Contents

[Pakistan project - assumptions and scenarios 1](#_Toc35334619)

[General assumptions 1](#_Toc35334620)

[Power sector changes 1](#_Toc35334621)

[Industry changes 1](#_Toc35334622)

[EV analysis 2](#_Toc35334623)

[Changes to vehicle assumptions (all scenarios) 2](#_Toc35334624)

[Policy scenarios 4](#_Toc35334625)

[Sensitivity analysis 6](#_Toc35334626)

[Battery cost curves update (1/16/20) 6](#_Toc35334627)

[Battery vintaging factors: 7](#_Toc35334628)

[4W LDVs 7](#_Toc35334629)

[2-wheelers 7](#_Toc35334630)

[3-wheelers 8](#_Toc35334631)

[Trucks 8](#_Toc35334632)

[Buses 8](#_Toc35334633)

# Pakistan-specific changes to core GCAM

## General assumptions

* SSP5, IMF growth rates

## Power sector changes

* Reduced oil in electricity generation
  + Share weight 0 after 2020
* Increased coal in electricity generation (adjusted share weights based on IGCEP)
* Increased hydro fixed output (based on IGCEP)
* Nuclear share weight adjustments

Add-on file: electricity\_water\_pak\_RO\_hydro\_nuclear\_coal.xml

#### Hydro

* For 2020-40, hydro and nuclear capacity comes from 2019 Indicative Generation Capacity Expansion Plan 2018-40 (IGCEP)
* Hydro generation from 2020-2040 given in Table 7-6
* Assumed linear increase from 2040-50 (based on average growth from 2020-40)
* Kept constant after 2050

#### Nuclear

* Assumed capacity factor of 0.8
  + <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>
* For 2020-35, calculated generation based on capacities of IGCEP committed nuclear plants
* Adjusted shareweights to get nuclear generation close to these numbers
* Final nuclear shareweights:

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **2015** | **2020** | **2025** | **2030** | **2035** | **2040** | **2045** | **2050** |
| 0.05 | 0.5 | 1 | 1 | 0.1 | 0.1 | 0.1 | 0.1 |

## Industry changes

* Added electricity fuel preference elasticity of -0.5
  + Add on file: input/Pakistan/industry\_pak
* Adjust industry income elasticity downward to adjust electricity generation closer to 150 TWh in 2020 (which is what IGCEP projects)
* input/Pakistan/industry\_incelas\_gssp5\_pak\_neg
  + industry income elasticities negative
* input/Pakistan/industry\_incelas\_gssp5\_pak\_low
  + industry income elasticities 50% of ref

# EV analysis

## Changes to vehicle assumptions (all scenarios)

In UCD\_trn\_data\_CORE:

* Use updated UCD database file (with the following changes that Brinda made):
  + Added data for all model periods
  + BEV cost assumptions updated from NREL for cars and trucks (three electrification advancement scenarios – slow, moderate, rapid)
  + Added BEV trucks and buses
    - Added share weights (A54.globaltranTech\_shrwt.csv), interpolation rule (A54.globaltranTech\_interp.csv), lifetime (A54.globaltranTech\_retire.csv), mappings (mappings/UCD\_techs.csv) – from Brinda’s files
  + Added NG infrastructure costs for trucks
  + Updated ICE intensity to match CAFÉ standards, lagged by 5 years
  + Latest files: UCD\_trn\_data\_CORE\_ModElec\_extYears\_NGT\_inf\_cost(12.6.19).csv, UCD\_trn\_data\_CORE\_HighElec\_extYears\_NGT\_inf\_cost(12.10.19).csv, UCD\_trn\_data\_CORE\_SlowAdv(01.06.20).csv

* Deleted operating subsidy for buses for all technologies
  + Subsidy was from old UCD database and made user cost equal across technologies to reflect equal fares for consumers– but did not capture cost differences between technologies or general cost to society (and was outdated as costs have been updated)
* Changed BEV mini car cost (purchase, other, and operating) and intensity to match India (all other 4W LDV assumptions are same ase India, unclear why this one was different). (1/28/20)
* 3-wheelers:
  + Added BEV 3-wheeler for SE Asia
  + Changed speed for 3-wheelers from 36 to 25 km/hour, based on feedback from SEP (1/28/20)
  + Changed annual travel per vehicle from 8478 km/ year (same as 2-wheelers) to 32000 km/year, based on feedback from SEP (1/28/20)
* Changed maintenance costs for SE Asia based on maintenance data from Pakistan (1/29/20)
  + These are for well-maintained vehicle; scaled by 0.7 to represent more realistic maintenance
* Changed load factor assumptions for trucks to make them the same across advancement scenarios. BEV load factors (for SE Asia only) are 80% of liquids load factor in 2020, increasing to be equal with liquids in 2050 (2/3/20).
* 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)
* Scaled liquids 2W costs by 0.59 based on Pakistan 2W cost data from Cabell. Cost of motorcycle in 2020 is about $800, about 59% of the cost assumption we have now
* Reduced capital costs (infrastructure) for BEVs. Based on lower labor/installation costs in Pakistan compared to US
  + 4W: reduced to $580/year
  + 2: removed
* Adjusted 2-wheeler purchase costs assuming levelized cost parity in 2020 under NEVP policies
  + Assumed LCOD parity now (based on feedback from SEP/Cabell), and back-calculated ratio of BEV to ICEV purchase cost (using Travis’s spreadsheet for calculating LCOD)
  + Same costs in 2020 across cost pathways; after 2020, 2/3-wheeler costs vary by advancement curve (slow, moderate, rapid)
  + 2/11: ratio updated using new operating costs (from SEP), lower liquids 2W costs in Pakistan (from Cabell), no infrastructure costs, and was done for each 2W class individually instead of using scooter ratio for all
    - Moped ratio: 2.762
    - Scooter ratio: 2.307
    - Motorcycle ratio: 1.994
* BEV 3-wheeler capital costs – calculated using BEV 2W costs and ratio of liquids 2W to 3W capital costs
  + Liquids motorcycle to 3W cost ratio: 1.37
  + To get 2020 BEV 3W capital cost (total), multiply ratio above by 2020 BEV motorcycle capital cost (purchase + other) after scaling for cost parity
  + After 2020, costs decrease based on battery cost curves

In other files:

* Added lifetimes for buses, 2-wheelers, and 3-wheelers (A54.globaltranTech\_retire.csv)
  + Bus – 25 years (assumptions copied from light trucks)
  + 2/3-wheelers
    - Final-calibration-year: lifetime = 15 years, half-life = 7 years, steepness = 0.35
    - Initial-future-year: lifetime = 15 years, half-life = 8 years, steepness = 0.3
    - Used retirement function to get these values – iterated to get similar retirement pattern as for cars
* 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)

EV share weights:

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

* + 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)[[1]](#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[[2]](#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[[3]](#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))

## 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

1. |  |
   | --- |
   | Sources |
   | * Berckmans, G., Messagie, M., Smekens, J., Omar, N., Vanhaverbeke, L., & Van Mierlo, J. (2017). *Cost projection of state of the art lithium-Ion batteries for electric vehicles up to 2030. Energies, 2017*(10), 1314. doi:10.3390/en10091314 |
   | * Goldie-Scot, L. (2019, 5 March). *A behind the scenes take on lithium-ion battery prices*. Retrieved from: https://about.bnef.com/blog/behind-scenes-take-lithium-ion-battery-prices/ |
   | * BNEF (2019, 3 December). Battery pack prices fall as market ramps up with market average at $156/kWh in 2019. Retrieved from https://about.bnef.com/blog/battery-pack-prices-fall-as-market-ramps-up-with-market-average-at-156-kwh-in-2019/?sf113554299=1 |
   | * Holland, M. (2018, 9 June). $100/kWh Tesla battery cells this year, $100/kWh Tesla battery packs in 2020. Retrieved from https://cleantechnica.com/2018/06/09/100-kwh-tesla-battery-cells-this-year-100-kwh-tesla-battery-packs-in-2020/ |
   | * Baik, Y., Hensley, R., Hertzke, P., & Knupfer, S., (March 2019). Making electric vehicles profitable. Retrieved from: https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/making-electric-vehicles-profitable |
   | * 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 |
   | * Curry, C. (2017 July 5). “Lithium-Ion Battery Costs and Market.” Retrieved from https://data.bloomberglp.com/bnef/sites/14/2017/07/BNEF-Lithium-ion-battery-costs-and-market.pdf |
   | * 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)
2. <https://www.autonomie.net/docs/ANL%20-%20BaSceFY17%20-%20Autonomie%20-%20Merge_Results_052317_181101.xlsx> [↑](#endnote-ref-2)
3. 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)