Electrification of Pakistan's Transport System

MODELING ELECTRIC VEHICLE PENETRATION AND ENERGY SUPPLY CHAIN IMPACTS

Version 1.0

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ABBREVIATIONS AND ACRONYMS

2W, 3W, 4W	Two-, three-, four-wheeler
A	Ampere
ADP	Automotive Development Policy
ARL	Argonne National Laboratory
BBL	Barrel
BC	Black carbon
BEV	Battery electric vehicle
BTU	British thermal unit
CAPEX	Capital expenditure
CBU	Completely built up
CD	Customs duty
CKD	Completely knocked down
CNG	Compressed natural gas
CO	Carbon monoxide
CO_2	Carbon dioxide
CPI	Consumer price index
CPPA-G	Central Power Purchasing Agency Guarantee
DES	Delivered ex-ship
DISCO	Distribution company
DOE	U.S. Department of Energy
EDB	Engineering Development Board
EFS	NREL Electrification Futures Study
EV	Electric vehicle
FBR	Federal Bureau of Revenue
FCEV	Fuel cell electric vehicle
FOB	Free on board
FY	Financial year
GCAM	Global Change Analysis Model
GDP	Gross domestic product
GHG	Greenhouse gas
GST	General sales tax
GWh	Gigawatt-hour
HDIP	Hydrocarbon Development Institute of Pakistan
HEV	Hybrid electric vehicle
HHV	Higher heating value
ICE	Internal combustion engine
ICEV	Internal combustion vehicle
IEA	International Energy Agency
IEP	Integrated energy planning

IFEM	Inland freight equalization margin
IGCEP	Indicative Generation Capacity Expansion Plan
IMF	International Monetary Fund
IRR	Internal rate of return
km	Kilometer
kW	Kilowatt
kWh	Kilowatt-hour
LDV	Light duty vehicle
LHV	Lower heating value
LNG	Liquefied natural gas
LSA	LNG Supply Agreement
LUMS	Lahore University of Management Sciences
MMCFD	Million cubic feet per day
MW	Megawatt
NEPRA	National Electric Power Regulatory Authority
NEVP	National Electric Vehicle Policy
NMVOC	Non-methane volatile organic compounds
NO_x	Oxides of nitrogen
NREL	National Renewable Energy Laboratory
NTDC	National Transmission and Despatch Company
O&M	Operations and maintenance
OC	Organic carbon
OGRA	Oil and Gas Regulatory Authority
OMC	Oil marketing company
OPEX	Operational expenditure
p.a.	Per annum
PAMA	Pakistan Automobile Manufacturers Association
PHEV	Plug-in hybrid electric vehicle
PKR	Pakistan rupee
PLL	Pakistan LNG Limited
PLTL	Pakistan LNG Terminals Limited
PM	Particulate matter
PNNL	Pacific Northwest National Laboratory
PSO	Pakistan State Oil
PV	Photovoltaic
RLNG	Regasified liquefied natural gas
ROE	Return on equity
RON	Research octane number
scf	Standard cubic feet
SEP	Sustainable Energy for Pakistan
SNGPL	Sui Northern Gas Pipelines Limited

SRO	Statutory Regulatory Order
SSGC	Sui Southern Gas Company Limited
SSP	Shared socioeconomic pathway
SUV	Sport utility vehicle
t	Tonne
T&D	Transmission and distribution
TCEB	Thar Coal Energy Board
TFER	Prime Minister's Task Force on Energy Reforms
TOE	Tonnes of oil equivalent
TOU	Time-of-use
UCD	University of California, Davis
UNECE	United Nations Commission for Europe
UOSC	Use of system charge
USAID	United States Agency for International Development
USD	U.S. dollar
WC	Working capital

1. INTRODUCTION

1.1 PURPOSE AND SCOPE

Initial analysis of the National Electric Vehicle Policy (NEVP) of Pakistan was undertaken by an integrated energy planning[2] team from November 2019 through August 2020. This technical reference document seeks to present the background, inputs and assumptions, methodology, and results of the policy analysis in detail. The intended audience is the technical modeler, analyst, or reviewer who seeks to understand specifically the modeling effort within this initial analytical phase, with the end-goal of interpreting, re-producing, or modifying the simulations or extending the models to conduct follow-on studies subsequently. These studies may examine in greater detail the energy sector, impacts to emissions, charging station infrastructure needs, and overall benefits-cost trade of the policy, among other areas of interest.

1.2 BACKGROUND

The National Electric Vehicle Policy (NEVP) was approved by Pakistan's National Assembly as part of the Finance Bill 2020 in June 2020 with various procedural and fiscal incentives for imports, local production, and charging infrastructure related to electric vehicles (EVs). The NEVP covered two- and three-wheelers, buses, and trucks, but deferred formal approval of policy provisions for cars and light duty vehicles (LDVs). The incentives would be available for five years, starting July 1, 2020. Implementation would be overseen by the Engineering Development Board (EDB) under the Ministry of Industries and Production. Meanwhile, the Automotive Development Policy (ADP) 2016-2021 and its subsequent amendment notification (May 2018) allows imports of completely built-up plug-in hybrid electric cars, SUVs and light vehicles (PHEVs) at a reduced customs duty of 25%. Detailed NEVP provisions are to be announced (except for cars and LDVs) and for the purpose of this study, it is assumed that they will as per the draft NEVP 2019.

Introduction and penetration of EVs will have a significant impact on Pakistan's energy supply chain due to additional electricity consumption for charging electric vehicles (EVs) and the corresponding fuel savings due to displacement of internal combustion engine vehicles (ICEVs) by EVs.

This study provides an indicative assessment of the volumetric and economic impact of policy measures and EV penetration goals on the national energy supply (production, imports and consumption) over the following ten years (2021-2030) and the corresponding costs or savings due to EV penetrations. The study also presents an initial high-level assessment of the impact on environmental emissions resulting from EV penetrations. A more detailed, future assessment will take into consideration changes in the marginal thermal power generation mix (to meet EV charging loads), lower fuel consumption by ICEVs, current Pakistan-specific emission controls and fuel quality standards.

The results presented here are based on EV modeling and analysis conducted specifically for Pakistan during November 2019 to July 2020 by an inter-organizational team[1] at the direction of the Prime Minister's Task Force on Energy Reforms (TFER) under multiyear technical

[1] The study was conducted jointly by staff from USAID office of Energy, USAID's Sustainable Energy for Pakistan (SEP) project and the U.S. DOE's Pacific Northwest National Laboratory (PNNL), National Renewable Energy Laboratory (NREL) and Argonne National Laboratory (ARL), in collaboration with the Planning Commission of Pakistan and several government stakeholders and academic institutions.

assistance on integrated energy planning (IEP)[2] provided by the United States Agency for International Development (USAID) and U.S. Department of Energy (DOE) to the Energy Wing of the Planning Commission, Ministry of Planning, Development and Special Initiatives, Government of Pakistan.

This EV study is part of the initial phase of USAID support under IEP ('Track I'), while follow-on work and further support on EVs will be provided as part of 'Track II' technical assistance, subject to agreement between the Government of Pakistan and USAID.

1.3 INDUSTRY TRENDS

The transport sector accounts for a fourth of global greenhouse gas (GHG) emissions, with road transport accounting for more than half of all transport-related emissions (Clarke, et al. 2015; Edelenbosch, et al. 2017). Road transport is also a major cause of air pollution, contributing about 10% of global black carbon (BC) emissions and 27% of nitrous oxides (NO_x) emission in 2015 (Crippa, et al. 2018). Private ownership of road vehicles is projected to increase with increases in both population and income (McCollum, et al. 2013; "Transport — IPCC" 2014). Switching to EVs, when coupled with power sector decarbonization efforts, is an effective strategy to lower GHG and air pollutant emissions and improve health (Zhang and Fujimori 2020a; McCollum, et al. 2013; Kyle and Kim 2011). Increasing EVs also reduces overall energy consumption as a result of improved efficiencies and can help increase energy security by reducing dependence on oil imports.

Costs of EVs are rapidly falling and several projections show cost parity with traditional internal combustion engine vehicles (ICEVs) between 2025-2030 (Schmidt, et al. 2017; Jadun, et al. 2017; Richardson 2013). In the meantime, various governments are adopting a range of incentives to encourage faster adoption of EVs in their transport fleets along with support for required infrastructure and shifts in electricity demand profiles. These include measures such as subsidies for EV consumers, taxes on ICEVs, government procurement of electric vehicle fleets, building networks of charging stations, and reinforcing the electricity grid (Wappelhorst 2018; Yang 2016; Hao, Wang, and Ouyang 2011). Several cities, including Paris, London, Los Angeles and Bangalore, have signed pledges with the intent to completely electrify their public bus fleets (Parik 2016).

With the large uncertainty in cost projections and the range of policy measures to incentivize EV adoption, several studies have explored different transport system transformation pathways. McCollum, et al. (2013) analyze several combinations of global technological advancements, availability of different fuels, and emissions targets and find that transport electrification frees up valuable resources, such as biomass, diversifies the primary energy mix in transport and increases energy security. Other studies investigate EV pathways in a range of countries including Colombia (González Palencia, Furubayashi, and Nakata 2014), China (Hao, Wang, and Ouyang 2011), India (Mittal, et al. 2017), and across Europe (Mersky, et al. 2016; Egnér and Trosvik 2018; Seixas, et al. 2015; Hawkins, et al. 2013), while others compare the impact of policies across different nations (Wu and Zhang 2017; Sierzchula, et al. 2014). These studies in general find that EV costs are dropping and widespread adoption can have numerous benefits, such as reducing direct transport emissions, conserving fuel, and lowering the cost of achieving climate stabilization targets (Zhang and Fujimori 2020b; McCollum, et al. 2013; Kyle and Kim 2011; Hao, Wang, and Ouyang 2011). However, large-scale transport electrification still requires significant policy support and investment in technological

[2] IEP consists of an organizational process to facilitate energy planning and decision-making. Its implementation is being supported by a joint effort of the Planning Commission, USAID, SEP, and U.S. DOE laboratories.

advancement to make EVs a cost-effective mobility option for consumers (Seixas, et al. 2015). While the high capital cost of EVs is a barrier to widespread adoption, measures such as fiscal incentives, public charging infrastructure, road priority, and public vehicle procurement can be effective policy levers to increase EV penetration (Wang, Tang, and Pan 2019; Egnér and Trosvik 2018; Mersky, et al. 2016; Lévay, Drossinos, and Thiel 2017). Nonetheless, a range of additional measures, including low carbon fuel mix, fuel economy improvements, and increased mass transit will be needed for effective decarbonization of the transport sector (Mittal, et al. 2017; Hao, Wang, and Ouyang 2011).

Lifecycle analysis indicates that EVs have lower impacts on global warming, increase in cumulative energy demand, particulate matter formation and fossil resource depletion compared to conventional ICEVs (Lombardi, et al. 2017). EVs have zero tailpipe emissions, which reduces localized air pollution in urban areas. Emissions associated with EV use shift to the electricity sector; the net impact of EVs on GHG emissions is sensitive to the fuel mix in power generation, while emissions of air pollutants are also sensitive to electric sector air pollution control policies. Ellingsen, Singh, and Strømman (2016) found that compared to ICEVs, lifecycle emissions for EVs powered by electricity from natural gas are 12-21% lower, while lifecycle emissions for EVs powered by wind generation are reduced by 66-70%. In contrast, EVs powered by coal-fired power plants have higher emissions than ICEVs powered by gasoline or diesel (Ellingsen, Singh, and Strømman 2016; Hawkins, et al. 2013; Wolfram and Lutsey 2016). This sensitivity underscores the importance of pairing EV incentives with efforts to decarbonize the electric grid if GHG reductions are a policy goal. While emission from the use of EVs can be much lower than that of ICEVs, they are higher for the production phase, with GHG emissions due to EV manufacturing roughly twice that of a comparable ICEV (Hawkins, et al. 2013). EV production is currently also more environmentally intensive in terms of mineral resource depletion and human, freshwater, and terrestrial toxicity potential (Hawkins, et al. 2013).

While EVs increase demand for electricity, they also provide an opportunity to balance the load curve, which is particularly valuable for integrating use of intermittent renewable sources, such as wind and solar, into the grid (Hu, et al. 2016; Richardson 2013). EVs can charge when excess electricity is available and potentially also provide electricity back to the grid when generation is insufficient to meet demand. Off-peak charging can also reduce the lifecycle emission of EVs compared to on-peak charging (Rangaraju, et al. 2015). However, this requires smart charging systems so that EVs can be utilized as a stabilizing force rather than additional load on the electric grid (Hu, et al. 2016; Tan, Ramachandaramurthy, and Yong 2016).

Developing countries are expected to see the largest growth in both population and incomes and a corresponding increase in transport service demand (Sims, et al. 2014; Dargay, Gately, and Sommer 2007). Pakistan's population is expected increase from 207.7 million in 2017 (Pakistan Bureau of Statistics, 2017 Census) to 279 million in 2050 (Planning Commission of Pakistan), while per capita income is expected to grow from about $1,300 in 2020 to $6,500 in 2050 (Planning Commission of Pakistan). Corresponding vehicle ownership is projected to increase by 18.3 million vehicles between 2021 and 2030 (SEP 2020). Although Pakistan has developed significant local manufacturing capability of conventional ICE vehicles, there is currently no local production of electric vehicles (Pakistan Business Council 2018). Thus, in contrast to countries like China which have domestic EV production (Ou, et al. 2017), Pakistan is much more susceptible to EV technology costs and advancement pathways as these will be largely determined by global trends. This would require the government to take a flexible approach when responding to the uncertainties in technology growth trajectories in order to achieve its EV penetration targets. However, Pakistan's electricity generation mix is projected to expand with commissioning of new gas and coal generation plants which could counteract desired decarbonization efforts due to transport sector electrification and cause adverse air quality and health impacts (Zhang & Fujimori, et al. 2020). This current work expands on existing efforts and supports exploration of the effectiveness of a suite of policy measures to meet EV penetration goals and the corresponding emission improvements within the context of electricity sector transformation in Pakistan, which faces large uncertainties in projections of its future growth and energy mix.

1.4 TRANSPORTATION POLICIES IN PAKISTAN

Pakistan has been facing severe energy shortages, with energy demand increasing faster than supply. Reasons for this include high population growth, technological and industrial development, inadequate infrastructure, lack of financial resources and delayed policy implementation (Aized, et al. 2018; Anwar 2016). Although Pakistan has large renewable resource potential, the country remains largely dependent on fossil fuels, which supply nearly 80% of primary energy (Rehman and Deyuan 2018; Anwar 2016). One third of the oil supply is imported, resulting in high expenditures and vulnerability to shocks in the global oil market (Anwar 2016; Malik, Ajmal and Zahid 2017). The transport sector is the largest consumer of petroleum products (Aized, et al. 2018; Memon 2011). The Government of Pakistan has made efforts to reduce oil use in the transport sector by promoting alternative fuels. Beginning in the 1990s, government incentives and regulations achieved widespread conversion of vehicles to run on compressed natural gas (CNG), as this fuel was cheaper and had transmission and distribution infrastructure in place. The number of CNG vehicles increased from 50,000 in 1999 to over 3 million in 2012, the second highest number in the world (Khan and Yasmin 2014). However, demand for natural gas from the power and industrial sectors has increased, and indigenous gas production has declined since 2012; this has resulted in natural gas shortages and increasing gas imports (EIA 2016). The government has since taken measures to limit additional adoption of CNG vehicles (Khan and Yasmin 2014). More recently, the focus has turned to EVs as a way to reduce fossil fuel use in transport, dependence on fuel imports and GHG and air pollutant emissions. The Automotive Development Policy (ADP) 2016-2021 primarily covers ICEVs and also specifies lower customs duties for import of hybrid and plug-in electric vehicles. The policy aims to provide policy consistency and predictability for investors (with a mid-term review) to cater for emerging developments, lower the threshold for new investments for assembly and manufacturing facilities of a make not already being assembled/manufactured in Pakistan and for revival of existing assembly/manufacturing facilities; provide an enforcement mechanism for quality, safety and environmental standards; ensure consumer welfare through provision of quality, safety, choice and value for money; promote enhanced competition and better quality with latest technology; and improve financing options by commercial banks.

The NEVP sets targets for EV penetration by vehicle type and defines incentives to lower barriers to EV adoption. Policy objectives, as stated in the NEVP, are as follows:

- Mitigate climate change through a reduction in emissions from transport sector
- Create a pivot to industrial growth in Pakistan and encourage auto and related industry to move towards local EV manufacturing
- Forge links with the global EV value chain for export potential of EVs and their parts
- Meet the objective of generating employment through ‘green economy’ initiatives
- Reduce oil import bill

- Use electricity in off-peak times for useful purposes
- Develop affiliated industry, such as battery manufacturing, charging infrastructure, etc.

In May 2019, the Prime Minister's Committee on Climate Change approved minimum mandated targets for guiding EV penetration in the country as per **Table 1**, along with expected penetration timeframes. These targets are mentioned in the draft NEVP 2019 and have been modeled under this study to assess the impact on Pakistan's energy supply chain.

The carbon intensity and reliability of Pakistan's electric grid will be an important factor in evaluating the impact of EV policies. Pakistan faces challenges in meeting electricity demand, with rolling blackouts common throughout the country (Aized, et al. 2018; Rehman and Deyuan 2018). Total power system capacity increased by 37% between 2012 and 2018 (draft IGCEP 2019-2047) and large capacity additions are planned in the future as the government aims to increase supply, diversify the fuel mix and reduce reliance on fuel imports. As of 2018, Pakistan's electricity generation was 74% thermal (mainly natural gas and oil), 24% hydropower, and 2% renewables (draft IGCEP 2019-2047). Pakistan has significant indigenous coal resources (Aized, et al. 2018). Until recently, these have not been exploited, but the draft IGCEP 2019-2047 includes plans for new coal-fired power plants that will increase coal capacity from 2,790 MW in 2018 (mainly imported coal) to about 30,000 MW in 2040 (mainly local coal) and generate 45% of electricity. This will largely replace electricity generated from oil and natural gas. Oil-fired power plants are planned to be phased out over the next few years, decreasing from 30% of generation in 2018 to nearly zero by 2025 (draft IGCEP 2019-2047; NEPRA 2017). There are large hydropower projects planned over the next 20 years with combined capacity of about 29,000 MW. Renewables are a small but growing share; solar and wind generated 2% of electricity in 2017-2018, projected to grow to 9% by 2040 (draft IGCEP 2019-2047).

Table 1: Electric vehicle penetration targets under NEVP

EV Penetration Targets	Medium-term Targets Five Years' Cumulative	Long-term Targets 2030	Ultimate Targets 2040
Cars (including vans, jeeps and small pickups)	100,000	30% of new sales (approx. 60,000/yr)	90% of new sales
Two-, three-wheelers & four-wheelers of UNECE 'L' category	500,000	50% of new sales (approx. 900,000/yr)	90% of new sales
Buses	1,000	50% of new sales	90% of new sales
Trucks	1,000	30% of new sales	90% of new sales

The cost of providing financial incentives for EV adoption is an area of significant concern for the government of Pakistan (GoP). The proposed tax, duty, and fee reductions for EVs will reduce government revenues from fuel and vehicle taxes. It should be noted that with the introduction of EVs, savings on fuel imports, use of off-peak electricity and associated reduction in idle capacity payments, charging revenues, and reductions in socioeconomic costs related to GHG and air pollutant emissions (for example, through improvements in health) will contribute to offsetting these expenses.

2. RESEARCH QUESTIONS

As discussed above, transport electrification in Pakistan will have implications for other sectors. We employ several models to represent potential transport development pathways and explore the interactions between transport, fuel use, electricity generation, emissions, and costs. In this analysis, we aim to address the following questions:

- How effective are various policy instruments in incentivizing EV adoption compared to a 'no-policy' base case?
- What are the penetration, economic and energy impacts of policy incentives for EV adoption?
- What is the sensitivity of EV adoption to technological and cost development?
- What are the impacts on power supply requirements and fuel consumption (for both ICEVs as well as electricity generation for EVs)?
- What are the impacts on vehicular and power sector emissions?
- What is the overall cost to the Government of Pakistan? How does foregone revenue to incentivize EV adoption compare to savings on fuel imports and other downstream costs (healthcare, productivity, etc.) due to lower emissions?

All of the above questions, with the exception of the last one, are the focus of the initial Track I phase of EV modeling and analysis conducted by SEP and DOE under USAID assistance on IEP to the Government of Pakistan (the results of which are summarized in a three-part series of policy briefs issued on September 25, 2020 by the Planning Commission). The financial and revenue impact of EV adoption, as well as more detailed assessment of corresponding emissions impacts, will be conducted subsequently by the Energy Planning and Resource Centre (EPRC), with continuing assistance from USAID under Track II IEP support.

3. METHODOLOGY

The detailed assumptions and data sources for the study in the SEP and GCAM models are given in **ANNEXURE A** and **ANNEXURE B**, respectively, while the main points are summarized below.

- All data and projections presented are based on Pakistan's **fiscal year** (July 1 to June 30).
- **Vehicle categories** are defined in **Table 2** below consistent with current on-road vehicle fleet.

Table 2: Vehicle categories

Category	Description
Two-wheelers (2W)	Motorcycles, scooters and mopeds*
Three-wheelers (3W)	Autorickshaws
Cars and light duty vehicles (LDVs)	Passenger cars, 4WDs, taxis, delivery vans, pickups (0-1 tonne cap.) and light utility vehicles (ambulances, etc.)
Buses	Buses and minibuses
Trucks	Freight trucks (>1 tonne cap.), tankers and heavy construction vehicles

*Motorcycles constitute the dominant fuel vehicle in the two-wheeler category in Pakistan. However, potential sales of new fuel motorcycles can be replaced by electric motorcycles, scooters and mopeds.

- **Vehicle growth projections:** Published historical 'registered' and 'on-road' vehicle data (e.g. National Transport Research Centre statistics) was found to be not clearly defined. Projections for incremental category-wise vehicle population growth during 2021-2030 were instead based on growth trends derived from previous five years' information on sales of locally manufactured vehicles [Pakistan Automobile Manufacturers Association (PAMA)] and imports [Federal Bureau of Revenue (FBR)]. Data for FY2019 shows a reduction in vehicles added (compared to FY2018) due to economic slowdown and rupee devaluation, and the slump increased in the second half of FY2020 as a result of the COVID-19 lockdowns. With respect to future vehicle populations, two scenarios were developed:
    - **Standard Scenario:** This assumes that healthy growth trends in vehicle additions (seen during FY2016 to FY2019) will resume from FY 2021 following the COVID-19 induced slump in sales during FY 2020 as the economy recovers. In this scenario, the robust historical growth rates for 2Ws (average of around 10% p.a.) have been halved to reflect eventual market saturation.
    - **Alternative Scenario 'a':** This assumes a continued downturn in the economy due to COVID-19 during FY2021 and a modest recovery from FY 2022 onwards with a further approximately 50% reduction in overall vehicle growth rates compared to the standard scenario.
- **EV adoption rates.** Future market penetration of EVs is estimated as a percentage of new vehicle sales (in five-year time steps, interpolated to an annual basis):
    - **Market cases:** EV/ICEV upfront and discounted lifetime cost comparisons were carried out using Pakistan-specific customization of DOE's Global Change Analysis Model (GCAM). Please see **Section 3.1** on GCAM.

- **Target case:** Linear EV penetration growth is assumed, starting from zero in 2020, to meet stated NEVP category-wise EV targets as percentage of all new vehicles sold by 2030.

- **Vehicle data:** Estimates for average vehicle category characteristics are based on published and web-based sources, academic research, limited local market surveys and comparison with GCAM's default global base assumptions (updated to 2015). Category-wise assumptions include:
  - Average annual distances travelled, validated against annual retail fuel sales data for cars/LDVs.
  - Energy consumption rates, factoring in vehicle conversion efficiencies and calorific content of fuels (gasoline, diesel and CNG) and electricity.
  - Composition of ICEVs by fuel type. The current fuel mix (gasoline, diesel or CNG) for ICEVs is based on high-level estimates, e.g., 2Ws use gasoline only, 3Ws predominantly use gasoline with limited CNG, cars and other LDVs predominantly use gasoline with some using diesel or CNG, buses primarily use diesel with some running on gasoline and CNG, while all medium to large trucks (>1 tonne carrying capacity) use diesel.
- **EV charging loads and fuel savings:** Based on the projection of total new vehicles to be added between FY2021-2030, EV market penetration rates and vehicle assumptions given above, the electricity demand (in GWh/year) for EV charging and the corresponding savings in fuels (in tonnes) due to ICEVs displaced were estimated for various scenarios/cases (defined below).
- **Cost of electricity supply for EVs:** For the additional electricity required to charge EVs, natural gas and local/imported coal based thermal, grid-connected wind and solar plants and residential rooftop solar photovoltaic (PV) generation are assumed to be the marginal generation sources that can be readily added or made available.
  - The costs for additional thermal power generation required to service EV charging loads are based on NEPRA[3] tariff determinations (assumed to reflect full generation costs) and allowable thermal plant heat rates. Fuel cost reflect full supply costs to power stations (not price or tariff, which includes additional taxes). Capacity charges can be applied selectively, depending on whether new or existing surplus power generation capacity is assumed to meet EV loads (in this brief, based on NTDC's IGCEP 2018,[4] no additional EV generation capacity has been assumed).
  - Rooftop solar PV costs are derived from local vendor information for a 5 kW-system consisting of PV panels, inverters, batteries (including one-time replacement), cabling and other equipment over a 25-year life.
  - For grid supplied power, average transmission and distribution (T&D) losses are taken from NTDC,[5] while T&D costs are based on use-of-system charges (UOSC) obtained from the Central Power Purchasing Agency Guarantee (CPPA-G). Auxiliary consumption at plant is assumed as per NEPRA allowance.

[3] National Electric Power Regulatory Authority.

[4] Integrated Generation Capacity Expansion Plan developed by the National Transmission and Despatch Company (NTDC).

[5] Power System Statistics, NTDC.

- Cost of commercial EV charging stations is based on capital cost (at 10% IRR over 15 years) and operating cost of charging stations derived from international web sources. It is assumed that an average of 20% of grid electricity used for EV charging over 2021-2030 will be supplied through commercial charging infrastructure (Levels 2 and 3), while the rest would be based on home charging (Level 1). This cost is added on to commercial electricity supply costs.
- The relative mix of RLNG, coal, wind and solar generation used to supply EV loads is based on plant-wise grid-connected generation projections for the entire country (i.e., the NTDC, K-Electric and Makran regional transmission systems), taking into account current technology-wise average plant capacity factors and plant-wise derating/retirement to 2030.

- **Fuel supply cost to power stations and ICEVs:** Fuel supply costs are based on the medium-term outlook for oil prices (taking into account the recent post COVID-19 volatility), T&D losses, and other supply chain costs and margins. Supply chain cost data are sourced from recent Oil and Gas Regulatory Authority (OGRA) tariff determinations for gas and refined products.
  - Liquefied natural gas (LNG) import is assumed as the marginal source of gas supply, with contract price assumed as percentage of Brent crude oil as per market outlook for long-term contracts.
  - Re-gasified LNG (RLNG) supply cost to gas utilities includes port charges, import terminal charges, retainage, and other fees/margins. RLNG supply cost to power stations adds on T&D cost/loss, while CNG supply cost adds on T&D cost/loss and CNG stations costs/margins.
  - For petroleum product pricing at the filling pump, the following approach has been used:
    - Brent crude oil price (FOB Sullom Voe) is based on the medium-term price outlook, while Dubai crude price (FOB Fateh) is based on assessed market differential with respect to Brent.
    - Arabian Gulf market price assessments for refined products are based on refining economics balanced to Dubai crude.
    - Import prices of refined products at Karachi add on premium/freight and port costs to Arabian Gulf market prices (ex-refinery prices are assumed at parity with import prices). Inland freight and margins of oil marketing companies/dealers for gasoline and diesel are added to obtain fuel supply cost at pumps.
- All costs are converted to U.S. dollars at the time of data compilation. Thereafter, U.S. dollar costs are corrected to 2019 base year using U.S. dollar inflation rate.

3.1 GLOBAL CHANGE ANALYSIS MODEL (GCAM)

Market-based EV penetration assessments were made using DOE's Global Change Analysis Model (GCAM). GCAM is a global, multi-sector, market equilibrium model. It represents the behavior of, and interactions between, the global energy, water, agriculture and land use, economy and climate systems. There are 32 geopolitical regions in GCAM, one of which is Pakistan.

The model runs in five-year time steps through to the end of the century and is calibrated to historical data through 2010 in GCAM 5.1.3, the base version used in this study. Exogenous model inputs include population, labor productivity, technology costs and characteristics, resource availability, policies, and other variables. GCAM is a dynamic recursive model; agents are assumed to act in order to maximize their own interests, but do not know future conditions when making decisions in each period. In each period, agents in the model interact with each other through markets, indicating their intended supply or demand for goods and services based on market prices. Prices are then adjusted in an iterative process until supply and demand are equal across all markets.

Model outputs include energy use, commodity prices, land and water use, global trade and emissions.

EV adoption is assessed by GCAM at five-year intervals (2025 to 2050) based on the following:

- Estimates of upfront vehicle manufacturing and purchase costs, which assume updated costs of EV components based on market research and subsequent updates to cost projections and accounting for battery augmentation and battery cost improvements. Vehicle purchase costs also include purchase/lease payments, taxes, duties, fees, registration charges, etc.
    - Vehicle purchase costs are affected by incentives under the NEVP, localization assumptions, and technology pathways.
- Levelized costs for vehicles include above purchase costs (amortized over the vehicles' lifetime), repair and maintenance costs, fuel costs based on energy intensity, distances travelled and applicable fuel tariffs (electricity, gasoline, diesel and compressed natural gas), annual token fees, road tolls and residential charging infrastructure costs.
    - Energy intensity is affected by technology pathways.
- Consumer preferences:
    - Share weight assumptions which factor in non-cost characteristics, such as availability, functionality and other consumer preferences.
    - Implicit discounting of future savings which factor in greater consumer sensitivity to higher initial costs versus any future lifecycle savings.

Details of GCAM model assumptions and analysis are given in **ANNEXURE B**.

3.2 SEP EV ENERGY IMPACT ASSESSMENT MODEL

Market penetration scenarios for EVs developed by GCAM provide an input to the SEP EV Energy Impact Assessment Model which is a spreadsheet tool designed to estimate the quantitative energy use and economic impact of EV penetration on Pakistan's power and fuel sectors. The model's approach and outputs are described briefly below:

- The SEP model uses published historical vehicle data to project growth in Pakistan's total vehicle fleet segregated by main vehicle categories: two-wheelers, three-wheelers, cars and light duty vehicles, buses and trucks. These projections factor in recent economic growth trends and the impact of COVID-19 under various scenarios. Given the market penetration scenarios developed by GCAM and the government's NEVP penetration targets (as percentage of new vehicles added), the SEP model estimates new EVs (on road) for each year from 2021 to 2030.

- Vehicle data for EVs and ICEVs (average distances travelled, energy consumption rates, conversion efficiencies, etc.), and replacement of ICEVs (by fuel type) with EVs, is an input to SEP's model based on published data, web sources, local information and market surveys, which are calibrated against GCAM's customized regional and default global base assumptions. Technical, commercial, and cost assumptions related to the supply and logistics of power and fuels are also an input to SEP's model, drawn from local published data by regulators and other agencies. The SEP model estimates oil and gas import and supply costs based on market practices and medium-term international crude oil price outlook.
- Based on estimated future EVs (on road) and the input data and assumptions described above, the SEP model computes the electricity demand (in GWh/year) for EV charging, the corresponding power generation requirements and the savings in fuels (in tonnes) due to ICEVs displaced under various scenarios/cases.
- The SEP model assumes a marginal generation mix to meet EV loads (drawn from IGCEP) and computes the cost of electricity supplied for EV charging (comprising marginal generation costs, transmission and distribution costs and losses) and fuel savings (comprising imports or ex-refinery supply, transportation and retail) for each scenario. The SEP model also estimates additional fuels required for power generation (gas and coal) depending on the projected generation mix and cost of future fuel imports (gasoline, auto diesel, LNG, and coal).

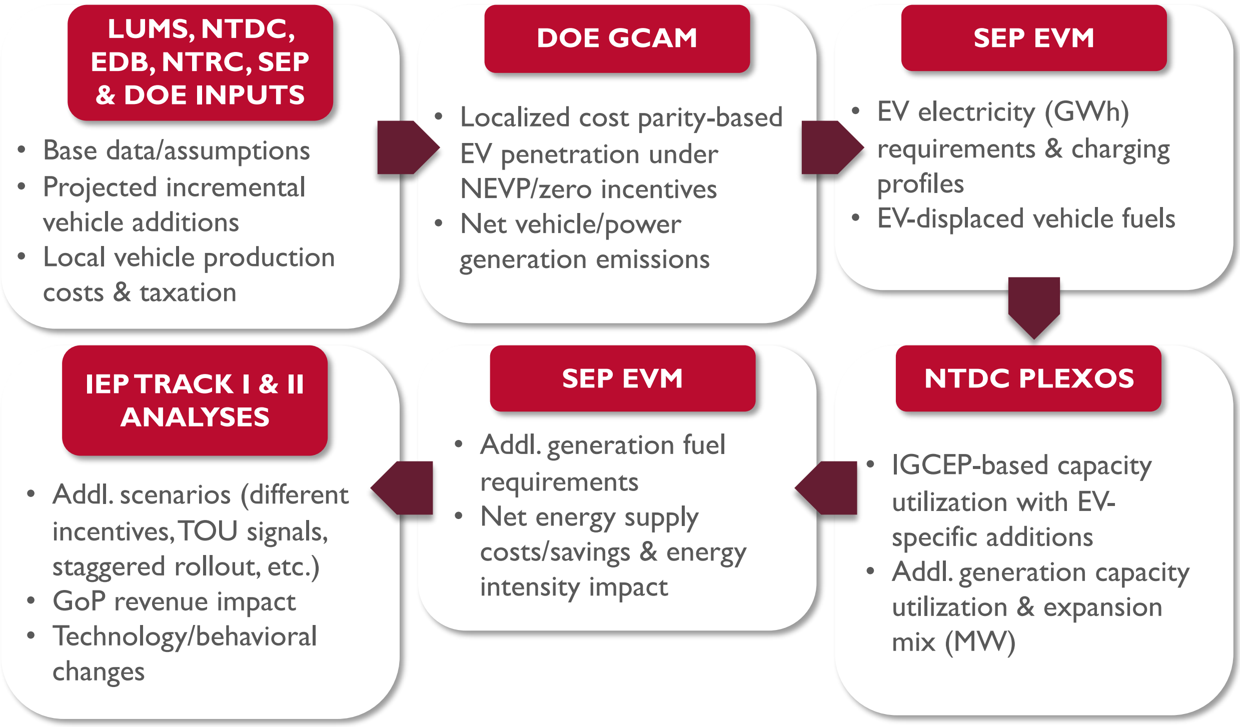
The economic analysis uses energy supply cost estimates (and not tariffs). Economic savings reflect the net lower cost of energy supply to the economy due to the higher efficiency of EVs relative to ICEVs for the same service (motive power). The SEP model also quantifies the impact on foreign exchange outlays due to decreased fuel imports for automobile use net of fuels imported for additional power generation to meet EV loads, e.g., liquefied natural gas (LNG) and coal. Any additional foreign exchange requirements for the import of EVs or related parts and charging equipment have not been calculated.

3.3 APPROACH AND CASE DEFINITIONS

Given the projections of total vehicles, EV penetrations and EV population on road, electricity required for EV charging and fuels by ICEVs and the supply cost of electricity and fuels, the study projects savings in fuels supply and costs of additional electricity supply. The economic savings reflect net lower cost of energy supply to the economy due to the higher efficiency of EVs relative to ICEVs for the same service (motive power). The analysis also quantifies the impact on foreign exchange outlays due to decreased fuel imports for automobile use net of fuels imported for additional power generation to meet EV loads, e.g., liquefied natural gas (LNG) and coal. Additional foreign exchange requirements for the import of EVs or related parts and charging equipment have not been computed.

Several entities and models were involved for this analysis, as illustrated in **Figure 1**.

Figure 1: Integrated approach used for EV modelling



- GCAM is primarily used to assess market-based EV adoption rates as a percentage of new vehicles added.
- The SEP model is a spreadsheet which assumes EVs (on the road) based on penetration curves obtained from the GCAM model and calculates their impact on additional electricity demand (and the corresponding EV charging loads) and fuels saved from lower use of ICEVs.
- The projected EV charging loads from the SEP model were provided to the National Transmission and Despatch Company (NTDC), Pakistan's national grid operator, to estimate the marginal power generation mix from existing and new capacity to serve EV demand under different scenarios. However, in order to derive marginal generation mix projections, IGCEP 2018 was adjusted based on de-rating, retirement, capacity factor, and generation addition data available at the time of the analysis (2020).
- The SEP model incorporates the estimated marginal generation mix (comprising of RLNG, coal, solar and wind plants assumed appropriate to service the additional EV loads) and computes the cost of electricity supplied for EV charging (comprising marginal generation cost, transmission and distribution costs and losses) and fuel savings (comprising imports or ex-refinery supply, transportation and retail) for different scenarios. The SEP model also estimates additional fuels required for power generation (gas and coal), depending on the projected generation mix and value of future fuel imports (gasoline, auto diesel, LNG, and coal).
- The impact on environmental emissions (due to EVs) based on lower fuels consumption in ICEVs, additional fuels used for power generation, quality of fuels for automotive use and power generation, and emission controls in place is estimated by GCAM using global or regional emission factors; a more detailed, Pakistan-specific emissions impact assessment will be conducted subsequently by EPRC under Track II support.

Various vehicle growth cases have been modeled to cover a broad range of possible uncertainties in base data and forecast assumptions, as follows:

- **Base cases** (market-based EV penetration assessment without NEVP 2019 incentives): Business-as-usual with duties and taxes as per the existing Automotive Development Policy (ADP) 2016 and Statutory Regulatory Order (SRO) 644 (I)/2018, with no EV-specific incentives, rebates, or exemptions assumed.
  - **Case A1**: EV penetration based on market factors under gradual localization of manufacture and slow technology advancement (i.e., slow decline in battery prices).
  - **Case A2**: EV penetration based on market factors under accelerated localization of manufacture and rapid technology advancement (i.e., rapid decline in battery prices).
- **Target case** (EV penetration assumed to meet targets for 2030 as defined in NEVP 2019): EV specific incentives, rebates, or exemptions taken as per NEVP 2019. All other fiscal incentives assumed as per ADP 2016 and SRO 644 (I)/2018.
  - **Case B0**: EV penetration to linearly increase from zero in 2020 to the category-wise target percentage of new vehicle sales by 2030.
- **Reference cases** (market-based EV penetration assessment with NEVP 2019 incentives): EV specific incentives, rebates, or exemptions taken as per NEVP 2019. All other fiscal incentives assumed as per ADP 2016 and SRO 644 (I)/2018.
  - **Case B1**: EV penetration based on market factors under gradual localization of manufacture and slow technology advancement.
  - **Case B2**: EV penetration based on market factors under accelerated localization of manufacture and rapid technology advancement.

Case A1 represents lowest market penetration of EVs, while Case B2 represents the highest market penetration of EVs. The above cases are run for the Standard Scenario and Scenario 'a' mentioned earlier.

The following table summarizes the key parameters used to distinguish between base, target and reference scenarios in GCAM.

Table 3: EV penetration scenarios

Scenario	Key Assumptions	
Baseline		Updated ICEVs and EV manufacturing and purchase costs, available EV technology, infrastructure costs, discount rate, implicit discount rate assumption and share weight assumptions
Policy	No policy	No policies to incentivize EV imports, local production and adoption
	NEVP	NEVP incentives in effect 2020-2030
Localization	Gradual localization	Local production of EVs increases gradually
	Accelerated localization	Local production of EVs increases at an accelerated rate
Technology advancement	Slow advancement	EV costs drop slowly due to slow reduction in battery cost and slow energy intensity improvement
	Rapid advancement	EV costs drop rapidly due to rapid reduction in battery cost and rapid energy intensity improvement

The GCAM scenarios/cases were run in various combinations as follows (**bolded** items were linked directly to the SEP model, others were retained for reference):

- **No Policy – Gradual localization - Slow technology advancement**
- No Policy – Gradual localization - Rapid technology advancement
- No Policy – Accelerated localization - Slow technology advancement
- **No Policy – Accelerated localization - Rapid technology advancement**
- **NEVP – Gradual localization - Slow technology advancement**
- NEVP – Gradual localization - Rapid technology advancement
- NEVP – Accelerated localization - Slow technology advancement
- **NEVP – Accelerated localization - Rapid technology advancement**

The above scenarios provide a range of EV market penetrations (as percentage of new vehicles) which are then applied to different growth scenarios for total vehicle additions for road transport (ICEVs plus EVs) in Pakistan.

4. ENERGY SECTOR IMPACTS OF EVS

The results of the model presented below are indicative and subject to the input data, assumptions and scenarios considered. A summary is provided in **Table 5** & **Table 6** and **Figure 2** & **Figure 3** for the Standard Scenario for the following cases:

Table 4: EV penetration cases modeled

Case	Description
A1: No NEVP-GradLoc-SlowTech	No policy – Gradual localization, slow technology advancement
A2: No NEVP-AccLoc-RapidTech	No policy – Accelerated localization, rapid technology advancement
B1: NEVP-GradLoc-SlowTech	NEVP – Gradual localization, slow technology advancement
B2: NEVP-AccLoc-RapidTech	NEVP – Accelerated localization, rapid technology advancement
B0: NEVP Targets	NEVP targets as per policy

Detailed results for the standard scenarios are presented in **ANNEXURE C**. Results of Scenario 'a', other scenarios or follow-on sensitivity cases/scenarios are not included here. Comparative total energy consumption figures for Pakistan are provided in **Table 7**.

The main takeaways of the EV analysis are as follows:

- The volumetric impact on the energy supply chain for EVs can be sizeable and can vary in a broad range depending on the scenario and assumptions. This will need to be continuously updated as more information becomes available to facilitate decision-making for long-term energy supply planning and capacity investments.
- There will be a significant overall economic benefit to the country due to the intrinsically higher efficiency of EVs compared to ICEV equivalents, since EVs use approximately 32% of the energy consumed by ICEVs (in BTU terms) for the same transportation service. The cost of additional power generation required is expected to be more than offset by the savings in automotive fuels alone.
- Significant foreign exchange savings will result due to reduced imports of transportation fuels.
- The adoption of EVs will reduce the flow of fuels and consumption by ICEV fuels and corresponding government revenues from taxes associated with those hydrocarbon products. Similarly, the incentives provided under the NEVP will reduce tax and customs revenues accruing from the import, production, sales, registration and use of ICEVs/parts. The use of electricity for EVs, particularly using domestic connections, will also increase the already unsustainable retail tariff subsidy burden on the government treasury. The financial impact on government revenues of EV adoption in the country has not been computed here and demands a separate analysis. Once quantified, this can be compared with the overall economic benefit to the country due to EVs in terms of a reduction in the cost of energy supply for road transport, reduced transportation costs and higher savings for citizens, reduced greenhouse gases and other emissions from the transportation sector and the industrial and employment opportunities generated by the new technology.

Table 5: Summary of cost savings under Standard Scenario

Case	Vehicles added Million 2021 to 2030			Cumulative Addl. Energy Supply (Cost)/Savings Million $ 2021 to 2030			Additional Foreign Exchange (Cost)/Saving at Import Level Million $ 2021-2030				
	Total	ICEVs	EVs	Cost of Power	Saving in Fuels	Net Saving	Gasl.	Diesel	LNG	Coal	Net
A1: No NEVP-GradLoc-SlowTech	18.26	16.57	1.70	(594)	924	330	778	6	(128)	(37)	619
A2: No NEVP-AccLoc-RapidTech	18.26	14.69	3.57	(1,271)	1,978	707	1,634	45	(273)	(79)	1,327
B1: NEVP-GradLoc-SlowTech	18.26	14.59	3.68	(1,420)	2,210	790	1,859	15	(305)	(88)	1,481
B2: NEVP-AccLoc-RapidTech	18.26	12.28	5.98	(2,299)	3,583	1,284	2,946	92	(491)	(143)	2,404
B0: NEVP Targets	18.26	13.11	5.15	(2,022)	3,145	1,123	2,367	320	(437)	(126)	2,124

Table 6: Summary of energy savings under Standard Scenario

Case	Addl. Elect. Consumed by EVs		ICEV Fuels Saved		Net Energy Saved		Additional Fuel Supply for Power Generation (for EV Charging)		
							LNG Import (Net of CNG)	Coal Import	Local Coal Prod.
	2030	2030	2030	2030	2030	2030	2030	2030	2030
	GWh	Trillion BTU	'000 Tonnes	Trillion BTU	Trillion BTU	Million TOE	MMCFD	'000 Tonnes	'000 Tonnes
A1: No NEVP-GradLoc-SlowTech	1,872	6.4	421	18.9	12.5	0.29	15.6	141.4	450.1
A2: No NEVP-AccLoc-RapidTech	4,030	13.8	909	40.7	26.9	0.62	33.2	304.5	969.2
B1: NEVP-GradLoc-SlowTech	4,068	13.9	916	41.0	27.2	0.63	33.6	307.4	978.2
B2: NEVP-AccLoc-RapidTech	6,828	23.3	1,543	69.1	45.8	1.06	55.9	515.9	1,641.9
B0: NEVP Targets	6,338	21.6	1,434	64.1	42.5	0.98	52.6	478.9	1,524.2

Note: 1tonne of oil equivalent (TOE) = 43.30 million BTU.

Table 7: Comparative total energy consumption in Pakistan

Energy Supply	Consumption in 2018
Total electricity	107 TWh
Fuels (gasoline, diesel, CNG) for land transportation	17.2 MTA
Total energy	55 MTOE

Source: Pakistan Energy Yearbook, 2019, Hydrocarbon Development Institute of Pakistan (HDIP).

Figure 2: Summary of key results under Standard Scenario (base, target and reference cases)

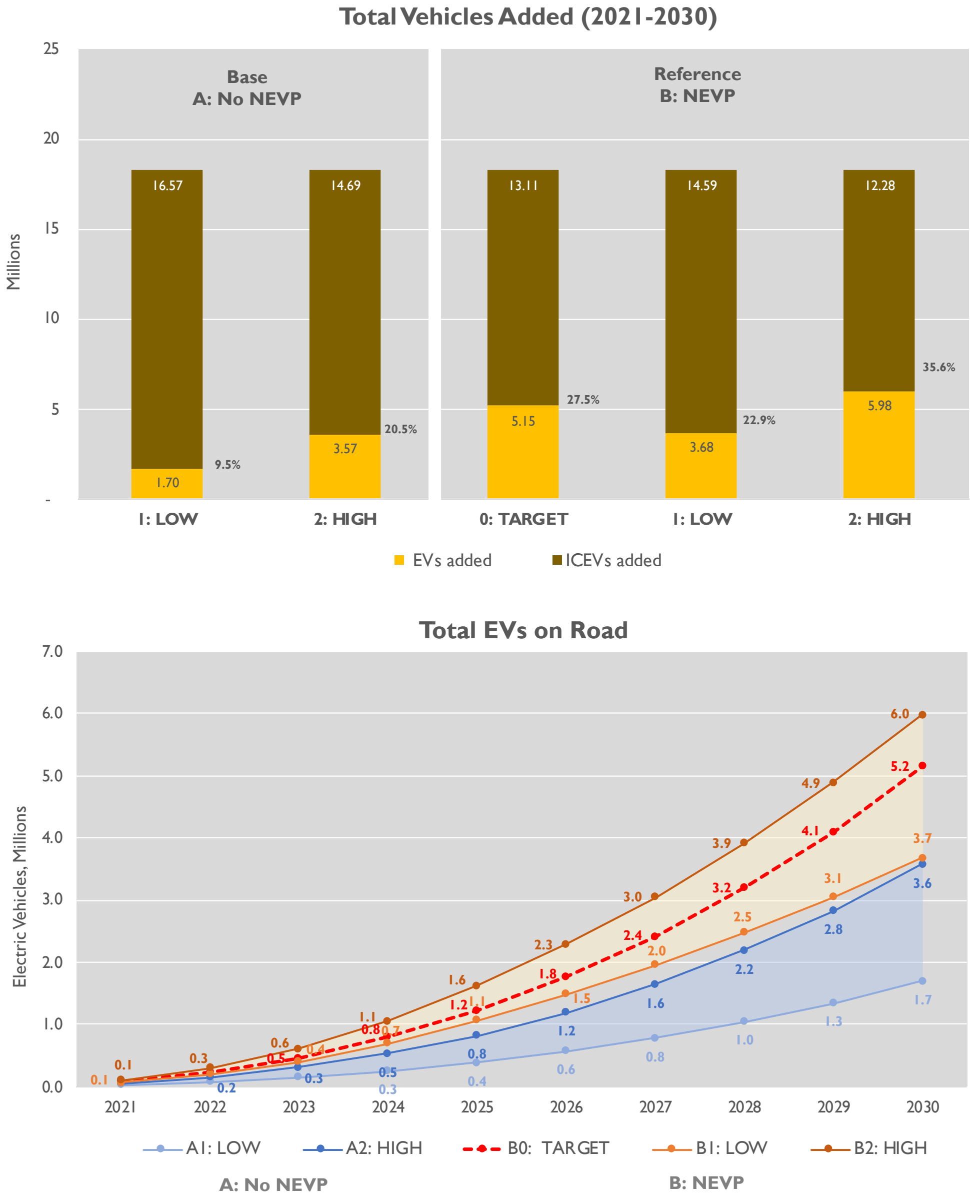
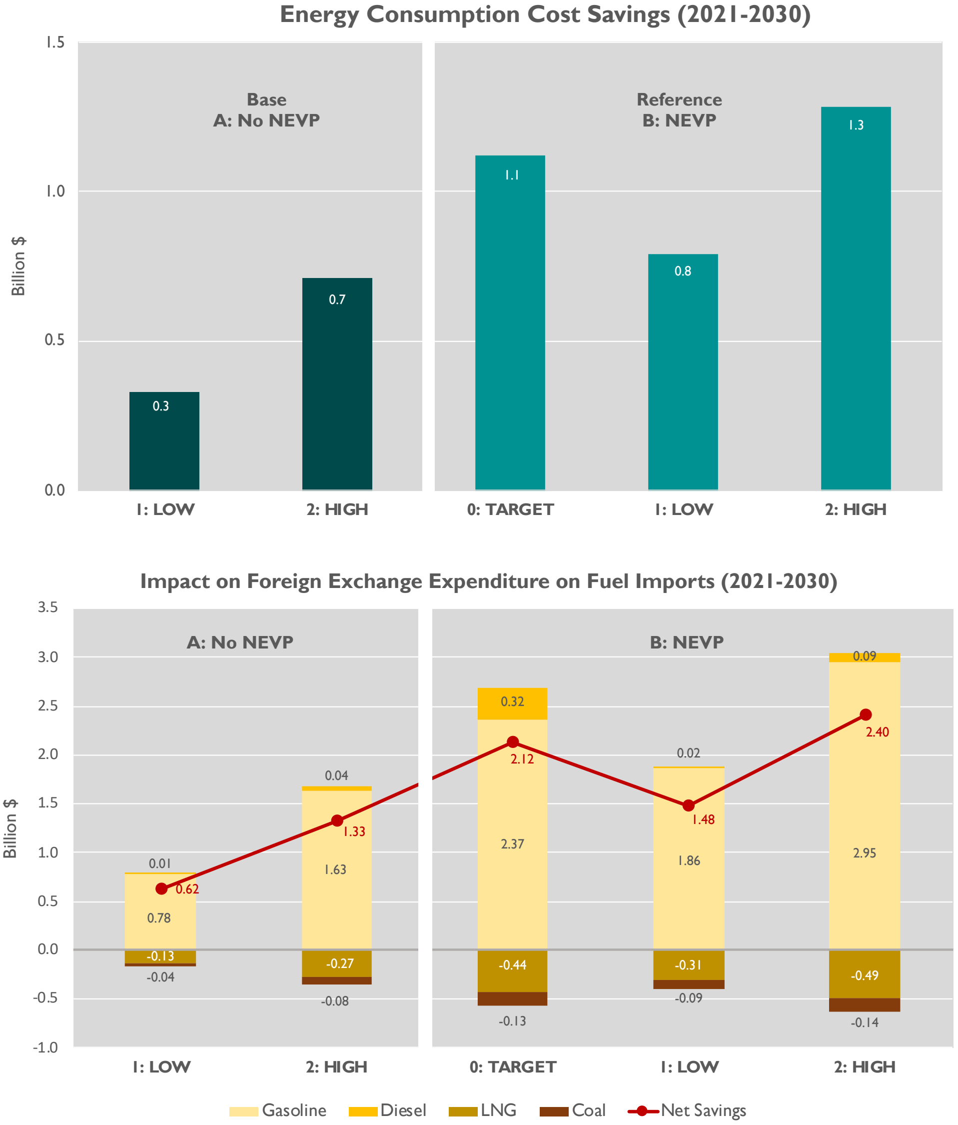


Figure 3: Summary of key results under Standard Scenario (base, target and reference cases) – cont.



5. IMPACT OF EVS ON ENVIRONMENTAL EMISSIONS

GCAM simulations indicate that the transportation sector makes up about 20% of Pakistan's CO_2 emissions. NEVP incentives with accelerated localization can reduce transport sector CO_2 emissions although additional fuel usage in thermal power generation (for EV charging) is likely to offset some of this advantage.

Transport electrification can also reduce air pollutant emissions, a major problem in Pakistan's urban centers (Ilyas 2007) and a policy goal of the NEVP. EV adoption reduces emissions of all non-CO_2 greenhouse gases and air pollutants with the highest impact on black carbon (BC), carbon monoxide (CO), non-methane volatile organic compounds (NMVOC), nitrogen oxides (NO_x) and organic carbon (OC), as a significant share of these emissions are from the transport sector. EV adoptions will reduce particulate matter (PM) emissions (approximated by summing BC and OC). Heavy duty vehicles have higher PM emissions factors than light duty vehicles, so there will be larger emissions reductions under scenarios with significant electric bus and truck adoption.[6]

A proper quantification of the environmental impacts due to the penetration of EVs will require the following data to be tabulated:

- Quantification of reduced fuel usage in ICEVs (gasoline, auto diesel, and CNG) over the study period.
- Quantification of higher natural gas/coal consumption for additional power generation to meet EV loads over the study period.
- Pakistan-specific fuel quality parameters over the medium term:
  - Natural gas for power generation (predominantly methane) and compressed natural gas (CNG) for transportation vehicles.
  - Imported coal (sub-bituminous) for power generation.
  - Local coal (lignite) from Thar coal field for power generation.
  - Gasoline and diesel for transportation vehicles.
- Projections of vehicle information (ICEVs types and numbers) and types of fuel burning.
- Current emission controls in place for stationary equipment (at power plants) and transportation vehicles.

The above data tabulation would need be carried as an extension of this study by the EPRC, with Track II IEP assistance from SEP/DOE subject to agreement between the Government of Pakistan and USAID. In the meantime, a high-level assessment is included here based on default global and regional assumptions used in GCAM for the data parameters enumerated above.

Key results of the preliminary emissions impact assessment for EVs in Pakistan are summarized in **ANNEXURE D**. The main takeaways are:

[6] Emissions factors are assumed to decrease over time, based on the general understanding that pollutant control technologies will be increasingly deployed as per capita GDP rises. Energy intensity of ICEVs is also assumed to decrease over time due to technological advances.

- Pakistan's transportation sector CO_2 emission will decrease with higher EV adoption. Direct emissions are reduced 3-8% beyond reductions in total emissions by 2050.
- Indirect emissions (originating from generation of electricity to power EVs) will, however, also increase with higher transport electricity demand.
- The net effect of transport electrification on CO_2 emissions is negative, i.e., total CO_2 emissions will decrease with higher EV adoption.
- However, the total effect will be relatively small, as the transportation sector makes up only about 20% of Pakistan's CO_2 emissions.
- PM emissions will decrease with higher EV adoption, with larger reduction in PM under scenarios with significant electric truck adoption.
- EVs will reduce transport emissions of all non-CO_2 GHG and air pollutants.
- The scale of impact on total non-CO_2 emissions is a function of the share of total emissions that are from the transportation sector: reductions in CH_4, NH_3, N_2O and SO_2 due to transport electrification will be overshadowed by emissions from other sectors.

ANNEXURE A. SEP MODEL DATA AND ASSUMPTIONS

A.1 STUDY PERIOD

A.1.1 Base Year

All data and projections presented are based on Pakistan's **fiscal year** (July 1 to June 30).

Base year FY2019; EV penetration assumed to start in FY 2021.

A.1.2 Assessment Period

2021 to 2030.

A.1.3 Integrated Modeling Responsibilities

Sustainable Energy for Pakistan (SEP)

Assessment of the impact of EV adoption on Pakistan's energy supply chain and associated costs/savings using custom-designed spreadsheet model.

U.S. Department of Energy (DOE) Laboratories (PNNL, NREL and ARL)

Assessment of category-wise EV market penetration based on EV/ICEV levelized cost-parity and consumer preference factors using customized Global Change Analysis Model (GCAM).

National Transmission and Despatch Company (NTDC)

Marginal electricity generation/supply mix to meet EV charging loads using Indicative Generation Capacity Expansion Plan (IGCEP) model in PLEXOS.

A.2 VEHICLE CHARACTERISTICS

A.2.1 Vehicle Categories

Pakistan's motorized vehicle population is classified according to the following main categories:

Table 8: Vehicle categories

Vehicle Category	Description
Two-wheelers (2W)	Motorcycles, scooters and mopeds*
Three-wheelers (3W)	Autorickshaws
Cars and light duty vehicles (LDVs)	Passenger cars, 4WDs, taxis, delivery vans, pickups (0-1 tonne cap.) and light utility vehicles (ambulances, etc.)
Buses	Buses and minibuses
Trucks	Freight trucks (>1 tonne cap.), tankers and heavy construction vehicles

*Motorcycles constitute the dominant fuel vehicle in the two-wheeler category in Pakistan. However, potential sales of new fuel motorcycles can be replaced by electric motorcycles, scooters and mopeds.

A.2.2 Vehicle Projections

There are significant discrepancies between 'on road' and 'registered' vehicle data provided in National Transport Research Centre (NTRC) reports (as well as inexplicably large year-on-year variations). This may be due to the methodology used in each case, e.g., annual token fees paid by 'on road' vehicles, which would underreport numbers or be subject to changes in provincial token collection practices, retirement of old vehicles not captured in total 'registered' data, etc.

SEP has estimated annual incremental vehicle additions instead of the total vehicle population for calculating future vehicle projections. Recent incremental data is available in the form of more reliable total domestic vehicle production from the Pakistan Automobile Manufacturers Association (PAMA) plus import statistics for the last five years from the Federal Bureau of Revenue (FBR) which are summarized below.

Table 9: Historical vehicle sales growth by category

	Two-, Three-wheelers		Cars and Light Duty Vehicles (LDVs)	
Year	**Vehicles Added** Local Sales Plus Imports	**Growth** % p.a.	**Vehicles Added** Local Sales Plus Imports	**Growth** % p.a.
2015-16	1,358,852		267,027	
2016-17	1,631,204	20.0%	269,357	0.9%
2017-18	1,931,713	18.4%	325,327	20.8%
2018-19	1,782,176	–7.7%	277,084	–14.8%
2019-20*	1,306,389	–26.7%	116,560	–57.9%
Average FY 2016-FY 2019 (4 years)	1,675,986	9.46%	284,699	1.24%
Average FY 2016-FY 2020 (5 years)	1,602,067	–0.98%	251,071	–18.72%
	Buses		**Trucks**	
Year	**Vehicles Added** Local Sales Plus Imports	**Growth** % p.a.	**Vehicles Added** Local Sales Plus Imports	**Growth** % p.a.
2015-16	1,251		5,865	
2016-17	1,183	–5.4%	8,282	41.2%
2017-18	848	–28.3%	9,804	18.4%
2018-19	1,099	29.6%	6,091	–37.9%
2019-20*	643	–41.5%	3,098	–49.1%
Average FY 2016-FY 2019 (4 years)	1,095	–4.23%	7,511	1.27%
Average FY 2016-FY 2020 (5 years)	1,005	–15.33%	6,628	–14.75%

*Data available for 11 months (to May 2020) extrapolated for entire FY 2020.

p.a.: Per annum.

The growth rates of 'vehicles added' do not show any consistent trend across years and vehicle categories. However, two-wheelers show a healthy growth rate averaging around 9.5% p.a. (FY2016 to FY2019), while FY2019 shows a marked downturn in vehicle additions (for all categories except buses). FY2020 shows a significant downturn driven primarily by the COVID-19 situation across all vehicle categories.

In Feb 2020, SEP had developed an initial projection of ten-year growth rates for 'vehicles added' which preceded the impact of COVID-19 during the second half of FY2020. Since data for FY 2020 were based on provisional reporting available at that time, SEP took into account actual historical data for four years (FY 2016 to FY 2019) and assumed moderate trend-based rates with a decrease by 50% (tapering off by 2030) in the case of two-wheelers to reflect eventual market saturation, as shown in **Table 10**.

Table 10: Projected vehicle growth rate assumptions

Vehicle Category	Vehicles Added % p.a.	
	Starting 2020	Ending 2030
Two-wheelers	5.0%	3.5%
Three-wheelers	3.0%	3.0%
Cars/LDVs	3.0%	7.0%
Buses	1.0%	3.0%
Trucks	4.0%	7.0%

The projected growth rates were revisited in July 2020 based on actual data for FY 2020. Following discussions with the PC and TFER, two main modeling scenarios were defined as follows:

- **Standard Scenario:** This assumes that healthy growth trends in vehicle additions (seen during FY2016 to FY2019) will resume from FY 2021 following the COVID-19 induced slump in sales during FY 2020, i.e., resumption of healthy growth rates (as witnessed in February 2020) from FY2021 onwards, with a one-year time gap as the economy recovers to pre-pandemic levels (**Table 11**).

Table 11: Projected vehicle growth rates under Standard Scenario

Vehicle Category	Vehicles Added % p.a.		
	2020 (Actual)	Starting 2021	Ending 2030
Two-wheelers	–26.70%	5.00%	3.50%
Three-wheelers	–26.70%	3.00%	3.00%
Cars/LDVs	–57.93%	3.00%	7.00%
Buses	–41.45%	1.00%	3.00%
Trucks	–49.13%	4.00%	7.00%

- **Alternative Scenario 'a':** This assumes a continued downturn in the economy due to COVID-19 during FY2021, with the slump in continuing till mid-2021, followed by moderate growth reaching around (or slightly less than) the growth rates assumed for the Standard Scenario by 2030 (**Table 12**).

Table 12: Projected vehicle growth rates under Scenario 'a'

Vehicle Category	Vehicles Added % p.a.

	2020 (Actual)	2021	Starting 2022	Ending 2030
Two-wheelers	–26.7%	–20.0%	2.0%	3.5%
Three-wheelers	–26.7%	–20.0%	2.0%	3.0%
Cars/LDVs	–57.9%	–10.0%	2.0%	6.0%
Buses	–41.5%	–10.0%	2.0%	3.0%
Trucks	–49.1%	–10.0%	2.0%	6.0%

These vehicle population growth rate projections are applied to the actual vehicles added in the base year FY2019 (summarized in

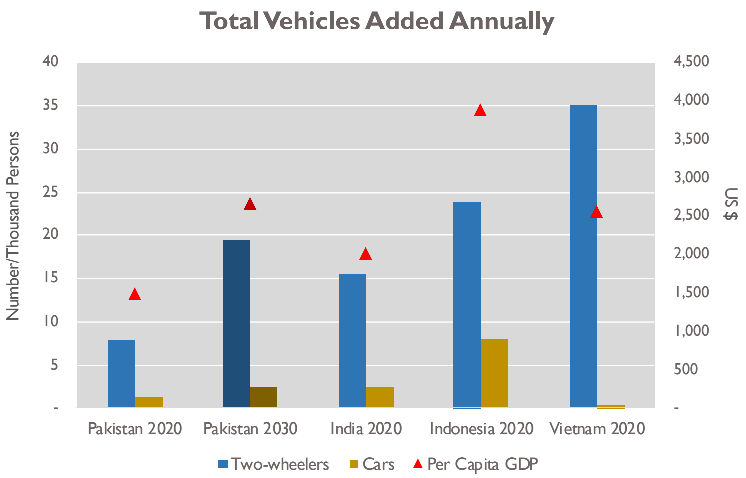
Table 13 below) to estimate total vehicles added between FY2020 and FY 2030. Two- and three-wheelers are assumed split into two-wheelers (98%) and three-wheelers (2%) based on historical vehicle data.

Table 13: Vehicle sales by category in FY 2019

Vehicle Category	**Vehicles Added in FY 2019** (Imports + Local Sales)		
Two-wheelers	1,782,176	98.0%	1,746,532
Three-wheelers		2.0%	35,644
Cars/LTVs			277,084
Buses			1,099
Trucks			6,091
Total			**2,066,450**

To verify projected vehicle populations for the dominant two-wheeler and cars/LDVs categories, SEP has compared current per capita vehicle additions in similar Asian economies with the Pakistan estimates for 2020 and 2030, which are plotted in **Figure 4**. The Pakistan estimates for the 2020-2030 period are found to be well within the range observed elsewhere, taking relative per capita GDP into account.

Figure 4: Regional per capita GDP and sales of two-wheelers and cars



A.2.3 Vehicle Use

The following average annual mileage has been assumed for each vehicle category, based on estimates of average daily distance traveled and days per year of vehicle use. This information has been corroborated through spot surveys conducted by LUMS as well as consultation with industry. The assumptions have also been cross-checked, where possible, against historical annual ICEV fuel consumption figures for the country. Finally, SEP estimates of the total annual vehicle mileage have been verified against GCAM's base year transportation service demand (passenger- and freight ton-km) computation for Pakistan, which also helps calibrate the DOE and SEP models. Close agreement with the figures assumed in **Table 14** was found in all such independent checks.

However, as model results are sensitive to such key assumptions, further corroboration/refinement of these figures should be undertaken through more detailed field research. Other factors, such as lower cost of operation of EVs, income and infrastructure growth, CPEC-related trade, etc., are also expected to influence future mileage projections.

Table 14: Annual mileage assumptions by vehicle category for Pakistan

Vehicle Category	**Avg. Distance Travelled/Vehicle** km/Day	**Duty Cycle** Days/Year	**Avg. Distance Travelled/Vehicle** km/Year
Two-wheelers	40	300	12,000
Three-wheelers	100	320	32,000
Cars/LTVs	35	300	10,500
Buses	240	300	72,000
Trucks	240	300	72,000

Note: Based on SEP and LUMS estimates, regional data and informal market surveys. Validated against annual OMC retail fuel sales data for 2Ws/cars (LTVs) and GCAM transportation service demand calculations.

A.2.4 ICEVs Displaced by EVs

Table 15: ICEVs displaced by EVs as percentage of new vehicle sales/year

Vehicle Category	**Percentage ICEVs Displaced by Fuel Type**		
	Gasoline	Diesel	CNG
Two-wheelers	100%		
Three-wheelers	90%		10%
Cars/LTVs	85%	5%	10%
Buses	10%	85%	5%
Trucks	0%	100%	

Note: Estimates based on the following assumptions:
Two-wheelers use gasoline only.
Three-wheelers predominantly use gasoline. The displacement assumed is 90% gasoline and 10% CNG.
Passenger cars and other LTVs predominantly use gasoline, with some diesel vans, jeeps and station wagons. According to the *Pakistan Economic Survey* (2010-2011), around 20% of LTVs in Pakistan at the time were using CNG, which has now declined because of gas shortage.
Buses primarily use diesel, with some running on gasoline and CNG.
All medium to large trucks in Pakistan use diesel.

A.2.5 Vehicle Energy Use

Table 16: Energy consumption by vehicle category

Vehicle Category	Avg. Consumption/Vehicle						
	Electricity	Electricity (GCAM)	Gasoline	Gasoline (GCAM)	Diesel	Diesel (GCAM)	CNG
	km/kWh	km/kWh	km/liter	km/liter	km/liter	km/liter	km/kg
Two-wheelers	12.0	20.02	40.0	59.11	–	–	–
Three-wheelers	9.9	10.58	30.0	24.65	–	–	42.9
Cars/LDVs	5.1	6.64	15.3	16.01	18.4	–	22.0
Buses	1.1	1.70	3.3	–	4.0	3.88	4.7
Trucks	0.9	1.22	2.7	–	3.2	5.28	–

Note: Estimates based on SEP literature search and LUMS inputs. Cross-checked through informal market surveys conducted by LUMS in Lahore.

EV electricity consumption calculated relative to gasoline engines based on conversion efficiency and calorific content.

Diesel consumption derived from gasoline engines based on relative engine efficiencies.

CNG consumption based on weight equivalence of gasoline to CNG (as CNG is sold by kg) and heat value of CNG relative to gasoline.

A.3 EV PENETRATION

The SEP model takes inputs on EV penetrations by GCAM as percentage of new vehicle sales (which are provided by vehicle category). Any variations in vehicle definitions versus SEP's model assumptions are accommodated via adjustments in EV adoption rates (GCAM output), e.g., EV penetration for cars/LDVs are corrected to include pickups/trucks of 0-1t capacity while all other data/assumptions for calculation of energy sector impacts are based on SEP's model.

A.4 EXCHANGE RATE AND INFLATION

All costs are converted to U.S. dollars at time of data compilation, and therefore fluctuations in PKR/USD exchange rate are not applicable.

- PKR 155/USD (Sep-Nov 2019) applicable to most of the compiled cost data.
- PKR/USD (for other periods) is the applicable rate during that period.

USD costs are corrected to 2019 base year based on USD inflation rate as follows:

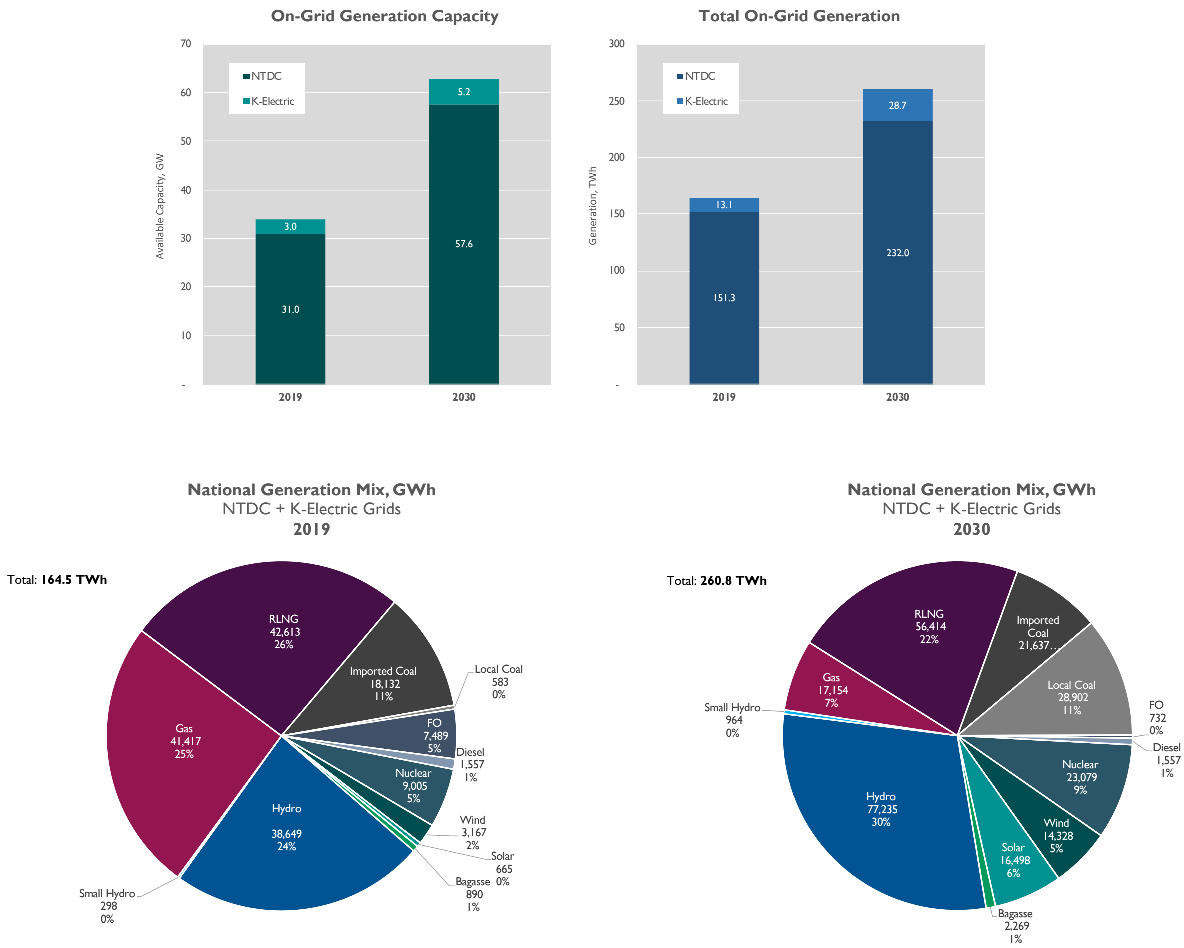
Year	2015	2016	2017	2018
USD inflation (based on CPI) % p.a.	0.7%	2.1%	2.1%	1.9%

A.5 POWER SUPPLY CHAIN

A.5.1 Power Generation Mix

Provisional power generation mix projections were employed for the SEP model as NTDC's IGCEP 2019-2047 was not available for simulating EV loads in NTDC's PLEXOS model. Plant-wise 2019 and 2030 energy mix (GWh) across NTDC and K-Electric grids was estimated using de-rated (available) generation capacities and weighted-average technology-wise capacity factors. No new generation capacity additions to service EV loads assumed as sufficient planned new and existing capacity is projected to 2030.

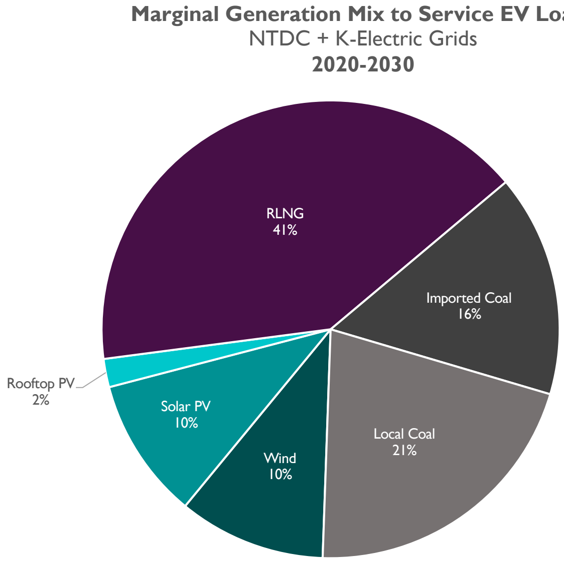
Figure 5: Projected national power generation capacity and mix



The marginal additional generation required to service EV loads is assumed to be catered for by idle off-peak system capacity available during 2021-2030. Only energy charges are considered as additional electricity production costs for EVs, as capacity payments are already committed for the committed capacity under the existing IGCEP. On-grid generation sources supplying EV loads at the end-consumption level are taken to be RLNG, imported coal, local coal, solar and wind IPPs, as these represent readily available or additional generators for the marginal and peaking electricity supplies required compared to other sources that have long gestation periods, high upfront costs or baseload allocations (e.g., nuclear, hydro, etc.). Additionally, for residential EV charging, rooftop PV systems are also considered.

The median 2019-2030 relative mix of above generation in the national electricity mix is assumed to service EV loads during 2020-30 (**Figure 6**). These provisional marginal generation mix assumptions can be subsequently further verified through the NTDC IGCEP model.

Figure 6: Marginal generation mix to service EV loads during 2021-2030



A.5.2 Power Generation Costs

Key power generation assumptions for supply of electricity to EVs are provided in **Table 17**. SEP assumes thermal (RLNG and coal), solar and wind IPPs as viable options for the additional electricity required, given projected capacity availability, relatively short capacity addition timeframes and expected EV load profiles. Other principal generation sources (e.g., hydro and nuclear) have long gestation periods or high upfront costs that do not make them viable candidates as marginal additional sources for servicing gradually increasing EV demand. Rooftop solar PV has also been considered for residential/self EV charging.

Table 17: Generation cost by source

Centralized Source	Heat Rate		Fuel Cost		Energy Charge	Var. Cost	Cap. Charge	Total Cost	Thermal Efficiency	
	BTU/ kWh @LHV	BTU/ kWh @ HHV	$/ MMBTU @ LHV	$/ MMBTU @ HHV	¢/kWh	¢/kWh	¢/kWh	¢/kWh	**@LHV** NEPRA	@HHV
RLNG (grid)		6,092		7.80	4.755	0.318	1.651	6.724	62.02%	56.01%
Imp. coal (grid)	8,751		5.34		4.678	0.467	3.748	8.893	38.99%	
Local coal (grid)	9,223		4.19		3.863	0.992	3.969	8.825	37.00%	
Solar (grid)							5.362	5.362		
Wind (grid)							4.209	4.209		
Distributed Source			Rs/kWh		¢/kWh					
Solar (rooftop PV)			10.10		6.516					

Note: LHV, HHV: Lower, higher heating value; MMBTU: Million British thermal units, kWh: Kilowatt-hours.

Generation costs based on NEPRA tariff determinations assumed to reflect full generation costs: RLNG (Haveli Bahadur/Balloki), Imported Coal (Sahiwal), Local Coal (Sindh-Engro Thar), Wind (Master Energy), and Solar PV (HNDS/Meridian/Herlious).

All generation costs are converted to $/kWh based on the PKR/USD assumption in NEPRA determination; thereafter it is assumed that costs will increase with dollar inflation.

Fuel cost reflect delivered costs at power plant.

Capacity charge includes fixed O&M, WC, insurance, ROE, debt repayment and interest charges divided by 'annual plant availability' (92% for RLNG, and 85% for coal). Capacity charge is selectively applied in SEP's model depending on new or surplus power generation capacity to meet EV loads (assessment based on NTDC IGCEP generation mix and surplus capacity).

RLNG is priced in $/MMBTU at HHV. Imported and local coal are priced in $/tonne and in $/MMBTU at LHV.

NEPRA quotes thermal efficiency at LHV for RLNG/coal.

Rooftop solar PV costs derived from local vendor information for a 5 kW system consisting of PV panels, inverter, batteries (including one-time replacement), cabling and other equipment over a 25-year life.

Auxiliary consumption assumed as per NEPRA allowance as follows: RLNG: 2.01%; Imported coal: 8.0%; Local coal (Thar): 9.0%.

A.5.3 Power System Losses

Power system losses have been assumed as shown in **Table 18** to arrive at the final energy delivered to EV charging stations/outlets.

Table 18: System transmission and distribution losses

System	Average Loss
Transmission losses (% of electricity sold to NTDC)	2.4%
Distribution losses (% of electricity sold to DISCOs)	17.6%
Total system T&D losses	**20.0%**

Note: Average system T&D losses taken from NTDC *Power Systems Statistics, 2018*. K-Electric T&D losses are comparable.

A.5.4 Power T&D Costs

Costs associated with transmission and distribution of electricity (wheeling) have been based on current average use of system charges, as shown in **Table 19**.

Table 19: System transmission and distribution costs

System	Average Use of System Charge (UOSC)	
	Rs/kWh	¢/kWh
Transmission cost	0.44	0.284
Distribution cost	1.60	1.032

Note: Average T&D costs (capex, opex, margins) are based on UOSC forecast by CPPA-G for transmission and distribution for 2020-21.

A.5.5 Charging Infrastructure Cost

Cost of commercial EV charging stations is estimated 0.023 $/kWh based on capex (at 10% IRR over 15 years) and opex of charging station cost derived from web sources. It is assumed that 20% of grid supply used for EV charging will use commercial charging infrastructure. This cost is added on to commercial electricity supply cost.

A.6 GAS SUPPLY CHAIN

Natural gas supply chain cost assumptions and add-ons are detailed in **Table 20** below for imported LNG-based supplies, as there is no additional domestic gas available in the country due to depleting reserves.

Table 20: Gas supply chain assumptions

Brent (FOB Sullom Voe) price: $55.0/BBL (SEP assessment based on medium-term outlook).

	BTU/lb	MMBTU/t @ HHV	BTU/scf	SCF/tonne
LNG quality	21,500	47.40	1,000	47,400

Cost Item	Rate	Basis & Units
LNG contract price	11.0	As % of Brent crude oil (FOB Sullom Voe)
Port charges	0.07	Port charges in excess of limit paid by supplier in $/MMBTU
Terminal charges	0.43	Paid to terminal owner (capex and opex) in $/MMBTU
PSO/PLL costs	0.55	Import-related costs borne by PSO/PLL in $/MMBTU
PSO/PLL margin	2.5	PSO/PLL margin as % of DES
LSA fee (SSGCL/PLTL)	0.025	LSA fee in $/MMBTU
Retainage	0.60	Retainage as % of DES
Gas transmission loss	0.55	As % of RLNG supplied to gas utilities
Gas transmission and distribution loss	12.1	As % of RLNG supplied to gas utilities
T&D (utilities) cost	0.45	Average T&D charges paid to gas utilities in $/MMBTU
CNG station costs	1.549	Expenses at CNG stations in $/MMBTU of CNG (basis Rs 11.38/kg as per OGRA)
CNG station margin	0.682	Margin of CNG stations in $/MMBTU of CNG (basis Rs 5.01/kg as per OGRA)

Note: LNG import assumed as marginal source of gas (contract price as % Brent) assumed as per market trend for LT contracts.

RLNG supply cost to gas utilities assessed from recent OGRA tariff determinations for RLNG cost to gas utilities, which includes port charges, LNG DES, terminal charges, PSO/PLL costs and margins, LSA fee (SSGCL/PLTL) and retainage.

RLNG supply cost to power stations include average gas T&D costs and transmission losses (in addition to RLNG fuel cost) based on recent OGRA tariff determinations (breakdown by transmission and distribution separately not available).

CNG supply cost includes average gas T&D costs, losses, and CNG stations costs (in addition to RLNG fuel cost) based on recent OGRA tariff determinations. T&D losses assumed as an average of SNGPL and SSGCL system losses.

A.7 COAL SUPPLY CHAIN

Coal supply costs, both for domestic lignite (Thar) and imported sub-bituminous coal, are provided in **Table 21** below.

Table 21: Coal supply chain assumptions

Type	Calorific Content MMBTU/t @ LHV
Imported coal (subbituminous)	25.556
Local coal Thar (lignite)	11.005

	Imported Sub-bituminous Coal	Value	Basis
A	International market FOB price, $/tonne	70.0	Average FOB price S. Africa, Australia, Indonesia), medium-term outlook (web sources)
B	Marine freight, $/tonne	20.0	NEPRA's tariff determination for HSRPEL (Sahiwal imported coal plant), Mar. 2015
C	Cargo insurance @ 0.1% FOB price	0.1% of A	
D	Other costs @ 10% FOB price	10% of A	
E	Jetty charges, $/tonne	9.5	
F	CIF (landed) price	A+B+C+D+E	
G	Inland transportation loss @ 2%	2% of CIF quantity	
H	Inland transport cost	2.73 ¢/t/km	Rs 3/t/km as per NEPRA Feb. 2018 freight determination for Sahiwal coal-fired plant, converted to $/t based on PKR 112/USD (Feb. 2018), adjusted for dollar inflation in 2018
I	Supplied to power plant	F+H	Adjusted for quantity loss

Thar lignite	Variable $/tonne	Fixed $/tonne	Total $/tonne	Basis
Coal price at plant	14.3	31.8	46.1	Based on NEPRA's levelized tariff for EPTPL Mar. 2015. Coal price is not linked to market trends and any revisions are assessed and announced by Thar Coal Energy Board (TCEB)

A.8 PETROLEUM SUPPLY CHAIN

A.8.1 Gasoline and Diesel Transportation Costs

Table 22: Gasoline and diesel inland transportation costs

Component	Gasoline 92 Rs/liter	Diesel 0.05 Rs/liter	Gasoline 92 $/BBL	Diesel 0.05 $/BBL
Inland freight equalization margin (IFEM)	3.37	0.95		
OMC margin	2.64	2.64		
Dealer commission	3.47	2.93		
Total	**9.48**	**6.52**	**9.72**	**6.69**

Note: For petroleum product pricing at pump, the following approach was used:

Dubai crude price FOB Fateh based on assessed market differential v Brent.

AG Platts product price assessment based on refining economics of hydro-cracking refinery on Dubai crude (positive margin after cash costs).

Landed prices at Karachi (AG Platts + premium/freight + wharfage at Karachi port) based on recent OGRA reports for kerosene (assumed ex-refinery prices at parity with import prices).

Wharfage at Karachi port based on web sources for oil imports at Pakistani ports.

Ex-refinery prices assumed at parity with imports.

Inland freight and distributor/dealer margins for gasoline and diesel, based on average T&D costs and margins of oil marketing companies, added to obtain fuel supply cost at pumps (data from OGRA website and web sources).

A.9 RETAIL ENERGY PRICES

Retail energy prices are not used in the SEP energy supply and cost impact analysis, as these include externally determined taxes and margins that are not reflective of the true economic cost to the country of the energy supply. However, GCAM computes fuel and electricity price projections internally for use in the levelized operational cost comparison between EVs and ICEVs. **Table 23** below shows a comparison of the actual average retail energy prices in Pakistan and GCAM computed values.

Table 23: Average retail energy tariffs in Pakistan (July 2020)

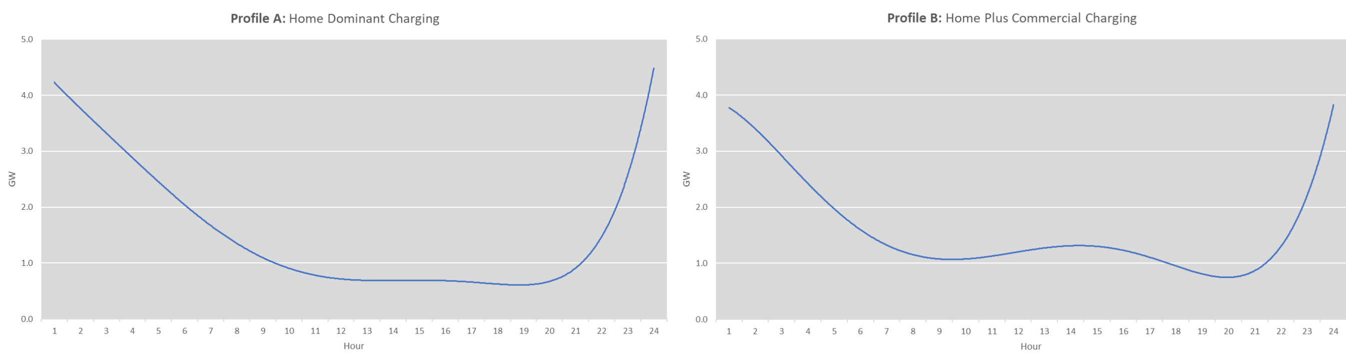
Product	Average Retail Price	
	$/kWh	$/liter
Electricity	0.11-0.16	–
Gasoline (92 RON)	–	0.60
Auto diesel	–	0.61
Product	**GCAM Computed Value**	
	$/kWh	$/liter
Electricity	0.146	–
Refined liquids	–	0.80

A.10 EV CHARGING LOAD PROFILES

Two representative EV charging profiles were devised by SEP (**Figure 7**), based on recent data from the U.S. and Australia (DOE and web sources). EV charging profile is assumed to remain unchanged throughout the year.

- EV Load Profile A assumes primarily home/off-hour charging (Level 1), with a current TOU tariff-based peak between 11 pm and 7 am.
- EV Load Profile B assumes a mix of home/off-hour (L1) and commercial/daytime (L2 & L3) charging with current time-of-use (TOU) tariffs.

Figure 7: Representative EV load profiles for a total daily requirement of 40 GWh



Note: Based on these load curves, SEP provided NTDC with hourly EV load profile data for different modeling scenarios, along with total annual EV GWh requirements, as an input to PLEXOS for determining the generation MW mix required to serve EV demand (existing and new capacity needed).

A.10.1 EV Load Profile Evolution

Initially, as EVs are introduced, predominantly nighttime L1 charging has been assumed. This could evolve into increasing levels of daytime commercial L2 & L3 charging once significant EV penetration has been achieved and charging infrastructure developed.

Table 24: EV load profile assumptions

Load Profile	EV Charging	Timeframe
A	Home dominant	To 2025
B	Home & work/commercial	Beyond 2025

Note: Load profiles A & B are based on current TOU retail electricity tariffs (commercial and domestic), with peak hours ranging between 5 pm and 11 pm, depending on the season. Alternative TOU tariff scenarios proposed specifically for EVs will require suitable modification of the profiles.

ANNEXURE B. GLOBAL CHANGE ANALYSIS MODEL (GCAM) AS APPLIED TO NEVP STUDY

GCAM is a global, multi-sector, market equilibrium model. It represents the behavior of—and interactions between—global energy, water, agriculture and land use, economy and climate systems. This section provides details with regards to the baseline structure of GCAM as adapted for analysis of the NEVP.

B.1 SOCIOECONOMIC ASSUMPTIONS

GCAM's default projections for Pakistan were adjusted to better align with projections made by stakeholders in Pakistan. Population and GDP assumptions are based on Shared Socioeconomic Pathway (SSP5),[7] as this aligned with the Government of Pakistan's own projections better than the default of SSP2. Near-term GDP growth rate assumptions were updated based on historical data and projections from the IMF. Long-term projections for population, gross domestic product (GDP), and GDP/capita are given in **Figure 8** below. The base year for GDP is 2010, and GDP in future years is a function of population and GDP per capita growth rates. GDP is given in constant 1990 dollars.

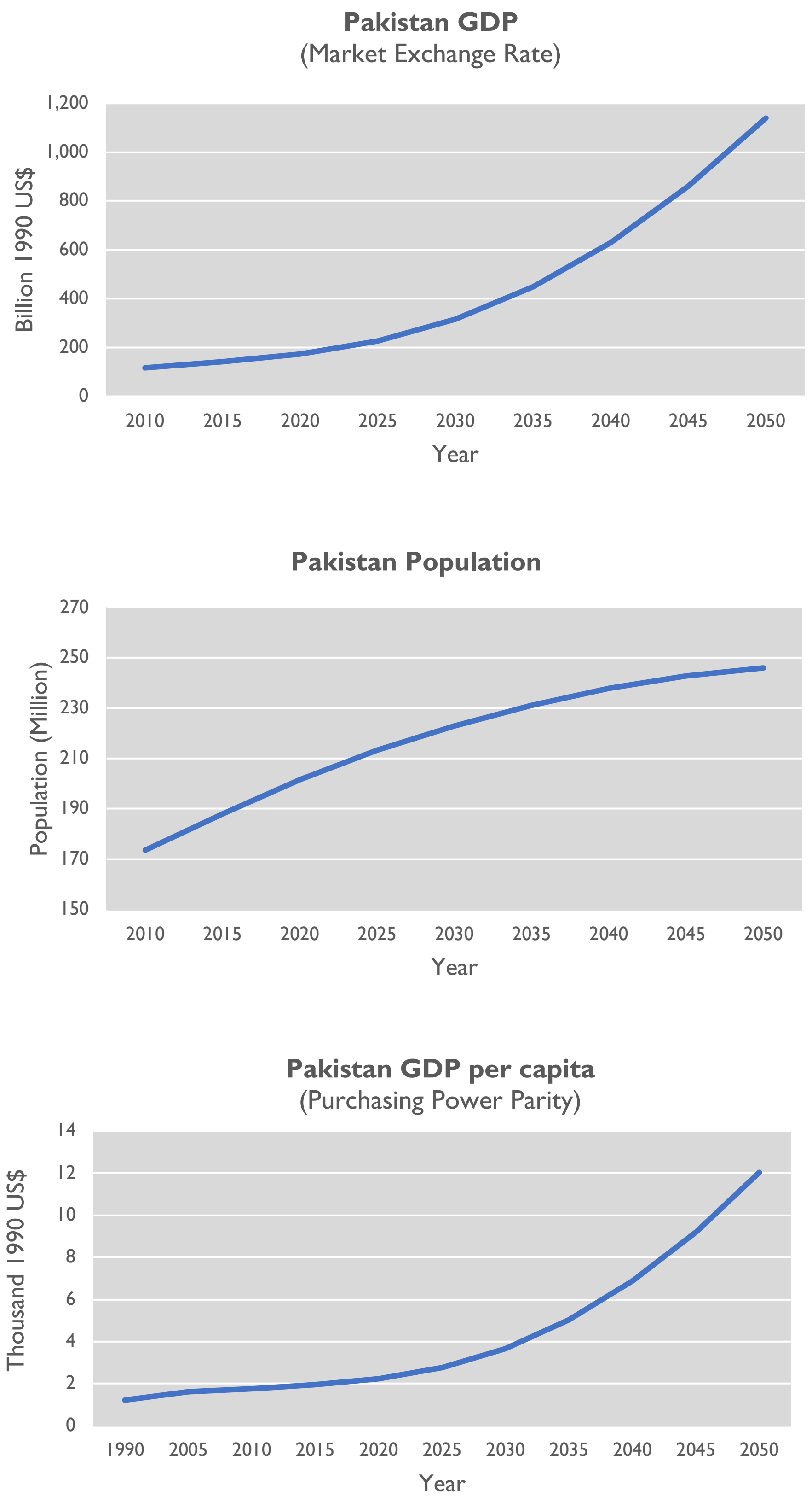
The GDP and population growth rates provide the basis for assessment of passenger-km and freight ton-km demand in the transportation sector, as transportation service demands (*D*) in region *r* and time period *t* are determined according to the following equation:

$$D_{r,t} = D_{r,t-1} [(Y_{r,t})/(Y_{r,t-1})]\ \alpha\ (P_{r,t})/(P_{r,t-1})]\ \beta\ [(N_{r,t})/(N_{r,t-1})]$$

where *Y* is the per capita GDP, *P* is the total service price aggregated across all modes, *N* is the population, and α and β are income and price elasticities, respectively.

[7] Shared Socioeconomic Pathways (SSPs) are scenarios of projected socioeconomic global changes up to 2100. They are used to derive greenhouse gas emissions scenarios with different climate policies. These scenarios include SSP1: Sustainability (Taking the Green Road); SSP2: Middle of the Road; SSP3: Regional Rivalry (A Rocky Road); SSP4: Inequality (A Road Divided); SSP5: Fossil-fueled Development (Taking the Highway)

Figure 8: Pakistan socioeconomic assumptions



B.2 TRANSPORTATION SECTOR

GCAM has a high level of detail represented in the transportation sector:

- The sector is divided into four final demands: passenger, freight, international aviation, and international shipping.
- The demand for transportation services (in passenger-kilometers or ton-kilometers) in each region and time period is driven by GDP, population, cost of transport services, and income and price elasticities. The final demands are further broken down into different modes (e.g., road, rail), sub-modes (e.g., bus, light duty vehicle), size classes (e.g., compact car, moped), and technologies (e.g. liquids, hybrid liquids, battery electric). The modal split depends on the vehicle technologies available in each region and time period; if a certain mode or vehicle class is excluded, the service demand shifts to other modes.
- At the passenger subsector level, a time value, determined by the wage rate (per-capita GDP divided by the number of working hours in a year) and exogenously specified vehicle speed, is incorporated into the competition between transport modes. This causes a shift towards faster modes of transportation as incomes increase.

Non-fuel costs, such as capital and maintenance costs, are exogenously specified for each transport technology. Fuel costs are endogenously calculated based on global demand and regional supply curves, which include technological change. Consumer prices are a function of the endogenously calculated global prices for all primary fuels, plus the costs of transformation (for example, oil refining) and cost adders for distribution costs. For some key values, such as global oil price, prices are calibrated in the base year (2010) to match historical benchmarks.

Table 25 shows fuel costs for electricity and refined liquids in the transportation sector under several scenarios as calculated by GCAM.

Table 25: Energy costs calculated under GCAM Pakistan EV scenarios (1975$/GJ)

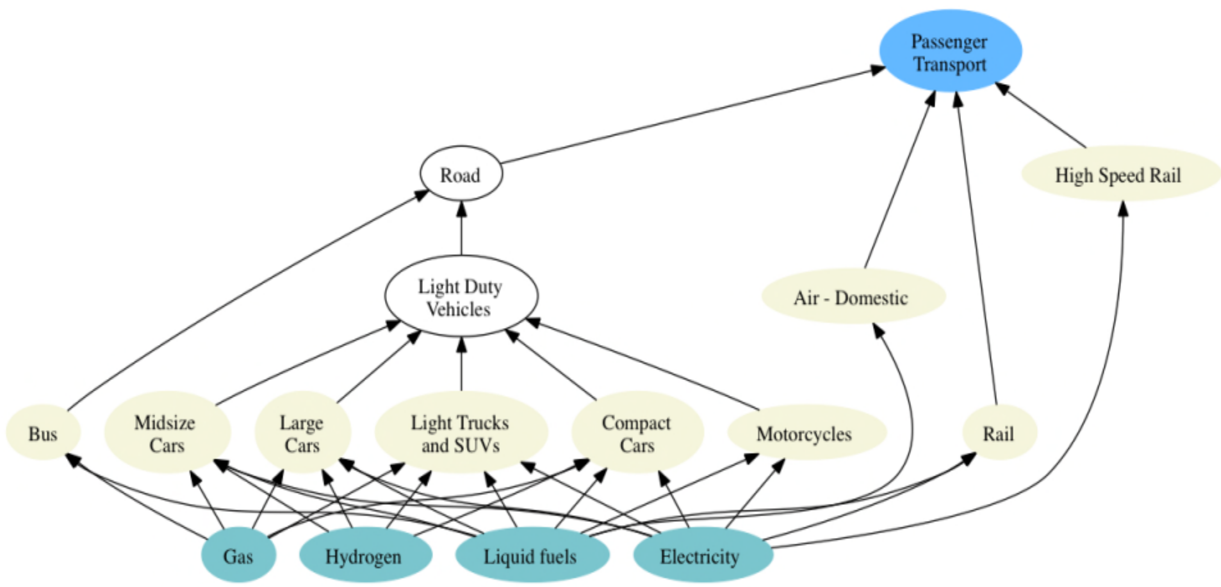
Scenario	Fuel	2020	2025	2030
Slow_GradLoc_noPolicy	Electricity	11.3548	11.3628	10.9203
Rapid_AccelLoc_noPolicy	Electricity	11.3550	11.3644	10.9232
Slow_NEVP_GradLoc	Electricity	11.3550	11.3641	10.9217
Rapid_NEVP_AccelLoc	Electricity	11.3552	11.3664	10.9255
Slow_GradLoc_noPolicy	Refined liquids end use	5.77107	5.87201	5.95218
Rapid_AccelLoc_noPolicy	Refined liquids end use	5.76658	5.85273	5.89481
Slow_NEVP_GradLoc	Refined liquids end use	5.77086	5.87133	5.95050
Rapid_NEVP_AccelLoc	Refined liquids end use	5.76635	5.85185	5.89323

- Older road vehicles are retired over time and new vehicles are added in each future model year.
- Transport service demands for each GCAM region are calibrated in the base year (2010 in the model version used for this analysis) so that transportation energy consumption matches IEA energy balance data. IEA data provides total fuel consumption in the road transportation sector; detailed breakdowns beyond this level (e.g., between passenger and freight, modes, and size classes) are based on regional data and assumptions. The

default assumptions and sources for the transportation module of GCAM are documented in Mishra, et al. (2013). However, some assumptions were updated to capture more recent data on EV technological development, as well as Pakistan-specific transport characteristics (discussed later).

- These cost elements are totaled and levelized to a single monetary cost per passenger-kilometer or ton-kilometer. The choice amongst modes of transportation is a function of the cost of travel, the time it takes and income. Kindly refer to the GCAM system representation in **Figure 9** below. The model calculates market shares for each transport technology based on a logit choice specification. This is a choice function that calculates market shares for each technology based on its cost and share weight and avoids a 'winner-take-all' result for the lowest cost option.[8]
- As non-fuel costs and other parameters, such as fuel intensity, are exogenous, consumer choices do not influence the characteristics of the transport technologies themselves. For example, higher EV adoption rates would not result in faster technological improvement and cost reduction.

Figure 9: GCAM transportation system



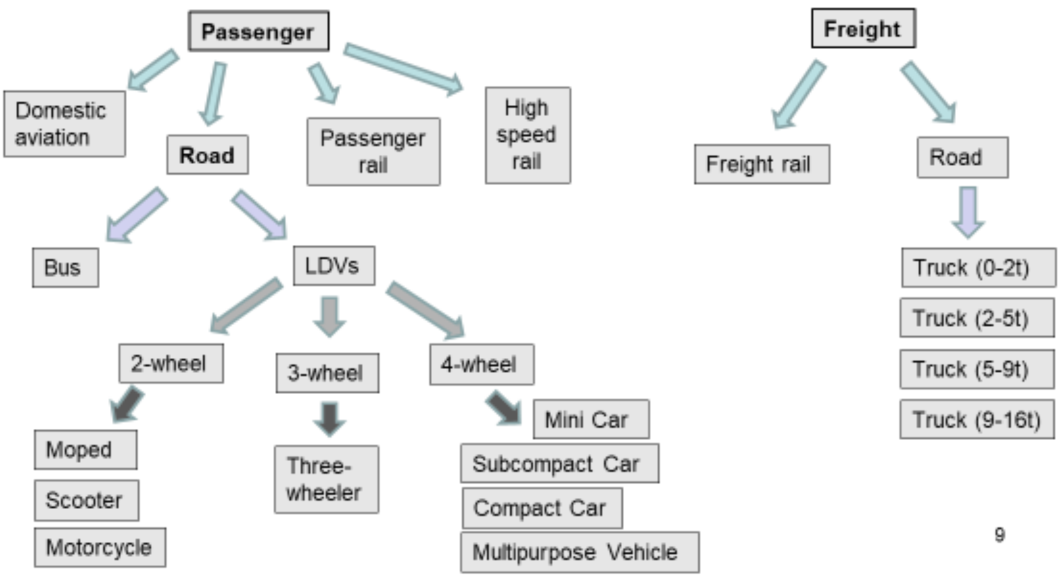
B.3 PAKISTAN-SPECIFIC TRANSPORTATION MODELLING

Refer to schematic for Pakistan's transport sector representation in GCAM shown in **Figure 10**. For this EV study, the focus of the GCAM runs is on road transportation up to 2050. Pakistan's road technologies in GCAM include two-wheelers (mopeds, motorcycles, and scooters), three-wheelers (e.g., autorickshaws), cars (mini cars, subcompact cars, compact cars, multipurpose vehicles and light delivery vehicles), buses, and trucks (0-2 tons, 2-5 tons, 5-9 tons, and 9-16 tons). All of these transport classes have the capability to include both

[8] https://jgcri.github.io/gcam-doc/energy.html#transportation.

conventional liquids and BEV technologies. Cars additionally can have hybrid liquids and fuel cell electric vehicle technologies.

Figure 10: Transportation modes in GCAM for Pakistan



B.4 VEHICLE ASSUMPTIONS

GCAM uses vehicle cost assumptions based on data from NREL (Jadun, et al. 2017) adjusted for battery costs (see below). Energy intensity comes from Jadun, et al. (2017) and other assumptions, such as load factor, annual distance traveled and base year energy use, come from Mishra, et al. (2013). When possible, these were adjusted in line with SEP assumptions and market research based on Pakistan-specific data (**ANNEXURE A**).

Each region in GCAM has a specific set of vehicle classes, and classes have different input assumptions. Pakistan's vehicle classes and their assumptions are summarized in **Table 26** below.

Table 26: Pakistan vehicle assumptions

Mode	Size classes	Technologies	Input assumptions
2-wheel LDV*	Moped Motorcycle (50-250cc) Scooter	Liquids Battery electric vehicle (BEV)	Annual travel per vehicle Base year energy use Intensity Load factor Speed Capital costs (purchase) Capital costs (other) Capital costs (infrastructure) Operating costs (maintenance) Operating costs (registration and insurance) Operating costs (tolls)

Mode	Size classes	Technologies	Input assumptions
3-wheel LDV	Three-wheeler	Liquids Natural gas BEV	Annual travel per vehicle Base year energy use Intensity Load factor Speed Capital costs (total) Operating costs (total non-fuel)
4-wheel LDV*	Mini car Subcompact car Compact car Multipurpose vehicle	Liquids Hybrid liquids Natural gas BEV Fuel cell electric vehicle (FCEV)	Annual travel per vehicle Base year energy use Intensity Load factor Speed Capital costs (purchase) Capital costs (other) Capital costs (infrastructure) Operating costs (maintenance) Operating costs (registration and insurance) Operating costs (tolls)
Bus	Bus	Liquids Natural gas BEV	Base year energy use Intensity Load factor Speed CAPEX (annualized purchase cost) and non-fuel OPEX
Freight truck*	Truck (0-2t) Truck (2-5t) Truck (5-9t) Truck (9-16t)	Liquids Natural gas† BEV	Base year energy use Intensity Load factor CAPEX (annualized purchase cost) and non-fuel OPEX
Walk	Walk	N/A	Base year service output Speed
Cycle	Cycle	N/A	Base year service output Speed
Rail	Passenger Rail Freight Rail	Coal (freight only) Electric Liquids Tech-adv electric Tech-adv liquids	Base year energy use Intensity Load factor CAPEX and non-fuel OPEX Operating subsidy Speed (passenger only)
Air domestic **Air international**	Air domestic Air international	Liquids	Base year energy use Intensity Load factor Speed CAPEX

Mode	Size classes	Technologies	Input assumptions
			Non-fuel OPEX
Ship domestic **Ship international**	Ship domestic Ship international	Liquids	Base year energy use Intensity Load factor CAPEX and non-fuel OPEX

* SEP assumes trucks 0-1t as part of cars/LDVs and an appropriate adjustment is made in the EV penetration curves by GCAM.

† In Pakistan, ICE trucks consume mainly diesel, as per SEP assumptions.

B.4.1 Vehicle Capital Costs

The current updated GCAM version contains vehicle assumptions for all model years (in 5-year timesteps). Battery electric technologies were added for trucks and buses in all regions. Purchase cost assumptions for both BEV and liquids cars, trucks, and buses from 2020 to 2050 were updated based on NREL's Electrification Futures Study (Jadun, et al. 2017).[9] BEV costs and energy intensity vary between technology advancement scenarios as discussed below.

Capital cost assumptions in GCAM are defined as:

- Purchase cost: Ex-factory cost or import cost before applying government duties/taxes
- Other capital costs: Duties and taxes added to purchase costs.

In the core version of GCAM, only car and truck technologies are vintaged. This feature was added for buses, two-wheelers and three-wheelers by adding lifetimes and retirement functions. For buses, these were copied from light trucks, which have a lifetime of 25 years. For two-three wheelers, the maximum lifetime was assumed as 10 years. The definitions of vehicle vintage parameters are given below:

- Retirement function: Phased retirement function, for technologies whose assumed lifetime is greater than one model timestep. Output is calculated using the following equation:

$$\text{Output fraction} = \frac{1}{1 + e^{\text{Steepness} \times (t - \text{Half-life})}}$$

Note: Lifetime: maximum lifetime of cohort

Half-life: number of years at which 50% of the cohort is retired

Steepness: shape parameter used by the s-curve-shutdown-decider retirement function

Table 27 gives a summary of key assumptions in GCAM for all vehicle categories.

Table 27: Vehicle parameters assumed in GCAM modeling

Category	Lifetime	Half Life	Steepness
Two wheelers	10	7	0.45
Three wheelers	10	7	0.45
Cars/4-wheel LDVs	25	12	0.193

[9] For cars, NREL's cost data was pegged to the UCD size class of U.S. midsize car. The ratios between vehicle costs in the original UCD database were used to scale the updated U.S. midsize car costs to other size classes and regions. For trucks, a cost per ton was calculated and used to scale costs to all truck size classes (determined by the midpoint of the load factor). Truck costs do not vary by region.

Buses	25	12	0.193
Trucks (0-2T)	25	12	0.193
Trucks (>2T)	40	20	0.122

Pakistan-specific manufacturing and purchase costs are illustrated later after applying regional correction factors, assumptions for local production (localization) and technology pathways with revised battery costs.

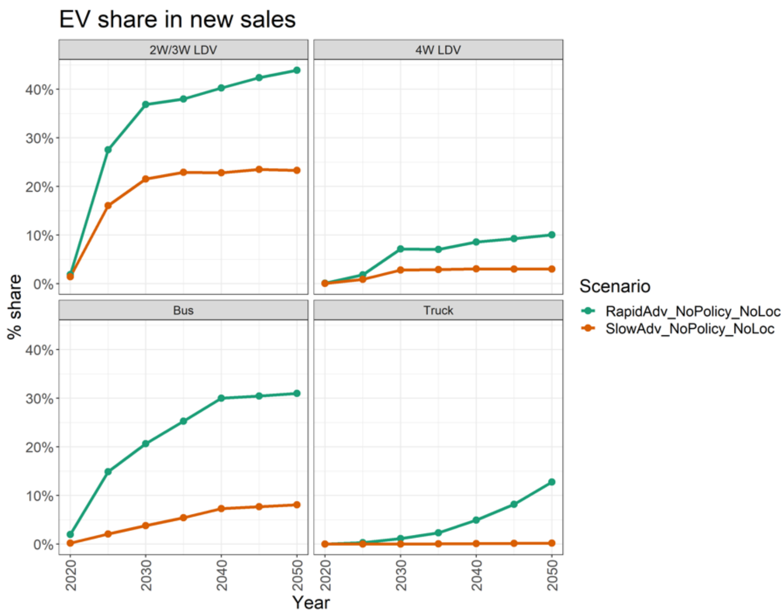
B.4.2 EV Technology Advancement Pathways

As future battery technology development remains quite uncertain, three EV technology advancement cases are represented in GCAM:

- **Slow:** Slow advancement in EV capital costs and fuel intensity
- **Moderate:** Moderate advancement in EV capital costs and fuel intensity
- **Rapid:** Rapid advancement in EV capital costs and fuel intensity.

The slow and rapid advancement cases represent the full range of possibilities for future EV development. EV penetration is influenced by the technology pathway assumed, as illustrated in **Figure 11** below.

Figure 11: EV penetrations versus technology pathways (no policy, no localization scenarios)



Recent data shows that battery pack costs have fallen faster than widely projected (Nykvist and Nilsson 2015; Berckmans, et al. 2017; Holland 2018; Kittner, Lill, and Kammen 2017). For example, according to Bloomberg New Energy Finance, battery costs in 2019 had dropped to $156 per kWh ("Battery Pack Prices Fall as Market Ramps Up with Market Average at $156/kWh in 2019" 2019), which NREL's Electrification Futures Study (EFS) projected would be only be reached by between 2025 and 2030 in the rapid case and not until after 2050 in the slow case (Jadun, et al. 2017).

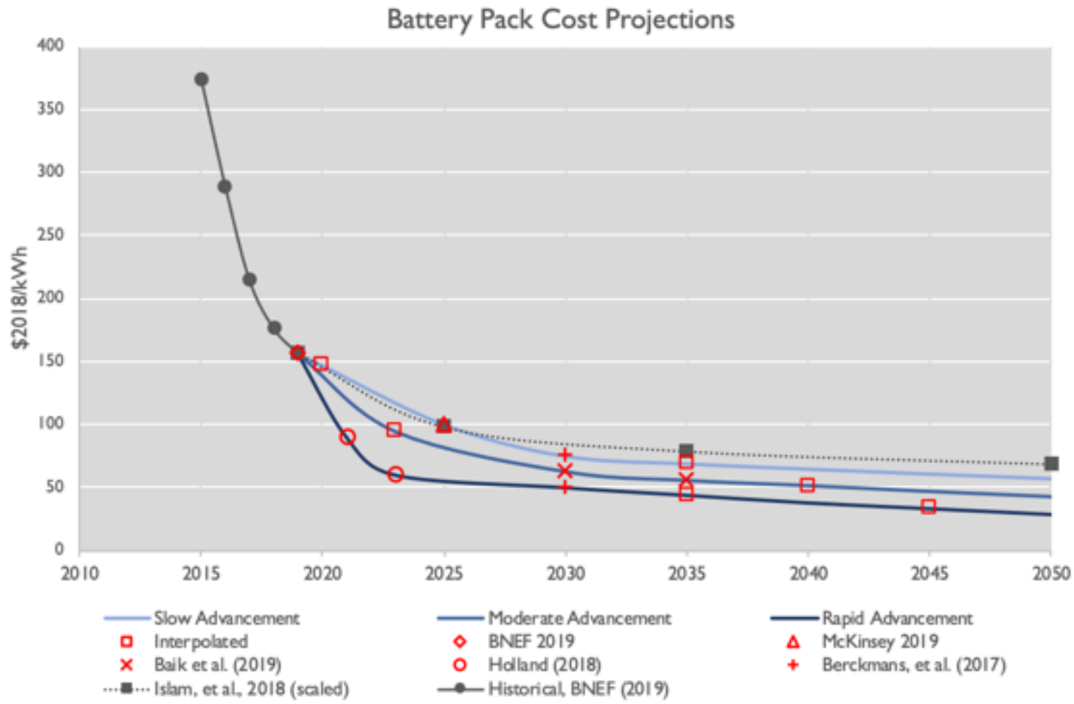
Table 28 shows previous and recent battery cost projections. Under the new projections, for slow advancement, battery costs drop from $156/kWh in 2018 to $68/kWh in 2050, while under rapid advancement battery pack costs reach $29/kWh in 2050.

Table 28: Projections of vehicle battery costs

	EFS (NREL) Battery Cost 2018 $/kWh				New Battery Cost 2018 $/kWh		
Year	Slow	Moderate	Rapid	Year	Slow	Moderate	Rapid
2016	285	285	285	2019	156	156	156
2020	269	257	242	2020	146.3	140.5	123
2025	248	222	188	2025	97.5	84.9	57.1
2030	229	188	136	2030	87.8	62	50
2035	209	167	93	2035	78.1	55	44
2040	200	159	83	2040	74.7	50.8	38
2045	191	149	83	2045	71.3	46.3	33.4
2050	183	140	83	2050	67.9	42.1	28.9

Updated battery cost curves and sources are given in **Figure 12** below for the three technology advancement pathways.

Figure 12: Battery cost projections



B.4.3 Battery Vintaging Factors

A battery vintaging factor is calculated to account for batteries not lasting the full vehicle lifetime (**Table 29**). It is assumed that batteries last 10 years and then take the weighted average of battery packs needed over a vehicle's lifetime, using the retirement function to estimate the share of vehicles still in use after certain timesteps. The cost of battery replacement is assumed as part of the vehicle manufacturing cost.

Table 29: Battery replacement cost assumptions

Percent of Market %	Year	Battery Packs	Weighted Average of Augmented Battery Packs to Last Vehicle Lifetime
4W LDVs and buses (starting in (2020)			
0.6	2030	1	**1.17**
0.18	2040	2	
0.07	2045	3	
Freight trucks (starting in (2020)			
0.65	2035	1	**1.35**
0.23	2050	2	
0.08	2060	3	

For cars, buses, and light duty trucks (vehicles with 25-year maximum lifetime), the battery vintaging factor is 1.17 and for medium and heavy-duty trucks (vehicles with 40-year maximum lifetime) it is 1.35. For two-three wheelers, it is assumed that no battery replacement is necessary.

The battery portion of the manufacturing cost of the vehicles is multiplied by the vintaging factor.

B.4.4 Impact of New Battery Costs on BEV Purchase Costs

Vehicle purchase costs (ex-factory) were updated to reflect the new battery cost curves for each vehicle category. While these assumptions are aggressive, they are based on recent data and projections considering the unexpectedly fast drop in battery costs recently witnessed. The battery share of total purchase cost was estimated (or derived) from published cost projections for vehicle components. An additional battery vintaging factor is added to account for batteries not lasting the full vehicle lifetime; this was not included in the old purchase cost. Purchase costs represent the ex-factory cost, excluding duties and taxes applied later to the costs. For each vehicle category, the new purchase cost is computed as follows:

Old battery cost = Old (from EFS data) purchase cost x Battery share of purchase cost

New battery cost = Old battery cost x (New battery $/kWh)/(EFS battery $/kWh) x Battery vintaging factor

New purchase cost= Old purchase cost – Old battery cost + New battery cost

A brief discussion on the approach is given below.

- For 2-wheelers, in the absence of data on battery share of cost from Autonomie (Moawad, et al. 2016), it was assumed that the battery is 37.5% of vehicle cost in 2020. This is based on assumption that 50% of the total cost of two-three wheelers are due to EV components and batteries constitute 75% of the EV component cost, which is generally true for compact cars from the Autonomie data. It was assumed that the battery share of purchase cost decreases at the same rate as it does for compact cars, from Moawad, et al. The costs were updated based on the new battery curves after scaling for cost parity with ICEVs in 2020 and creating slow, moderate and rapid curves using NREL's battery costs and the same battery cost share as described above. Instead of the percent change from NREL, we decrease future costs based on the scaled 2020 value and percent change from 2020 battery costs.

Old battery cost = 2020 purchase cost x Battery share of purchase cost

New battery cost = Old battery cost x (New battery \$/kWh)/(2020 battery \$/kWh) x Battery vintaging factor

New purchase cost= Old purchase cost – Old battery cost + New battery cost

- For 3-wheelers, the purchase costs were modified. New costs were calculated the same way as for two-wheel and cars/LDVs, but since the assumption is purchase costs rather than manufacturing, an extra factor was added for the manufacturing cost share of purchase cost. Therefore, costs are calculated as:

  Old battery cost = 2020 capital cost x Battery share of purchase cost x Purchase cost share of total capital cost

  New battery cost = Old battery cost x (new battery \$/kWh)/(2020 battery \$/kWh) x Battery vintaging factor

  New capital cost = Old capital cost – Old battery cost + New battery cost

  Taxes and fees for the Southeast Asia region in the default GCAM assumptions are 35% of the price (Mishra, et al. 2013), so 65% of the total capital cost is assumed to be purchase cost.

- For trucks, CAPEX and non-fuel OPEX (\$/vehicle-km) were modified by estimating the battery share of the levelized cost. Due to lack of data on the cost components of medium and heavy-duty truck classes, the battery share of manufacturing cost for BEV 100 pickup trucks was assumed from the Autonomie data (again using the average non-battery tech curve) for all truck classes. The manufacturing cost share of non-fuel levelized cost was based on the component cost shares for compact cars using 2020 moderate advancement costs. Thus, the new costs were calculated as:

  Old battery cost = Old (NREL) CAPEX/non-fuel OPEX x Purchase cost share of CAPEX/non-fuel OPEX x Battery share of purchase cost

  New battery cost = Old battery cost x (new battery \$/kWh)/(EFS battery \$/kWh) x Battery vintaging factor

  New CAPEX/ = Old CAPEX/non-fuel OPEX – Old battery cost + New battery cost
  non-fuel OPEX

- Similar to trucks, the battery share of cost was estimated based on recent electric bus prices in China, the battery size of Proterra's 440 kWh e-bus, and the 2019 battery pack price of \$156/kWh. Based on this, the share is 12.5% of cost in 2020, which was decreased over time at the same rate as the battery share of cost for BEV 100 pickup trucks from Moawad, et al. (2016). The capital cost share of non-fuel levelized cost comes from the EFS report. New costs are calculated as:

  Old battery cost = Old (EFS) CAPEX/non-fuel OPEX x Purchase cost share of CAPEX/non-fuel OPEX x Battery share of purchase cost

  New battery cost = Old battery cost x (New battery \$/kWh) / (EFS battery \$/kWh) x Battery vintaging factor

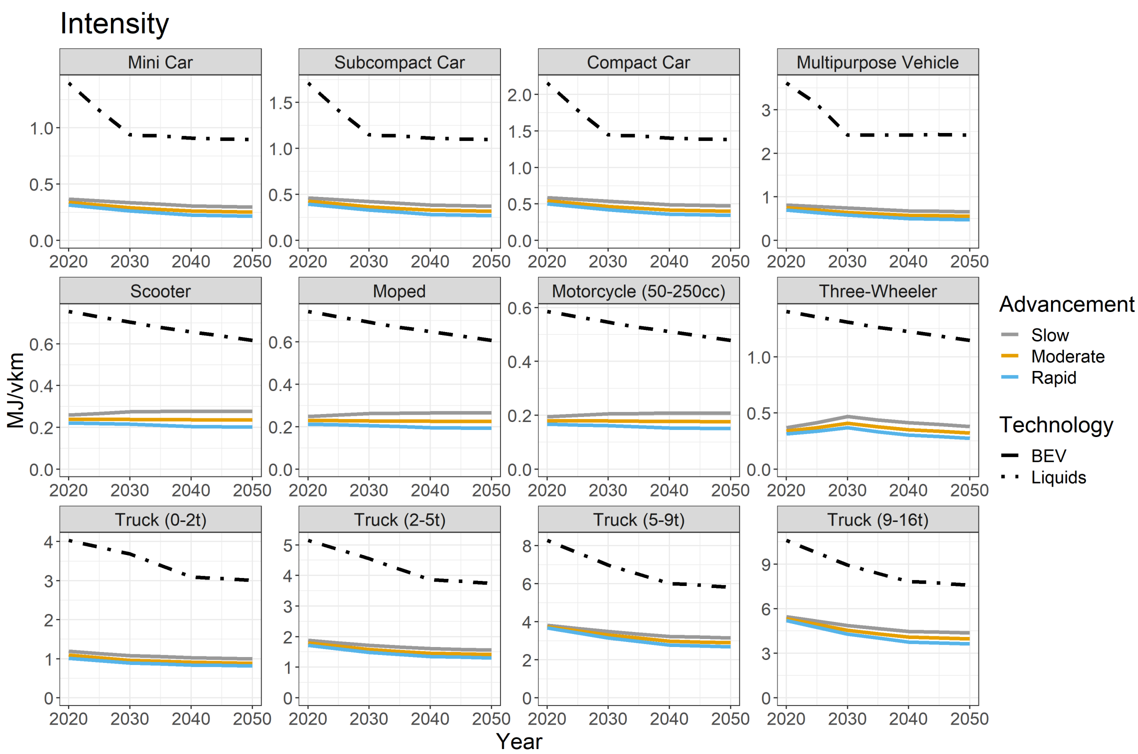
New CAPEX/non-fuel OPEX = Old CAPEX/non-fuel OPEX – Old battery cost + New battery cost

- Infrastructure costs also vary between the technology advancement scenarios based on the NREL EFS data but are left unchanged and only manufacturing (capital) costs are updated based on the new battery cost curves below.

B.4.5 Energy Intensity

Energy intensity of EVs varies with technology advancement scenario. Intensity under rapid advancement is on average 12-23% lower than intensity under slow advancement, as shown in **Figure 13**.

Figure 13: Energy intensity comparison by EV advancement pathway



B.5 PAKISTAN-SPECIFIC TRANSPORTATION CHANGES

A number of updates were made to the assumptions for Southeast Asia, including Pakistan:

- BEV three-wheelers were added as a technology to reflect locally available vehicle types. Based on SEP assumptions, the three-wheeler annual travel per vehicle was increased from 8,478 kilometers per year to 32,000 kilometers per year.
- The purchase cost assumptions for two-three wheelers in Southeast Asia were updated based on market data in Pakistan. A typical gasoline-powered motorcycle model in Pakistan costs about $800, about 59% of the purchase cost assumption in the UCD database, so all liquids two-wheeler purchase costs were scaled by this percentage. Assuming electric two-wheelers are already at levelized cost parity with conventional ICE two-wheelers in Pakistan, purchase costs for BEVs in 2020 were estimated using ICEV cost assumptions and assuming equal levelized costs. Duties/taxes in Pakistan under the ADP and NEVP are then applied to the purchase cost.
- As Pakistan-specific cost data is limited in GCAM, the BEV three-wheel purchase costs in 2020 were estimated using the ratio of liquids motorcycles to three-wheelers in Southeast Asia in the original UCD database. This ratio (1.37) is then multiplied by the BEV motorcycle purchase cost to calculate three-wheel BEV purchase costs under the assumption of levelized cost parity between ICEVs and EVs in 2020. After 2020, purchase costs decrease according to the battery costs given in the three technology advancement pathways.
- The BEV mini car manufacturing costs and fuel intensity were updated to match the assumptions for India. This was the only car class and technology where assumptions did not match those in India, for unclear reasons, so this discrepancy was corrected.
- In addition, market survey data provided by ANL indicated that purchase costs for ICE light trucks and buses are significantly lower in Pakistan than the U.S. Based on the data available, vehicles in Pakistan were about 40% of the cost of comparable U.S. vehicles, so the purchase costs for ICE buses, 0-2 ton trucks, and 2-5 ton trucks were scaled down from their U.S. values to represent this regional knockdown factor.
- Cost assumptions for ICE buses and trucks are given as levelized non-fuel cost (per vehicle-kilometer traveled); Based on cost assumptions for compact cars, purchase costs constitute about 76% of non-fuel levelized costs, and after applying the 40% capital cost regional knockdown factor to that share of the levelized cost, the purchase costs for ICE buses and trucks are estimated. This applies to all technology pathways within these classes. The cost difference appears to be less significant for heavy-duty trucks, so these costs are left unchanged at par with U.S. costs. Duties/taxes in Pakistan are then applied to the assumed purchase costs.
- In GCAM, bus costs are levelized by dividing by annual distance traveled of 51,708 km/year, while SEP assumes buses travel 72,000 km per year. For consistency, the bus levelized costs were scaled by 51708/72000 to implicitly change annual distance traveled.
- BEV truck load factors are set to 80% of liquids load factors in 2020 and linearly increase to be equal with liquids trucks in 2050. This change was made for Southeast Asia only.
- The charging infrastructure cost assumptions for BEVs come from Jadun, et al. (2017), but these were based on costs in the U.S. A large portion of these costs were for labor associated with installation and upgrades to residential electrical systems. However,

labor costs are much lower in Pakistan and many households have electrical service with a higher voltage compared to the U.S. It was assumed that one charger is required per vehicle for a typical residential power plug with 230V/10A and 100-35 km of driving daily. Based on market data in Pakistan, a Level 2 charger costs $350-500, installation cost is $50-100, and residential electrical service upgrades cost $80-135. It was assumed that an average charging infrastructure capital cost will be $580 for 4W LDVs. Charging infrastructure costs were not applied for two-wheelers, as vehicle specifications indicate two-wheeler batteries are sufficiently small that no additional charging infrastructure for residential use is required. However, the $580 charging infrastructure cost was applied to three-wheelers because of the high annual distance travelled per vehicle.

- SEP collected information on typical maintenance costs for company and staff vehicles, as well as information from an informal survey of auto workshops, vehicle drivers, etc., around Islamabad. This was used to adjust vehicle maintenance cost assumptions for LDVs. Actual average maintenance costs could be much lower than the data collected, as many owners tend to pay for maintenance only when unavoidable (Ilyas 2007). Therefore, the values were scaled to 70% to represent more realistic maintenance practices.
- The GCAM data system uses a default discount rate of 10% for consumer vehicle purchases. It should be noted that this value is only used to calculate a fixed charge rate, which converts capital costs to annualized costs as part of the levelized cost calculation. The discount rate was changed to 15%, based on loan rates of 20-21% in Pakistan[10] and inflation of 5.5% over the past five years.[11]

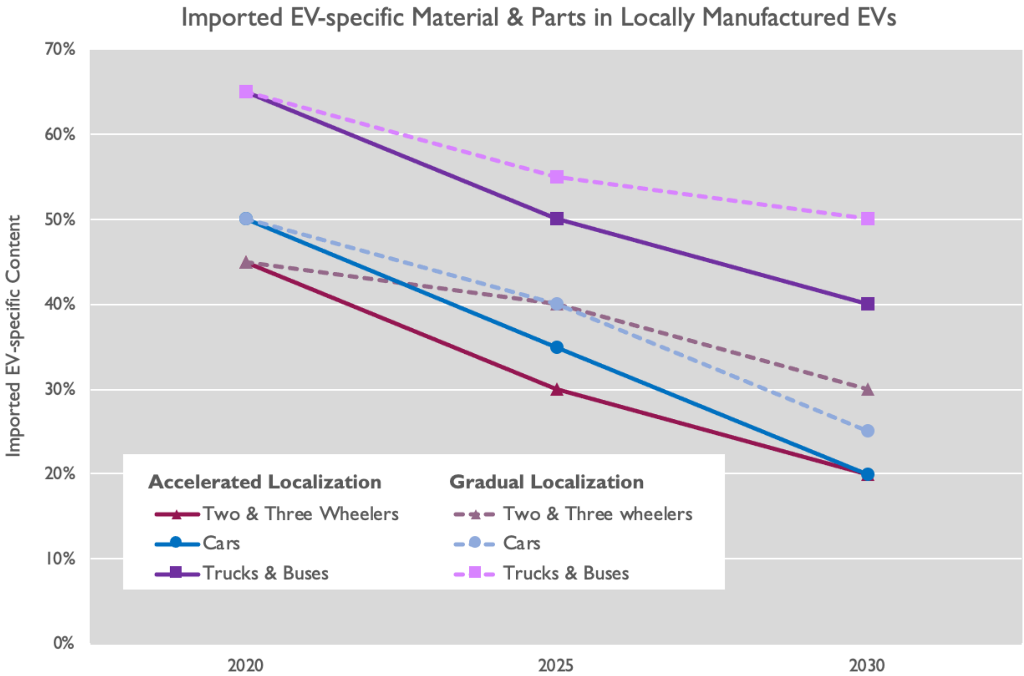
B.5.1 Localization Assumptions

There are principally two localization scenarios which have been used to develop EV penetration assessments: gradual localization and accelerated localization. Scenarios for gradual and accelerated localization are used to quantify imported EV-specific material and parts in locally manufactured/assembled electric vehicles which decline over time and help reduce vehicle purchase costs. Imported EV-specific content assumed is illustrated in **Figure 14** below for the two localization scenarios.

[10] https://www.mawazna.com/loans/carLoanSteps/2?car_value=2980000&loan_amount=2533000&loan_period=7&model_year_value=&banks_included=1%2C10%2C11%2C15%2C19%2C20&city=Islamabad&model_year=2020&car_make=1&down_payment=15&loanTerm=7&source_of_income=1&income_value=25000&bank=1&bank=10&bank=11&bank=15&bank=19&bank=20.

[11] https://www.statista.com/statistics/383760/inflation-rate-in-pakistan.

Figure 14: Projected imported EV-specific content in locally manufactured vehicles



For the two localization scenarios, composition of EV-specific imports in various vehicle categories are given in **Figure 15** for the following: local vendor imports of parts and raw material; completely-knocked-down (CKD) subassemblies; and completely-built-up (CBU) components.

Figure 15: Composition of EV-specific imports under different localization scenarios by vehicle category

B.6 Policy Scenarios

Table 30 summarizes the various EV policy scenarios modeled. These are run in combination with Slow and Rapid Advancement cost pathways (see below), for a total of eight scenarios.

Table 30: EV policy scenarios modeled

No.	Scenario	Scenario Shorthand	Description	Applies to
1	Reference	NoPolicy_NoLoc	No policies supporting EV adoption EV duties/taxes/registration based on assumption of no local manufacturing	Consumer vehicles (2, 3, 4-wheel LDVs) Buses Freight trucks
2	NEVP EV Duty Reductions, no EV localization	NEVP_NoLoc	NEVP recommendations for duty/tax/registration reductions for EVs, with no development of local manufacturing	Consumer vehicles (2, 3, 4-wheel LDVs) Buses Freight trucks
3	NEVP EV Duty Reductions, gradual EV localization	NEVP_GradLoc	NEVP recommendations for duty/tax/registration reductions for EVs, with gradual development of local manufacturing	Consumer vehicles (2, 3, 4-wheel LDVs) Buses Freight trucks
4	NEVP EV Duty Reductions, accelerated EV localization	NEVP_AccelLoc	NEVP recommendations for duty/tax/registration reductions for EVs, with accelerated development of local manufacturing	Consumer vehicles (2, 3, 4-wheel LDVs) Buses Freight trucks

B.7 DUTIES AND TAXES

Pakistan's vehicle taxes and duties are notified as a percentage of the vehicle purchase price. For ICEVs, these are based Pakistan's Automotive Development Policy 2016-2021, along with data on local manufacturing and imports of conventional liquids vehicles (Pakistan Business Council 2018). **Table 31** below illustrates the duty, taxes, and registration provisions for EVs in Pakistan under NEVP (2019) and ADP (2016).

Table 31: Vehicle duties and taxes in Pakistan under the NEVP

	Category	Year											Comment
		Y1	Y2	Y3	Y4	Y5	Y6	Y7	Y8	Y9	Y10	Y11+	
A.	**NEVP**												
A.1	Import of used EVs	15% CD											
A.2	Imported CKDs	1% GST, nil registration fee											'CKD' applies to whole vehicle (LUMS clarification)
A.3a	Import of CBUs with EV-specific parts	1% CD, 1% GST											'CBU' refers to complete EV subassemblies (LUMS clarification)

<table>
<tr><th></th><th>Category</th><th colspan="11">Year</th><th>Comment</th></tr>
<tr><th></th><th></th><th>Y1</th><th>Y2</th><th>Y3</th><th>Y4</th><th>Y5</th><th>Y6</th><th>Y7</th><th>Y8</th><th>Y9</th><th>Y10</th><th>Y11+</th><th></th></tr>
<tr><td>A.3b</td><td>Import of CBUs with localized EV-specific parts</td><td></td><td></td><td colspan="5">25% CD, 1% GST</td><td></td><td></td><td></td><td></td><td>‘CBU’ refers to complete EV subassemblies containing parts that are otherwise being manufactured locally (LUMS clarification)</td></tr>
<tr><td>A.4</td><td>Import of EV-specific components and modules</td><td colspan="7">1% CD, 1% GST</td><td></td><td></td><td></td><td></td><td>Refers to EV-specific parts or components of subassemblies not being manufactured locally (LUMS clarification)</td></tr>
<tr><td>B.</td><td colspan="13">Two- & three-wheelers</td></tr>
<tr><td>B.1</td><td>Imported EVs</td><td colspan="5">1% GST</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>B.2</td><td>Locally manufactured EVs</td><td colspan="7">< 1%GST</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>B.3</td><td>All 2W/3W EVs</td><td colspan="11">Nil registration fee and annual token</td><td></td></tr>
<tr><td>B.4</td><td>Import of EV specific parts and components (not manufactured locally) complying with intl. standards</td><td colspan="2">1% CD
1% GST</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>Differs from A.4</td></tr>
<tr><td>B.5</td><td>Imported EVs</td><td colspan="11">25% CD</td><td>Not clear if three-wheelers covered under PCT Code 8703-8090 (‘Other vehicles, with only electric motor’)</td></tr>
<tr><td>B.5</td><td>Import of 2W CBUs with swappable batteries</td><td colspan="11">1% CD, 1% GST</td><td>For import of first 20,000 CBUs and related charging infrastructure by manufacturers who demonstrate setup for local manufacture of such units and battery charging infrastructure (no timeline specified)</td></tr>
<tr><td>C.</td><td colspan="13">Cars/LTVs</td></tr>
<tr><td>C.1</td><td>Locally manufactured EVs</td><td colspan="7">< 1%GST</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>C.2</td><td>Locally manufactured EVs</td><td colspan="11">Nil registration fee and annual token</td><td></td></tr>
<tr><td>C.3</td><td>Imported EVs</td><td colspan="5">Nil registration fee and annual token</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>C.4</td><td>Import of EV specific parts and components (not manufactured locally) complying with intl. standards</td><td colspan="2">1% CD
1% GST</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>Contradicts with A.4</td></tr>
</table>

	Category	Year											Comment
		Y1	Y2	Y3	Y4	Y5	Y6	Y7	Y8	Y9	Y10	Y11+	
C.5	Import of up to 3-year old used EVs	Allowed											>3-year old imports not allowed under ADP 2016 for both ICEV & EV. 15% CD in A.1 not mentioned here
C.6	Imported EVs	25% CD											SRO issued subsequent to ADP 2016
C.7	HEVs	50%/25%											For engine sizes below/above 1,800 cc
C.8	PHEVs	50%											
D.	**Buses**												
D.1	Imported/locally manufactured EVs	Import of first 200 electric buses at 1% CD, 1% GST with the agreement that the other 800 buses will be manufactured in Pakistan (no timeline specified)											GoP will purchase 1,000 EVs and out-source to commercial operators CD on additional EV imports not specified
D.2	Import of EV specific parts for locally manufactured EVs	1% CD 1% GST											Applicability timeline not specified (to be defined in ADP 2021)
D.3	All EVs (buses)	Nil registration fee and annual token											Applicability timeline not specified (to be defined in ADP 2021)
D.4	Imported HEVs	1% CD											Only HEVs mentioned in ADP 2016
E.	**Trucks**												
E.1	Imported/locally manufactured EVs	Import of first 200 electric trucks at 1% CD, 1% GST with the agreement that the other 800 trucks will be manufactured in Pakistan (no timeline specified)											GoP will purchase 1,000 EVs and out-source to commercial operators CD on additional EV imports not specified
E.2	Import of EV specific parts for locally manufactured EVs	1% CD 1% GST											Applicability timeline not specified (to be defined in ADP 2021)
E.3	All EVs (trucks)	Nil registration fee and annual token											Applicability timeline not specified (7 years?)
E.4	Imported EVs	1% CD on HEVs											Only HEVs mentioned in ADP 2016

National EV Policy (NEVP), 2019 (Fig. 1, Page 12)

Automotive Development Policy 2016-2021 (ADP 2016)

SRO 644(1)/2018 (May 24, 2018)

Note: CKD: Completely knocked-down; CBU: Completely built-up; CD: Customs duty; GST: General sales tax; HEV: Hybrid electric vehicle; PHEV: Plug-in hybrid electric vehicle

As the GCAM model is resolving multiple subclasses of EVs, as would be needed to capture fully the duty and tax structure in the above table, assumptions are made in support of a weighted average cost multiplier for each vehicle mode and class and fuel type. Simplified general assumptions related to vehicle duty and taxes used in the GCAM model are shown in **Table 32**.

The common goals of the NEVP and ADP are to accelerate local manufacturing of EVs. Accordingly, GCAM cost inputs assume increasing local manufacturing of EVs from 2020 to 2030, which modulates overall duties over the decade. Assumed percentages of the new sales market due to local production, CKD imports, and CBU imports are provided in the table below.

Table 32: Simplified duty, taxes, and registration assumptions for EVs in Pakistan as implemented in GCAM model

<table>
<tr><th>Item</th><th>2020</th><th>2025</th><th>2030</th><th>2035</th><th>2040</th><th>2045</th><th>2050</th></tr>
<tr><td>Duties on CBUs (all types, all vehicles)</td><td>1% CD</td><td>25% CD</td><td>50% CD</td><td>50% CD
+ 1% addl. CD on imports</td><td>50% CD
+ 2% addl. CD on imports</td><td>50% CD
+ 3% addl. CD on imports</td><td>50% CD
+ 3% addl. CD on imports</td></tr>
<tr><td>Duties on CKDs (all types, all vehicles)</td><td>1% CD on EV components</td><td>1% CD on EV components</td><td>30% CD</td><td>30% CD
+ 1% addl. CD on imports</td><td>30% CD
+ 2% addl. CD on imports</td><td>30% CD
+ 3% addl. CD on imports</td><td>30% CD
+ 3% addl. CD on imports</td></tr>
<tr><td>Taxes (all vehicles unless otherwise noted)</td><td colspan="3">1% GST</td><td>6.33% GST
0.93% FED (cars)</td><td colspan="2">10.67% GST
1.87% FED (cars)</td><td>17%GST
2.8% FED (cars)</td></tr>
<tr><td>Registration (all vehicles unless otherwise noted)</td><td colspan="3">0%</td><td>0.33% (2/3W, cars)
0.67% (buses, freight trucks)</td><td colspan="2">0.67% (2/3W, cars)
1.33% (buses, freight trucks)</td><td>1% (2/3W, cars)
2% (buses, freight trucks)</td></tr>
</table>

Pakistan's vehicle taxes and duties are given as a percentage of the vehicle purchase price. For ICEVs, these are based on Pakistan's Automotive Development Policy 2016-2021, along with data on local manufacturing and imports of conventional liquids vehicles (Pakistan Business Council 2018). The final duties, taxes, and fees are assumed to be constant over time for ICEVs (**Table 33**).

Table 33: Final duty, tax and fee assumptions for ICEVs in GCAM model

Category	Duty, Tax & Fees for ICEVs (% of purchase price)
Two-wheelers	27.2%
Three-wheelers	29.6%
Cars	35.6%
Buses	35.1%

B.8 LOCALIZATION OF EV MANUFACTURING

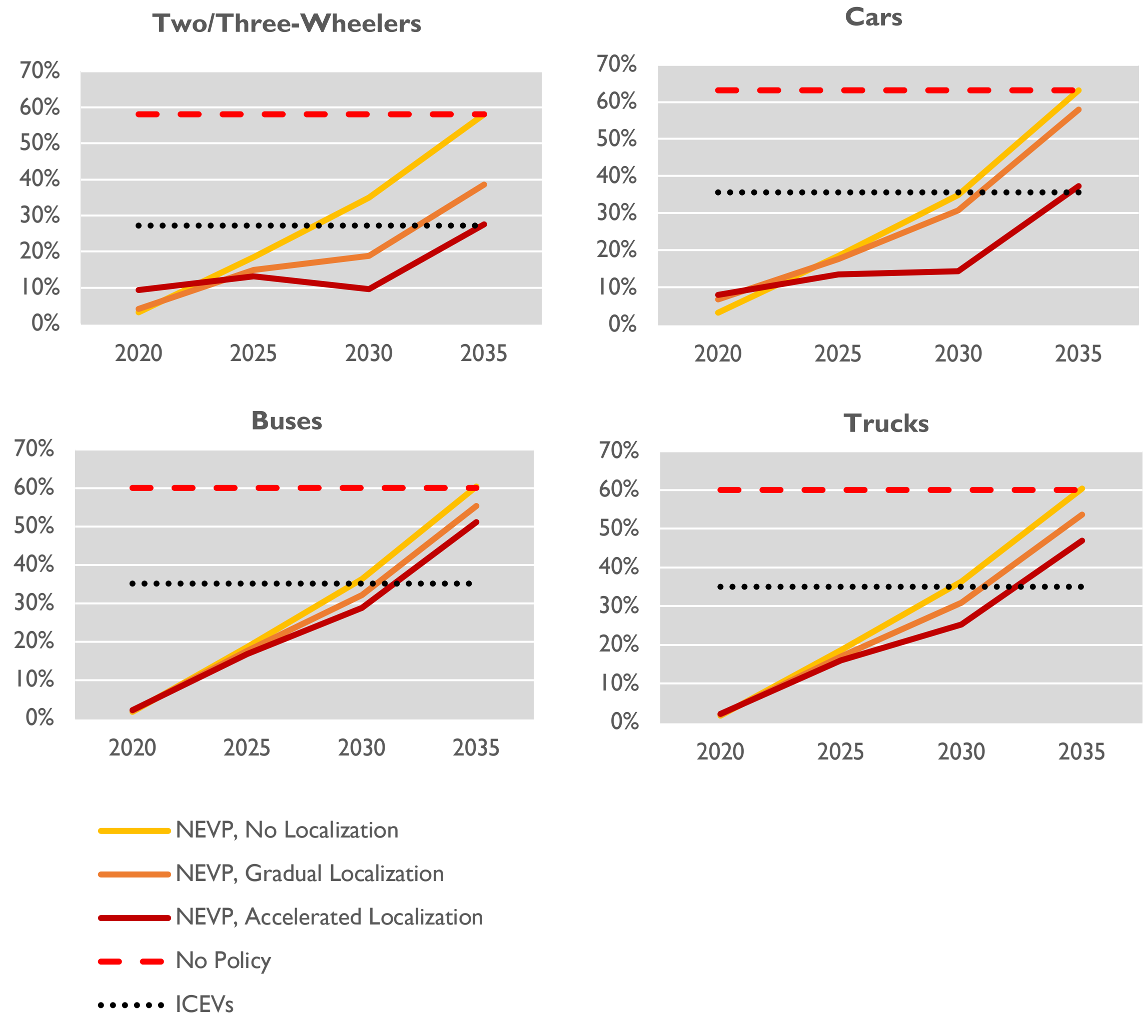
The NEVP proposes varying taxes, duties, and fees for imports and local production. For imports, duties differ depending on whether materials and parts are EV-specific or not, and whether whole vehicle imports are completely built up (CBU) or complete knocked down (CKD) units. To model the NEVP, assumptions are made about the level of EV production localization for each vehicle class. This presented a challenge for representing the policy in GCAM. For each vehicle category, taxes, duties, and fees (under the NEVP incentives) for EVs are calculated for the two localization scenarios as a percentage of the vehicle purchase cost. Only EV costs vary by policy scenario; costs and all other assumptions for ICEVs are equal across scenarios. In addition, ICEV tax, duty, and fee multipliers are constant over time, as they are not affected in the planned NEVP measures. Taxes, duties and fees on EVs under NEVP and localization scenarios are given in **Table 34** and illustrated in **Figure 16**.

Table 34: Final duty, tax and fees for EVs

Category	**Duties, Taxes, & Fees for EVs** % of Purchase Price			
Scenario	2020	2025	2030	2035
2/3Ws				
NEVP, No Localization	3%	19%	35%	58%
NEVP, Gradual Localization	4%	15%	19%	39%
NEVP, Accelerated Localization	9%	13%	10%	28%
No Policy	58%	58%	58%	58%
Cars				
NEVP, No Localization	3%	19%	35%	63%
NEVP, Gradual Localization	7%	18%	31%	58%
NEVP, Accelerated Localization	8%	13%	14%	37%
No Policy	63%	63%	63%	63%
Buses				
NEVP, No Localization	2%	19%	36%	60%
NEVP, Gradual Localization	2%	18%	32%	55%
NEVP, Accelerated Localization	2%	17%	29%	51%
No Policy	60%	60%	60%	60%
Trucks				
NEVP, No Localization	2%	19%	36%	60%
NEVP, Gradual Localization	2%	17%	31%	54%
NEVP, Accelerated Localization	2%	16%	25%	47%
No Policy	60%	60%	60%	60%

Note: Duties, taxes and fees above are based on assumptions of shares of EVs and EV-specific parts that are imported and locally produced over time.

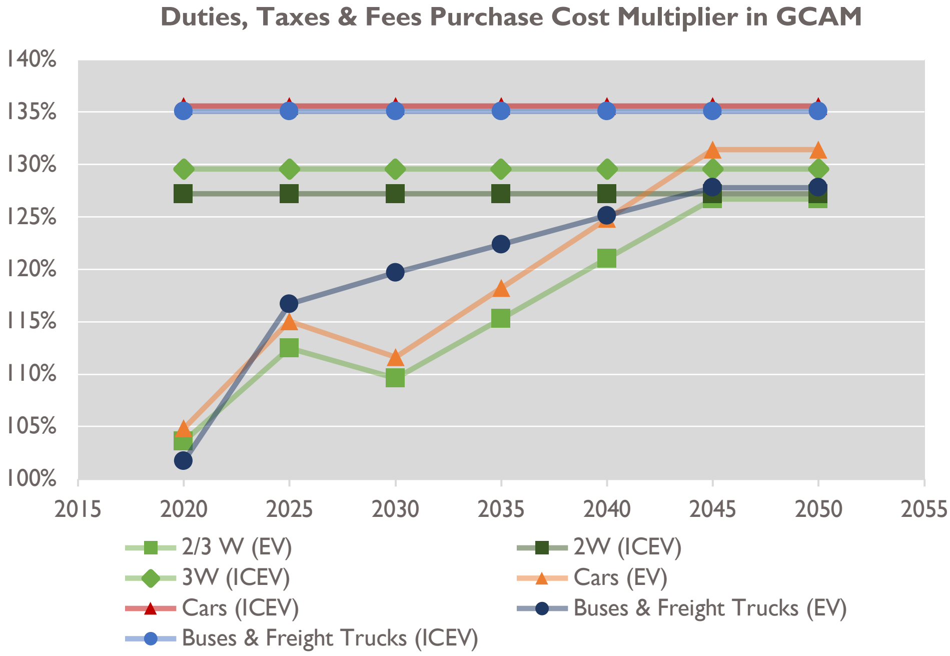
Figure 16: Duties and taxes on EVs/ICEVs by category



B.9 EV MANUFACTURING COST MULTIPLIERS

The resulting manufacturing cost multipliers for each vehicle category are shown in **Figure 17**. The duty/tax multipliers are applied to the manufacturing cost (ex-factory) to estimate purchase cost for consumers. The dip for the two- and three-wheelers and cars are a result of aggressive transitions to local manufacturing ahead of 2030 and the resulting reductions in duties. After the NEVP period, duties are assumed to gradually approach the levels of ICEVs by 2045, though differences in imports versus local production continue to drive smaller differences in duties in 2045 and beyond between EV and ICEVs for all vehicle classes. Since GCAM runs in five-year time intervals, NEVP incentives are quantified for 2025 and 2030.

Figure 17: Duties, taxes, and fees cost multipliers as implemented in GCAM study



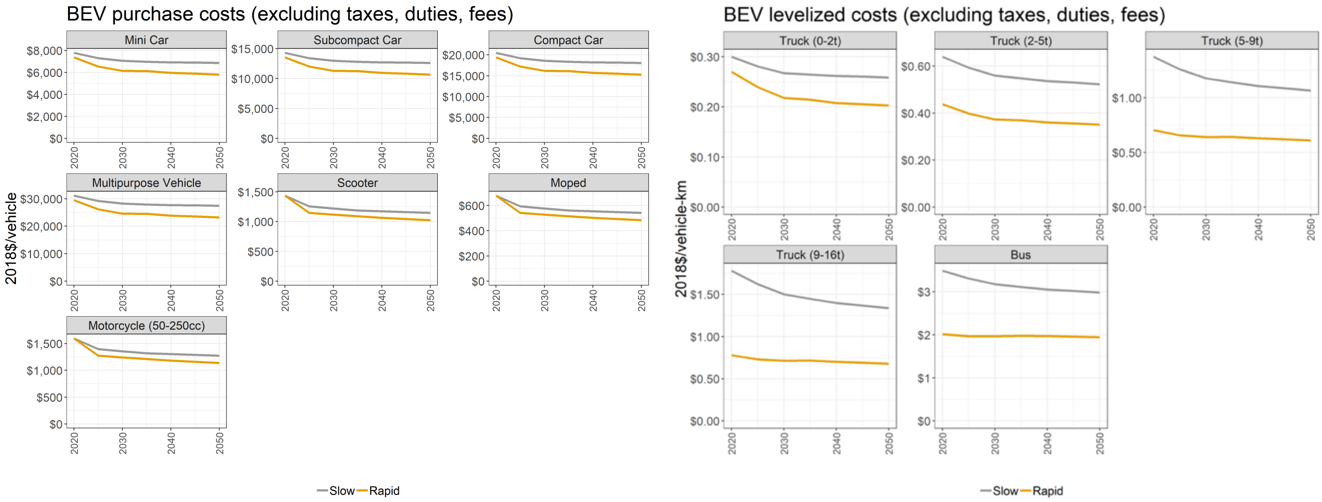
Since vehicle classes have different types of capital cost assumptions, we implement the cost multipliers based on Pakistan's taxes, duties, and fees in different ways. For 2-wheel and 4-wheel LDVs, we simply change capital costs (other), which represents sales tax and other costs not included in the manufacturer-suggested retail price, to the given percentage of the purchase price. For 3-wheelers, taxes are included in capital costs (other), and for Southeast Asia average 35% of purchase price (Mishra et al. 2013). We adjust that 35% to the given taxes, duties, and fees multiplier for each scenario. For buses and trucks, the cost assumption is levelized CAPEX and non-fuel OPEX. We use the cost assumptions for multipurpose vehicles (under the Moderate Advancement scenario) to estimate the purchase cost share of levelized cost. This is about 54% for ICEVs and 58% for BEVs, because of the higher capital costs of BEVs. We use these shares to apply taxes, duties, and fees multipliers to truck and bus costs.

In 2020, the NEVP incentives are more generous for imported EVs and EV-specific parts in the absence of localized production, so the tax, duty, and fee multipliers are lower in the scenarios with lower localization since imports make up a larger share of EVs. In 2025 and 2030 this is reversed; taxes, duties, and fees are lower in scenarios with higher localization because the NEVP incentives are aimed at incentivizing local production. Beyond 2030, after the NEVP is no longer in effect, these costs remain lower for vehicles with higher levels of local production.

B.10 ICEV AND BEV COSTS

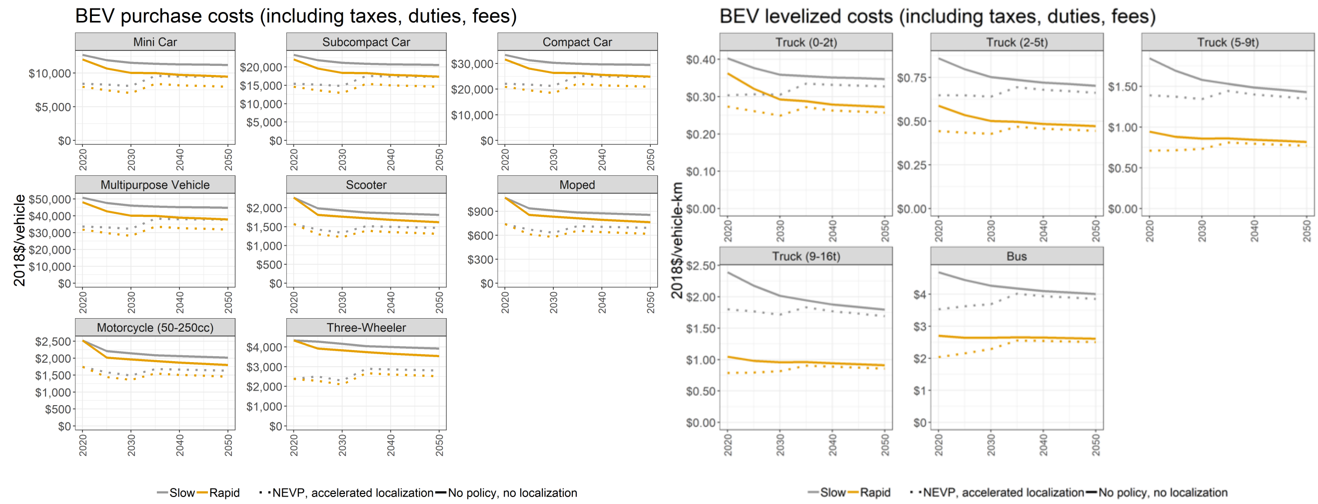
The manufacturing cost of ICEVs and EVs are based on GCAM estimates localized to Pakistan for gradual and accelerated localization and slow and rapid technology advancement factors for each category of vehicles. These are given in **Figure 18** below for 2018 $/vehicle.

Figure 18: GCAM projections for BEV manufacturing costs in Pakistan



Purchase costs of ICEVs and EVs are estimated after applying duties and taxes applicable under Pakistan's auto and EV policies to the manufacturing costs. These are given in **Figure 19** for 2018 $/vehicle.

Figure 19: GCAM projections for BEV purchase costs in Pakistan



Levelized purchase cost of vehicles is defined as:

$$\text{Cost per vehicle-km} = \frac{(\text{Capital costs x vehicle fixed charge rate}) + \text{Annual operating costs}}{\text{Annual distance traveled}}$$

The vehicle fixed charge rate is used to amortize capital costs and is defined as:

$$\text{Fixed charge rate} = \text{Discount rate} + \frac{\text{Discount rate}}{(1 + \text{Discount rate})^{\text{Amortization period}} - 1)}$$

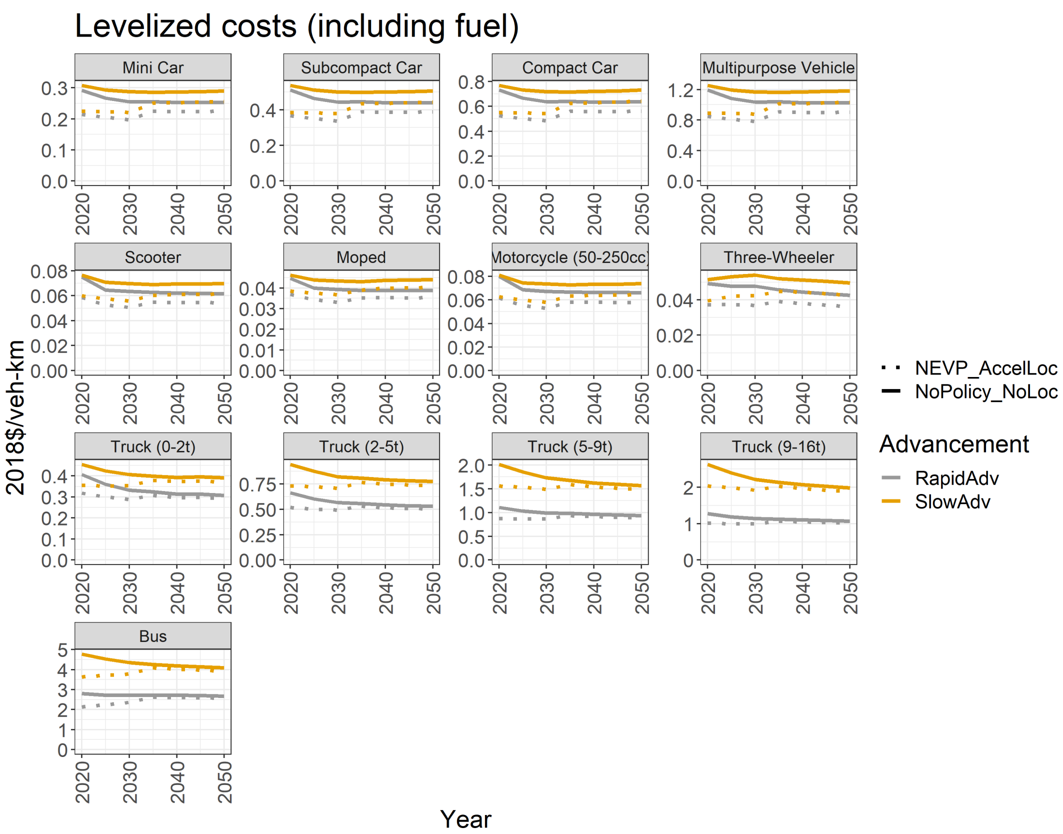
Levelized vehicle costs include:

- Capital cost amortized over 10 years at 15% real discount rates based on Pakistan vehicle finance lending rates (20%) adjusted to remove inflation (5%).
- Operating (fuel and non-fuel) costs after factoring in vehicle distances travelled, fuel intensities, and domestic charging infrastructure costs.

Levelized costs by vehicle type are illustrated in **Figure 20** (2018 $/vehicle-km) for the gradual/accelerated localization and slow/rapid technology advancement factors for each category of vehicles. Lifecycle cost parity of ICEVs and BEVs is based on the levelized vehicle costs shown.

Various cases/scenarios are assumed for localization and technology advancement factors which influence vehicle costs. EVs reach purchase cost parity with ICEVs on a levelized basis sooner under accelerated localization and rapid technology advancement scenarios compared to gradual localization and slow technology. This is because the equivalent taxes, duties, and fees (as a percentage of the purchase cost) reduces for accelerated localization, while vehicle manufacturing cost reduces with rapid technology advancement. The range of possible costs is wider for large vehicles, such as freight trucks, as the battery makes up a larger share of the total cost for these vehicles and electrification of heavy-duty vehicles is subject to higher uncertainty.

Figure 20: Levelized BEV cost projections by category and scenario



B.11 CONSUMER PREFERENCES FOR BEVS

GCAM accounts for non-cost related consumer preferences in vehicle purchase decisions via two methods explained below.

B.11.1 Share Weights

Transport technologies in GCAM each have a share weight value, which generally represents non-cost factors influencing adoption, such as product availability, supply chain and service network maturity, and consumer preferences. Share weights serve as a representation of consumer preferences in two ways: first, to calibrate the model to historical IEA energy balance data and absorb regionally specific preferences in historical years, and second, to allow new technologies to be phased in gradually. EV share weights for all vehicle types are calibrated to 0 in the base year (2010) and gradually increase to 1, on par with conventional liquids vehicles. To reflect current levels of EV penetration, the share weight assumptions were modified to show near-zero EV penetration in 2020. Share weights increase to 1 (indicating parity with conventional liquids vehicles on all non-cost characteristics, such as availability, functionality and consumer preferences[12]) in 2030 for light-duty vehicles and 2040 for buses and freight trucks. Share weights increase more rapidly for two-three wheelers to reflect lower barriers to adoption for these smaller vehicles. While it is difficult to choose an exact share weight value in a given year to represent consumer preferences, the values represent a gradual phasing in of new technologies and increasing consumer acceptance; when share weights reach 1, EVs compete with ICEVs for market share based only on cost.

Table 35: EV share weights

Category	2010	2015	2020	2025	2030	2035	2040
2/3W LDV	0	0.025	0.05	0.6	1.0	1.0	1.0
4W LDV	0	0.025	0.05	0.4	1.0	1.0	1.0
Truck, bus	0	0.025	0.05	0.4	0.6	0.8	1.0

B.11.2 Implicit Discounting of Future Cost Savings

Research has shown that consumers considering energy efficient technologies with higher capital but lower operating costs, including EVs, consistently discount the future savings they will receive (Lee and Lovellette 2011; Gallagher and Muehlegger 2011). To highlight the importance of accurate perceptions of the cost advantages of EVs, for instance to demonstrate the effect of informational campaigns, some selected scenarios were run with higher EV operating costs. These new operating costs for each LDV size class were tailored to represent a 30% discounting of future operational cost savings. Ideally this would be done by discounting both maintenance and fuel costs at a 30% rate, but as fuel costs are modeled endogenously, GCAM uses the fuel costs from the model output to calculate new maintenance costs that, when levelized, encapsulate higher discounting of all operating costs.

This method is used to model consumer behavior in addition to the share weights, as research shows discounting of future savings is a persistent effect even with mature technologies.

[12] Note that share weights do not include consumer behaviors like a higher discount rate applied to future costs savings, which persists even with mature technologies.

Implicit discounting decreases EV penetration, as upfront capital costs are more salient to the consumer than future cost savings.

B.12 POWER SECTOR CHANGES

Default GCAM power sector projections for Pakistan were adjusted based on the draft Indicative Generation Capacity Expansion Plan (IGCEP) 2019-2047 (April 2020). The key elements are explained below:

- Hydro fixed output was adjusted based on the generation projections in the IGCEP.
- The half-life of existing oil-fired power plants (time in which 50% of the cohort is retired) was reduced to reflect plans for their early retirement in the IGCEP.
- Share weights for coal, natural gas, and nuclear generation were adjusted to approximately match the fuel mix in electricity generation from 2020-2030 assumed by SEP.

The IGCEP provides an overview of Pakistan's existing power system, forecasts future electricity demand, and presents the results of expansion planning studies conducted by the Load Forecast and Generation Planning (LF&GP) of Power System Planning (PSP), National Transmission and Despatch Company (NTDC). In addition, GCAM utilizes updated capital costs for intermittent and dispatchable renewable technologies based on NREL's Annual Technology Baseline 2018 edition.

B.12.1 Fossil Fuel Based Generation

As the IGCEP does not include plans to expand generation from refined liquids, the refined liquids share weight in electricity generation in GCAM is set to 0 after 2020. Coal share weights are also increased to reflect plans in the IGCEP to expand coal-fired power generation. However, GCAM does not fully match IGCEP in this case because of feedback that the Government of Pakistan aims to revise the coal generation plan from IGCEP downward in the next version.

Table 36: Refined liquids-fired generation share weights

Year	2010	2015	2020	2025	2030	2035	2040	2045	2050
Default	1	0.95556	0.911111	0.866667	0.822222	0.777778	0.733333	0.688889	0.644444
Adjusted	1	0	0	0	0	0	0	0	0

Table 37: Coal-fired generation share weights

Year	2010	2015	2020	2025	2030	2035	2040	2045	2050
Default	0.00081317	0.00856	0.010038	0.01179	0.013864	0.016317	0.019215	0.022637	0.026672
Adjusted	0.00081317	0.250407	0.15	0.25	0.5	0.7	0.8	0.7	0.6

B.12.2 Hydroelectric Generation

Hydropower electric generation in GCAM is given as fixed output. Hydro generation for 2020-2040 has been based on the hydro generation projections given in the IGCEP. From 2040-2050, a constant linear increase in hydro generation has been assumed at the 2020-2040 average rate. Hydro generation is held constant beyond 2050, as the analysis in this study only goes through to 2050.

Table 38: Hydro generation share weights

Year	2010	2015	2020	2025	2030	2035	2040	2045	2050
Default	0.117706	0.120892	0.124078	0.127264	0.13045	0.140089	0.149728	0.159367	0.117706
Adjusted	0.117706	0.143935	0.238579	0.422274	0.530093	0.573574	0.66302	0.749482	0.117706

B.12.3 Nuclear Generation

Share weights for nuclear technologies were increased between 2015 and 2050 to align nuclear generation in GCAM with IGCEP plans. For 2020-35, generation is calculated based on capacities of committed nuclear plants in the IGCEP, assuming a capacity factor of 0.8.[13] The nuclear share weights are then iterated to get generation close to the IGCEP projections.

Table 39: Nuclear generation share weights

Year	2010	2015	2020	2025	2030	2035	2040	2045	2050
Default	0.024771	0.05	0.05	0.058333	0.066667	0.075	0.083333	0.091667	0.1
Adjusted	0.024771	0.05	0.5	1	1	1	0.1	0.1	0.1

B.13 INDUSTRY CHANGES

After making these adjustments to the power sector, electricity generation was found to be significantly higher in GCAM in early years compared other sources. In particular, GCAM industrial electricity in 2015 was higher than reported by the Pakistan Energy Yearbook and International Energy Agency. An industry electricity fuel preference elasticity of -0.5 was added and industrial income elasticity decreased by 50% to tune industrial and total electricity consumption closer to these data sources.

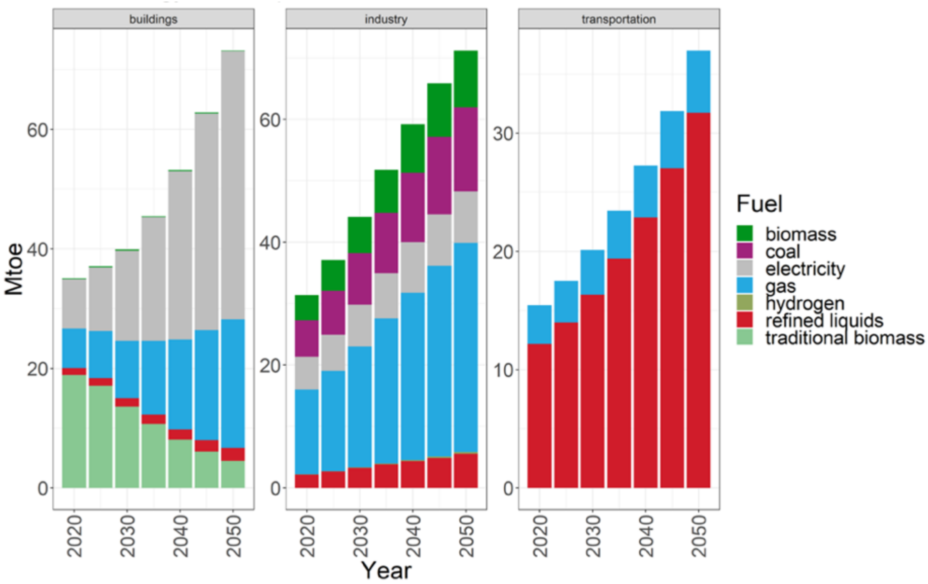
B.14 GCAM BASELINE MODELING RESULTS

This section presents GCAM's baseline representation of Pakistan's energy and transportation sector as applicable to assess EV penetration rates. However, for estimation of energy sector impacts (savings in auto fuels and consumption of electricity for EV charging), vehicle data are based on SEP's model.

In the baseline GCAM results, energy consumption increases over time along with population and GDP. Traditional biomass use declines and is replaced with electricity and natural gas. Demand for electricity increases from 159 TWh in 2020 to 630 TWh in 2050, an average of 4.7% per year, largely driven by the building sector. The industrial sector sees increased demand for all fuels, particularly natural gas. Refined liquids use increases, with consumption concentrated mainly in the transportation sector.

[13] http://world-nuclear.org/getattachment/Our-Association/Publications/Online-Reports/World-Nuclear-Performance-Report-2018-Asia-Edition/world-nuclear-performance-report-asia-2018.pdf.aspx.

Figure 21: GCAM final energy consumption for Pakistan



The electricity fuel mix is adjusted to approximately reflect plans in the IGCEP 2019, so generation from oil decreases, while coal, hydropower, solar, and wind electricity all increase. CO_2 emissions nearly triple by 2030, with increases in all sectors. Industry and electricity are the highest-emitting sectors. The largest percentage increase is from the electricity sector due to increased coal use, resulting in increased carbon intensity.

Figure 22: GCAM electricity generation by technology

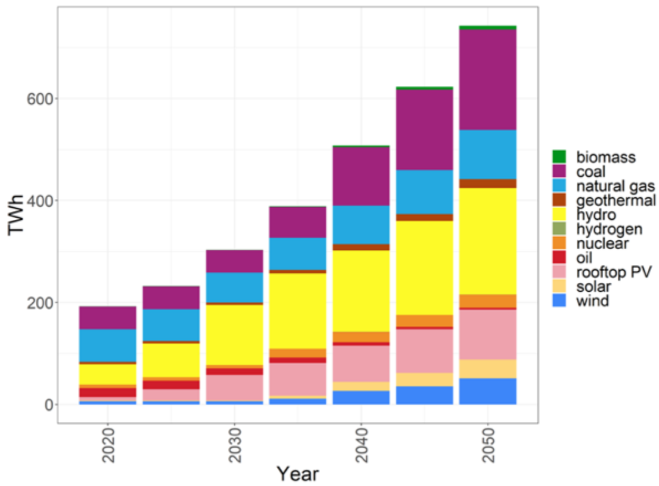
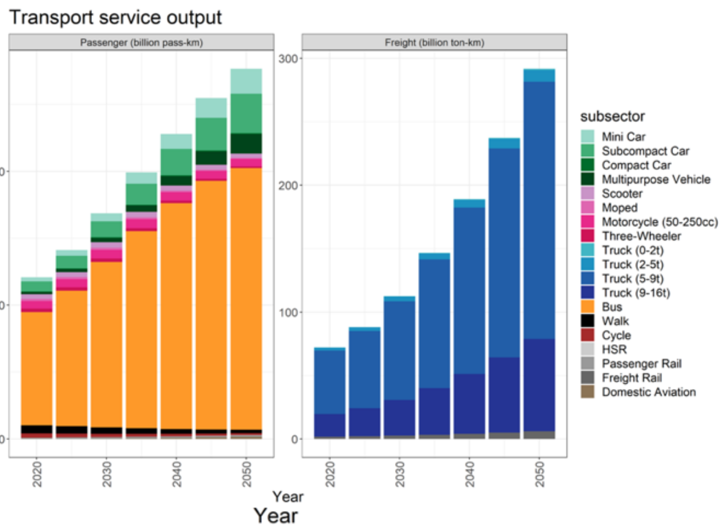


Figure 23: GCAM CO_2 emissions by sector

Transport service output in Pakistan is expected to grow significantly over the time frame considered in this study (**Figure 24**). Passenger service output is projected to grow by 130% from 2020 to 2050 while freight service output triples. Modal shift is observed over time, as demand shifts to faster modes along with increasing per capita GDP. The share of passenger service provided by cars increases from 10% to 23% between 2020 and 2050, while the share provided by two-wheelers decreases from 9% to 3%. The share of walking and cycling similarly decreases from 8% to 1% of passenger transport. The largest share of passenger service demand, about 70%, is met by buses, and this share remains relatively constant over the time frame considered.[14] Within freight transport, most service demand (about 97%) is met by trucks rather than freight rail, predominantly by the larger truck classes (5-9 tons and 9-16 tons).

Figure 24: Pakistan transport service output



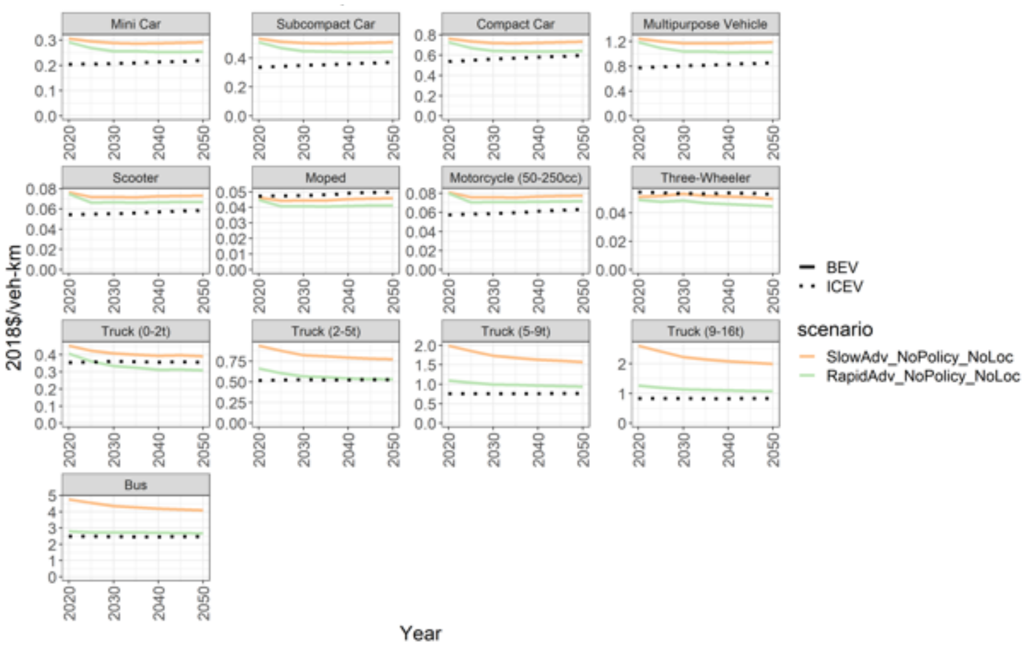
14 There are indications intracity bus travel was significantly reduced in Pakistan compared to India and China, due to cultural preference. While our data were not conclusive enough to modify share weights determining modal split, bus travel in some cities has been unreliable enough and two- and three-wheelers offer a cheaper travel mode that many have chosen.

ANNEXURE C. STANDARD SCENARIO MODELING

This section provides a detailed overview of the EV adoption projections, the costs and savings, and the energy supply and demand impacts which result from potential outcomes of the NEVP.

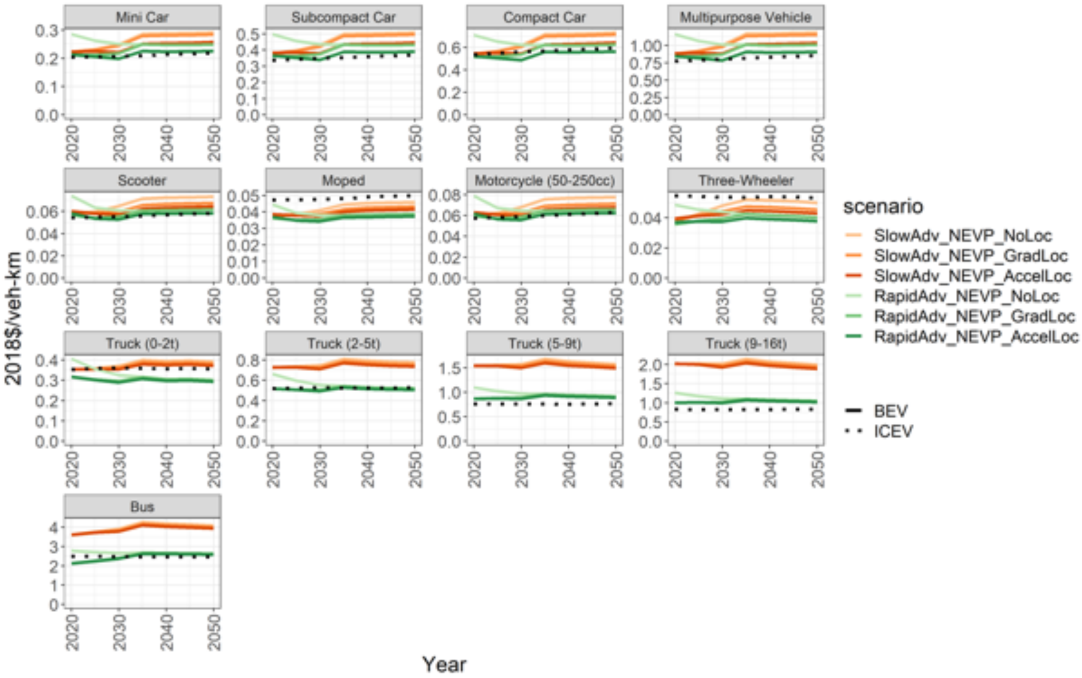
C.1 GCAM PAKISTAN EV/ICEV COST PROJECTION INPUTS

Figure 25: Levelized costs of transportation technologies by vehicle category without NEVP



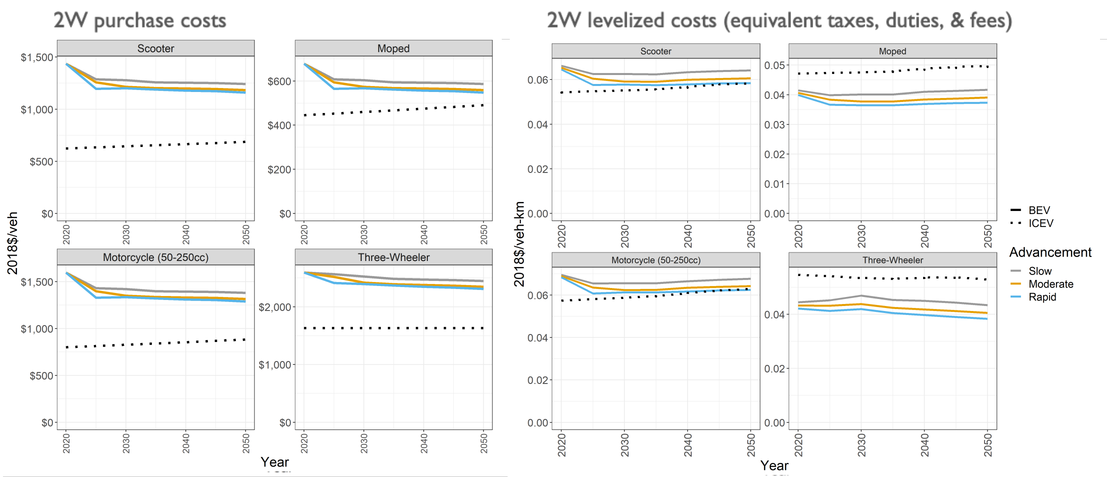
Levelized cost of EVs are comparable to ICEVs for cars/LDVs, lower for two/three wheelers and higher for buses/trucks, except for rapid advancement/NEVP case where EVs are competitive (**Figure 26**).

Figure 26: Levelized costs of transportation technologies by vehicle category with NEVP



Levelized costs for EVs are lower, but purchase costs much higher, than ICEV versions of two/three-wheelers (**Figure 27**).

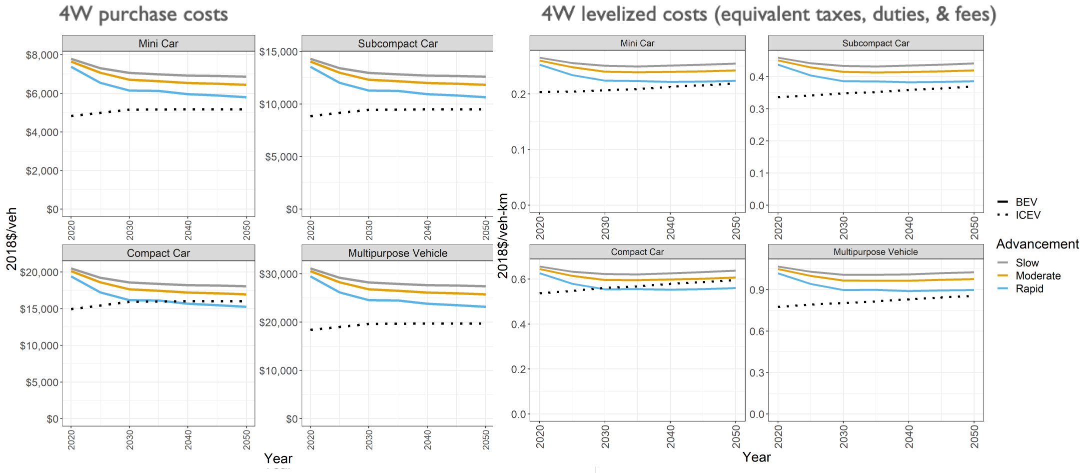
Figure 27: Vehicle purchase and levelized cost inputs for two- and three wheelers



Note: BEV two-wheeler purchase costs calculated on assumption of levelized cost parity with ICEVs in 2020, based on market trends. BEV three-wheeler costs based on adjusted BEV two-wheeler costs and cost difference between ICEV two-wheelers and three-wheelers.

Levelized and purchase costs of EVs are higher than ICEV versions of cars/LDVs, but approach cost parity in some cases (**Figure 28**).

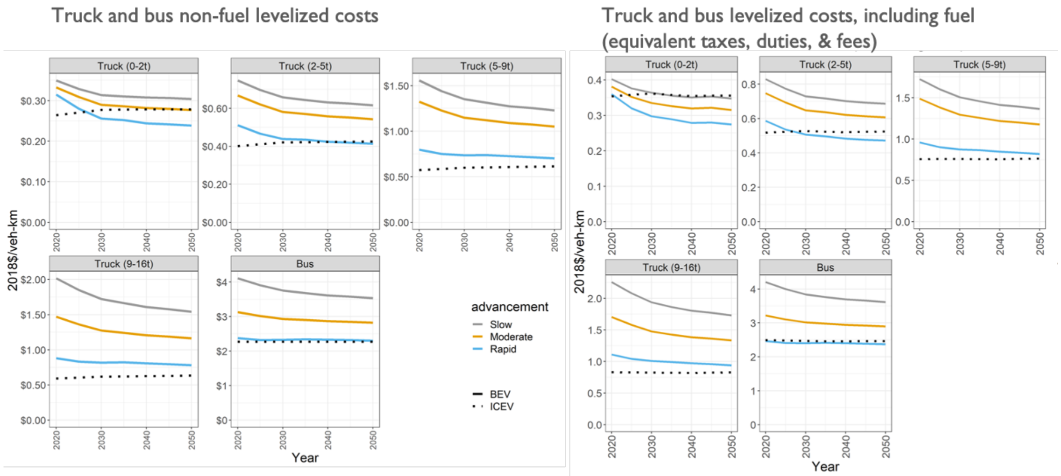
Figure 28: Vehicle purchase and levelized cost inputs for cars/LDVs



Note: Future development of EV costs and technology is uncertain. The three cost advancement pathways aim to account for this uncertainty and provide a range of possible scenarios.

Levelized and purchase costs for EVs are higher than ICEV versions for trucks and buses, except for <2t trucks in rapid advancement case beyond 2026 (**Figure 29**).

Figure 29: Vehicle purchase and levelized cost inputs for trucks and buses



C.2 GCAM PAKISTAN EV MARKET PENETRATION

C.2.1 EV Adoption Projections

EV adoption is assessed by GCAM at five-year intervals (2025 to 2050) based on the following:

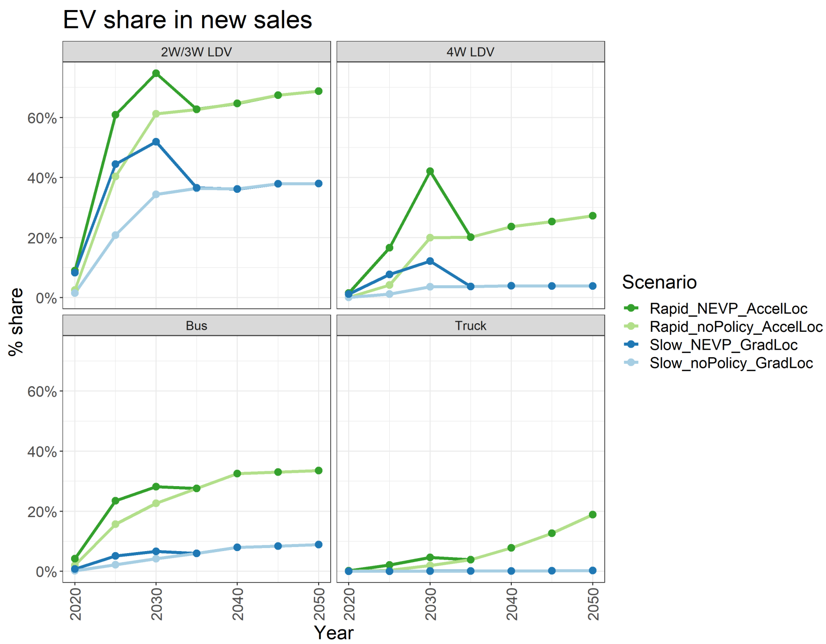
- Estimates of upfront vehicle manufacturing and purchase costs, which assume updated costs of EV components based on market research and subsequent updates to cost projections, and accounting for battery augmentation and battery cost improvements. Vehicle purchase costs also include purchase/lease payments, taxes, duties, fees, registration charges, etc.
    - Vehicle purchase costs are affected by incentives under the NEVP, localization assumptions, and technology pathways.

- Levelized costs for vehicles include purchase cost (amortized over the vehicles' lifetime), repair and maintenance cost, fuel costs based on energy intensity, distances travelled and applicable fuel tariffs (electricity, gasoline, diesel and CNG), annual token fees, road tolls and residential charging infrastructure costs.
  - Energy intensity is affected by technology pathways.
- Consumer preferences:
  - Share weight assumptions which factor in non-cost characteristics, such as availability, functionality and other consumer preferences.
  - Implicit discounting of future savings which factor in greater consumer sensitivity to higher initial costs versus any lifecycle savings.

The EV adoption (or penetration) rates computed by GCAM are illustrated in **Figure 30Error! Reference source not found.** for all vehicle categories for the following four cases which cover the range from low to high:

- No Policy – Gradual Localization - Slow Technology Advancement
- No Policy – Accelerated Localization - Rapid Technology Advancement
- NEVP – Gradual Localization - Slow Technology Advancement
- NEVP – Accelerated Localization - Rapid Technology Advancement

Figure 30: Share of EVs in new vehicles added



C.2.2 Discussion

NEVP duty/tax reductions increase EV penetration (**Figure 30**). The effect decreases by 2030-2045 as incentives taper off. NEVP encourages in-country manufacturing of EVs/components, which further decreases duties 2020-30. Two/three-wheelers show high EV penetration in all scenarios, as they are already at or near cost parity. NEVP buys 5-15% higher penetration by 2030. Once BEV capital costs drop enough, high truck energy intensities give EVs a large fuel cost advantage. This only occurs in the rapid cost advancement scenario. Vehicle costs are exogenous in GCAM, so there are no feedback resulting from higher EV adoption (e.g., cost reduction due to economies of scale, learning by doing). Because of this, the NEVP and no policy penetration curves converge as EV benefits under the NEVP are reduced.

EV market penetration is highly sensitive to the technology advancement pathway assumed. Policy and cost scenarios result in a wide range of EV adoption outcomes. EV penetration also differs greatly by vehicle class, as the smaller EVs reach cost parity with their ICEV counterparts much sooner than larger vehicles. For example, two- and three-wheelers are expected to reach lifecycle cost parity with their ICEV counterparts earlier. Similarly, EV share in certain size classes of new car sales reach cost parity sooner, such as compact cars. Electric buses have somewhat higher EV penetration than cars owing to high passenger capacity. For freight trucks, there is especially high uncertainty regarding future technology advancement. Once BEV capital costs drop enough, BEV trucks have a fuel cost advantage and the share of electric trucks in new sales rises.

The tax, duty, and fee reductions under the NEVP are more effective in incentivizing EV purchase for vehicles where EV and ICEV costs are closer to parity. For all vehicle classes, the share of EVs in new sales decreases after the NEVP benefits phase out in 2030. However, this may not be realistic; a limitation of GCAM is that it does not capture feedback to vehicle costs or adoption rates, such as economies of scale, learning-by-doing, or shifts in consumer preferences due to increased familiarity with EVs. It is possible that policies to support EV purchase and manufacturing would have longer-lasting impacts than those shown in the model results.

For electric two- and three-wheelers, which are already cost competitive with ICEVs, the NEVP incentives are effective in increasing penetration by making EVs cheaper than their ICEV equivalents. Between 2020 and 2030, after which the policy incentives phase out, the NEVP benefits increase the EV share in new sales and, when combined with higher localization and rapid technology advancement, the effect is even larger. Service demand for two-three wheelers decreases over time, as it shifts to faster modes with growth in per-capita GDP. However, faster EV cost improvement and NEVP incentives both increase two- and three-wheeler usage in the near term.

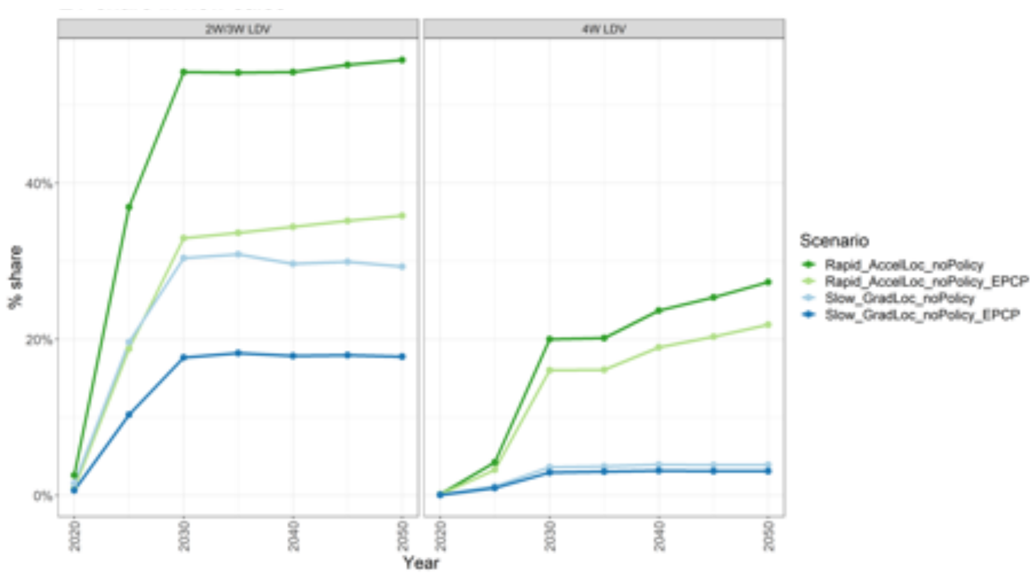
Buses and trucks see a smaller bump in EV penetration as a result of the NEVP, since EVs are relatively more expensive than their ICEV counterparts and adoption is low between 2020 and 2030. In addition, the NEVP only affects purchase costs, and operating costs, including fuel and maintenance, are a larger share of total levelized costs compared to smaller vehicles. NEVP incentives along with accelerated localization increase EV bus share while for trucks, the NEVP has little effect on EV penetration as it cannot make up for the large difference in costs between EVs and ICEVs.

The EV adoption projections shown in **Figure 30** serve as inputs to the SEP model to compute the corresponding energy sector impacts. The SEP model takes inputs on EV penetrations by GCAM as percentage of new vehicle sales (which are provided by vehicle category). Any variations in vehicle definitions versus SEP's model assumptions are accommodated via adjustments in EV adoption rates (GCAM output), e.g., EV penetration for cars/LDVs are corrected to include pickups/trucks of 0-1t capacity while all other data/assumptions for calculation of energy sector impacts are based on SEP's model.

C.2.3 Sensitivity of EV Penetration to Elevated Perceived Cost Pathway (EPCP)

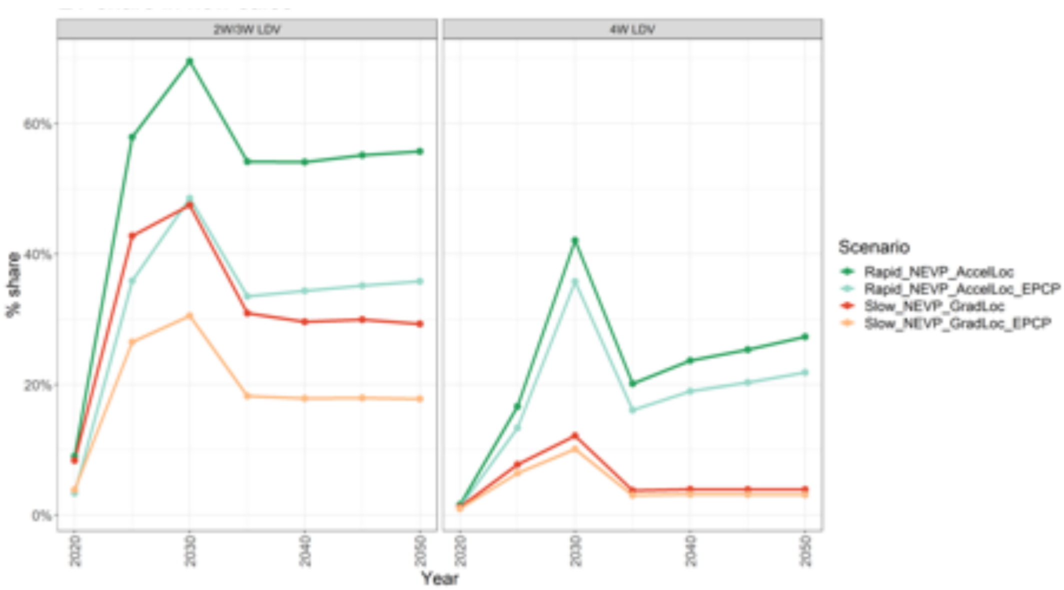
For two- and three-wheelers, share of new EV sales in 2030 ranges from 20% to 65% of the total, while for four-wheelers, the market share ranges from 3-4% at worst and 24% at best without the NEVP incentives under the assumed elevated perceived cost pathway (EPCP) criterion (**Figure 31**), in which future maintenance and fuel savings of EVs over ICEVs are discounted at 30% over the vehicle lifetime, based on 2030 costs and fuel intensities to reflect consumer sensitivity to upfront EV purchase costs over potential future lifetime savings.

Figure 31: EV market penetration under ECPC without NEVP by vehicle category



With the NEVP incentives, two- and three-wheeler share of new vehicle sales in 2030 increases to between 36% to 75%, and for four-wheelers to 14%-47% under ECPC assumptions (**Figure 32**).

Figure 32: EV market penetration under ECPC with NEVP by vehicle category



C.2.4 EV Penetration Utilized Under Various Cases Modeled

EV penetration levels under EPCP computed by GCAM were used in the SEP EV Energy Impact Assessment Model for the period 2021-2030 as shown in **Figure 33** below.

Figure 33: EV penetration levels assumed for base, target and reference case energy impact modeling

Vehicle Category	EV Penetration Scenarios (% of New Vehicles Added) Under EPCP									
	A1: Low No NEVP		A2: High No NEVP		B0: Target NEVP Targets		B1: Low NEVP		B2: High NEVP	
	2025	2030	2025	2030	2025	2030	2025	2030	2025	2030
Two-wheelers	8.1%	17.2%	17.0%	35.5%	25.0%	50.0%	22.0%	30.2%	33.2%	51.1%
Three-wheelers	18.5%	28.8%	31.4%	50.1%	25.0%	50.0%	41.6%	44.2%	52.3%	64.1%
Cars/LDVs	1.4%	4.4%	4.4%	19.4%	15.0%	30.0%	7.5%	12.8%	15.8%	40.6%
Buses	2.2%	4.2%	15.7%	22.7%	25.0%	50.0%	5.2%	6.6%	23.5%	28.1%
Trucks	0.0%	0.0%	0.4%	1.9%	15.0%	30.0%	0.0%	0.1%	2.0%	4.6%

C.3 TOTAL VEHICLE PROJECTIONS

Figure 34: Annual EV additions under under base, target and reference cases

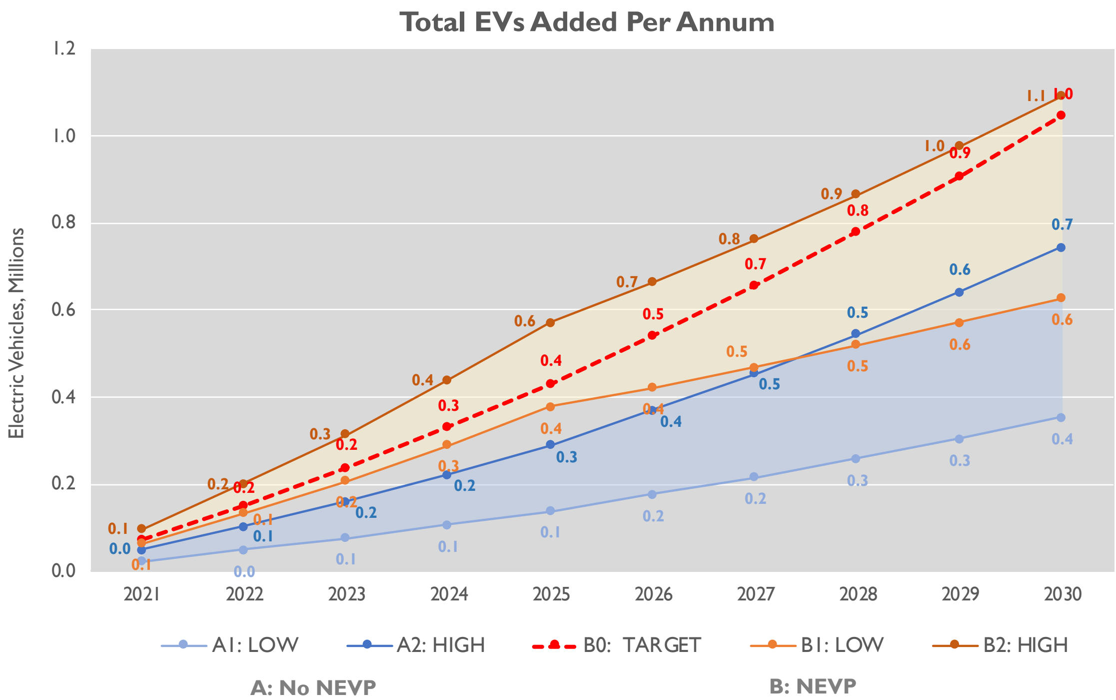


Figure 35: Total EVs on road under base, target and reference cases

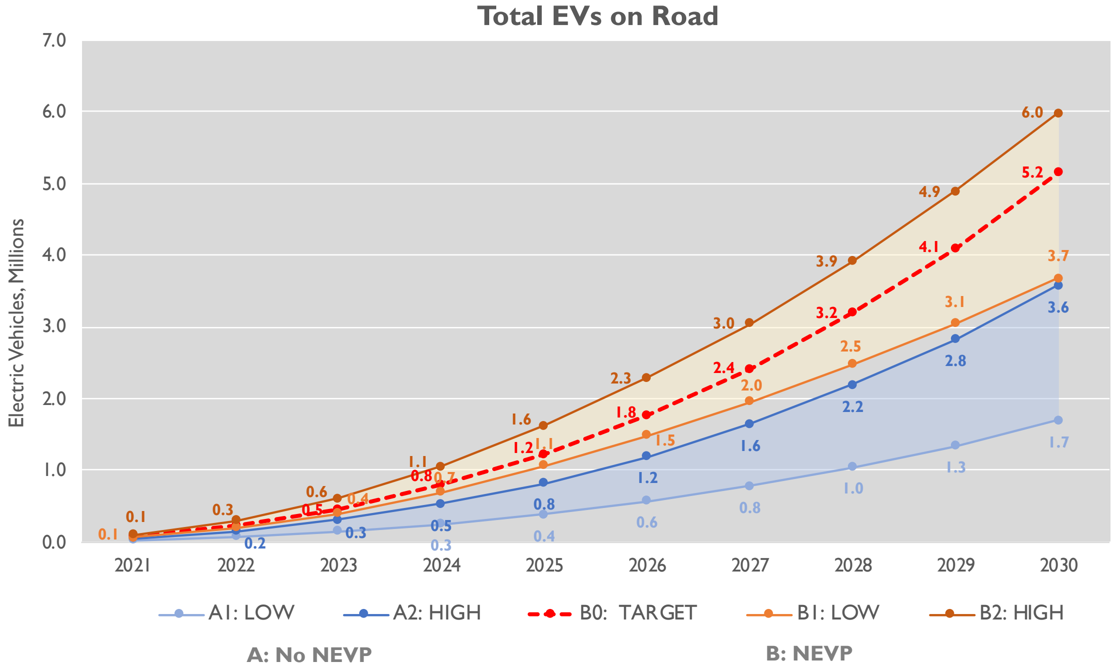
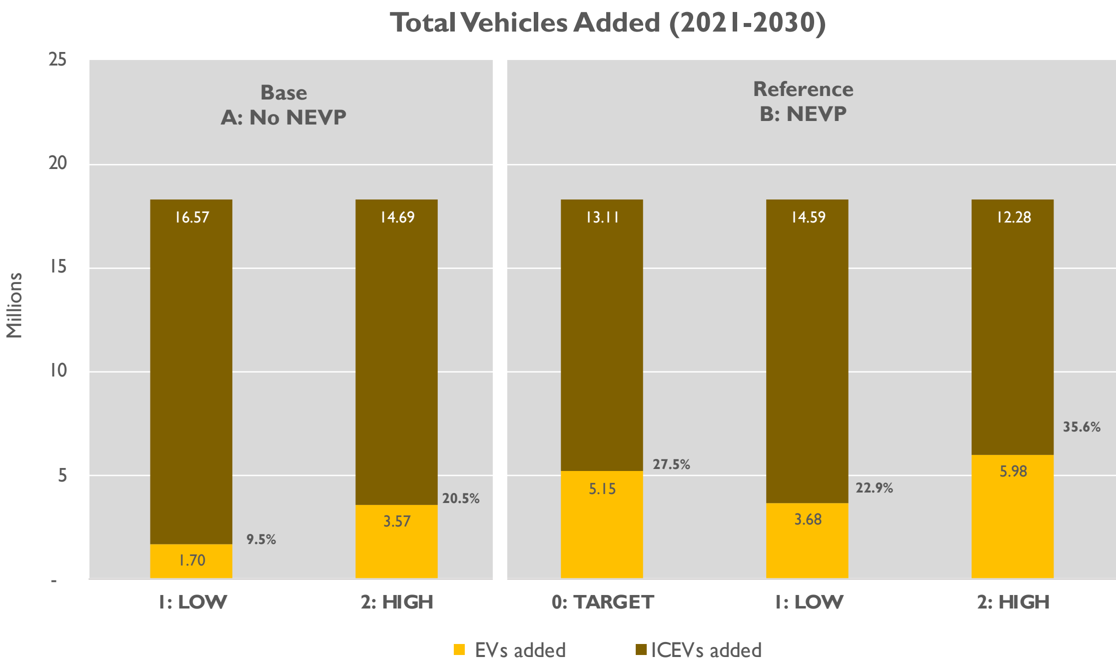


Figure 36: Total EV and ICEV additions during 2021-2030 under base, target and reference cases



C.4 IMPACT OF EVS ON PAKISTAN'S ENERGY SUPPLY CHAIN

C.4.1 ICEV Fuel Savings Due to EV Adoption

Figure 37: Annual ICEV fuel savings due to EVs under base, target and reference cases

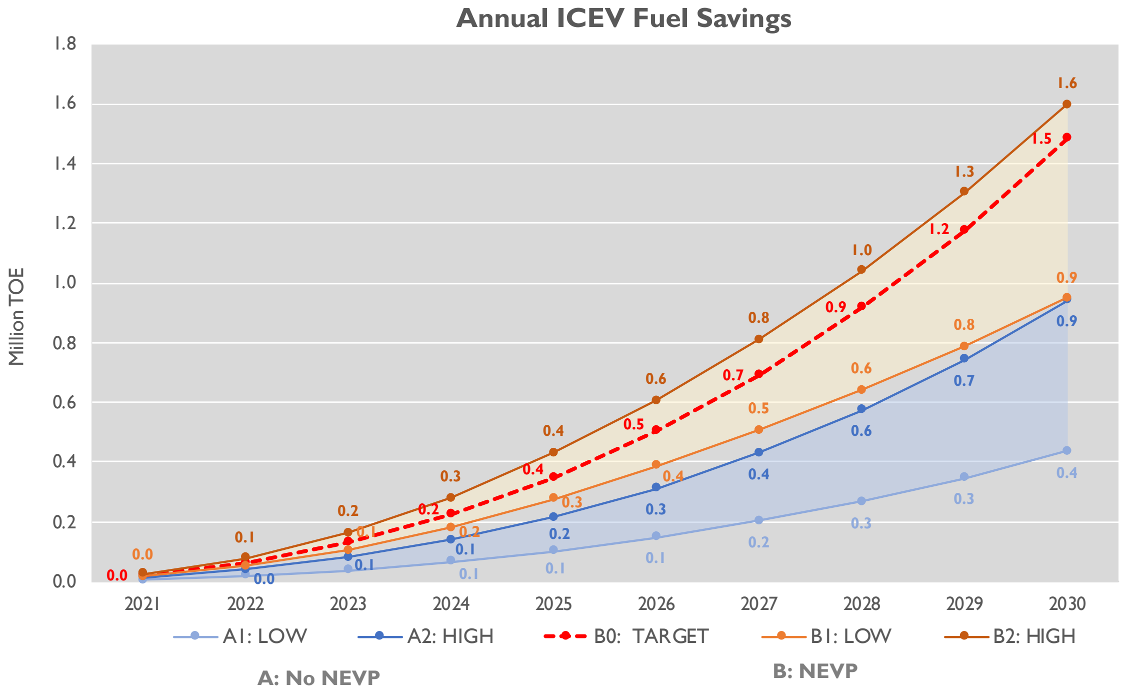
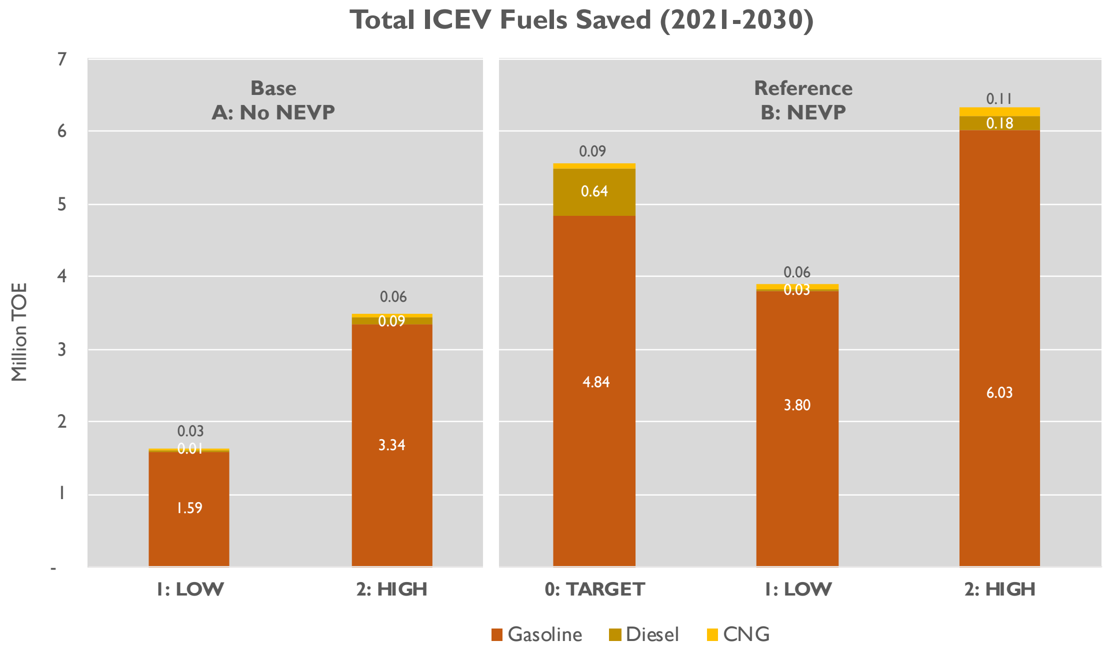


Figure 38: Total ICEV fuel savings due to EVs during 2021-2030 under base, target and reference cases



C.4.2 Electricity Consumed by EVs

Figure 39: Annual electricity consumed by EVs under base, target and reference cases

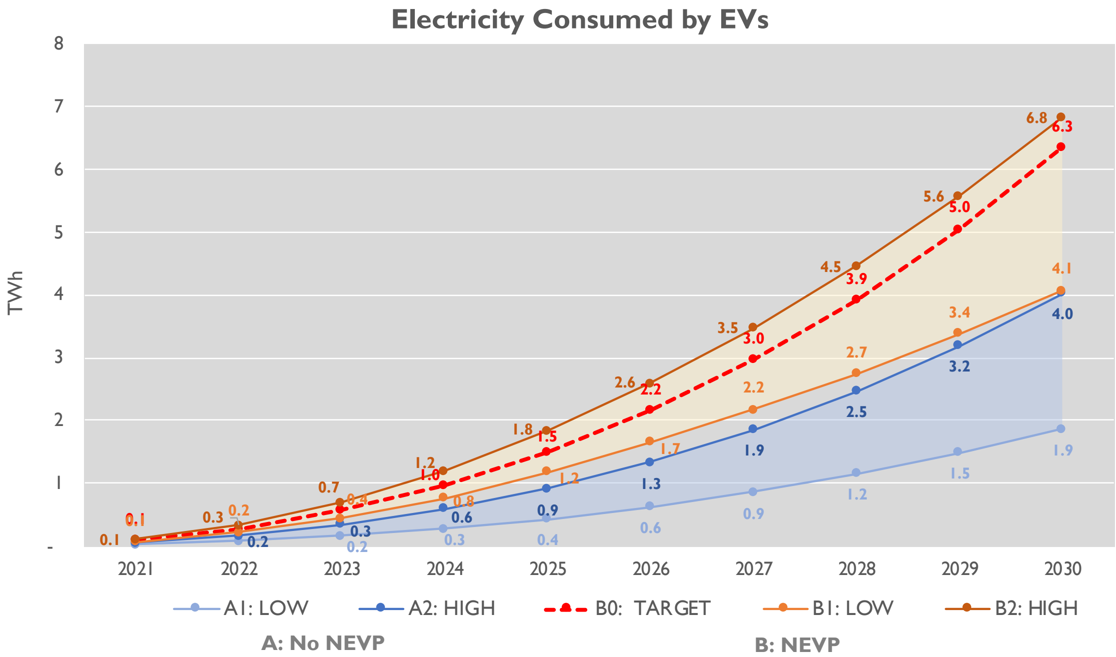
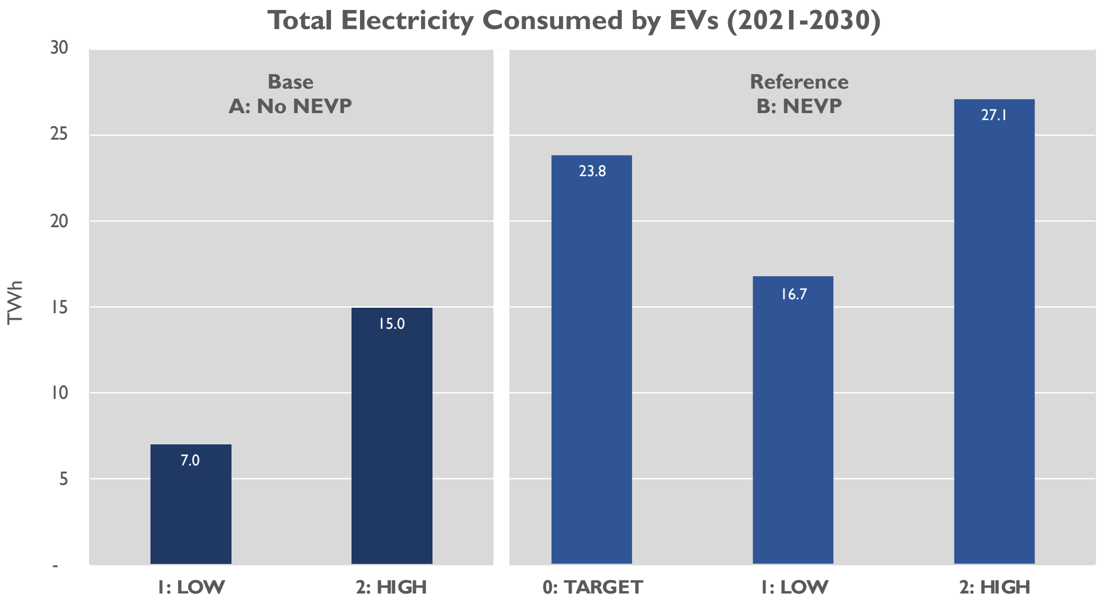


Figure 40: Total electricity consumed by EVs during 2021-2030 under base, target and reference cases



C.5 ENERGY SUPPLY COST SAVINGS DUE TO EVS

Figure 41: Total fuel savings/(costs) due to EVs during 2021-2030 under base, target and reference cases

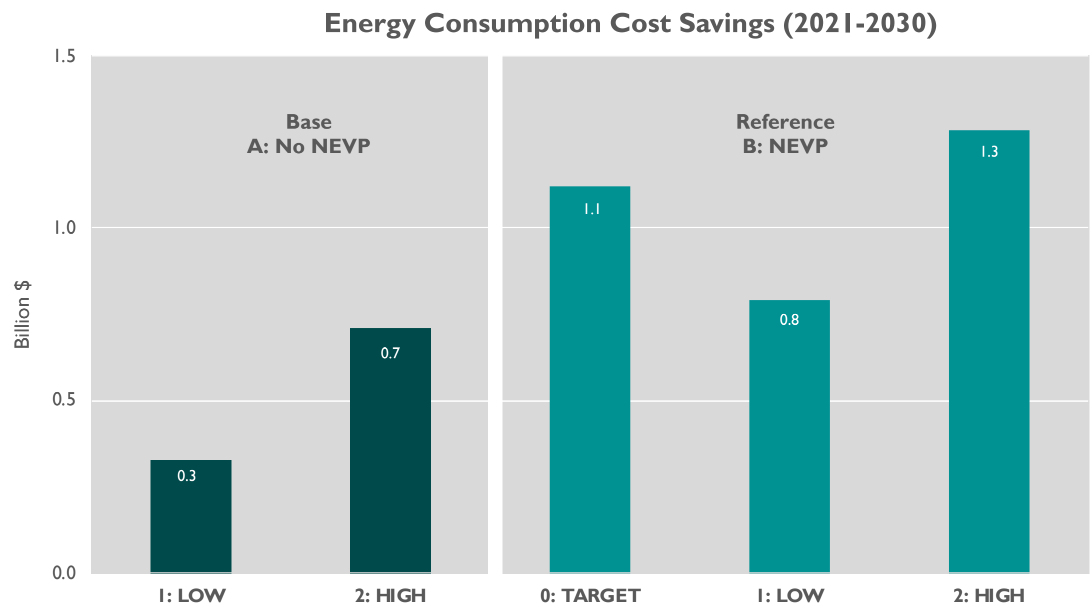
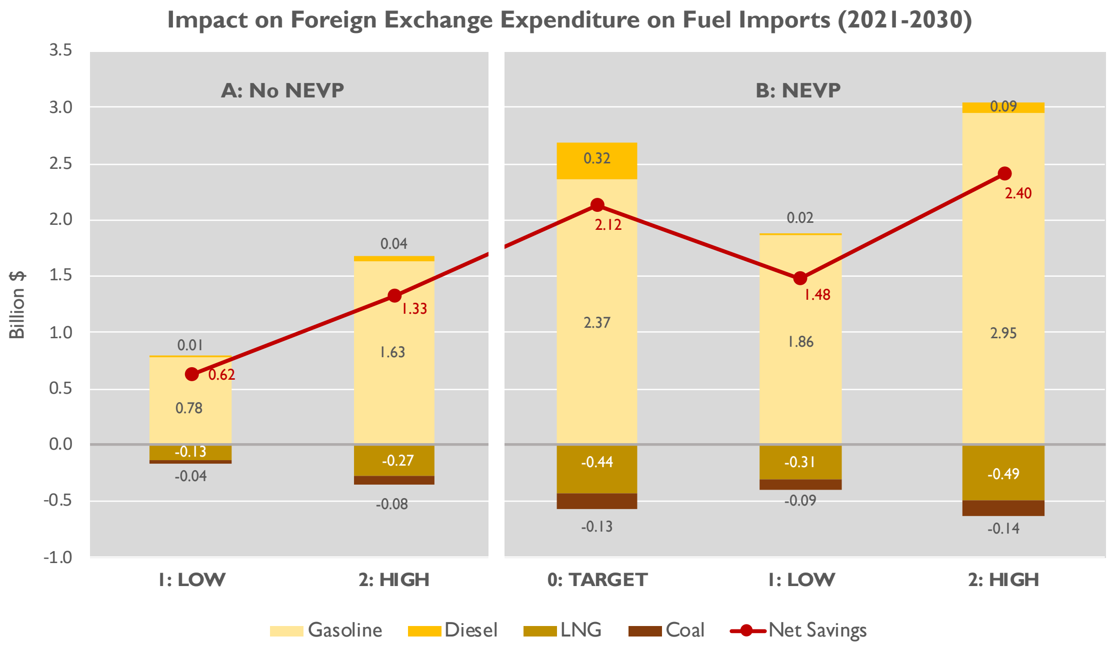


Figure 42: Foreign exchange savings/(costs) on fuel imports due to EVs during 2021-2030 under base, target and reference cases



C.6 SUMMARY RESULTS OF CASES MODELED

Figure 43: Vehicle and energy impacts of EV adoption under base, target and reference cases for 2021-2030

Case	Vehicles Added Million			Cumulative Addl. Energy Supply Cost/Savings Million $			Additional Power Consumed by EVs	ICEV Fuel Savings	Addl. LNG Import (for Power Net of CNG)	Addl. Coal Import (for Power)
	Total Vehicles	ICEVs	EVs	Cost of Power	ICEV Fuels Saved	Energy Supply (Cost)/ Savings	GWh	'000 Tonnes	MMCFD	'000 Tonnes
	2021 to 2030			2021 to 2030			2021 to 2030		2030	2030
Case **A1**	18.26	16.57	1.70	594	924	**330**	6,997	1,575	15.6	141.4
Case **A2**	18.26	14.69	3.57	1,271	1,978	**707**	14,971	3,374	33.2	304.5
Case **B1**	18.26	14.59	3.68	1,420	2,210	**790**	16,722	3,766	33.6	307.4
Case **B2**	18.26	12.28	5.98	2,299	3,583	**1,284**	27,080	6,114	55.9	515.9
Case **B0**	18.26	13.11	5.15	2,022	3,145	**1,123**	23,818	5,389	52.6	478.9

Figure 44: Vehicle and energy impacts of EV adoption under base, target and reference cases in 2030

Case	Total EVs on Road	ICEV Fuel Savings	Net Foreign Exchange Savings on Fuel Imports	Additional Power Consumed by EVs	Addl. Energy Supply Cost/Savings
	Million	Million TOE	Million $	GWh	Million $
Case **A1**	1.70	0.44	166	1,872	88
Case **A2**	3.57	0.94	357	4,030	190
Case **B1**	3.68	0.95	360	4,068	192
Case **B2**	5.98	1.60	606	6,828	324
Case **B0**	5.15	1.48	565	6,338	299

Figure 45: Net energy saved due to higher efficiency EVs relative to ICEVs in 2030 under base, target and reference cases

Case	Additional Electricity Consumed	ICEV Fuels Saved	Net Energy Consumption Savings	
	Trillion BTU/year	Trillion BTU/year	Trillion BTU/year	Million TOE/year
Case **A1**	6.4	18.9	12.5	0.29
Case **A2**	13.8	40.7	26.9	0.62
Case **B1**	13.9	41.0	27.2	0.63
Case **B2**	23.3	69.1	45.8	1.06

Note: 1 tonne of oil equivalent (TOE): 43.3 million BTU basis imported crude oil [EYB]
Total energy end consumption: 55.0 MTOE (2017-18) [*Pakistan Energy Yearbook*]

C.7 KEY OUTCOMES OF EV MODELING AND ANALYSIS

C.7.1 General Takeaways

- NEVP incentives can more than double no-policy EV penetration rates; the effect decreases by 2030-2045 as incentives taper off.
- EV penetration more than doubles even without policy incentives if BEV prices decline rapidly and local manufacture is accelerated compared to slow price decline and gradual localization case.
- NEVP 2030 targets fall between high and low market-driven EV projections.
- NEVP encourages in-country manufacturing of EVs/components, which can help decrease vehicle purchase costs further.
- Two/three-wheeler EVs already at levelized-cost parity. However, higher capital costs may require concessional financing/swappable batteries under rollout strategy for facilitating early adoption.
- NEVP targets for buses and trucks are likely not realizable under cost-based market forecasts. However, major future BEV cost reductions could significantly impact truck fuel savings.

C.7.2 Standard Case Outcomes

- By 2030, under NEVP, additional electricity consumed by EVs ranges between 4.1-6.8 TWh, with corresponding ICEV fuel savings of 0.9-1.6 MTOE (compared to 18.2 MTOE of gasoline, diesel and CNG consumed for transportation in 2018).
- Under NEVP, ten-year additional electricity supply would cost between $1.4-2.3 billion depending on the scenario considered, while fuel supply savings in the range of $2.2-3.6 billion are possible, resulting in net energy supply savings of $0.8-1.3 billion for the period 2021-2030.
- Under NEVP, ten-year fuel import savings would fall in the range of $1.5-2.4 billion for automotive use, net of additional power generation fuel needs, depending on the scenario considered.

- Ten-year ICEV fuel supply and forex savings reduce by 45-58% without NEVP, depending on the scenario considered.
- Carbon emissions reductions due to EVs partially offset by increased thermal power generation to service vehicle charging.
- Non-CO_2 vehicular emissions reduced due to EVs, with corresponding improvement in urban air quality levels.

ANNEXURE D. PRELIMINARY GCAM IMPACT ASSESSMENT OF EVS ON TRANSPORTATION EMISSIONS

D.1 ASSUMPTIONS

This section provides an initial assessment of emissions impacts of the NEVP which is based on energy intensity assumptions detailed in Section B.4.5, the generation supply mix provided in Section B.14, and the following non-Pakistan-specific emissions controls assumptions:

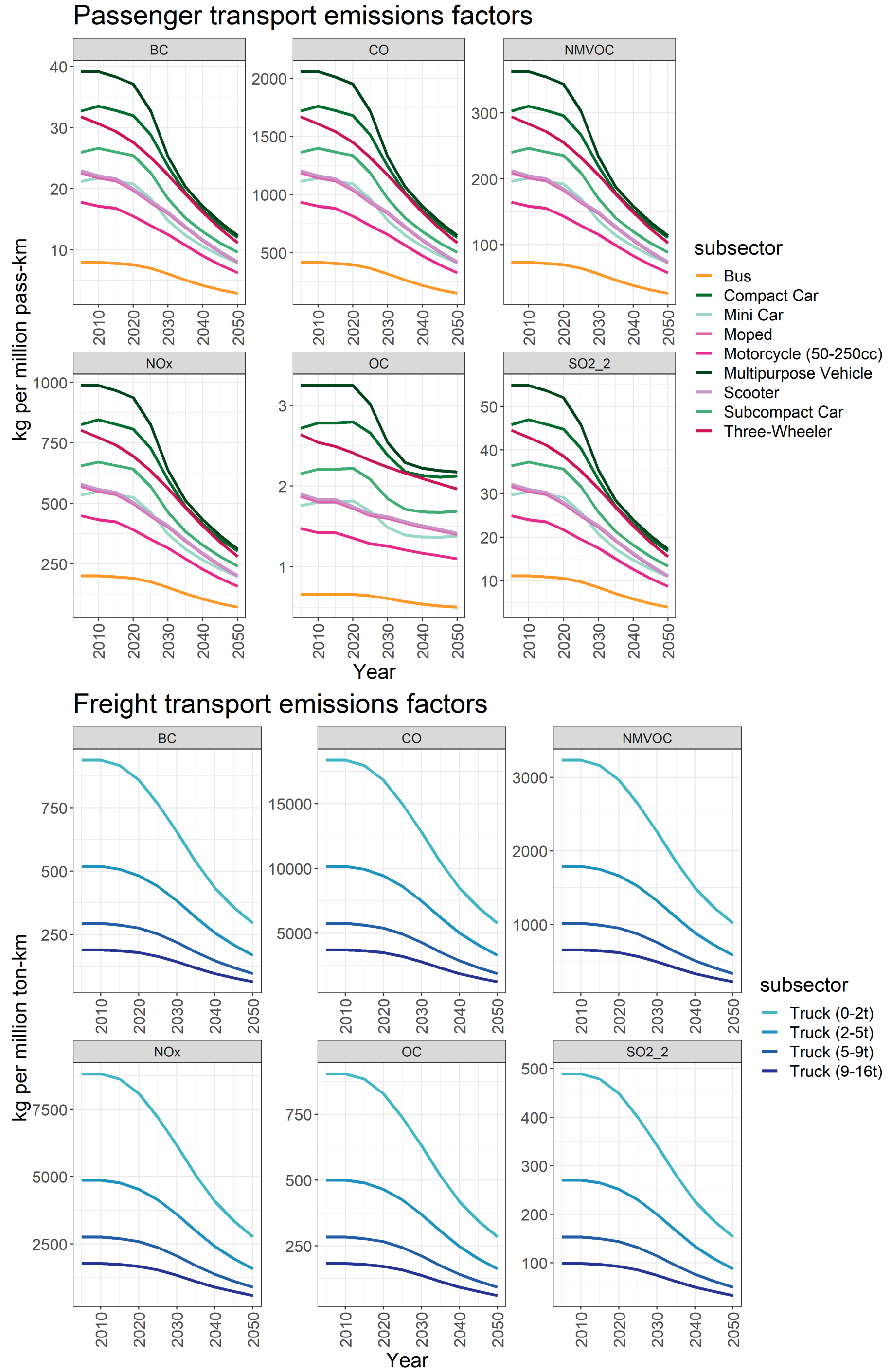
- Pollutant emissions SO_2, NO_x, CO, non-methane volatile organic compounds (NMVOC), ammonia (NH_3), methane (CH_4), and N_2O are derived from the EDGAR model.[15] BC and OC particulates are derived from Lamarque et al. (2010).[16] Though these data capture fuel and combustion characteristics, they are aggregated across the transportation and power sectors and gas/diesel (as 'refined liquids' fuels) in mass units.
- Emissions factors (in units of mass/energy) are derived from these sector-wide emissions normalized by IEA energy balance data by the same sectors. As energy consumption varies according to service output, emissions trends follow through the emissions factors.
- Emissions controls are assumed as a function of GDP growth per the expression provided in the GCAM documentation[17] with a steepness factor of 3.5. CO_2 emissions are defined exogenously as 19.6 kg/GJ and are not assumed to be mitigated over time.

[15] https://edgar.jrc.ec.europa.eu/methodology.php.

[16] https://acp.copernicus.org/articles/10/7017/2010/.

[17] http://jgcri.github.io/gcam-doc/emissions.html.

Figure 46: Passenger (top) and freight (bottom) non-CO_2 emissions controls



D.2 EMISSIONS PROJECTIONS UNDER NEVP SCENARIOS

Figure 47: CO_2 emissions from Pakistan's electricity and transportation sectors under various EV scenarios

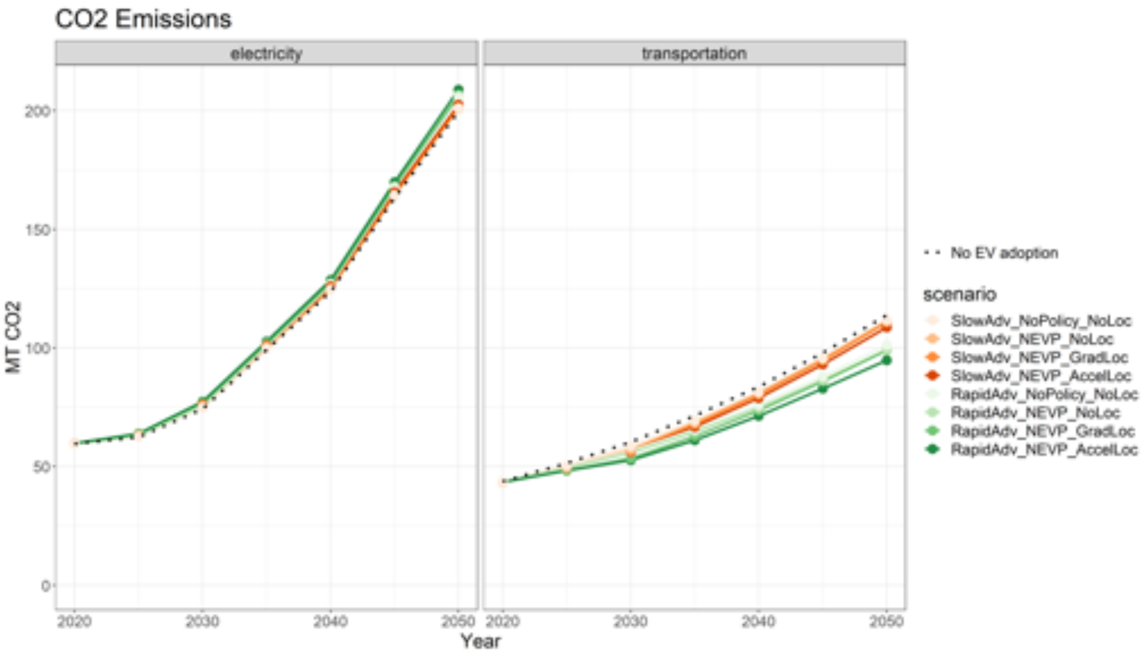


Figure 48: Direct and indirect CO_2 emissions from transportation under various EV scenarios

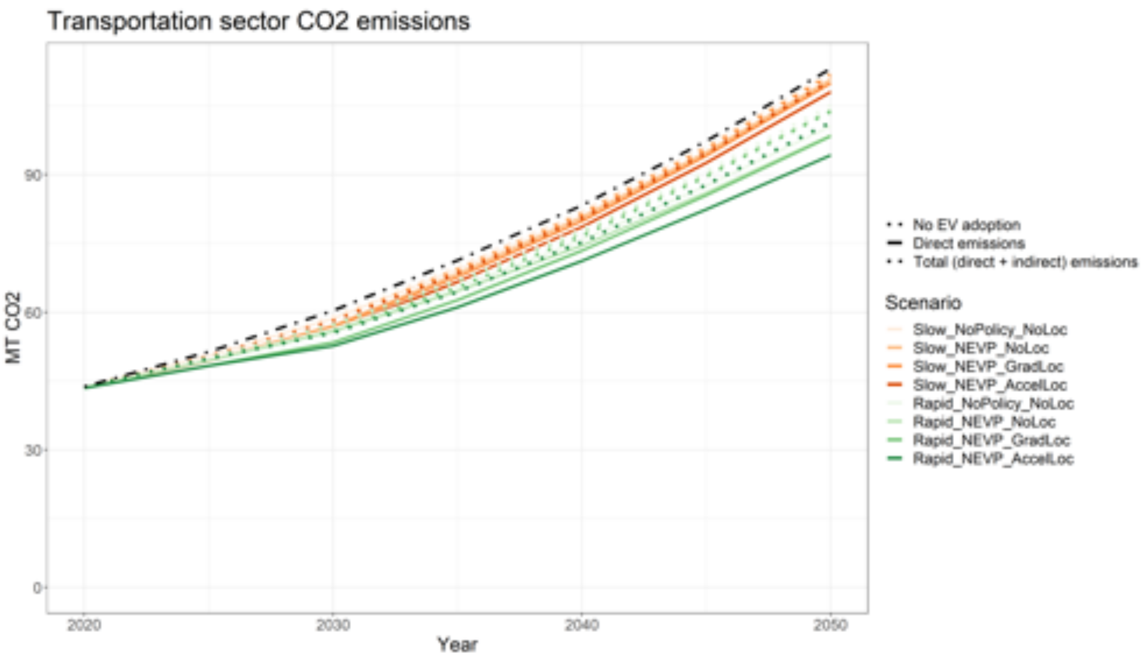


Figure 49: Transportation electrification impacts on total CO_2 emissions under various EV scenarios

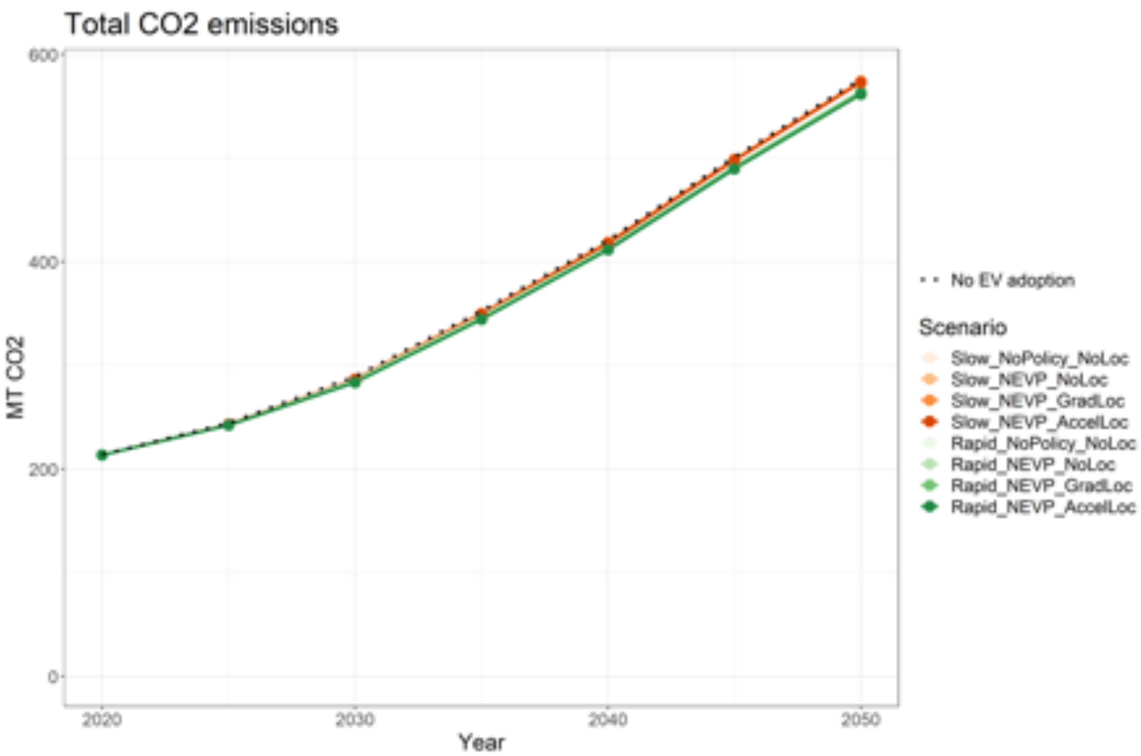


Figure 50: Particulate matter emissions from transportation under various EV scenarios

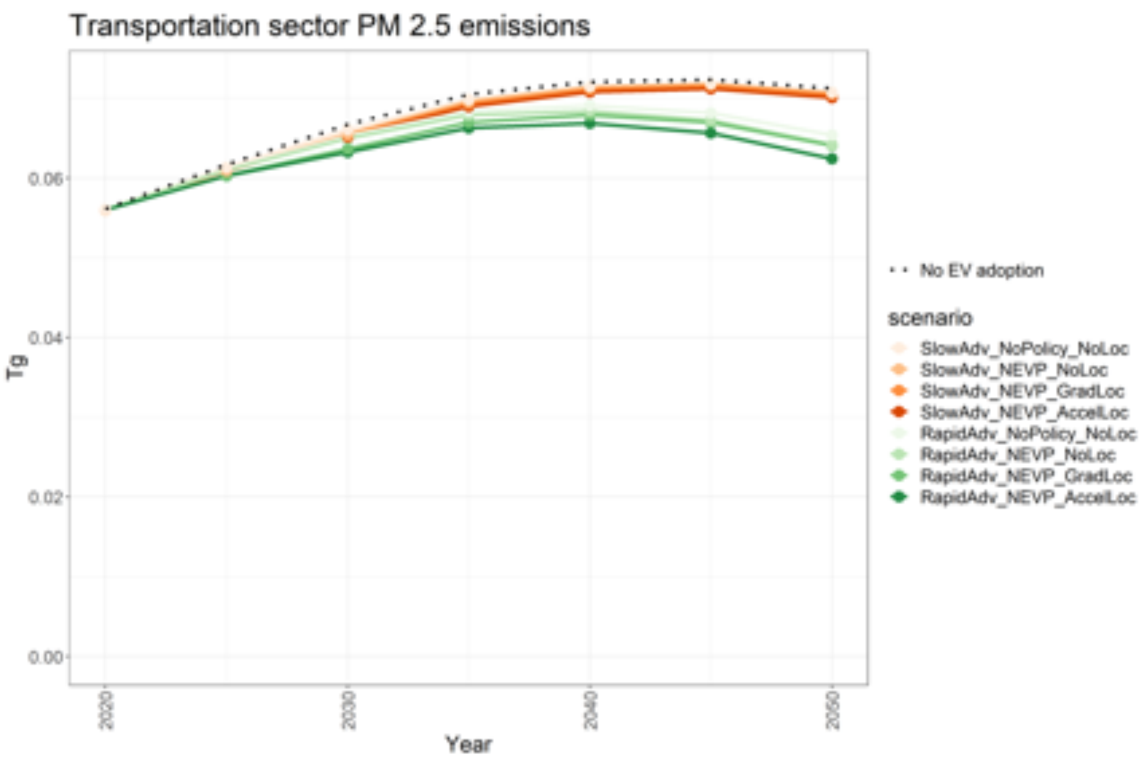


Figure 51: Non-CO_2 emissions from transportation under various EV scenarios

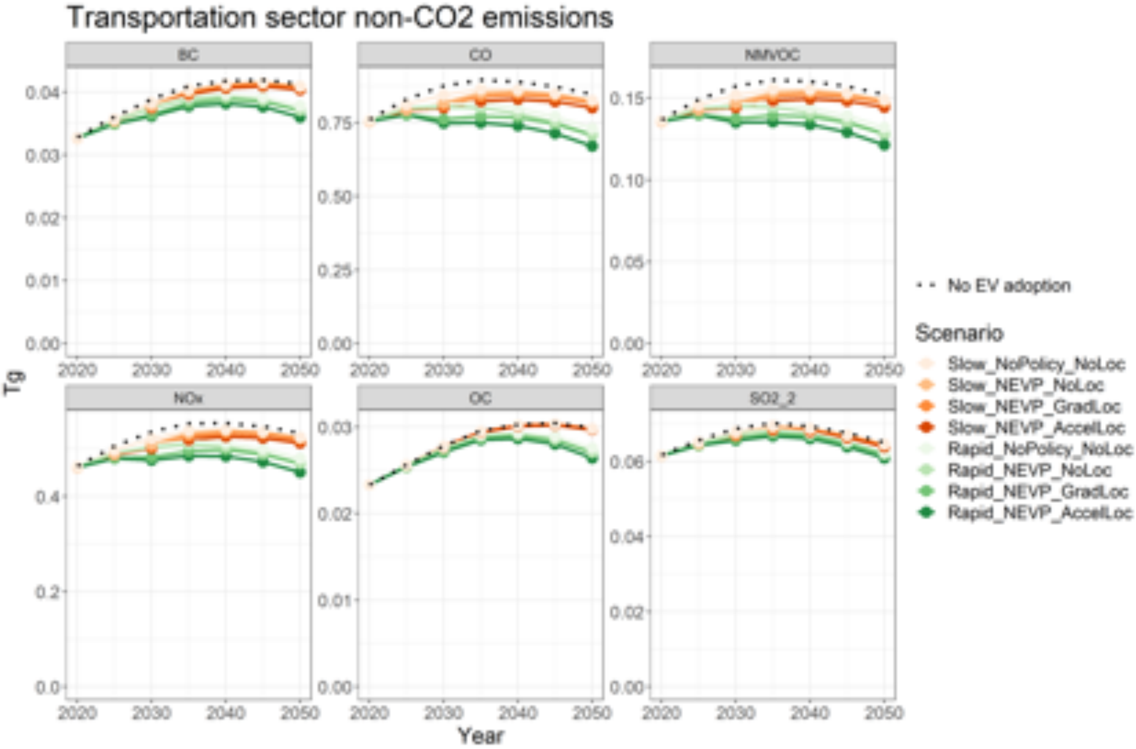
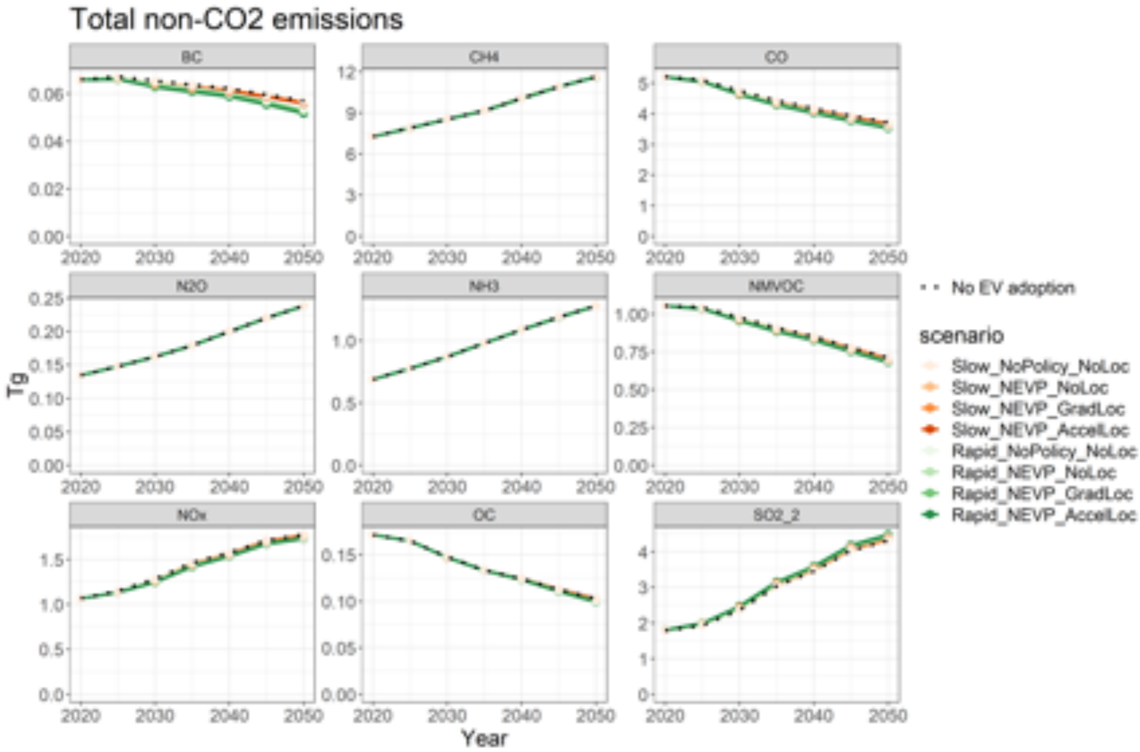


Figure 52: Transport electrification impact on total non-CO_2 emissions under various EV scenarios



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