Techno-economic analysis of electric vehicle policy: The case of Pakistan

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Dedication

This thesis is dedicated to my parents, my friends and my mentors who have equipped me with the knowledge, curiosity, empathy and motivation that enabled me to explore, tackle challenges and grow as an individual.

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I express my most sincere gratitude to **Dr. Kafait Ullah** for being such a tremendous mentor and guide me throughout this outstanding journey. His illuminating views, constructive criticism and consistent feedback made me sail through numerous obstacles. I also extend my humble gratitude to all the faculty and GEC members for their unconditional support. I pay special regards to my parents for their constant encouragement and prayers that have made this endeavor memorable and worthwhile.

Abstract

The transport sector is responsible for a significant amount of all energy-related emissions around the world. To curb the problem of climate change countries around the world are planning for the transformation of their transport sector, aiming to replace conventional fossil fuel-powered vehicles with electric-powered vehicles. Pakistan has recently developed its first National Electrical Vehicle Policy intending to achieve a 30% share of electric vehicles by the year 2030. This study develops a model to evaluate the techno-economic feasibility of incorporating a 30% battery-powered electric fleet in Pakistan's existing transport and energy system. The energy mix of a country plays an important role in determining net economic impacts. The study investigates both cars and motorbikes for, capital costs, fossil fuel savings, additional generation requirements under different energy mix scenarios, and their cumulative influence on Pakistan's economy. The results for the model show that Pakistan would require a mere 2% increase in its existing energy generation to accommodate a 30% electric vehicle fleet. The cost of additional generation energy for powering electric vehicles is significantly less than the cost of fossil fuel offset under the conceived energy mix scenarios. The results indicate that annual vehicle kilometers traveled is a key parameter in determining net economic impacts and that in the case of Pakistan importing electric vehicles to achieve its targets, electric bikes would have better long-term economic prospects than electric cars. The study builds a strong case for domestic electric vehicle manufacturing for developing countries like Pakistan.

Keywords: Energy system modeling; Techno-economic feasibility; Scenario analysis; Developing countries; Electric vehicle policy; Pakistan

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List of abbreviation

BAU………………………………………………………………Business as Usual
BEV…………………………………………………Battery Powered Electric Vehicle
BPF………………………………………………………………Base Price of Fuel
CAVE……………………………………………Cost of Advanced Vehicles and Energy
cc………………………………………………………………………..Cubic Capacity
OCED………………………Organization for Economic Cooperation and Development
DOE……………………………………………………………..Department of Energy
Dloss……………………………………………………………...Distribution losses
EV………………………………………………………………...Electric Vehicle
G………………………………………………………Annual Generation Required
GHG………………………………………………………………...Greenhouse Gas
HEV………………………………………………………………Electric Vehicle
IPP………………………………………………………Independent Power Producers
IRR…………………………………………………………Initial Rate of Return
KWh………………………………………………………………Kilo-Watt Hour
L…………………………………………………………..Service Life of Vehicle
LCA…………………………………………………………..Life Cycle Analysis
LEC……………………………………………………Levelized Cost of Electricity
Mi…………………………………………………Fuel Consumption per Kilometer
MSRP…………………………………………..Manufacturers Suggested Retail Price
NPV……………………………………………………………Net Present Value
NREL…………………………………………National Renewable Energy Laboratory
NVEP……………………………………………………National Electric Vehicle Policy
Ni………………………………………………………………………Vehicle Type
NOIDC……………………………………………Net Oil Importing Developing Countries
OGRA………………………………………………Oil and Gas Regulatory Authority
O&M……………………………………………………Operation and Maintenance
PPA……………………………………………………..Power Purchase Agreement
PAMA…………………………………Pakistan Automotive Manufacturers Association

Chapter 1

INTRODUCTION

1.1 Background

The internal combustion engine has been pivotal in the establishment of the global transport industry. Its use over centuries in vehicles has led to connectivity, economic progress, and prosperity around the world. During this period the world has also witnessed an unprecedented level of increase in carbon emissions that is causing global warming around the world. Global warming would not only have disastrous effects on the environment but also threatens human well-being. The transport sector alone is responsible for approximately 23% of total energy-related GHG emissions in 2010, of which 72% comes from road transport only [1]. The solution to this problem requires us to curb our use of fossil fuels and to harness and utilize clean energy to power the global economic engine.

Electric vehicles are powered by electric current using batteries and produce zero emissions. The idea to transform the transport sector from a conventional fossil-fuel-powered combustion engine to a cleaner electric powered engine is not a new one. Years of ambition and technological advancements have now made possible the inclusion of electric vehicles in the transport infrastructure [2]. Yet the decision for the adaptation and inclusion of electric vehicles by a country involves a deep understanding of their technology coupled with its tricky economic dynamics. Although many countries have joined EV30@30 (an international campaign, setting a goal for countries to reach a 30% share of EVs by 2030), developed countries are resourceful and better equipped to be the early adopters of EV [3].

Developing countries like Pakistan on the other have struggled to produce meaningful results in this global transformation. The world population is projected to hit 8.4 billion by 2030, developing countries that still hold the bulk of the world's population will account for 97% of this increase by further adding 1.2 billion people to the world's population [4,5]. This shows that the majority of the global EV impact resides in the adaptation of electric vehicles by the population of these countries.

1.2 Pakistan's electric vehicle scenario and ambitions

Pakistan situated in South Asia is the world's fifth-most populous country [3]. Pakistan has a vehicle ownership rate of 11 vehicles per 1000 people compared to 809 motor vehicles per thousand people in the United States of America [6]. The transport industry in Pakistan is dominated by a handful of vehicle manufacturers none of which manufacture electric vehicles for consumers in Pakistan. Pakistan has recently proposed NEVP in 2020, aiming to achieve a 30% mix of battery-powered electric vehicles in its existing fleet of internal combustion engine vehicles by the year 2030 [7]. This comes right after the targets proposed by the Indian government to have a 30% penetration of electric vehicles in its total fleet of motor vehicles by 2030 [8].

Fig. 1.1 Electric vehicle charging [9]

The goals and incentives of the NVEP are as follows [7]:

- 30% of car sales by 2030 and 90% by 2040
- 30% of two- and three-wheeler sales by 2030 and 90% by 2040
- 30% of truck sales by 2030 and 90% by 2040
- 50% of bus sales by 2030 and 90% by 2040

To achieve these targets of the NVEP the government of Pakistan's is also framing the best possible incentives to foster the local EV manufacturing industry, for this the NVEP also proposed:

- a reduction in the goods and services tax from 17% for conventional vehicles to 1% for EVs
- a reduction in the goods and services tax from 17% for conventional vehicles to 1% for EVs
- lower electricity tariffs for EVs
- an import duty of only 1% for charging equipment
- plans for a direct current fast-charging network
- incentives for manufacturers including lower financing rates from the state bank

With these incentives, Pakistan aims to build a steady but substantial electric fleet over the years.

1.3 Pakistan's Energy Scenario

Electric vehicles are powered by electricity so ideally the electricity used to power the electric vehicles should also come from clean sources of energy. Pakistan's energy mix is dominated by thermal sources of electricity generation while renewables hold only a small share of energy generation.

Fig. 1.2 Solar park located at Bahawalpur [10]

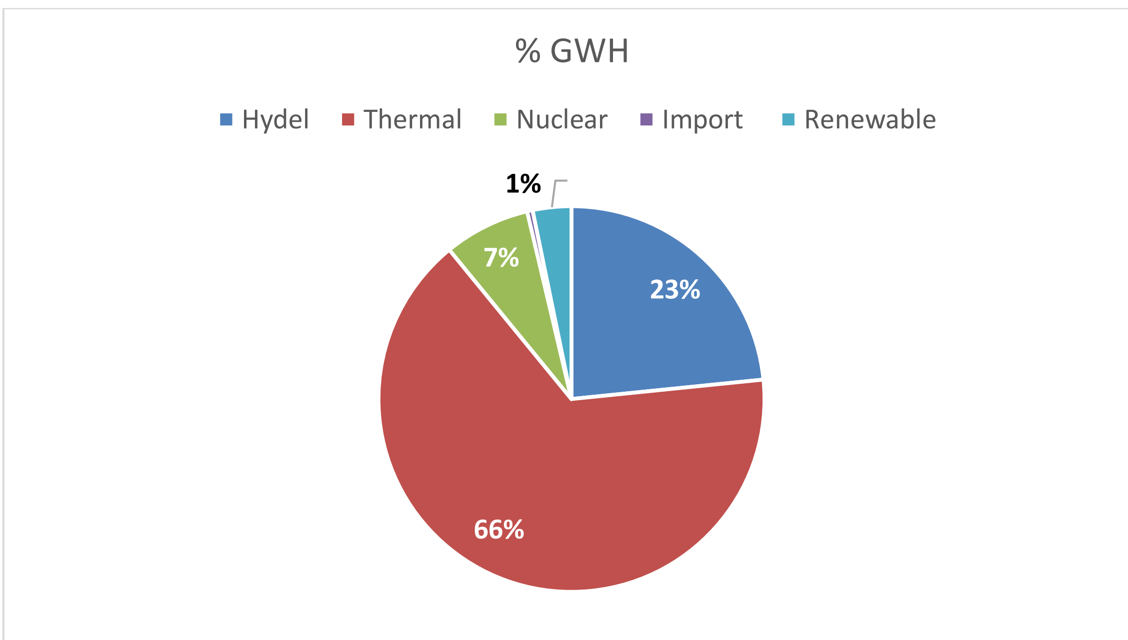


Fig. 1.3 Pakistan energy mix 2017-18

As shown in Fig 1.3 in the energy mix of 2017, Pakistan generated 28,239 GWh (23%), 79,300 GWh (66%), 8720 GWh (7%), 3904 GWh (3%) of energy from Hydel, thermal, nuclear and renewable sources respectively while 555 GWh (1%) of energy was imported from Iran. Pakistan produces thermal energy from Gas, RFO, RLNG, HSD and

Coal power plants, all of which require fossil fuel to generate electricity. Pakistan has also previously struggled to keep energy supply in line with energy demand which had led to energy shortages. It is important to consider the effects the energy mix plays in the ability of a country to have an economically viable electric fleet.

1.4 Advantages and Disadvantages of Electric Vehicles

While electric cars have lots of advantages they also have to overcome a few challenges [11].

These are the following advantages over combustion engine cars:

- Environmentally friendly
- Easier integration with renewable energy solutions
- Reduced noise pollution
- Less complex than ICVs
- Replaceable batteries extend service life
- Cheaper maintenance costs
- Fossil fuel savings
- Homebased charging

These are the following disadvantages over combustion engine cars:

- High capital costs
- Longer charging times
- Short driving ranges
- Higher investments in supporting infrastructure

1.5 Challenges and Problem identification

Pakistan's trade balance has worsened over the last 10 years. Oil imports accounted for a significant portion of the import bill recorded at US$14.4 billion out of the total imports value of US$54.8 billion in the fiscal year 2018-19 [12,13]. Pakistan's transport sector burnt around 64.3% of the overall consumption of various petroleum and oil products in the fiscal year 2017-18 [14]. Hence, like other NOIDCs, a 30% EV fleet will have huge financial and economic implications for Pakistan [15]. A recent report by NREL on the EV policy for Pakistan, specifically mentions the potential of exploiting the domestic

EV manufacturing industry, hence highlighting the need to compute the net economic effects of these policies [7]. Pakistan also needs to plan for the additional generation capacity required for these new EVs from renewable and clean energy resources given that thermal-based generation was 65.69% of the total generation in 2017- 18 [16]. Understanding the techno-economic dynamics of EV's and the energy mix of a country will enable EV manufacturers, electric utilities, and policymakers to better strategize for the electric transport future. The decision of EV adaptation and its implementation is likely to be influenced by a country's economic position, prompting a mindful analysis and modeling of its transport-energy system for a comprehensive cost-benefit analysis [17].

1.6 Justification of research

Phasing out of ICVs is eminent as BEVs get cost-effective with decreasing battery costs over the last several years. Counties would have to incorporate electric vehicles to meet the demand of international originations and binding agreements like the Paris agreement. Techno-economic planning is required before such initiatives are implemented. Pakistan would not any have to account for the energy generation required for electric vehicles but must see how to make these electric vehicles economically sustainable. Global demand for EVs is expected to grow and developing countries need policy foresight otherwise they will miss out on global targets. Pakistan, like other developing countries, has the potential to be a huge EV market given its margin of growth in vehicle ownership rates. Car ownership rates for the two most populous nations China and India are 17% and 6% respectively, whereas, Vietnam and Bangladesh are still at 2% [18]. Equally important as cars are to also factor in the inexpensive two-wheelers primary dominant in developing countries in South and Southeast Asia. Two-Wheelers are not only popular in Pakistan and India, but data shows that eight-in-ten also own a scooter in Thailand, Vietnam, and Indonesia [18]. The potential of PV in Pakistan is great and with its growing market. The selection of this topic is made by taking the following consideration:

- EV growth in the energy market
- Climate Change initiatives
- Potential contributing impact of developing countries

1.7 Objectives of research

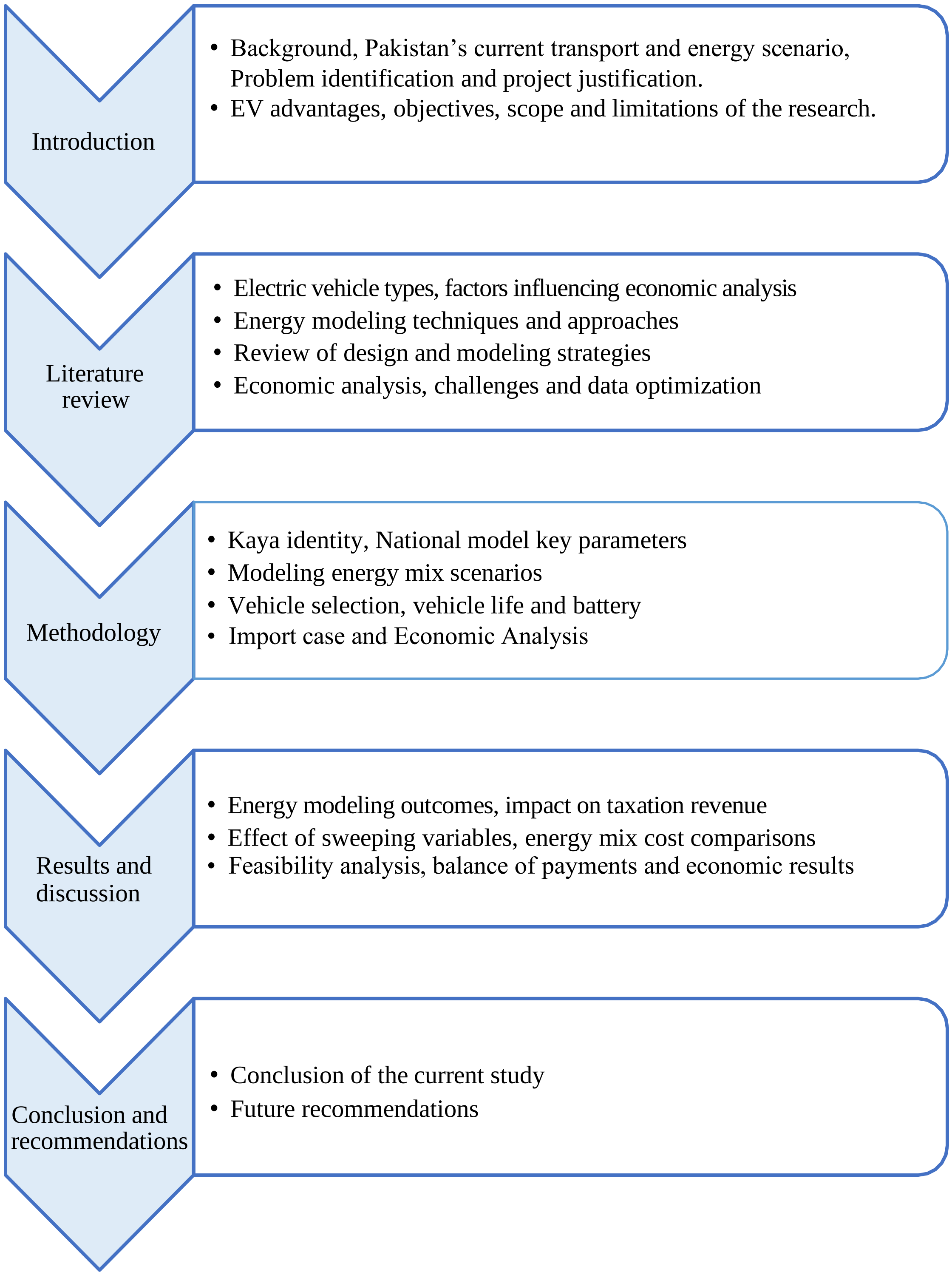
The overall broader objective of this research is to develop a computer-based model to study the techno-economic feasibility of electrifying the transport sector using the case of Pakistan under the NVEP.

The main objectives of transport energy modeling are to find:

i. The number of BEVs Pakistan would require for achieving its targets.
ii. The additional energy generation requirement of the electric fleet.
iii. The cost of additional generation requirements under various energy mix scenarios.
iv. The cost and amount of fossil fuel are offset by the electric fleet.
v. Net economic impacts of the electric fleet on the government of Pakistan.
vi. Develop and compare economic impact for the case of indigenous domestic production versus import-based scenario.

1.8 Scope and limitations of research

This study uses the transport sector of Pakistan as a reference to build the techno-economic model. Data collection and modeling have been carried out on two-wheeler motorbikes and four-wheeler passenger cars whereas the electrification of other locomotives such as busses, trucks, rickshaws will not be addressed to avoid complexity. Pakistan's energy mix has been used to construct energy mix scenarios. The model includes and accounts for the capital costs of vehicles, fuel, and energy while the cost and economic viability of charging infrastructure i.e. vehicle charging stations and the capital cost in setting up the energy generation infrastructure have not been accounted for. The model will however account for changes in capital investments if any, on the import bill for ICV's and BEV under the import-based scenarios. The model has been constructed in a way to account for the limited data availability in Pakistan. The model parameters are variable so that effects on the economic feasibility can be seen using various data sets and assumptions.



Figurative flow chart

Summary

Solar energy to curb pollution and mitigate the problems of climate change the world needs to move towards cleaner technologies of energy production and utilization. Electric vehicles offer an environmentally cleaner alternative to internal combustion engine vehicles and thus are the future of the global transport system. Pakistan like other countries have developed its electric vehicle policy and plans to have 30% of electric vehicles in its current transport fleet. Under NVEP Pakistan also aims to offer incentives to the local manufacturing industry to set up electric vehicle infrastructure. Although electric vehicles offer a variety of benefits the decision to include them needs a techno-economic assessment to assess their feasibility in the long run.

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Chapter 2

LITERATURE REVIEW

2.1 Electric Vehicles

Electric vehicles are powered by an electric motor, unlike internal combustion engine cars. The electric motor can be powered by batteries or by a fuel cell. The battery pack inside can be plugged into a home-based charging unit or a dedicated charging station for charging the electric vehicle. Unlike their conventional counterparts that have lots of mechanical moving parts, electric vehicles are less complex and only host a few parts to function [19]. As the electric vehicle runs on electricity powering the motor and does not contain any liquid fuel components hence it does not produce any carbon emissions from its tailpipe. Electric vehicles are based on environmentally friendly technology.

Electric vehicles come in many types, based on how the car is powered.

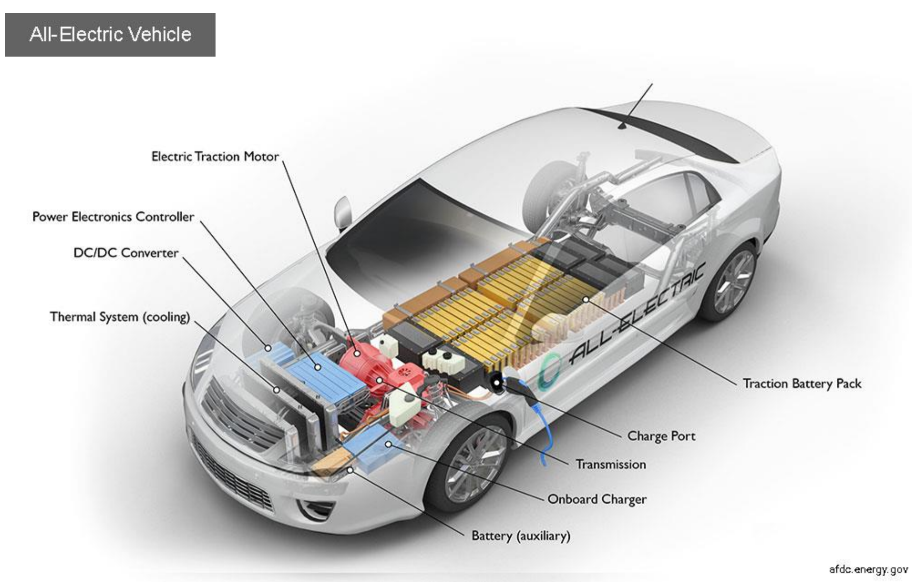

Fig 2.1 Electric vehicle components [20]

The vehicle hosts a battery pack, electric traction motor, power electronics controller, power inverter, onboard charger, DC/DC converter, transmission, and a cooling system [19].

2.2 Types of electric vehicles

Based on the working mechanism of the electric car there is more than one type of electric vehicle. Commercially they are classified into 3 main types;

i. Battery electric vehicle
ii. Plug-in Hybrid
iii. Hybrid

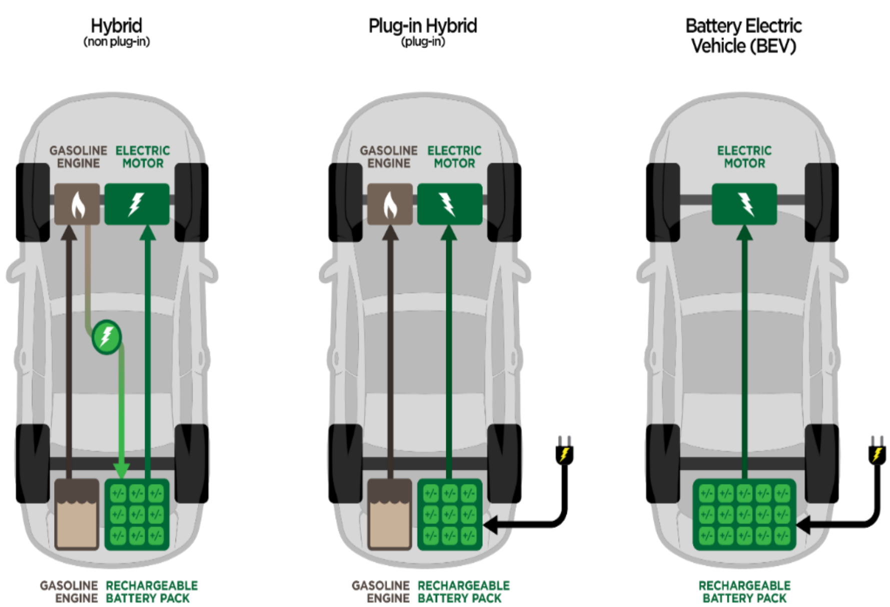

Fig 2.2 Types of electric vehicles [21]

The hybrid electric vehicle has both a gasoline engine and an electric motor to power the vehicle. The battery pack installed inside the vehicle charges on the two-drive system as the car generates its electricity. This energy is stored in the battery pack and utilized at alternative times between the gasoline engine and electric motor.

The plug-in hybrid is very similar in its construction to the hybrid electric vehicle. Like the hybrid, it also has two ways to run the vehicle, via the gasoline engine or the electric motor through the battery. The main difference in plug-in hybrids is that the built-in battery pack can be charged from an external source. When the battery storage power depletes the car switches to take power from the gasoline engine instead.

The third type of electric vehicle is the battery electric vehicle. BEV's do not have a dual power source, they do not host a gasoline engine and only rely on the battery pack to power the vehicle. Battery electric vehicles can be referred to as purely electric vehicles as they have simple components, are less complex, and run solely on battery power. The only option to charge the BEV is through an external power source. The study uses the BEV to build its national model because this type of electric vehicle does not produce carbon emission through the use of fossil fuels and would be the best bet to compete against eliminating the need for an internal combustion engine.

Fuel cell vehicles also form part of the electric vehicle family but because of them not being commercialized on the scale that BEV has seen over the last few years fuel cell vehicle were not accounted for in this study. With advances in fuel cell technology in the coming future, the use of fuel cells however will hold equal importance in contributing to transform the transport sector [22].

2.3 Energy modeling techniques

Top-down and bottom-up are both well-known methods to use for energy modeling strategies. They vary greatly in their processing of information. They can aid researchers in sequencing and ordering sets of data and knowledge. These techniques have not only been applied in fields of energy but also have their application in a variety of fields including scientific theories, software design, structural humanities, and policy development and implementation [22].

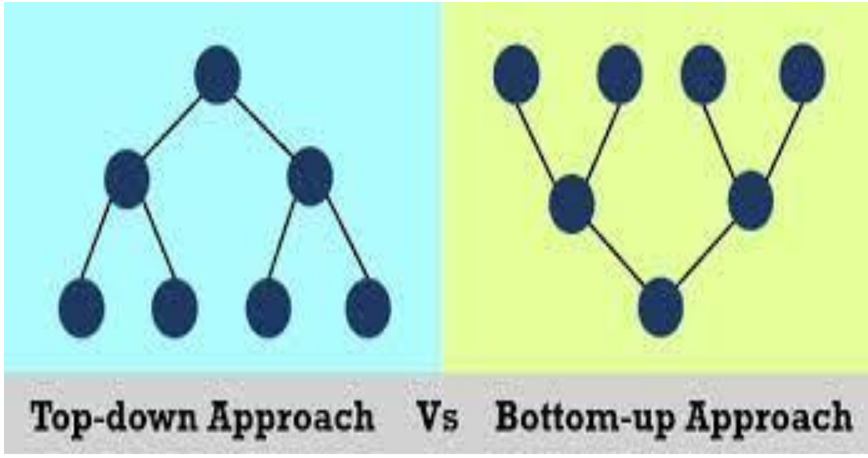

Fig 2.3 Modeling approach techniques [23]

2.31 Bottom-up approach.

A bottom-up approach is joining different segments of low-level data to build a complex multi-dimensional complex system. The resultant system is an array of smaller subsets that make up individual components of the wider network of processes. The data that is collected to form the bottom-up approach designs are subjected to processing and plugged to produce eminent results. The individual pieces that make up the elementary system are broken down in a great deal, enhancing data resolution. The seed model is a representation of how the approach used grows in complexity and completeness as it is subjected to different forms of data treatment. The elements of the systems developed in isolation serve a global purpose as they are subjected to optimization techniques forming a top-level system.

Energy modeling uses the same concepts of the approach and designs unitary energy data packets and oversees the effect of variables on those data sets. The correlation is developed and then tested on individual parts of the system to develop coregency. Data assumptions are often needed to build models which is a bottom-up approach that has a decentralized impact on the overall system.

2.32 Top-down approach.

A top-down approach follows a different route of design and refinement. It is the reverse engineering of already composed well-integrated systems. It is often known as a decomposition approach as it produces subsets from an already bigger more complex structure of data. The system broken down is then used to model the problem. The system does not offer a great data resolution but often uses predictive strategies to link the results based on subsystem analysis. It is easier to manipulate, and data variables have a great effect on the overall mapping of results until the system is resolved in its base elements. It starts with a bigger picture of the energy system and then refines it.

2.4 Review of transport energy models

This study highlights key variables and modeling strategies that can be replicated for other NOIDCs to build a holistic framework to conduct the techno-economic analysis. While studies have been conducted, mostly in developing countries to assess the techno-economic feasibility of EVs (mainly focused on four-wheelers). A study in California using the Costs for Advanced Vehicles and Energy model found that the vehicle portfolio scenario had a slightly negative influence on California's economy. The negative influence was because of the high cost of advanced vehicles and, therefore, the resulting gasoline savings generally could not offset the high incremental expenditure on vehicles and alternative fuels [24]. A study that evaluated the introduction of BEVs in the private vehicle fleet of Milan, Italy; found that an EV fleet share of 30% would require 755 GWh of energy which would represent just 2.5% of the electric energy consumption in the province of Milan [25].

Schill et al. [26] found that the EV fleet’s consumption would increase from 0.1-0.2% in 2020 to 1.3-1.6 % of total power consumption in Germany by 2030 under different scenarios, whereas Hartmann et al. [27] found a 1.5% daily demand fluctuation on the German grid with 1 million EV’s. Keller et al. [28] concluded that the electrification of vehicles led to a combined electricity and transport system cost reduction because of savings associated with the offset of fossil fuels in British Colombia, Canada.

Studies have also used modeling tools and modeling approaches and investigate the electric vehicle penetration in different countries [29,29–35], however, there are potential knowledge gaps that need to be addressed.

2.5 Kaya identity framework

The conceptual national model takes inspiration from the Kaya Identity Framework which uses the VKT and energy consumption per vehicle-km relationship and tailors it to suit Pakistan's transport framework as per the available data [33]. Various modeling approaches have been used to collect data from driving patterns of sampled drivers and extrapolated them to generate results and simplify the vehicle models [29,36,37]. Hence, the accuracy of these models is dependent on sample size, availability, and accuracy of driving patterns [38,39]. The usefulness of driving patterns in generating extensive data is primarily useful in evaluating changes in peak demand dependent on EV charging hours as per the consumers' preferences and length of trips to see the impacts of the charging range.

Lack of data availability of driving patterns in Pakistan and its ability to affect the accuracy of results also led the model to be developed using VKT as a variable representing an average consumer driving pattern. Taljegard et al. [40] applied a similar method for calculations, although employing different means for data collection and assumptions for its energy model used a fixed VKT value to assess the Scandinavian-German EV fleet. In the developed national model, key parameters such as vehicle life, the energy consumption of vehicles, and BEV penetration percentages can be varied.

2.51 Kaya identity relationship

The relationship, known as a Kaya identity, is denoted by Eq

$$v*e = \Phi_l \quad (1)$$

In the kaya equation *v* denotes VMT, *e* denotes the energy intensity in KWh per km and

Φ_l represents the commutative energy use for the whole transport fleet [33]. The approach to predicting energy intensity and energy use for an extended period is often a challenge as variables vary greatly over time. The kaya framework however considers fleetwide average intensity that can be projected with stability. The identity is useful in predicting energy use in segmented portions of the transport energy sector and has been used extensively in this regard [22]. For example, this framework allows us to treat electric non-autonomous and autonomous cars and light trucks all separately, adjusting use intensity for vehicle type as well as allowing the composition of the fleet to migrate from one type to another.

However, it may be noted that greater autonomy in transport by some countries might lead to disruptions in traditional forecasts as these shifts alter the needs of the population patterns in the use of transport. There is no silver bullet to address these difficulties, but we gain a little tractability with a conceptual framework based on tailoring the form in the identity to adapt to these changes.

2.6 CAVE transport energy model

G. Wang et al. [24] used the CAVE model to investigate a vehicle portfolio scenario in California. The model simulated results for over 20 years of electric vehicle penetration under different scenarios. The model was deployed to compute general equilibrium for the transport sector to estimate the macroeconomic impacts of the advanced vehicle scenario on the economy of California. The cars were categorized as passenger vehicles and other types of heavy-duty vehicles. The results of the study showed that conventional vehicles will continue to dominate the vehicle market and consumption of gasoline will increase [24]. These results were drawn using variable fuel prices and large price elasticity case the vehicle scenario to be economically slightly negative.

The gasoline offset was not able to compensate for the price of energy consumed; this was primarily because of higher electricity prices. The model assumes a fixed cost of vehicles but over the year’s battery costs have detreated and adjusting capital costs of cars will be important to account in the modeling analysis. The CAVE model also includes hybrids in the analysis which also use gasoline engines and would not provide an idea comparison between the two different types of technologies. For the CAVE study, it can be deduced that small changes in variables have a large impact on the feasibility of results and because data availability in Pakistan is scarce so the model for Pakistan must be designed to incorporate sweeping variables. This will help solidify the analysis and help studies hereafter to deduce the impact of individual variables on the overall transport economy.

2.7 Challenges to modeling approaches

Studies that account for techno-economic feasibility do not account for import cases by factoring in the impact of localization, this is primarily important for developing countries as they are yet to achieve complete domestic EV production and might have to rely on vehicle imports. Secondly, models need to be designed to address data variability, often a challenge using bottom-up approaches for developing countries. Thirdly, studies like the CAVE model use the retail price of electricity and fossil fuel to account for energy costs, it will be interesting to evaluate and compare the fuel component of energy generation (using different energy mix scenarios) with the fossil fuel offset by the BEVs [24]. This comparison is particularly useful in decision making for NOIDCs.

Summary:

Electric vehicles are driven by an electric motor which in turn is powered by battery storage. Electric vehicles are of 3 main types, battery-powered, a hybrid, and plug-in hybrid. This study uses only battery-powered electric vehicles for comparison because all other commercially available vehicle has two drive system with an added gasoline engine which would not offer a true comparison and contrast. Energy modeling is the process of designing and accounting for the energy-intensive processes in the transport energy nexus. The top-down and bottom-up approach has been used by several energy models, but the study uses a bottom-up approach for better data resolution and accurate analysis. The study takes inspiration from the kaya identity framework and the CAVE model to design and built a similar model for the transport energy scenario in Pakistan.

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Chapter 3

Research Methodology

3.1 Framing the national model

The most effective way to predict the impact of EV's on electric systems is by employing computer-based models [38]. The use of computer-based modeling makes it easier to generate results based on a variety of scenarios. It also helps to plugin in desired values of key variables to conduct sensitivity analysis and obtain a wider range of results for comparative analysis. To develop the national model this study uniquely employs a bottom-up approach. Top-down models usually perform a regressive analysis and offer less data resolution. The use of the bottom-up approaches, on the other hand, is far more detailed. Data is collected and designed proceeding from a level unitary level and then a model is built using carefully calibrated data modeling techniques according to the needs of the study. In short, the bottom-up approach can obtain energy consumption of the entire fleet by aggregation of a group of individuals blocks representing the overall system [41].

When estimating energy demand, both top-down and bottom-up techniques can be used. Studies have employed bottom-up concepts to model energy consumption, energy demand, estimate vehicle emissions, and to model or design the other types of complex energy systems [42–45]. In this study, a single-vehicle is taken as a unit and the model is further developed and designed to capture the entire footprint of the 30% penetration as per vehicle fleet characteristics of vehicles in similar vehicle segments. Energy generation scenarios are then built upon the results of the vehicle modeling according to the energy mix in Pakistan.

3.2 National model key parameters

The conceptual national model takes inspiration from the Kaya Identity Framework. The kaya identity is based on two key parameters, VKT, and energy consumption per vehicle-km [33]. The national model takes this relationship and further optimizes it to suit Pakistan's transport energy framework as per the available data.

To estimate the impact of EV's on the electricity system using the bottom-up approach, data is needed for BEV penetration percentage; VKT; the fuel consumption per km; and the service life of the vehicle as shown in Table xx.

Table 3.1: National model parameters

Model Variables	Unit
VKT	Km
Mi	Lit/Km or KWh/km
L	Years
BEV penetration percentage	-

Various modeling approaches have been used to collect data from driving patterns of sampled drivers and extrapolated them to generate results and simplify the vehicle models [29,36,37]. Hence, the accuracy of these models is dependent on sample size, availability, and accuracy of driving patterns [38,39]. The usefulness of driving patterns in generating extensive data is primarily useful in evaluating changes in peak demand dependent on EV charging hours as per the consumers' preferences and length of trips to see the impacts of the charging range.

Lack of data availability of driving patterns in Pakistan and its ability to affect the accuracy of results also led the model to be developed using VKT as a variable representing an average consumer driving pattern. Taljegard et al. [40] applied a similar method for calculations, although employing different means for data collection and assumptions for its energy model used a fixed VKT value to assess the Scandinavian-German EV fleet. In the developed national model, key parameters such as vehicle life, the energy consumption of vehicles, and BEV penetration percentages can be varied.

3.3 Modeling energy mix scenarios

The advantages of EV over internal combustion engine vehicles for the environment will strongly depend on the energy mix of the country [32]. Electricity required to charge the EV fleet should ideally come from clean renewable resources [46]. Data from NEPRA is used for the energy mix in Pakistan [16,47]. Pakistan has a significant thermal-based generation but has begun to steadily incorporate renewables like solar and wind in its energy mix. To study the impact of BEVs, the energy mix of a country needs to be investigated because the energy sources used to generate electricity for the BEV fleet will not only impact generation costs but also GHG emissions [48].

Previous studies conducting LCA for drawing comparisons between conventional vehicles and EVs have explored the impact of different types of power sources and energy mixes but mainly for evaluating GHG emissions [48–50]. This study, however, focuses on the impact of the energy mix on the costs of energy generation required to power the BEV fleet.

Table 3.2: Energy mix scenarios

Generation Scenario	Pakistan's Energy Mix (Year)	Energy Sources	BEV Penetration
Scenario 1	2017-18	Business as usual	30%
Scenario 2	2017-18	Thermal based generation	30%
Scenario 3	2020-21	Solar based generation	30%

To study, how energy mix and the inclusion of renewable energy sources play part in the fuel cost of energy generation for BEVs, three scenarios have been generated. The national model uses the levelized cost of fuel per KWh for each energy source from NEPRA to calculate the total cost of fuel required for electricity generation in each scenario [16]. Table 3.2 shows the energy generation scenarios used in the study. In scenario 1, the energy required to fuel the 30% electric fleet is assumed to be generated in a similar proportion, from each energy source, as the proportion of that source in

Pakistan's energy mix. This scenario represents business as usual considering Pakistan continues to produce energy with a similar energy mix as in 2017-18. In scenario 2, the energy required to fuel the 30% electric fleet is assumed to be generated from only thermal energy sources, proportionate to their relative thermal share in Pakistan's 2017-18 energy mix. This scenario would represent the generation cost of electricity solely attributed to thermal generation sources in Pakistan's energy mix, hence considers zero contribution of renewable generation. Scenarios 1 and 2 will account for the levelized KWh fuel cost of each energy source to calculate the total cost of energy generation resulting from that scenario. Comparisons between these scenarios would highlight how different sources in the energy mix impact overall fuel generation costs in Pakistan.

In scenario 3, the study considers that the energy required to power the 30% electric fleet would be generated solely by solar photovoltaics power plants. A significant proportion of Pakistan's energy is generated by IPP's and purchased by NEPRA at an agreed PPA [51]. Several solar-based power projects (or solar IPPs) have come online in Pakistan in years using the PPA model. Due to zero fuel costs of solar photovoltaics, this scenario uses levelized KWh cost of energy as per PPA awarded to the IPP's. Levelized costs of PPA differ from project to project as the levelized cost/KWh has been decreasing over the years, due to sharply falling PV prices relative to other renewable energy sources [52]. The study uses the latest PPA awarded to Enertech Bostan Solar as an example to derive generation costs for scenario 3 [53]. Evaluating various generation scenarios and the associated energy costs, not only highlights the importance of the energy mix but also evaluates its economic impacts.

3.4 Vehicle selection

Suzuki, Honda, and Toyota are the most sold vehicle manufacturers in the Pakistani auto industry [54]. The customers have a limited number of vehicles models to choose from, as compared to the variety of cars and bikes available in the American, European and Japanese markets [55]. PAMA classifies the sales and production of vehicles according to their engine cubic capacity [56].

A unique characteristic of the Pakistani automobile market is the presence of the 70cc motorbike which holds a market share of 80% of all motorbikes sold in Pakistan [55]. Motorbikes represent a significant majority of vehicles in urban centers in Asia. High population density and congestion makes the two-wheelers an affordable and attractive option for the consumers [46]. Table 3.3 categorizes PAMA sales data of conventional vehicles sold in Pakistan over the last 15 years into three segments; segment 1 (below 1000cc), segment 2 (1000cc to 1500cc), segment 3 (1500cc-2000cc) and segment 4 (below 150cc). Toyota Altis 1.6L and Toyota Grande 1.8L are also being sold in Pakistan in the 1500-2000cc segment but PAMA data does not mention official sales numbers of these cars hence only Honda Civic is included in this segment as shown in Table 3.3.

Motorbikes with low engine cubic capacities constitute most of the motorbikes sold as shown in Table 3.4. For the ease of data collection, motorbikes below and equal to 150cc are classified under one segment of motorbikes. Vehicles with higher engine cubic capacity are priced higher. Segmentation according to engine cubic capacity congregates vehicles in a similar price range. The segmentation would then ease the selection of BEVs that are the likely replacements for the conventional vehicles from each segment. Studies often adopted segmentation to conduct the individual evaluation of different features in different categorizations of vehicles, for example, a study in Italy decided to classify Milan's EV fleet according to their battery capacity [25]. ICVs coupled in each segment signifying a comparable purchase price range and performance allow for a coherent comparison, simplifying the model design and the assumptions that would follow [57].

The number of electric cars required is 30% of each car in each segment. The ICV dominating each segment in terms of sales by a significant margin is pivotal because it not only reflects consumer choice but will also significantly influence energy consumption. Toyota Corolla and Suzuki Mehran constitute 69% and 47.3% of sales in segments 2 and 3 respectively while Honda constitutes 68.51% of the total sale of the motorbike segment.

Table 3.3: PAMA car sales data [56]

Engine capacity (cc)	Segment	ICV model (*i*)	Total Sales (2003-18)
1500 to 2000	Segment 1	Honda Civic	125,143
1000 to 1500	Segment 2	Honda City	185,461
		Suzuki Baleno	13,114
		Suzuki Liana	16,765
		Suzuki Swift	41,491
		Toyota (Corolla)	575,473
		Nissan (Sunny)	26
		Kia (Classic NGV)	627
		Kia (Spectra)	134
Below 1000	Segment 3	Suzuki Khyber/Cultus	247,939
		Suzuki Wagon R	63,453
		Suzuki Alto	122,051
		Hyundai (Santro Plus)	27,517
		Daihatsu (Cuore)	68,882
		Suzuki Mehran	475,756

Table 3.4: PAMA motorbikes sales data [56]

Engine capacity (cc)	Segment	ICV model (*i*)	Total Sales (2003-18)
Below 150	Segment 4	Honda	8,463,677
		DYL Motorcycles	801,005
		Suzuki	330,816
		Sohrab	88,993
		Hero	269,640
		Ravi	251,534
		Yamaha	51,201

	Road Prince	728,396
	United	1,226,052
	Habib	141,879

BEVs are selected for each segment of the ICVs. Hyundai Ioniq Electric, Nissan Leaf S Plus, Tesla Model 3 Long Range are selected for comparison to the ICVs in segments 1, 2, 3, and 4 respectively. Increasing cubic capacity correlates with higher prices in ICVs, similarly, in BEVs, a higher battery capacity leads to a higher driving range and purchase price. Selection for BEVs is done keeping in context the purchase prices of available BEVs in the electrical automobile market in comparison to ICVs in each segment by compromising on driving range.

Table 3.5 shows the performance specifications of the selected BEVs and how it compares with the most sold ICV in each segment. All BEVs generally have better torque and horsepower when compared to ICVs [58]. Two-wheelers form a significant portion of road transport especially in developing countries in Asia, hence their inclusion in the model is very important [59]. So, for the motorbike segment, an electric motorbike Okinawa praise plus from India, a country neighboring Pakistan is selected, because of extremely high purchase prices of electric bikes available in the American market which will not reflect a fair comparison as an alternative consumer choice.

India’s automobile market is comparable to Pakistan especially in the high-volume two-wheeler segment’s penetration [7]. The national model assumes that for future sales 30% of ICVs in Pakistan belonging to the respective segment to be replaced by the chosen BEV i.e Tesla replaces 30% ICVs in segment 1, Nissan leaf replaces 30% ICVs in segment 2, Hyundai Ioniq Electric replaces 30% of ICVs in segment 3 and Okinawa praise replaces all motorbikes in segment 4.

Table 3.5: Selected ICVs and BEVs specifications

Vehicle Type		ICV				BEV			
Vehicle Model (*i*)		Honda Civic 1.8	Toyota Corolla 1.3	Suzuki Mehran	Honda CD 70	Tesla Model 3 (Long Range)	Nissan Leaf S Plus	Hyundai Ionic Electric	Okinawa I-Praise +
Segment		1	2	3	4	1	2	3	4
Build Specifications	Engine cubic capacity (cc)	1799	1299	796	72	-	-	-	-
	Battery/Fuel tank capacity (liter/KWh)	47	55	32	8.5	75	62	28	3.3
	Full Charge/Tank Range (km)	423	550	448	467	518.2	384.6	200	160
Performance Specifications	Torque (Nm)	169	121	59	-	510	340	295	-
	Horsepower (hp)	138	84	39	-	412	214	118	-
	Top Speed (km/h)	220	240	140	93[b]	233	157.7	165	70
	Fuel Consumption (km/Lit)/ (KWh/km)	9[a]	10[a]	13[a]	55[c]	13.6[b]	14.9[b]	12.8[b]	2.06

Data from manufacturers datasheet

[a] ICV fuel consumption data [60], [b] EV database [61–63],

[c] Assumed value

3.5 Purchase Price

The purchase price is taken to be the manufacturer's suggested retail price [64–71]. MSRP excludes freight charges, tax, and license fees. Freight charges and actual dealer prices may vary according to the city of purchase so the freight charges for inland transportation of the ICVs charged by manufacturers are not taken into consideration and are also neglected for the scenario of BEVs being imported into Pakistan.

3.6 Vehicle life and Battery

Vehicle service life indicates how long a vehicle will stay in service before it is scrapped. It is an important parameter when assessing the economic feasibility of the decision to import BEV's or to analyze net savings over a vehicle's lifetime. The service life of a vehicle varies among countries and is increasingly attributed to technology and overall vehicle built quality improvements [72]. The average life of an internal combustion engine car is 11.8 years in the US, 13.24 in Japan, 13.9 years in the UK [73–75]. Data is deficient on the service life of ICVs in Pakistan, however comparable data estimates from Pakistan's neighboring country India show that cars and motorcycles having low engine displacements, like the ones sold in Pakistan have a service life of 15 years [76,77]. Therefore, results for ICVs are evaluated using the service life of 15 years. Moreover, A. Roy Chowdhury et al. [78] using data from various countries also indicates a strong correlation between the GDP of a country and the average age of vehicles in its fleet (The poorer the country, the higher is the age of its vehicle fleet).

Although several studies have been conducted on the life of EV batteries, due to the relatively new induction of these vehicles on road, estimates vary on the life of BEVs. It can be anticipated that the life of the vehicle is closely linked to the life of the battery pack because it is a vital component among a relatively few components needed to manufacture an EV [58]. The battery life of an EV undergoes degradation over time [79].
The first mass-market BEVs developed in 2010, had estimated battery pack costs of US$1,000 per KWh. Today, Tesla's Model 3 battery pack costs US$190 per KWh, which is more than a 70% drop in the price over 6 years [80]. The prices of batteries are expected to further decrease, and studies have predicted the future cost of batteries to drop to US$80 per KWh by 2030. Customers would then likely opt for a battery

replacement instead of buying a new vehicle over concerns of reduced range [81]. Many EV batteries are already warrantied for at least eight years, most manufacturers guarantee a certain amount of battery life within that time frame [72,82–84].

Battery technology continues to improve with manufacturers now claiming breakthroughs that will enable batteries to last 16 years and travel more than 2 million kilometers [85]. Even with the currently available eight-year warranty if a driving range conscious consumer goes for a one-time replacement of the batteries, he will be able to achieve a life of at least 15 years. Considering the build quality and technology improvements in newly built vehicles, the model uses an average life of 15 years for BEVs to evaluate results.

3.7 Fuel Consumption

The fuel efficiency of a BEV is significantly higher than that of a traditional ICV, hence fuel costs are much lower for BEVs than ICVs [38]. Fuel consumption (Mi) for ICVs is the distance traveled per liter of fuel and for BEV is the distance traveled per KWh. The national model is programmable for the values of Mi. Fuel consumption is different for each vehicle model and is explicitly stated by the manufacturers worldwide but ICV manufacturers in Pakistan do not explicitly state fuel consumption values.

For this study, data from a consumer survey is used for conventional cars and an assumed value of 55km/liter is used for conventional motorbikes [60]. The model uses Mi for each ICV in calculations but for older discontinued ICV models, the fuel consumption of the most sold vehicle is used as the fuel consumption of a vehicle that is discontinued in its respective segment. The model uses energy consumption data for combined energy consumption in mild weather for the selected electric cars and data from manufacturers' data sheets is plugged in for the electric motorbike [61–63].

3.8 Fossil Fuel offset

VKT is a measure of how much a vehicle is driven annually. VKT is a vital parameter for the generation of results, a higher VKT results in higher fuel consumption by ICVs and is also directly proportional to energy required for charging the entire BEV fleet. VKT varies by country, several countries in Europe have values ranging from 12 to 14 thousand kilometers, 13.4 thousand km in Australia, 17.5 thousand in Singapore, while the US has the highest value of 21.7 thousand kilometers among all OCED countries [86–89]. Data for Pakistan's national average VKT is not available, but because VKT is such a key parameter for the evaluation of results, the model is designed to be able to generate results based on a range of values of VKT. VKT is varied from 0 km to 22 thousand km to analyze its effect. This allows the extrapolation of the results of this study based on the available data hereafter.

30% inclusion of BEVs in the fleet will result in fossil fuel savings. To calculate total saving, the model calculates total fuel consumption by the 30% existing ICV fleet. Fuel cost for ICV is the per liter price of petrol and the charging cost for BEV is the per KWh cost of electricity consumed. Pakistan has a fixed retail price of petrol across all the provinces, determined by OGRA. The price of electricity, however, depends on distribution companies that have different commercial and residential rates in every region. The model accounts for costs from the government's perspective, so instead of using the retail cost of electricity to the consumer, the cost of fuel required for energy generation is used in calculations. Similarly, to calculate the total cost of fuel offset by BEVs for the national model, the base price of petrol is used in the calculations instead of its retail price. Base price represents the cost of petrol without taxes, freight charges, or dealer margins. Table 3.6 shows the breakdown of the petrol price.

Table 3.6. OGRA Fuel Cost Breakdown [90]

Fuel Cost Heads	Price/Litre US$ (Jan 2020)	Percentage of Total Cost
Base Price	0.479	63.95%
Petroleum Levy	0.096	12.86%
Sales Tax	0.109	14.53%
Dealers commission	0.024	3.17%
OMC's Margin	0.018	2.41%
Inland	0.023	3.08%

Freight Equalization Margin		
Total Retail Price	0.749	100.00%

TFC is the cumulative cost of the fuel consumed by a 30% existing ICV fleet in all segments annually. The TFC is calculated by the product of VKT, the Mi of the respective car model i in each segment, Ni , and BPF. Equation 1 illustrates the use of the bottom-up approach in the calculation [34]. TFC for each segment is calculated then summed over all segment to get annual fuel cost that will be saved by 30% of ICVs, using a variable value of VKT

$$TFC = \sum_i (BPF * VKT_i * Mi_i * N_i) \quad (2)$$

3.9 Additional energy requirement

Electrical vehicles replace fossil fuel but require electricity for charging. The annual generation required for BEVs (G), is calculated by multiplying VKT with the Mi of each selected BEV model type i and, Ni required in each segment, as shown in Equation 2. The energy required for BEVs is summed over each segment to get the total electricity required for a 30% electric fleet in one year. Equation 2 represents the disaggregated form of the kaya identity modeled on our conceptual framework where VKT is varied over the defined range of values [33]. The generated energy required by the electric fleet will have to be transmitted by the national grid so to get the amount of total annual energy required (E), $Tloss$ and $Dloss$ of the national grid in Pakistan is accounted for and hence are added to obtain E as shown in Equation 3 [48].

$$G = \sum_i (VKT_i * Mi_i * N_i) \quad (3)$$

$$E = G + T_{loss} + D_{loss} \quad (4)$$

3.10 Import case

Electrical vehicles replace fossil fuel but require electricity for charging. The generated energy required by the automobile industry in Pakistan producing ICVs has not been able to reach 100% localization levels. Many of the parts used in automobiles are imported to Pakistan and assembled. Auto manufacturers in the industry have different localization levels, with Honda at 51%, Toyota at 55%, and Suzuki at 70%, whereas motorbikes have a much higher localization of up to 96% [91]. To give the results an extended dimension, specifically for the implication of import policies the model calculates the imported portion of the cost of ICVs considered in the model. For this study, ICVs from other auto manufactures with discontinued car models are adjusted with the localization level of the highest sold vehicle manufacturer over the 15 years in each segment.

3.11 Methodology for economic analysis

Cost-benefit analysis is used among other elements, in the evaluation process to serve as a basis for policy-driven decision making [92]. The model analyses the economic impact using all the elements previously defined in detail. Net fuel savings is a factor of the annual cost of fuel saved from by ICVs and the cost of annual energy generation incurred for BEVs as shown in Equation 4,

Net fuel savings = Cost of fuel saved from ICVs - Cost of energy required for BEVs (5)

Using scenario 1 (BAU), for the import case specifically, capital cost will be incurred when BEVs are imported to eventually replace ICVs, but we must also consider here the decrease in import costs for ICV parts that no longer have to be imported given their localization mix in local ICV manufacturing. The net capital cost and net trade balance are calculated as shown in Equation 5 and 6 respectively,

Net capital cost = Cost of importing BEVs - Cost of importing local ICV parts (6)

Balance of payments = Net fuel savings - Net capital cost (7)

Economic evaluation allows the model to determine the period it takes for Pakistan to balance the capital investment in importing BEVs from the resulting yearly fuel savings. This is important because Pakistan has often struggled to maintain a substantial amount of foreign exchange reserves and oil import is a major portion of its import bill. The decision to import vehicles would not be feasible if the time required to achieve the balance of payments increases more than the life of the vehicle. The study calculates the time required for cars and motorbikes separately to draw comparisons in results.

Summary

The national model is designed by modifying the kaya identity relationship and tailoring it to the needs of Pakistan’s transport energy system. The study uses variables to help in generating a wide range of outcomes. Three energy mix scenarios, business as usual, thermal-based, and renewable-based generation are used as the basis of building the economic model. The passenger vehicle class of vehicles are divided into segments based on the purchase price and engine capacity, this eases the process of selecting options of electric vehicles for comparisons among different economic classes in Pakistan. The additional generation capacity and fossil fuel offset are accounted for to calculate the net economic impact of the replacement. Furthermore, an import case is built to calculate the value of variables for which the model will be economically viable and sustainable.

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Chapter 4

RESULTS AND DISCUSSION

The obtained results have been divided into subcategories as mention below. The first part deals with the vehicle energy modeling results that were obtained by characterizing vehicles into segments according to engine capacity. This section allows us to evaluate energy consumption across different segments and will be helpful in electric vehicle penetration and adaptation studies targeting sections of the transport sector. The second part deals with the impact on indirect taxation through reduced gasoline consumption, highlighting the need for taxation reforms by the government. The third part deals with energy mix modeling scenarios and their comparisons to highlight the spread of costs across different sources of energy and their combinations to power the electric vehicle fleet. The fourth part deals with the import case and its implications on the economy and finally, the last part evaluates all these results holistically and conducts a sensitivity analysis to see the impact of changing variables like VKT on the results of the study.

4.1 Modeling outcomes

Vehicle modeling suggests that Pakistan would require 4.2 million BEVs to achieve its targets over the next 10 years. As Pakistan is heavily dominated by the two-wheeler motorbike segment, results show that 3.7 million electric bikes would be required as opposed to just 0.58 million electric cars. Using VKT of 15,000 km and 10,000 km for cars and bikes respectively, 1.4 billion liters of fossil fuel can be offset every year by incorporating a 30% electric fleet. 1.4 billion liters of fuel amounts to a direct saving of US$1.08 billion in which US$693 constitutes the base price of the fuel consumed.

In terms of energy, the BEVs would require an additional generation of 1978.6 GWH, if they travel an equal distance to their counterparts. This energy that needs to be injected into the national grid incorporates the loss of energy during transmission and distribution would amount to 2398.04. Electric vehicles can not only charge at charging stations but also at home. In totality, Pakistan would require just 2% of its total current generation capacity to power its electric fleet. In the fiscal year, 2017-18 Pakistan generated 120,718.67 GWh of energy from all generation sources. New power-producing setups have already been planned by NEPRA. Most of the power plants having a total capacity of 27,658 MW will come online by 2025 as planned by NEPRA [16]. Pakistan plans to steadily incorporate these BEVs over the next 10 years hence the gradual increase in energy usage by these vehicles is unlikely to overburden the demand-supply balance, which previously has been a challenge for the government.

Table 4.1 Results according to each vehicle segment

Vehicle Segment	Total number of ICVs	30% BEVs required	Fossil fuel saved (Litres/year)	Energy Required (*E*) (GWh/year)
1500-2000cc	125,143	37,543	62,571,600	92.82
1000-1500cc	832,957	249,887	364,131,702	676.87
Below 1000cc	1,005,598	301,679	346,522,723	701.99
Below 150cc	12,353,193	3,705,958	673,810,527	926.36
Total	14,316,891	4,295,067	1,447,036,552	2398.04

Table 4.1 shows that motorbikes would consume 6.7 million liters of fuel and cars cumulatively would consume 7.7 million liters of fuel. Hence, the consumption of these segments is almost comparable. This is because even though an individual bike uses less fuel than a car but a large number of bikes in Pakistan's transport sector when combined have an effect almost matching the fuel spent by cars. Hence, even though the motorbike segment constitutes the majority of BEVs but demands 926.36 GWh (38.6%) of the total additional energy requirement of 2398.04 GWh. This reflects both the vast prevalence of motorbikes and their impact on the Pakistani automobile sector.

In 2016, the global EV electricity demand was 54 TWh which is approximately the annual energy demand of Greece [35]. Comparisons between countries must be carefully drawn because energy demand is largely dependent on EV penetration levels as well as several other factors that influence energy demand. One must also account for the vast difference in vehicle ownership rates between countries. There are 11 vehicles per capita in Pakistan as compared to 809 vehicles in the united states [6]. The same is the case of motorbikes, as Bishop et al. [29] predict an energy demand by the UK electric bike fleet to be 0.015%, the UK electric bike fleet would have 247,000 motorcycles whereas Pakistan would require a fleet of 3,705,958 bikes as shown in this study [29].

4.2 Impact on Taxation

The use of electric vehicles would offset the amount of fossil fuel required by the ICVs. As per the study report by NREL on EV policy, an important implication on how increasing EV sales would impact fuel taxes considering indirect taxation on fuel brings in substantial revenue for the functioning of the government [7].

Results indicate that Pakistan's government would lose out on US$157 million in terms of sales tax and 139 million in terms of petroleum levy as shown in table 4.2. This amounts to a total revenue loss of US$296.9 million per year in fossil fuel taxes. Table 4.2 shows the lost fuel tax revenue from electric motorbikes and electric cars separately under sales tax and petroleum levy. The results of the study also show that varying VKT directly affects revenue lost. The higher the VKT, the higher loss of revenue. As these are taxes collected from fuel and alternate for electric vehicles would be to collect taxes from electricity, but as electric vehicles can charge at home raising electricity process would impact the whole economy.

Table 4.2 Effect on Fuel Taxes

Fuel cost heads	**Price/Litre USD (Jan 2020)** [90]	**Revenue Lost at 30% BEV penetration (USD/year)**		**Total (USD/year)**
		Bikes (10k VKT)	**Cars (15k VKT)**	

Sales Tax	0.109	73,333,443	84,153,221	157,486,664
Petroleum Levy	0.096	64,935,162	74,515,839	139,451,001

4.3 Energy mix scenarios

Results were generated based on 3 distinct energy mix scenarios, scenario 1 and 2 deal with current and thermal-based energy mixes while scenario 3 considers only renewables to power the electric fleet. The results of scenario 1 (BAU), where all energy generation would come in a similar proportion, from each energy source, as the proportion of that source in Pakistan's 2018 energy mix. Fig 4.1 shows the distribution of annual energy required and its associated fuel costs from each source of generation and fig 4.2 and 4.3 show the split between electric cars and bikes specifically. As indicated, the majority of energy is contributed by hydel, gas, RFO, and RLNG power plants. The share of energy sources in this mix considers business as usual so the contribution of hydel is 23% but other renewable resources (wind and solar) just have a small share in the energy mix of 1.77% and 0.58% respectively.

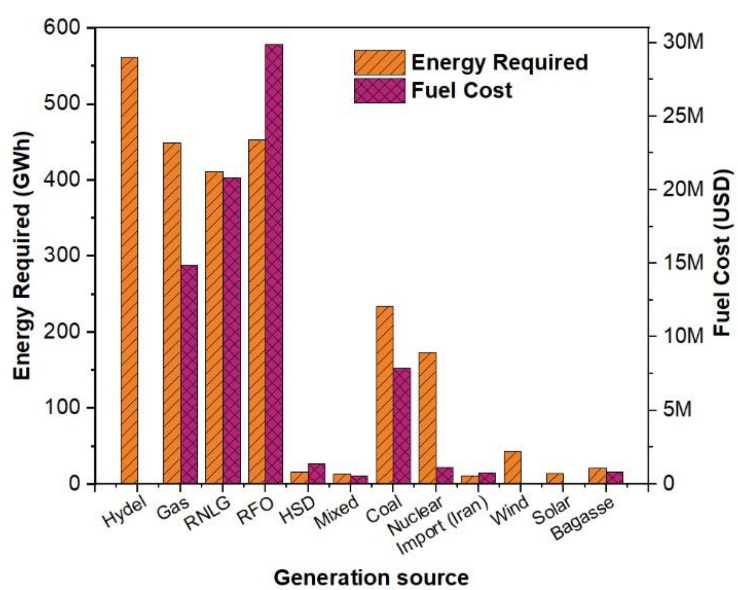

Fig. 4.1 Required energy split and fuel costs in scenario 1 (Total)

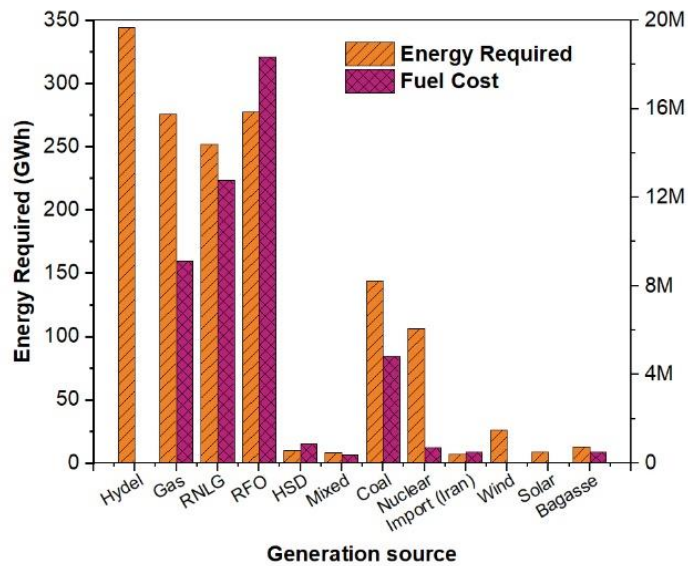

Fig. 4.2 Required energy split and fuel costs in scenario 1 (Cars)

In Fig 4.1 the cost of fuel from hydel, wind, and solar is zero. This is because these renewables are the fuel that's abundant in the environment and do not cost the government. While most of the thermal generation as shown in the fig is costly and requires large investments in the import of fossil fuel every year.

Results of Scenario 1 show that a fuel cost of US$75.4 million will be incurred per year. The breakdown of this cost indicates that the majority of the cost comes from fossil fuel sources. RNLG, RFO, HSD, mixed generation, and coal in scenario 1 would make up 96% of the overall generation costs. RFO costs US$0.066 per KWh as per the energy mix, this means RFO alone would cost US$29.9 million per year.

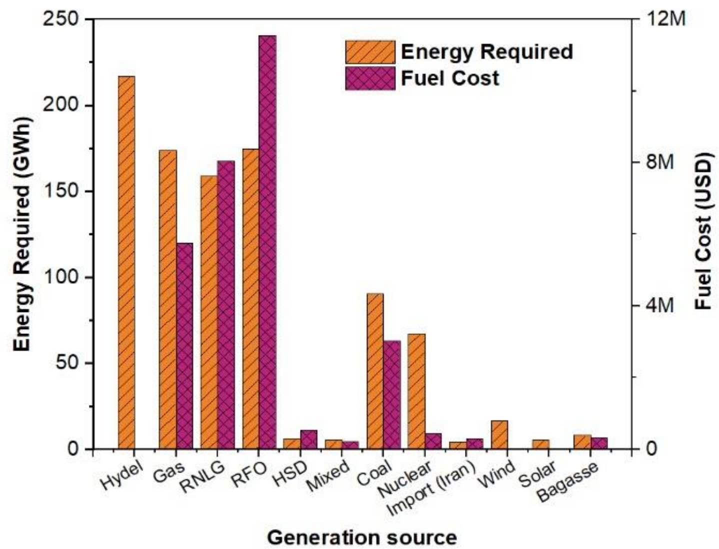

Fig. 4.3 Required energy split and fuel costs in scenario 1 (Bikes)

As stated previously, US$693 million per year will be saved as the base price of fossil fuel by 30% BEV fleet and as per scenario 1, and an additional energy generation cost of US$78 million per year will be incurred. Hence, a US$615 million net fuel saving per year can be achieved by the incorporated electric fleet in scenario 1.

Fig 4.4 showcases scenario 2, the energy required for BEVs would come in relative proportions of thermal generation as per Pakistan's 2017-18 energy mix. RFO, Gas, and RLNG contribute 28.7%, 28.52, and 26.1% respectively. The total thermal generation will add up to a total fuel cost of $114 million per year in scenario 2. In this scenario, the cost of HSD is US$0.089 per KWh even more expensive than RFO, but because HSD constitutes just 1% of the energy mix in this scenario the overall cost does not amount to a very significant value. The lowest costs per KWh is of generation from coal and gas. Coal and gas cost 3.34 cents and 3.31 cents per KWh respectively.

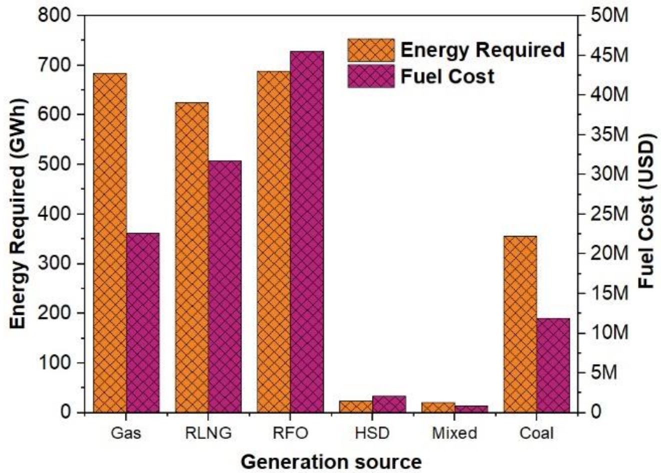

Fig. 4.4 Required energy split and fuel costs in scenario 2 (Total)

Hence, in scenario 2, US$693 million per year of base fuel offset by BEVs would be saved, however, an additional energy generation cost of US$114 million per year would be incurred. This amounts to a total of US$579 million net fuel saving per year. These saving were achieved by the incorporated electric fleet even when the additional energy generation was generated by just thermal-based generation sources.

Scenario 3 takes the case of solar generation to power the electric vehicle fleet. This case unlike the previous cases considers levelized costs of tariffs for solar-powered PV plants. In scenario 3, the cost of energy generation would amount to US$90 million per year. Using the same calculation in previous scenarios the US$693 million cost-saving resulting from fossil fuel consumption will lead to a net savings of US$603 million a year. This covers the installation and maintenance cost of the solar PV power plant. Powering the electric fleet by Renewable ensures that emissions from generation as well as utilization are saved as compared to using expensive and environmentally damaging sources of energy.

4.4 Energy mix scenarios comparisons

All 3 scenarios showcase potential savings by the incorporation of electric vehicles. This is a pleasing result as it suggests that even using the current energy mix setup in the county benefits can be extracted from electric vehicles. Scenarios 1 and 2 can be compared to give us an idea of how the thermal-based generation compares to business as usual. Even though positive economic results have been achieved in the thermal-based scenario it is still a cause of emissions. Even in terms of cost comparisons between scenario 1 and scenario 2, a resultant saving of US$36 million per year is achieved.

The contribution of renewable energy in Pakistan's energy generation mix is 23.39% by hydel and just 3.23% from all other renewable sources combined, but still was able to reduce the overall cost of energy generation by a significant margin [16,47]. Scenario 3 highlights that solar IPP contracts worth US$90 million per year alone would be able to generate enough energy to power the Pakistan electric fleets as per 2030 targets. In conclusion, the generation of electricity for BEVs in all 3 scenarios would result in significant net fuel cost savings.

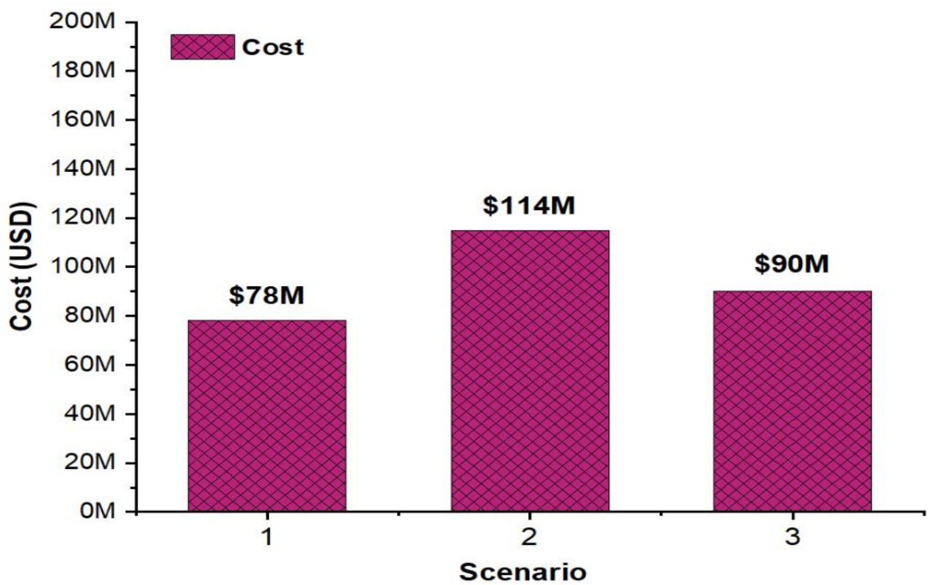

Fig. 4.5 Annual energy required cost comparisons.

In the previous 3 scenarios, we used the energy mix of 2017-18 as the base for calculations but it is interesting to also note the variation in results that will result from using a different base of the energy mix to conduct calculations. For the sake of realizing how crucial is the role of an evolving energy mix in net savings, let's take the energy mix of 2013-14 instead of 2017-18 (BAU) for our calculations in scenario 1 [47].

Simulation-based on the same energy transport model for the year 2013-14 show that the cost of generation by fuel would be US$183 million as compared to the US$788 million in the 2017-2018 energy mix. This difference in the cost between years indicates that Pakistan’s energy mix is getting cheaper over the years with the inclusion of renewables. Another factor that is also a contribution to the reduction of costs is that there is a notable shift in producing power from cheaper sources of energy. Over the years Pakistan has shifted most of its generation from expensive sources like RFO and HSD power plants to cheaper sources like gas and coal [16,47]. Even though these sources produce emissions, but they are significantly cheaper than the previously relied on sources of energy employed by the IPP model. the increase in renewable is most significant for wind followed by solar and bagasse.

4.5 Impact of varying variable

VKT is a key variable of the study based on the kaya identify framework. The results establish a directly proportional relationship between VKT and fuel consumption. As VKT increases we see a significant linear increase in the fossil fuel offset for ICV as well as the energy required for BEVs. This means a higher VKT would mean higher savings and vice versa.

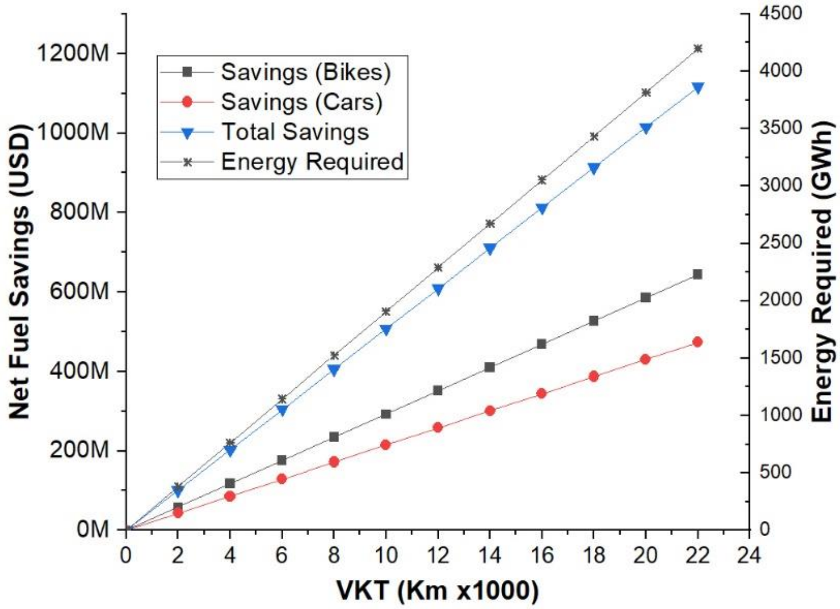

Fig 4.6 Impact of VKT (on net fuel savings and additional annual energy required for BEVs)

Fig 4.6 shows how a sweeping VKT can vary the results of the national model. In all cases, the base price of petrol used by the electric fleet is subtracted from the cost of energy required by the BEVs. As an example, if we take a VKT of 10,000 km for all types of vehicle segments the cumulative cost of energy generation would amount to US$ 62 million. In comparison, the ICV's, in this case, would have consumed a base fuel cost of US&570 million. The net resulting saving for this would be US$ 570 million as shown in figure 4.6. Similarly, the graph also shows that VKT and electricity generation required are directly proportional, i.e. as VKT increases more GWh of energy is required to charge the electric fleet, this is both true for motorbike and car segments independently.

4.6 Import case for BEVs

Now for the case considering the government imports, BEVs to incorporate a 30% electric fleet, the purchase of BEVs and additional fuel for energy generation would result in the flight of foreign exchange reserve, but the government will save on imports of fossil fuels used for ICVs and also on the imported cost portion of the replaced ICVs.

Fig 4.7 and Fig 4.8 shows the net flow of money and the years it will take for the investment to return for an annual VKT value of 15,000 km for both electric cars and electric bikes using the data from scenario 1 (BAU). The incorporation of BEVs is only sustainable if the payback period of the imported vehicles is less than the vehicle's life. Results show that electric cars would not be feasible because the balance of payment is not achieved on the investment in the vehicle's lifetime, but for a VKT of 15,000 km import of bikes would be economically feasible as shown in fig 4.7.

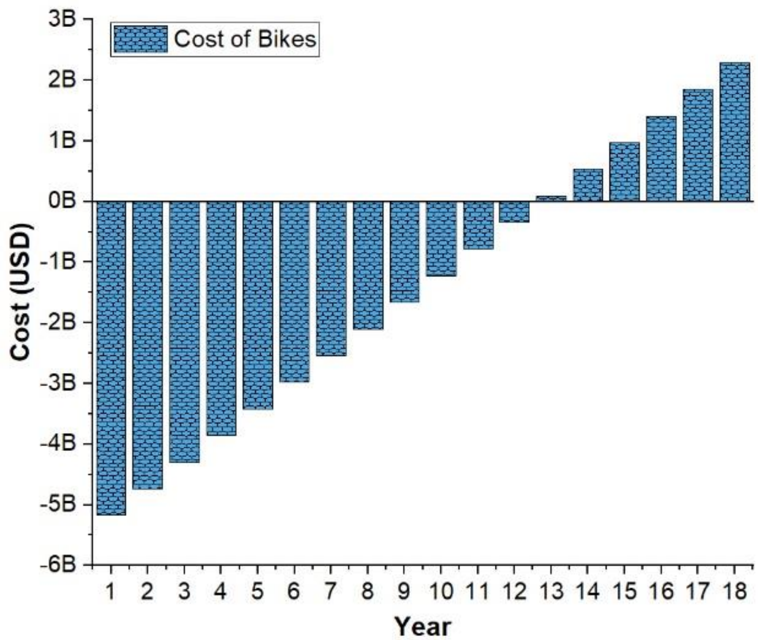

Fig 4.7 Balance of payments for electric bikes

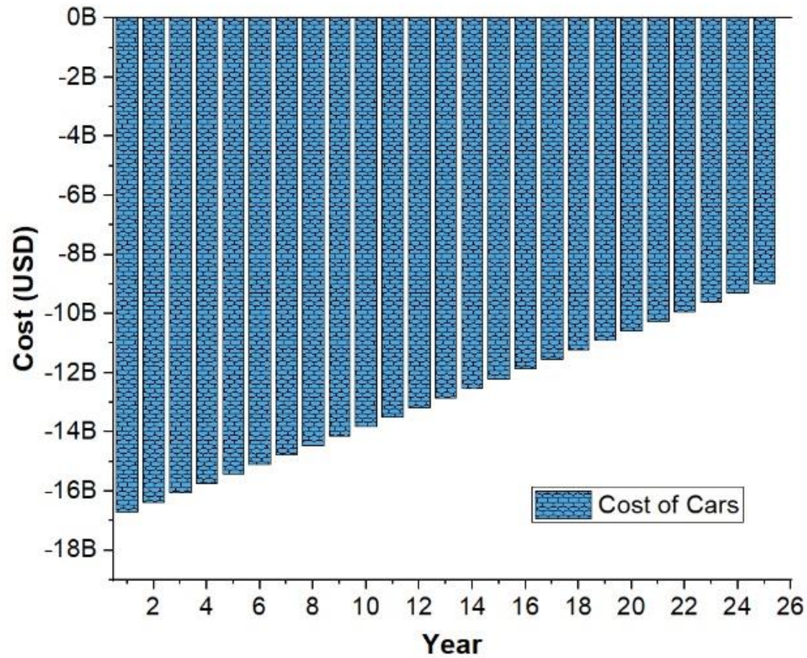

Fig 4.8 Balance of payments for electric cars

4.7 Economic feasibility analysis

Varying VKT can impact feasibility. As VKT increases, the number of years required for the return on investment decreases. Taking 15 years of life, the cut-off value of VKT that makes the investment sustainable should be greater than 13 thousand km for motorbikes as shown in Fig 4.9. According to the model results, any value of VKT within the selected range would not be able to generate a positive balance of payment to make electric cars a sustainable investment, hence the balance of payments can only be positive if electric cars are manufactured and sold locally rather than being imported. This demonstrates that in case Pakistan decides to import electric cars to achieve its targets instead of local manufacturing, the economic impact will be detrimental and will give rise to a negative balance of payments.

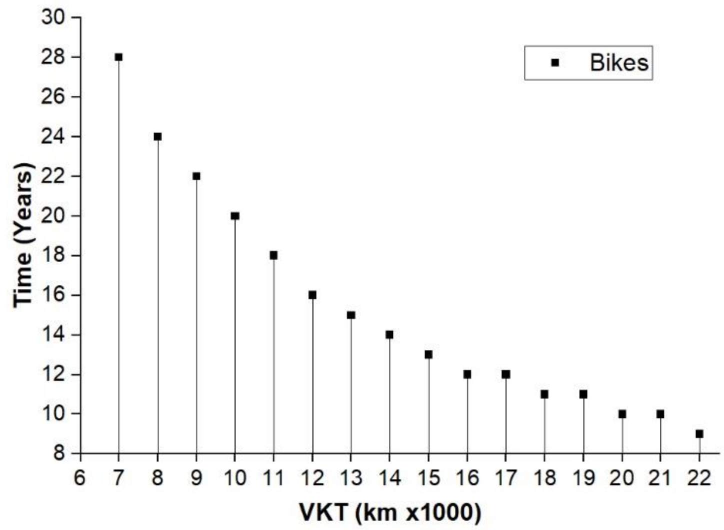

Fig 4.9 Change in time of balance of payments by varying VKT for electric bikes

Given the higher capital costs of importing electric cars balance of payments through the import of electric cars can never be achieved within its lifetime while high values of VKT are needed to achieve the balance of payments for electric bikes as well. Developing countries like India and Indonesia have used domestic markets to attract investment and providing incentives to purchase EVs produced locally [7]. Even for the case of Norway achieving an unprecedented BEV market share of 18% was a result of traditional vehicle manufacturers entering the EV market [93].

Summary

A 30% electric vehicle fleet will require just 2% of Pakistan's current generation capacity. Results show that for all three scenarios of energy generation the fossil fuel saving resulting from the induction of BEVs will be enough to offset the cost required for additional energy generation. Electric bikes would enable a larger chunk of the transport sector to be electrified while using the same amount of energy required by electric cars. In the case of Pakistan importing BEV's, bikes will achieve a balance of payments within their lifetimes in contrast to electric cars. The inclusion of electric vehicles will impact indirect tax revenue generated from gasoline. The study finally highlights that only through indigenous domestic manufacturing would Pakistan be able to achieve positive economic feasibility and maximum benefits for the goals envisioned in its NEVP.

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Chapter 5

Conclusion and Recommendations

5.1 Conclusion

The national model shows that for the government of Pakistan to achieve its goal of incorporating 30% EVs in the country's current fleet of bikes and cars, an additional 2398 GWh per year of energy would be required. The additional energy required for the electric fleet just amounts to a 2% increase in the current generation capacity of the country. Pakistan has previously suffered and struggled to achieve energy demand-supply parity hence any notion of BEVs adversely impacting that demand-supply balance should not hinder governmental pace in adaptation of NEVP.

The study shows that fossil fuel savings resulting from the inclusion of BEVs are significant enough to offset the fuel cost required for additional energy generation. For similar values of VKT, this result stands true for all 3 energy mix scenarios evaluated in the study. It is also evident that an overall cheaper energy mix having more renewable inclusion further increases the net fuel savings, hence the government needs to diversify its energy mix by plugging in more renewable generation sources. Renewable generation in-turn will also lower GHG emissions further strengthening the benefits of BEV adaptation.

The study shows that the Pakistani automobile is heavily dominated by two-wheelers in contrast to cars but in a 30% BEV fleet, electric bikes would constitute 38% of the total BEV energy requirements. The inclusion of a 30% electric bike fleet would enable a greater segment of the population to be electrified whilst utilizing the same amount and cost of energy used by a 30% electric car fleet. In the case of Pakistan importing BEV's to achieve its targets, bikes would be able to achieve the balance of payments within the lifetime of the vehicle for values of VKT higher than 13 thousand km in contrast to electric cars that we're unable to produce a positive balance of payments in any segment.

Given the lower upfront purchase cost of electric bikes compared to electric cars they might be better contenders for enabling electric adaptation for other developing countries like Pakistan. The study also shows that the automobile sector accounts for a significant amount of tax collection from fuel consumed by ICV's. To compensate for the revenue lost governments need to formulate alternative taxation strategies being mindful that they don't impede consumer decision to opt for BEVs.

Extrapolating the results of the study indicates that only through indigenous domestic manufacturing would Pakistan be able to achieve positive economic feasibility and maximum benefits for the goals envisioned in its NEVP. BEVs, especially electric bikes, requires fewer components than the more complex ICVs so the domestic industry should be incentivized and promoted to establish production setups. The focus should be on setting up the industry that manufactures BEV parts such as batteries and motors so that local assembly of cars can be achieved.

The study highlighted Pakistan still unable to achieve 100% localization levels with conventional vehicles, and if Pakistan fails to identify the potential of indigenous production of BEVs now, it would miss out on the global revolution of electrical transformation in transport. The study findings can also be beneficial for other countries.

5.2 Limitations and future work

VKT is vital for drawing out accurate evaluations, the study used a varying VKT value because of the unavailability of data for Pakistan. Research should be focused on data collection by reliable techniques to determine VKT for developing countries in each vehicle segment for enhanced data resolution. Another important parameter to focus on is the service life of cars, research gaps exist on determining accurate lifespans not only for ICVs in Pakistan but also for relatively new BEVs globally, this will help in a variety of comparisons among these vehicles.

Auto manufacturers in Pakistan should be compelled to release official data on vehicle fuel consumption or the government should set up testing facilities in which fuel consumption patterns of vehicles should be monitored before allowing it to be available in the market.

The benefit of segmentation of the vehicle fleet is particularly beneficial to identify and compare parts of the transport sector and link them with studies regarding vehicle penetration and adaptation. A significant volume of ICVs belongs to the cheaper, lower cc segments, as BEVs get cheaper and low-cost variants are designed, the gap of upfront cost in the purchase price for vehicles in cheaper ICV segments will reduce and can lead to higher BEV penetration. This link can be established and further investigated in future studies to identify and specifically design strategies targeting vehicle segments showcasing higher EV adaptation potential in developing countries.

Apart from fuel tax another source of indirect taxation from ICVs also comes through vehicle registration fees and different taxes deducted during a vehicle purchase. With the NEVP now offering a reduction in the goods and services tax for EVs, the added effect of this reduction should be further investigated for future policies. A good charging infrastructure would have to be provided for the BEVs considering the growing but still a relatively small range of these vehicles. The study shows a substantial amount of net fuel saving resulting from the BEV fleet, further research can be carried out to see if this saving can by itself aid in enabling the development of the required EV charging infrastructure in the country. Future research is still needed to study the type, spatial density, cost, and feasibility of the infrastructure required that will enable an EV revolution in developing countries like Pakistan.

Summary

The study highlights data gaps and suggests future research potential. Research should be conducted to collect reliable data on VKT values not only for the general population but also concerning car segments to offer better data resolution that will aid in decision making. Automakers have a responsibility to ensure transparency in releasing tested data and accurate specifications on vehicles being sold in the market or a regulatory agency should oversee these matters. The study lays the foundation for studies on vehicle penetration and adaptation by highlighting and establishing links to design strategies regarding certain vehicle segments. Finally, the study prompts research on electrical vehicle infrastructure in the country to ease the electric transport revolution under NVEP.