**Electrification of the transport System: Impacts of national policies vs external drivers. A case study for Pakistan.**

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**Abstract**

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Table of Contents

[1. Introduction 3](#_Toc35524365)

[1.1. Background 3](#_Toc35524366)

[1.2. Literature Review 3](#_Toc35524367)

[1.3. Research Question 3](#_Toc35524368)

[2. Methodology 3](#_Toc35524369)

[2.1. GCAM Overview 3](#_Toc35524370)

[2.2. GCAM Transport Sector Details 3](#_Toc35524371)

[2.3. GCAM Scenarios Details 3](#_Toc35524372)

[3. Results 4](#_Toc35524373)

[3.1. Baseline Results 4](#_Toc35524374)

[3.2. Scenario Results 4](#_Toc35524375)

[4. Discussion & Conclusions 4](#_Toc35524376)

[References 4](#_Toc35524377)

[Appendices 5](#_Toc35524378)

[Appendix A Pakistan-specific changes to core GCAM 5](#_Toc35524379)

[A.1 Socioeconomic assumptions 5](#_Toc35524380)

[A.2 Power sector changes 5](#_Toc35524381)

[A.1.1 Fossil Generation 5](#_Toc35524382)

[A.1.2 Hydropower 6](#_Toc35524383)

[A.1.3 Nuclear 6](#_Toc35524384)

[A.2 Industry changes 6](#_Toc35524385)

[A.3 Transportation changes 6](#_Toc35524386)

[A.3.1 General updates to transportation assumptions 6](#_Toc35524387)

[A.3.2 Pakistan-specific transportation changes 7](#_Toc35524388)

[A.3.3 Battery cost curves update (1/16/20) 9](#_Toc35524389)

[A.3.4 4W LDVs 10](#_Toc35524390)

[A.3.5 2-wheelers 10](#_Toc35524391)

[A.3.6 3-wheelers 10](#_Toc35524392)

[A.3.7 Trucks 11](#_Toc35524393)

[A.3.8 Buses 11](#_Toc35524394)

[Appendix B EV analysis 11](#_Toc35524395)

[B.1 Policy scenarios 11](#_Toc35524396)

[B.2 Sensitivity analysis 13](#_Toc35524397)

# Introduction

# Background

Background on electrification trends in general, role in decarbonization and regional projections across the globe

# Literature Review

1. Lit review and role of EV penetration global/national
2. Price takers vs Price makers.
3. Developing vs Developed.
4. Uncertainties in demand growth.
5. Lack of other studies

# Research Question

Research question to analyze the role of policies vs technology

# Methodology

# GCAM Overview

# GCAM Transport Sector Details

# Scenarios Details

* 1. Baseline Assumptions
  2. Policies
     1. NEVP overview
     2. Representation in GCAM
  3. Technological/Costs/Prices
     1. SEP/NTDC cost adjustments for Pakistan

# Results

# Baseline Results

# Scenario Results

# Discussion & Conclusions

1. Summary of results
2. Implications for other regions
3. Local policies versus external forces

# References

# Appendices

# Pakistan-specific changes to core GCAM

## Socioeconomic assumptions

We began by adjusting GCAM’s default projections for Pakistan to better align with projections made by stakeholders within Pakistan. We used Shared Socioeconomic Pathway (SSP) 5 assumptions for population and GDP growth rather than the default of SSP 2, as these aligned better with data from the Pakistan Planning Commission. GDP growth rate assumptions were also updated to reflect the latest IMF data on GDP growth rates.[[1]](#footnote-1)

## Power sector changes

Default GCAM power sector projections for Pakistan were adjusted based on the 2019 Indicative Generation Capacity Expansion Plan (IGCEP) 2018-40. This report gives 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 Dispatch Company (NTDC). In addition, we use updated capital costs for intermittent and dispatchable renewable technologies, which come from NREL’s Annual Technology Baseline 2018 edition.

### Fossil Generation

As the IGCEP does not include plans to expand generation from refined liquids, we set the refined liquids share weight in electricity generation to 0 after 2020. We also increase coal share weights to reflect plans in the IGCEP to expand coal-fired power generation. However, we do 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.

Refined liquids share weights

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **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 |

Coal share weights

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **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 |

### Hydropower

Hydropower electric generation in GCAM is given as fixed output. We base hydro generation for 2020-2040 on the hydro generation projections given in the IGCEP. From 2040-2050, we assume constant linear increase in hydro generation at the 2020-2040 average rate. We hold hydro generation constant beyond 2050, as the analysis for this project only goes through 2050.

Pakistan hydro generation (EJ):

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **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 |
| **Adjusted** | 0.117706 | 0.143935 | 0.238579 | 0.422274 | 0.530093 | 0.573574 | 0.66302 | 0.749482 |

### Nuclear

Share weights for nuclear technologies were increased between 2015 and 2050 to align nuclear generation in GCAM with IGCEP plans. For 2020-35, we calculated generation based on capacities of IGCEP committed nuclear plants, assuming a capacity factor of 0.8.[[2]](#footnote-2) We then iterated on the nuclear share weights to get generation close to the IGCEP projections.

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **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 |

## Industry changes

After making these adjustments to the power sector, electricity generation was 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. We added an industry electricity fuel preference elasticity of -0.5 and decreased the industrial income elasticity by 50% to tune industrial and total electricity consumption closer to these data sources.

## Transportation changes

### General updates to transportation assumptions

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 the table below:

|  |  |  |  |
| --- | --- | --- | --- |
| **Mode** | **Size classes** | **Technologies** | **Input assumptions** |
| 2-wheel LDV | Moped  Motorcycle (50-250cc)  Scooter | Liquids  BEV | Annual travel per vehicle  Base year energy use  Intensity  Load factor  Speed  Capital costs (purchase)  Capital costs (infrastructure)  Capital costs (purchase)  Operating costs (maintenance)  Operating costs (registration and insurance)  Operating costs (tolls) |
| 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  FCEV | Annual travel per vehicle  Base year energy use  Intensity  Load factor  Speed  Capital costs (purchase)  Capital costs (infrastructure)  Capital costs (purchase)  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 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 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  Non-fuel OPEX |
| Ship Domestic, Ship International | Ship Domestic,  Ship International | Liquids | Base year energy use  Intensity  Load factor  CAPEX and non-fuel OPEX |

These assumptions are contained in the file UCD\_trn\_data\_CORE.csv. We use an updated version of the database with several changes from the core GCAM version based on Mishra et al (2013). The updated version contains vehicle assumptions for all model years (in 5-year timesteps rather than 15). Battery electric technologies were added for trucks and buses in all regions. Adding new technologies also requires corresponding additions in other files - share weights (in A54.globaltranTech\_shrwt.csv), interpolation rule (A54.globaltranTech\_interp.csv), lifetimes (A54.globaltranTech\_retire.csv), and mappings (mappings/UCD\_techs.csv). Cost assumptions for both BEV and liquids cars, trucks, and buses were updated based on NREL’s Electrification Futures Study (Jadun et al. 2017). This report contains slow, moderate, and rapid electrification development pathways, which were developed into three sets of the UCD assumptions. BEV costs and energy intensity vary between these technology advancement scenarios. The new assumptions also add natural gas truck infrastructure costs, and update liquids vehicle energy intensities to match CAFÉ standards in the US (lagged by 5 years for other regions). Finally, we delete operating subsidies for buses across all technologies and regions. In the original UCD assumptions the subsidies made the user cost equal across technologies to reflect equal fares for consumers – however, this was no longer the case after updates to vehicle costs. In addition, we aim capture the actual cost differences between bus technologies in order to model how these impact EV adoption, so using unsubsidized costs is more appropriate.

In the core version of GCAM, only car and truck technologies are vintaged. We add this feature for buses, 2-wheelers, and 3-wheelers by adding lifetimes and retirement functions. For buses, these were copied from light trucks, which have a lifetime of 25 years. For 2- and 3-wheelers, the maximum lifetime is 15 years. In the retirement function, the half-life is 8 years and steepness is 0.3.

To reflect current levels of EV penetration, we modify the share weight assumptions 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) in 2030 for light-duty vehicles and 2040 for buses and freight trucks. Share weights increase more rapidly for 2- and 3-wheelers to reflect lower barriers to adoption for these smaller vehicles.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
|  | **2010** | **2015** | **2020** | **2025** | **2030** | **2035** | **2040** |
| **2/3W LDV** | 0 | 0.025 | 0.05 | 0.6 | 1 | 1 | 1 |
| **4W LDV** | 0 | 0.025 | 0.05 | 0.4 | 1 | 1 | 1 |
| **Truck, bus** | 0 | 0.025 | 0.05 | 0.4 | 0.6 | 0.8 | 1 |

EV share weights:

### Pakistan-specific transportation changes

We also make a number of updates to the assumptions for the Southeast Asia region, which contains Pakistan (Pakistan is not its own region in the vehicle assumptions). We add BEV 3-wheelers as a technology to reflect locally available vehicle types. Based on feedback from collaborators at SEP, we change 3-wheeler speed from 36 to 25 kilometers per hour and increase annual travel per vehicle from 8478 kilometers per year to 32,000 kilometers per year.

We update the cost assumptions for 2- and 3-wheelers in Southeast Asia. As NREL’s Electrification Futures Study (Jadun et al. 2017) does not report data for these vehicles, we rely on market data in Pakistan to determine current costs. A representative gasoline-powered motorcycle model in Pakistan costs about $800, about 59% of the cost assumption in the UCD database, so we scale all liquids 2-wheeler purchase costs by this value. Based on feedback from collaborators at SEP, electric 2-wheelers are already at levelized cost parity with conventional ICE 2-wheelers in Pakistan. Therefore, we back calculate purchase costs for BEVs in 2020 by class using ICEV cost assumptions and assuming equal levelized costs. After 2020, costs decrease according to the battery costs given in the three technology advancement pathways.

As BEV 3-wheelers do not exist as a technology in the current core GCAM and Pakistan-specific cost data is limited, we estimate BEV 3-wheel capital costs in 2020 using the ratio of liquids motorcycles to 3-wheelers in Southeast Asia in the original UCD database. This ratio (1.37) is then multiplied by the BEV motorcycle cost calculating purchase costs under levelized cost parity. After 2020, costs decrease according to the battery costs given in the three technology advancement pathways.

We also update BEV mini car costs and intensity 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 we correct this discrepancy.

The infrastructure capital 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. We assume one charger required per vehicle, 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 is $50-100, and residential electrical service upgrades cost $80-135. We assume an average charging infrastructure capital cost of $580 for 4-wheel LDVs. We remove charging costs entirely for 2-wheelers, as vehicle specifications indicate 2-wheeler batteries are sufficiently small that no additional charging infrastructure for residential use is required. We do assume 3-wheelers require the $580 charging infrastructure cost because of the high annual distance travelled per vehicle.

Collaborators at 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. We use this to adjust our vehicle maintenance cost assumptions for LDVs. Actual average maintenance costs could be much lower than the values collected, however, as many owners tend to pay for maintenance only when unavoidable. We scale the values by 70% to represent more realistic maintenance.

In addition, market survey data provided by collaborators at ANL indicated that capital costs for light trucks and buses are significantly lower in Pakistan than the US. For the data available, vehicles in Pakistan were about 40% of the cost of comparable US vehicles. As GCAM truck costs are based on US data and do not vary by region, unlike LDVs, and bus cost assumptions are nearly identical between the US and Pakistan, we scale costs for buses, 0-2 ton trucks, and 2-5 ton trucks to represent this regional knock-down factor. Cost assumptions for buses and trucks are given as levelized non-fuel cost (per vehicle-kilometer traveled); we use cost assumptions for compact cars to calculate that purchase costs are about 76% of non-fuel levelized costs, and apply the 40% capital cost regional knockdown factor to that share of the levelized cost. This applies to all technologies within these classes. The cost difference appears to be less significant for heavy-duty trucks, so we leave these costs unchanged.

Bus costs were levelized by dividing by annual distance traveled of 51,708 km/year, while SEP assumes buses travel 72,000 km per year. For consistency, we scale bus costs for all technologies by 51708/72000 to implicitly change annual distance traveled. We also adjust BEV truck load factor assumptions for consistency across technology advancement scenarios. 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 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. We change the discount rate to 15%, based on loan rates of 20-21% in Pakistan today[[3]](#footnote-3) and average inflation of 5.5% over the past five years.[[4]](#footnote-4)

### Battery cost curves update (1/16/20)

Recent data shows that battery pack costs have fallen faster than projected, including in the Electrification Futures Study on which the slow, moderate, and rapid technology advancement pathways were based. For example, according to Bloomberg New Energy Finance (BNEF) battery costs in 2019 had dropped to $156 per kWh, which the EFS projected would be only be reached by between 2025 and 2030 in Rapid Advancement, 2040 in Moderate, and not until after 2050 in Slow (Jadun et al. 2017). We modify the vehicle costs for each curve based on more aggressive battery cost projections. Intensity and infrastructure costs also vary between these technology advancement scenarios based on the EFS data, but we leave these unchanged and only update capital costs based on the new battery cost curves below.

|  |  |  |  |
| --- | --- | --- | --- |
| New battery cost curves (2018$/kWh)[[5]](#endnote-1) | | | |
|  | **Slow** | **Moderate** | **Rapid** |
| 2019 | 156 | 156 | 156 |
| 2020 | 146.3 | 140.5 | 123 |
| 2025 | 97.5 | 84.9 | 57.1 |
| 2030 | 87.8 | 62 | 50 |
| 2035 | 78.1 | 55 | 44 |
| 2040 | 74.7 | 50.8 | 38 |
| 2045 | 71.3 | 46.3 | 33.4 |
| 2050 | 67.9 | 42.1 | 28.9 |

|  |  |  |  |
| --- | --- | --- | --- |
| EFS (NREL) battery cost curves (2018$/kWh) | | | |
|  | **Slow** | **Moderate** | **Rapid** |
| 2016 | 285 | 285 | 285 |
| 2020 | 269 | 257 | 242 |
| 2025 | 248 | 222 | 188 |
| 2030 | 229 | 188 | 136 |
| 2035 | 209 | 167 | 93 |
| 2040 | 200 | 159 | 83 |
| 2045 | 191 | 149 | 83 |
| 2050 | 183 | 140 | 83 |

Battery cost curves and sources



#### Battery vintaging factors:

We calculate battery vintaging factor to account for batteries not lasting full vehicle lifetime. We assume batteries last 10 years and take the weighted average of battery packs needed over vehicle lifetime, using the retirement function to get share of vehicles still in use after certain timesteps.



For cars, buses, and light duty trucks (vehicles with 25-year max lifetime), the battery vintaging factor is 1.17, and for medium and heavy-duty trucks (vehicles with 40-year max lifetime) it is 1.35. For 2 and 3-wheelers, we assume no battery replacement is necessary.

#### 4W LDVs

We update capital costs (purchase) to reflect our new battery cost curves. We extract the share of the battery in vehicle purchase cost for compact cars by year from Autonomie data (ANL) [[6]](#endnote-2). This data provides cost projections for vehicle components under low, average, and high non-battery technology advancement curves; we use the average case for this analysis. We then extract the percent difference between NREL’s battery cost assumptions and our new curves by year. For each size class, the new purchase cost is computed as:

New cost = old cost \* (1 – ((battery cost % change from NREL) \* (battery share of cost) \* (battery vintaging factor))

#### 2-wheelers

* Variable modified: capital costs (purchase)
* New costs calculated the same as for 4W LDVs, but didn’t have data on battery share of cost, so assumed battery is 37.5% of vehicle cost in 2020
  + This is based on assumption that 50% of the total cost of 2/3W are due to EV components and batteries constitute 75% of the EV component cost, which is generally true for compact cars from the ANL data
  + Battery share of cos decreases at same rate as compact car (from ANL vehicle components)
* Two and three-wheel costs were from UCD study, not NREL, so didn’t vary by advancement scenario. Before applying additional battery cost improvements above, applied NREL’s battery cost curves for slow, mod, rapid, respectively (assuming same battery share of cost as above).
* Note: assumed BEV cost parity with ICEVs in 2020 (see UCD edits above)

#### 3-wheelers

* Variable modified: capital costs (total)
* New costs calculated the same as for 2-wheelers, but assumption is total capital costs instead of purchase. Assumed purchase cost is 65% of total capital cost (rest is taxes and infrastructure)
  + New cost = old cost \* (1 – ((battery cost % change from NREL) \* (battery share of cost) \* (purchase cost share of capital cost) \* (battery vintaging factor))
* Note: assumed BEV cost parity with ICEVs in 2020 (see UCD edits above)

#### Trucks

* Variable modified: CAPEX and non-fuel OPEX ($/vkm)
* Used battery share of cost for BEV 100 pickup trucks from ANL/Autonomie (average non-battery tech curve) for all truck classes due to lack of data on cost components of medium and heavy-duty truck classes.
* Capital (purchase) cost share in CAPEX and non-fuel OPEX based on calculation of component cost shares for compact cars using 2020 Moderate costs
* New cost = old cost \* (1 – ((battery cost % change from NREL) \* (battery share of cost) \* (share of capital cost in LCOD) \* (battery vintaging factor))

#### Buses

* Variable modified: CAPEX and non-fuel OPEX ($/vkm)
* Estimated battery share of cost based on recent e-bus prices in China, battery size of Proterra’s 440 kwh e-bus, and $156/kWh price point in 2019[[7]](#endnote-3). Share is 12.5% of cost in 2020, and we decrease it over time at same rate as the battery share of cost for BEV 100 pickup trucks (ANL)
* Capital cost share of CAPEX and non-fuel OPEX from NREL (chart above)
* New cost = old cost \* (1 – ((battery cost % change from NREL) \* (battery share of cost) \* (share of capital cost in LCOD) \* (battery vintaging factor))

# EV analysis

## Policy scenarios

Scenarios as of 3/16:

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Scenario 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* | National Electric Vehicle Policy (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* | National Electric Vehicle Policy (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* | National Electric Vehicle Policy (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 |

Scenarios are run in combination with Slow and Rapid Advancement cost pathways (see below).

Pakistan’s vehicle taxes and duties:

**ICEVs:**

|  |  |
| --- | --- |
| **Vehicle Category** | **Final Duty, Tax & Fees (% of purchase price)** |
| Two-wheelers | **27.2%** |
| Three-wheelers | **29.6%** |
| Cars | **35.6%** |
| Buses | **35.1%** |

**EVS (proposed BEV tax/duty/fee reductions under National Electric Vehicle Policy):**

The NEVP proposes varying taxes, duties, and fees for imports and local production. For imports, duties differ depending whether materials and parts are EV-specific or not, and whether whole vehicle imports are completely built up (CBU) or complete knock down (CKD) units. To model the NEVP, we make assumptions about the level of localization of EVs for each vehicle class. There are three localization scenarios: a base case with no EV localization, a gradual localization case, and an accelerated localization case.

EV benefits under the NEVP are largely proposed to last 7 years, but as GCAM uses 5-year time steps, we model the NEVP over 10 years, from 2020 to 2030.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Base Case (no localization)** |  |  |  |  |
| **Vehicle Category** | **2020** | **2025** | **2030** | **2035** |
| Two-wheelers | 3% | 19% | 35% | 58% |
| Three-wheelers | 3% | 19% | 35% | 58% |
| Cars | 3% | 19% | 35% | 63% |
| Tractors | 2% | 19% | 36% | 60% |
| Buses | 2% | 19% | 36% | 60% |
| Trucks | 2% | 19% | 36% | 60% |
|  |  |  |  |  |
| **Gradual Localization** |  |  |  |  |
| **Vehicle Category** | **2020** | **2025** | **2030** | **2035** |
| Two-wheelers | 4% | 15% | 19% | 39% |
| Three-wheelers | 4% | 15% | 19% | 39% |
| Cars | 7% | 18% | 31% | 58% |
| Tractors | 2% | 17% | 30% | 52% |
| Buses | 2% | 18% | 32% | 55% |
| Trucks | 2% | 17% | 31% | 54% |
|  |  |  |  |  |
| **Accelerated Localization** | Final taxes, duties, and fees | | | |
| **Vehicle Category** | **2020** | **2025** | **2030** | **2035** |
| Two-wheelers | 9% | 13% | 10% | 28% |
| Three-wheelers | 9% | 13% | 10% | 28% |
| Cars | 8% | 13% | 14% | 37% |
| Tractors | 2% | 15% | 23% | 44% |
| Buses | 2% | 17% | 29% | 51% |
| Trucks | 2% | 16% | 25% | 47% |

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’s suggested retail price, to the given percentage of the purchase price. For 3-wheelers, taxes are included in capital costs (other). Default taxes and fees for the Southeast Asia region are 35% of the price (Mishra et al. 2013), so 65% of the total is assumed to be purchase price. The taxes, duties, and fees multiplier for each scenario is applied to that portion of the cost. 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.

## Sensitivity analysis

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. As a sensitivity to highlight the importance of accurate perceptions of the cost advantages of EVs, for instance to demonstrate the effect of informational campaigns, we run a high and low case (slow advancement, NEVP gradual localization and rapid advancement, NEVP accelerated localization) with higher EV operating costs. We calculate new operating costs for each LDV size class 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, we use the fuel costs from the model output to calculate new maintenance costs that, when levelized, encapsulate higher discounting of all operating costs. We use this method to model consumer behavior because this effect was not fully captured in the share weights, as research shows discounting of future savings is a persistent effect even with mature technologies.

We also ran a sensitivity isolating the main policy measures included in the NEVP, to see which are most impactful for EV adoption. The measures isolated were the goods and services (GST) tax reductions, custom duty reductions on completely built up (CBU) imports, and custom duty reductions on complete knock down (CKD) imports. We calculate new tax, duty, and fee multipliers for purchase costs to show the effect of each policy lever, and run these on top of the high and low cases above.

1. Check the reasoning/sources behind these changes (and whether these should still be used as baseline assumptions in all scenarios). [↑](#footnote-ref-1)
2. <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> [↑](#footnote-ref-2)
3. <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> [↑](#footnote-ref-3)
4. <https://www.statista.com/statistics/383760/inflation-rate-in-pakistan/> [↑](#footnote-ref-4)
5. |  |
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   | Sources |
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   | * Jadun, P., McMillan, C., Steinberg, D., Muratori, M., Vimmerstedt, L., & Mai, T. (2017). *Electrification futures study: end-use electric technology cost and performance projections through 2050* (NREL/TP-6A20-70485). Retrieved from https://www.nrel.gov/docs/fy18osti/70485.pdf |
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   | * Moawad, A., Kim, N., Neeraj, S., & Rousseau, A., (2016). Assessment of Vehicle Sizing, Energy Consumption, and Cost Through Large-Scale Simulation of Advanced Vehicle-Technologies (ANL/ESD-15/28). Retrieved from https://www.autonomie.net/pdfs/Report%20ANL%20ESD-1528%20-%20Assessment%20of%20Vehicle%20Sizing,%20Energy%20Consumption%20and%20Cost%20through%20Large%20Scale%20Simulation%20of%20Advanced%20Vehicle%20Technologies%20-%201603.pdf |

   [↑](#endnote-ref-1)
6. <https://www.autonomie.net/docs/ANL%20-%20BaSceFY17%20-%20Autonomie%20-%20Merge_Results_052317_181101.xlsx> [↑](#endnote-ref-2)
7. Sources:

   $395k-593k per bus in China (<https://en.wikipedia.org/wiki/BYD_K9>)

   $300-900k per bus in China (<https://www.citylab.com/transportation/2019/06/electric-bus-china-grid-ev-charging-infrastructure-battery/591655/>)

   Proterra is producing an e-bus with 440 kWh battery capacity (<https://www.sustainable-bus.com/news/proterra-set-a-new-us-record-for-electric-bus-battery-capacity/>), with total cost ~$750k: <https://www.greentechmedia.com/articles/read/proterra-rolls-out-bus-battery-leasing-program-with-mitsui> [↑](#endnote-ref-3)