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

Molly Charles1, Zarrar Khan1, Sha Yu, Steve Smith, Juliet Homer, Travis Douville, Trevor Hardy, Others from USAID ?,

*1 Joint Global Change Research institute, Pacific Northwest National Laboratory (PNNL), College Park, MD 20740, USA*

*2 PNNL Richland*

*3 USAID*

**Abstract**

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# 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

Add overview of vehicle modes and classes, and what assumptions are given per vehicle type (unless this belongs in main body)

The main set of vehicle assumptions are contained in energy/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 core 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.

The infrastructure capital cost assumptions for BEVs also 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 the $580 charging infrastructure cost applies to 3-wheelers because of the high annual distance travelled per vehicle.

We also update BEV mini car costs and intensity to match India, as all other car assumptions were based on India but mini cars in SE Asia had higher costs for unclear reasons. We base vehicle maintenance costs for 2, 3, and 4-wheelers on Pakistan-specific data. As these were for well-maintained vehicles, we scale the values by 70% to represent more realistic maintenance.

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.

* Changed costs for buses (to implicitly change annual vkt). Costs were levelized by dividing by vkt of 51707.82 km/veh/year; we changed this to 72000 km/veh/year for consistency with SEP (2/4/20).
* Scaled bus, 0-2t truck, and 2-5t truck costs (all techs) based on ANL data on costs in Pakistan – cost is about 40% of comparable vehicle in the US. Applied this knockdown factor to the 76.45% purchase cost share of CAPEX/non-fuel OPEX calculated for compact cars (2/5/20)

In other files:

* Share weight changes:
  + Changed BEV share weights to show phase-in effect. Market penetration should be near zero in 2020 (add on file is Pakistan/transportation/BEV\_delayed\_adv.xml – wasn’t working right making changes through data system)
  + From Brinda’s file – share weights for NG vehicles go to 0.25 in 2050/2100 (default is to 1)
* Discount rate:
  + Changed consumer discount rate for vehicles (energy.DISCOUNT\_RATE\_VEH in constants.R) to 0.15, based on real interest rates in Pakistan

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

Modified Slow, Moderate, and Rapid cost curves based on more aggressive battery cost projections (see GCAM inputs and assumptions v4).

We base these new curves off the previous slow, moderate, and rapid curves from NREL data. Intensity and infrastructure costs also vary between these advancement scenarios. We do not modify these variables and only update capital costs based on these new battery cost curves.

New battery cost curves (2018$/kWh)[[3]](#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 |

NREL’s battery cost curves (2016$/kWh)

|  |  |  |  |
| --- | --- | --- | --- |
|  | **Slow** | **Moderate** | **Rapid** |
| 2016 | 273 | 273 | 273 |
| 2020 | 258 | 246 | 232 |
| 2025 | 238 | 213 | 181 |
| 2030 | 219 | 180 | 131 |
| 2035 | 200 | 160 | 90 |
| 2040 | 192 | 152 | 80 |
| 2045 | 183 | 143 | 80 |
| 2050 | 175 | 135 | 80 |

#### Battery vintaging factors:

Calculated battery vintaging factor based on retirement curve, to account for batteries not lasting full vehicle lifetime. Assumed batteries last 10 years and took weighted average of battery packs needed over vehicle lifetime, using retirement function to get share of vehicles still in use after x years



* Cars, buses, light duty trucks (vehicles with 25-year max lifetime): 1.17
* Medium and heavy-duty trucks (vehicles with 40-year max lifetime): 1.35
* 2 and 3-wheelers (vehicles with 15-year max lifetime): 1

### 4W LDVs

* Variable modified: capital costs (purchase)
* Extracted the share of battery in vehicle purchase cost for compact cars from ANL, under average non-battery tech curve[[4]](#endnote-2)
* Extracted percent change from NREL’s battery costs to our new battery costs by year
* For each vehicle size class:
  + New cost = old cost \* (1 – ((battery cost % change from NREL) \* (battery share of cost) \* (battery vintaging factor))
* Note: Assumed mini car capital costs from India region.

### 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[[5]](#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):**

These embed assumptions about the level of localization of EV manufacturing. (See GCAM Inputs and Assumptions file from Travis for localization assumptions that go into this)

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **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% |

* Changing vehicle costs based on Pakistan’s taxes and duties:
  + 2-wheelers, 4-wheel LDVs – changed capital costs (other) as this represents taxes, fees, etc.
  + 3-wheelers – assumption is capital cost (total). Assumed x % of total is purchase cost to apply different taxes (differ by scenario/whether or not taxes are already included – see UCD edits R script)
  + Buses and trucks – assumption is CAPEX and non-fuel OPEX ($/vkt). Assumed x % of total is purchase cost to apply different taxes, based on assumptions for multipurpose vehicle (differ by scenario/whether or not taxes are already included – see UCD edits R script)
* High subsidy (for cost parity)
  + Calculated from cost of transportation techs output – multiplied cost difference between BEV and liquids by load factor to get subsidy per vehicle

## Sensitivity analysis

* As a sensitivity to highlight the importance and effect of informational campaigns, etc., we run a high and low case (slow advancement + NEVP gradual localization and rapid advancement + NEVP accelerated localization) with higher EV operating costs
  + Adjusted operating costs were calculated for each LDV size class to represent a 30% discounting of future operational cost savings associated with EVs
  + We believed 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
  + See discountOpexSavingsOnly\_tcd031520.xlsx for calculations
* We also ran a sensitivity isolating the main policy measures included in the NEVP, to see which are most impactful for EV adoption
  + Measures isolated: goods and services (GST) tax reductions, custom duty reductions on completely built up (CBU) imports, custom duty reductions on complete knock down (CKD) imports
  + Multipliers for these scenarios are in GCAM Inputs and Assumptions\_v12\_\_031720.xlsx

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. |  |
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   [↑](#endnote-ref-1)
4. <https://www.autonomie.net/docs/ANL%20-%20BaSceFY17%20-%20Autonomie%20-%20Merge_Results_052317_181101.xlsx> [↑](#endnote-ref-2)
5. 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)