ultra-low emissions vehicles by 2025 with that figure targeted to be increased to 40% by 2030. Manufacturers failing to meet this target would be subjected to high fines [80]. EU has also approved various electric vehicle

related projects, e.g., a $ 49.89 million Green Emotion project aiming at transport electrification and smart mobility results. While in the US, with the purchase of certain EVs, you would be eligible for a $7,500 federal tax exemption [81]. As of June 2010, China put into trial a program to provide 9,299.01 Yuan for the private purchase of new BEV in five cities [82].

Based on the above factors, the governing body of a developing country would need to adopt a combination of strict laws and favorable consumer initiatives to develop an EV favorable environment. This would propel consumers to adopt EV as their daily means of transportation. For example, the Government of India has announced subsidies of Rs 15,000 per kWh for the two-wheelers electric vehicles with an additional cap subsidy of 40% [83]. Furthermore, with research indicating that upfront investment cost and tax cuts are two of the most important factors, 63% and 20% respectively, in promoting inhouse car manufacturing [49]; tax breaks and government-aided investment can further contribute towards the EV centric transport sector establishment. Intending to put seven million EVs on the road and further tax incentives to Tesla Motors, India is gearing up to step up its EV sector. Further, the Government of Thailand has introduced promotional privileges for EV cars and auto part makers; the Board of Investment offered privileges that included tax holidays of 5-8 years and import duty exemptions for cars and machinery [84]. Tamara et al. conducted an assessment on the effectiveness of the subsidy for PEV in China, which analyzed the adoption of PEV in a different mode of subsidy model. The way to eliminate the subsidy for high-income consumers and increase it for low-income consumers result high adoption in PEV in comparison to equalized subsidy mode [85]. Similarly, a study conducted based in Canada reviled that the incentives and fuel costs play important roles in the preference of consumers, and lead to choosing the green vehicle for their daily purpose rather than a conventional one [86]. A study [87], presented an analysis of large-scale and small-scale subsidy policies taking an example of 14 cities from the USA. The authors suggested that the one-time big subsidy is not sufficient to improve the cost competitiveness; continuous small level policies from state/ local level should be in action. Though these are small initiatives compared to that of developed countries, developing countries need to take some drastic changes and set attainable goals and initiate favorable programs to back the new EV infrastructures.

As such, a combination of lucrative incentives and tax breaks, strict laws, and attainable EV market share targets will ensure that EVs will take over the transportation market in developing countries. However, a consistent concern on this sector must be required; in most of the developing countries like Nepal, the policies change with the change of government, which is a major challenge that developing countries face now these days.

Infrastructures

Electric Vehicles need a particular set of infrastructures. First and foremost of which would be to set up a reliable electric supply for the charging stations. This can either be done by upgrading the existing transmission and distribution systems or developing a completely new electric system to sustain the new and future EV loads. Upgradation of the transmission system would in large part include reconditioning of the transmission lines, while the up-gradation of the distribution system would require the replacement of the old transformers with higher-capacity ones, one that would be able to handle the charging station loads. More charging stations should also be constructed. Further research needs to be conducted to decide the placement of charging stations in a developing country. This research would also need to consider the elevation changes per kilometer. Thailand has targeted establishing a charging station within a radius of 200 kilometers from one another [84]. However, the infrastructure should be developed with proper feasibility study; overestimated infrastructure may be un-utilized and nu-economic for a long period [88]. Technological advancement in the coordinated charging system, reliable communication, and distributed charging mechanism can help to maximize the benefit of EVs [89].

One of the significant advantages of the petroleum-based vehicle is the plethora of infrastructures built around it to support the day-to-day running of the ICE vehicles. With the petroleum stations, auto repair shops and servicing stores built in every conceivable corner of the world with access to roads, major investments are required if we are to place charging stations and specialized auto repair shops and service centers in a similar manner in these places. For a country with large capital, this type of project would depend on the availability of raw materials and time. However, the same cannot be said for developing countries. These countries do not have the luxury of building a product-based infrastructure when they are not even able to facilitate their citizens with clean water and paved roads. With studying indicating lack of charging infrastructure to be among the top reasons as to why India may not achieve its aspiration of 30% new sales share to be PEVs by 2030 [49]. This further adds to the overall importance of building EV load handling capable infrastructure to aid in the overall EV market development in a country. Another study states shortage of charging stations to be the number one contributing factor to barriers to EV adoption [49]. This is not to say that infrastructure building should not be a priority. Building these infrastructures would lead to a better transportation system, and with that in place, this clean means of transportation would lead to a better manageable and pollution-free future. Also, as the majority of the vehicle using population are situated in the major cities in developing countries, area-specific charging stations and up-gradation of the electrical supply should be given priority over establishing a charging network all over the country itself.

Investment by EV and EV related Companies

With the infrastructure of charging stations and reliable electric supply in place, the next step would require participants from EV and EV-related companies. Tesla has been developing its own charging network spanning all over North America, Europe, Asia, and Australia. It has installed over 1,870 supercharger stations in the US alone [90]. Vitra, an EV charging technology company has been developing a Vehicle-to-Grid technology that would enable an EV to either charge from the grid or supply the power to the grid thereby establishing a bilateral connection with the grid [91]. Electric Vehicle Association of Thailand, an association, composed of private and academic individuals, has been actively working in Thailand to promote usage of EVs and

supporting industrial manufacturing and researches [92]. EV companies such as KIA, BYD, Mahindra and MG have set up service centers all over Nepal, especially in Kathmandu, to provide services for the EVs in Nepal. Providing tax breaks for these companies will encourage these companies to get involved in the EV infrastructure development, thus establishing a mutually beneficial relationship between the EV companies and a developing country. However, there may be some investment risk in developing nations, since the market is so volatile. There is less investment from the government side, and it will be hard for a company to invest in such a volatile market, where the political stability is not good. In addition, the size of the potential market is the next big factor, that must be considered before investing in a new sector like EV.

Options of EV Models

With increasing pressure from the government and environment regulating bodies, all of the top automobile companies of the world like Toyota Motor Corporations, Volkswagen Group and Daimler AG have started offering an EV alternative along with their petroleum-based options. This is to comply with the strict laws and also to compete in the $162.34 billion EV market. And with the EV market projected to reach $802.81 billion by 2027, the higher number of EV models options to choose from will only decrease the cost of EV and while simultaneously providing the consumers with more competitive options of EVs [93]. With the release of newer EV models like Nissan Leaf, Nissan Sylphy ZE, Hyundai Kona EV, and BYD e6, the Association of Southeast Asian Nations had projected upmost of 6 million EVs by 2020 [94]. Models of EVs in the market no longer have compromised facilities. This is in stark contrast with the situation of EVs at the beginning of the 2000s, where the EVs had fewer features, high price, poor mileage, low services and lack of charging infrastructures. With various models of EVs like Tesla Model 3, Hyundai Kona Electric and Audi e-tron providing ranges from 399.117 kilometers per charge to 498.897 kilometers per charge and the availability of 30 minutes fast charge, EV is suitable even for a long-distance journey. Performances and safety of EVs have also been developed enough to be on par and in some criteria, exceed the petroleum alternatives. Thus, introducing a multitude of EV options to a developing country will influence the customer to consider EV as their next vehicle. However, the EV company must consider the potential market cap of a specific vehicle type before their penetration in a country for their sustainability. For example, it will be very difficult to sustain a product with their regular operation and maintenance if there are just a few products; the product will not be sustained for a long term, and it will be difficult to maintain that model after a few years.

Running cost and conveniences

When it comes down to it, the effectiveness of EVs would depend on whether consumers are willing to adopt them or not. A consumer would opt for a cheaper alternative. One can talk about the progressive environmental impacts that EVs will carry with it, but it comes down to the consumer and on whether or not they are willing to buy an EV and use it as their daily driver. The pull that money has on the decision-making of which vehicle to buy is more relevant in a developing country. The exemptions in import duties and tax breaks, coupled with saturation of the EV market lead to a decrease in the cost of EVs. Further, with the introduction of new monetary incentives from the government, the EV is becoming a more affordable alternative means of transport. Insurance companies even provide customers with cheaper fully comprehensive insurance if they drive EVs. Nepal Electricity Authority in Nepal is gearing up to provide electricity at the rate of NRs. 8.90 for EV charging, which would be cheaper when compared with the normal rate of electricity. After a detailed comparison between Hyundai IONIQ Electro Trend and Hyundai i30 1.4 T-GDI Trend DCT based on the total cost including running costs like fuel and insurance, it is concluded that though more expensive at first, the Hyundai IONIQ Electro Trend beat its petroleum-based counterpart after five years in total cost [95]. As the running cost of an EV is cheaper when compared with a petroleum-based counterpart, it stands to reason that a consumer of a developing country would gravitate towards the cheaper alternative. Further, with a convenient infrastructure like fast charging, enough parking lot, customer-friendly law and exchange schemes, the EVs will attract new customers.

Carefully addressing these specific points will ensure the smooth transition of the transport sectors from petroleum-based vehicles to EVs. This will entail a careful analysis of limited budget spending and full fledge information campaign aimed towards the customers. However, the facility on servicing, exchanging/ replacing motor parts should make good, which will be based on the market cap of a specific brand and vehicle model. Basically, the maintenance charge of a vehicle is very high in developing countries, especially when there is limited number of products within that area. Having a limited product, the company/ service center does not focus on the specific product, and they tend to cover their benefit with a limited consumer; it increases the servicing cost. Hence, it is very important to look over the market cap of a specific product within an area/ nation, especially in a developing country like Nepal.

Discussion and the way forward

Because of global warming and an inconstant supply of remaining petroleum products, the transportation sector has been making headway in developing a capable electricity-based transportation sector. With the increasing demand for EVs every year, the transportation sector's transformation is gaining a rapid pace. Countries and companies have spent billions of dollars to figure out the optimum mix of infrastructures, charging topologies and charging station construction through rigorous and educated trials and errors. This has been the case for more than a decade in various developed countries. However, with developing countries focusing their limited budget on other infrastructures, there has been little to no investment in this form of transport. Additionally, developing countries require a careful separation of funds for various infrastructures. If they are to increase their effort in reversing global warming while also developing a strong base for their transport sector, one that can sustain the future EVs, the developing countries will have to focus on the infrastructures for the EVs. With the trend of vehicles moving toward EV, developing countries have a unique opportu-

nity to develop an EV-focused infrastructure development. With the infrastructures to support conventional vehicles still not established, a developing country finds itself with a blank slate.

Multiple problems and difficulties in implementing EV based transport sector already are being addressed through different approaches all over the world. Furthermore, if a developing country is to start investing in their electric transport sector, these trials, errors and successes have to be carefully studied to figure out what factors are to be addressed. The developing countries do not have enough resources and budget to spend on the required test and research in the EV sector. An economical way around to refrain from losing a portion of the country's budget to research is a careful study and evaluation of EV projects and technologies, currently being implemented in the developed countries. Different types of EVs, types of charging stations and infrastructure requirements have been studied in detail to develop an optimum path to ensure sustained development of the electric transportation sector in developing countries. However, the potential of EVs can only be realized in a developing country with a focus on five factors: (a) governing body's initiatives and laws, (b) infrastructure development, (c) investment by Government and EV related companies, (d) availability of various EV options and (e) running cost and convenience. With proper focus on the following steps, a developing country can apply the tested and proven solutions already implemented by developed countries:

- Introduce EV-friendly initiatives and regulations.
- Develop infrastructure to accompany and aid the growing EV market and use this growing market to develop its energy production rate.
- Attract the EV producers to finance various products to increase their customer group.
- Introduce numerous options or EVs in the market and develop healthy competition. Thereby, providing customers with various EV options to choose from.
- Take advantage of the decreasing price of EV technologies and further lower the running cost of EVs.
- Lastly invest in developing a convenient infrastructure, programs, and laws to ensure that the new customers ultimately gravitate towards EVs.

In this article, the following conclusions are drawn from the study of EV sector-related parameters for the significant development of the EV sector in developing countries:

- With multiple forms of EVs currently under production and development, it stands to reason that a country with a limited budget should focus on the HEV and BEV. These types of EVs have tested and time-proven track records. Furthermore, with numerous reputed automakers already manufacturing these forms of EVs, these types of EVs are more economically competitive and affordable.
- Public multiplex charging stations are to be constructed in business concentric city areas, while multiple charging parking lots are to be constructed along major highways to support the high volume of EVs in it. The multiplex charging station will effectively concentrate the high number of EVs to particular points throughout the city. These concentrated points of energy demand in the cities can be effectively met through the construction/ up-gradation of power distribution infrastructures up until these points only, effectively limiting the cost requirement. Furthermore, charging parking lots along the highway side will provide easy charging access to the EVs at a moment's notice.
- Favorable EV policies should be introduced, and tax exemptions should be provided to EV-related companies. These will attract EV companies to invest in developing countries. Also, with favorable plans and policies in place, more customers will be attracted to buying EVs for their daily commute.

With Nepal posed to have excess power production from the development of new hydropower projects, it can be taken as an example of a rapidly developing energy market. Also, the majority of Nepalese have access to electricity, the number of EV users is prone to increase. With the elimination of load shedding in major cities and rapid construction of distribution lines in the rural areas, Nepal's economy is on the upwards track. The overall development of the basic infrastructures has also been in the works. In the near future, Nepal will begin to look for ways to increase its energy demand, owing to its blooming energy generation sector. Further, with its citizens warming towards the prospect of owning four-wheelers because of the improving economy, Nepal is in a prime position to develop its EV sector.

With the information discussed, a pathway for Nepal's EV sector has been developed with a focus on five parameters: cost, policy and finance, infrastructure, company-driven development, and target group/market. In the current scenario, even in the absence of clear policies in place, Nepal boasts some small EV-related companies like Yatri, Niu, Hulas, and so on. The introduction of EV-related policies will bolster the already present EV sector. The construction of dedicated feeders to the city-based multiplex will encourage the customer into buying EVs. Moreover, with a handful of highways in operation, the construction of parking lot charging stations will create a good base for long-distance EV travel. However, the rate can be further increased by introducing budget-friendly EVs. With the increase in the number of middle-class families, budget options would ensure that EV's market share increases. The increment of tax in EV from 10% to 60% as per the recent budget plan of the Nepalese government has further increased the overall cost of EVs in Nepal, but with the introduction of application-based energy tariffs, the EVs running cost can be lowered as well [96]. Having minimum EV-related laws and regulations, Nepal should introduce carefully thought-out laws and regulations focused on city customers. The introduction of precise and investment-friendly regulations will incentivize various companies to extend their business in Nepal. This would encourage the private sectors to construct large-scale EV charging parking lots. Furthermore, power quality, especially in the cities, should be strengthened to aid the supply for newly developed and upcoming charging stations. Finally, with the development of an entirely new sector of business, the country will technically and financially prosper. Rather than focusing on introducing EV features like 30 minutes fast charging, three-phase fast home charger and vehicle to grid technologies; more focus should be placed on developing reliable

and inexpensive EV technologies that will suffice the needs of medium-class Nepalese communities. Also, all this information can in turn be used in a similar manner for various other developing countries as well.

With the foundation of studies fulfilled by this paper, future research and projects can be conducted to complement this paper addressing the following points:

- Use of Geographical Information System to purpose/ select places for construction of multiplex EV charging stations in the business concentric city areas and along the highways.
- Conducting a developing country-based study of an increasing rate of EV users, and how the practice of EV influences and contributes towards the overall development of a country.
- Developing of new electrical distribution system capable of handling the large momentary loads of EVs.
- Development of detailed EV-focused plans and policies to drive up the EV sector with a particular focus on middle-class families.
- Conducting a detailed study to identify possible hindrances while new EV-based regulations are in the process of being implemented.
- Economic analysis between costs of establishing the petroleum-based transport sector to the cost of establishing the electricity-based transport sector.
- Forecasting the increase in energy to be served and impacts due to the increase of EVs for a fixed period.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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