Explanatory Note on the Transport Emissions Calculation Model

Project Number: 52230-001
May 2020

PRC: Xiangtan Low-Carbon Transformation Sector Development Program

MEMORANDUM

TO: Asian Development Bank, Xiangtan Program Management Office
FROM: Rachael Jonassen, PhD
DATE: May 24, 2020
RE: Emissions Estimates for Low-Carbon Transportation Strategy in Yuhu and Yuetang Districts, Xiangtan County

1. Overview

This memorandum accompanies a report to ADB summarizing projected impacts of Low Carbon City Development in the municipality (county) of Xiangtan, China. The report summarizes each of the project-based and policy-based actions that will be undertaken as a result of the requested loan and indicates the ways in which those actions can be expected to influence the trajectory of GHG emissions over the lifetime of the loan (to 2045). This memo details assumptions and calculations used to estimate the impacts of project-based and policy-based actions related to transport in Yuhu and Yuetang Districts.

The baseline scenario represents a 'Business as Usual" (BAU) case where the composition of the bus fleet and all incentives for use of the various modes of transport available do not change from today (2020). Under the BAU scenario, all factors that could be influenced by the project-based and policy-based loans are held constant at 2020 values. Only the external factor of population changes in the BAU scenario. The "ADB Scenario" represents the case where each project-based and policy-based action is implemented over time. The ADB Scenario examines the effect of six project-based actions and six policy-based actions. These actions are:

Project-based modifications examined:

1. Change in bus fleet engine types - and corresponding switch in fuel types.
2. Change in bus lane placement, features, and operating characteristics.
3. Changes in availability of charging piles and charging stations.
4. Changes in availability and characteristics of bicycle lanes.
5. Changes in availability and characteristics of pedestrian walkways.
6. Improvements in interconnectivity of low carbon transport modes.

Policy-based modifications examined:

1. Changes in parking fees, parking availability and rule enforcement.
2. Improvements in accessibility of public bicycles.
3. Enforcement of restrictions on electric motor bikes.
4. Improvements in operation of multi-modal hubs.
5. Promotion of LC transport (e.g. bus operation, bicycle use and parking, car sharing, pedestrian safety, clean private vehicles).
6. Discouraging the use of fossil fuel transport options (vehicle emissions).

Policy-based actions are designed to occur in two tranches with different implementation dates and the effects of policies on human behavior are also phased over time as they reach greater numbers of the relevant population.

Projected impacts of project-based and policy-based actions related to transport are plotted against emission trajectories for two scenarios, referred to as "Worst Case" and "Best Case" scenarios. Emission trajectories for the BAU and Goal scenarios are derived from two Integrated Assessment Models (IAMs) as reported by the IPCC in the Fifth Assessment. These IAMs provide a global representation of emission trajectories that are used by the international climate change community. At the global scale, these are called Representative Concentration Pathways (RCPs). IAMs create projections of global emissions by socio-economic modeling using a grid-cell discretization of the Earth.

Emission estimates from project and policy-based actions in Xiangtan are compared to solutions derived from the IAM grid cell containing Xiangtan for the RCP 8.5 scenario, developed by the MESSAGE modeling system, and the

RCP 2.6 scenario, developed by the IMAGE modeling system. This grid cell does not contain Changsha or other major Chinese cities; therefore, it is reasonable to believe that the results primarily represent emissions due to activities in Xiangtan. For the transport sector, RCP 8.5 represents the "Worst Case" scenario, in which the global economy follows a pathway of emissions close to that China is now following as it continues to expand the use of coal and oil as energy sources, while RCP 2.6 represents the "Best Case" scenario, exhibiting an early peaking of GHG emissions followed by a rapid decline. These are the two most extreme RCP scenarios; thus, movement from one to the other represents the most ambitious goal.

2. Assumptions

2.1. BAU Bus Scenario

1. Gui'an EFs scale to unknown fuel sources, as observed in all-China data.
2. Bus annual VKT is as reported for Gui'an and remains constant throughout the loan period. This value (55,000 km/yr) agrees closely with the all-China value for 10-12m busses (56,000 km/yr).
3. Assume all busses are 12 m in length and eBusses are 100% electric battery powered.
4. Assume 8 years lifetime for eBus.
5. Assume bus batteries are reused (stationary) after the bus no longer uses them, lowering lifetime GHG emissions drastically.
6. For the purposes of this analysis, we assume that when busses are replaced, the replacements use the same fuel and have the same emission profile as the original.

2.2. Bus Fuel Switch

1. All replacements occur over a five-year period from 2020-2025.
2. The new ADB-funded busses will be 10.5m eBusses.
3. Busses must be replaced every eight years (all-China regulation).For the purposes of this analysis, we assume that when busses are replaced, the replacements use the same fuel and have the same emission profile as the original.
4. GHG emissions are calculated using well-to-wheels (WTW) emission factors that are averages for China.
5. Emission factors represent average total kilometers travelled by busses in China. These EFs assume 56,000 km/yr annual VKT constant throughout the loan period.
6. Assume bus batteries are reused (stationary) after the bus no longer uses them, lowering lifetime GHG emissions drastically.

2.4. Bus LOS EFs

1. Bus EFs changes resulting from LOS changes are scaled using data from gas ICE POVs adhering to China 4 emissions standards, as these are the most recent standards with available data.
2. Bus priority lanes are expected to result in a two-level improvement in LOS from "saturated traffic" to "free flow" traffic for busses using priority lanes, according to current and anticipated vehicle travel speeds provided by XT PMO.
3. Bus EFs are assumed to scale to LOS in direct linear relation to the relative values for automobiles conforming to China 4 emission standards.
4. These EFs assume 56,000 km/yr annual VKT constant throughout the loan period, 8-year lifetime for all bus types, and reuse of bus batteries after the bus no longer uses them, lowering lifetime GHG emissions drastically.

5. The number of busses operating on enhanced LOS lanes is assumed to be proportional to the fraction of XT bus routes upgraded with priority lanes, and assumes the fraction of busses of each fuel type operating on the enhanced LOS lanes is the same as in the general fleet.
6. The BAU case assumes no change in the bus fleet composition.
7. These calculations ignore the embodied GHG emissions from construction of bus lanes.

2.5. Mode Shift

1. Bus EF is averaged across fuel types, weighted by bus type numbers. See Section 5.2.1. Bus Fuel Switch.
2. Trip VKT for each mode and commuter trips per day are assumed to follow values reported on XT urban comprehensive transportation system planning (for 2015) provided by Zhou Lin of the Shenzhen Urban Transport Planning Center in a spreadsheet titled "XT average distance travelled_2015" on 22 October 2019. Based on comparisons with total annual VKT per POV reported by other sources, it is assumed this trip distance represents a one-way trip; therefore, daily commute distance is estimated by doubling the reported number of commuter trips per day. Annual VKT assumes 365 travel days per year because it is assumed that non-work-related trips will still occur on non-work days.
3. In order to account for levels of carpooling and ridesharing indicated by the POV LF and the additional distance traveled by POVs picking up and letting off additional passengers (Wang et al. 2017), average one-way trip distance is assumed to be the weighted average of typical trip distance for a single-occupant POV and typical trip distance for a carpooling vehicle, with weights determined by the percentage of single-occupant and fully-occupied POVs, as indicated by POV LF.
4. BAU case represents absence of additional policy interventions. Modal preference is assumed to follow ADB survey of XT commuters performed in August 2019 throughout the loan period for the BAU case.
5. Changes in modal preference occur on an annual basis and can be represented by a Markov Transition Matrix for all modes of interest.
6. Policy interventions target specific mode transitions and can be represented by a percentage change in preference of one mode over another.
7. Commuters remain "loyal" to the prior year mode unless influenced by specific policy interventions. This "loyalty" is represented by a percent value. Loyalty values less than 100% imply some commuters will shift to a new mode in the following year.
8. Calculations do not account for any XT commuters using the train. This assumption is inconsistent with expenditures planned in the loan to improve train-bus transfers.
9. Number of commuter trips each year is assumed to be proportional to population that year. Proportion of the population that is working age, commuter trips per worker per day, and average commute trip distance all assumed to remain constant throughout the loan period.

2.6. More EV POVs

1. Share of EVs in the XT fleet follows the intervention scenario recommended in "Modal Shift" calculations and all accompanying assumptions, with the exception that modal shift in this scenario occurs only within the POV market, while the total percentage of XT commuters traveling by car remains constant.
2. POV market share of diesel vehicles is expected to rapidly decline in response to national, regional, and local policies to remove diesel vehicles. This decline is represented with a logistic decay model beginning with a ban on sales of new diesel cars and LDVs in XT beginning in 2026.
3. Number of charging stations and charging piles of each type conforms with current XT policy throughout the loan period.
4. EV energy demand per kilometer travelled is expected to decline according to the scenario presented by Huo et al. (2010). EV POV emissions based on electricity demand per kilometer assumes an unchanging

Hunan-specific grid EF. ICE and EV POV emissions based on WTW EFs from Gui'an assume EFs for each vehicle type remain constant throughout the lifetime of the loan.

5. BAU scenario assumes no additional mode shift towards EVs, no ban on diesel POVs, and no improvements in EV POV operating efficiency.

2.7. Car Pooling

1. Number of passengers in a POV is assumed to follow a Poisson Distribution.

2. In the policy scenario, the parameter of the Poisson distribution (λ) increases yearly in response to policy interventions according to a logistic growth model.

3. Maximum value of λ is set by the average capacity of a vehicle, and when λ increases above this value, unsafe numbers of riders occur.

4. Market share of gas ICE, diesel ICE, and EV POVs inthe XT fleet is assumed to follow the intervention scenario recommended in "Modal Shift" calculations, with a gradual decline in diesel ICE POV market share and gradual increase in EV market share. No other modal shift is included in the BAU or intervention scenarios.

5. Trip VKT for POVs and commuter trips per day are assumed to follow values reported on XT urban comprehensive transportation system planning (for 2015) provided by Zhou Lin of the Shenzhen Urban Transport Planning Center in a spreadsheet titled "XT average distance travelled_2015" on 22 October 2019. Based on comparisons with total annual VKT per POV reported by other sources, it is assumed this trip distance represents a one-way trip; therefore, daily commute distance is estimated by doubling the reported number of commuter trips per day. Annual VKT assumes 365 travel days per year because it is assumed that non-work-related trips will still occur on non-work days.

6. In order to account for levels of carpooling and ridesharing indicated by the POV LF and the additional distance traveled by POVs picking up and letting off additional passengers (Wang et al. 2017), average one-way trip distance is assumed to be the weighted average of typical trip distance for a single-occupant POV and typical trip distance for a carpooling vehicle, with weights determined by the percentage of single-occupant and fully-occupied POVs, as indicated by POV LF.

2.8. ICE Fuel Standards and Emission Standards

1. Standards enforcement refers to existing standards for automobiles and motorcycles. The focus is to ensure existing automobiles and motorcycles conform to the pollution control and durability standards now in force. Such standards of concern that are relevant to GHG emissions include: criteria pollutant emissions, efficiency (L/100km), and durability.

2. ICE Fuel Standards BAU scenario without ADB-funded intervention assumes no improvement in average fuel demand (L/100km) for ICE POVs and MCs.

3. An alternative BAU scenario (REF scenario of Wang et al. (2017)), modeling a gradual decline in average fuel demand (L/100km) for ICE POVs and MCs, is presented for comparison.

4. The EEI (energy efficiency improvement) scenario presented by Wang et al. (2017) is assumed to represent the greatest improvement that XT policies could achieve. A policy scenario is developed with a logistic growth model describing the convergence of the REF and EEI scenarios presented by Wang et al. (2017).

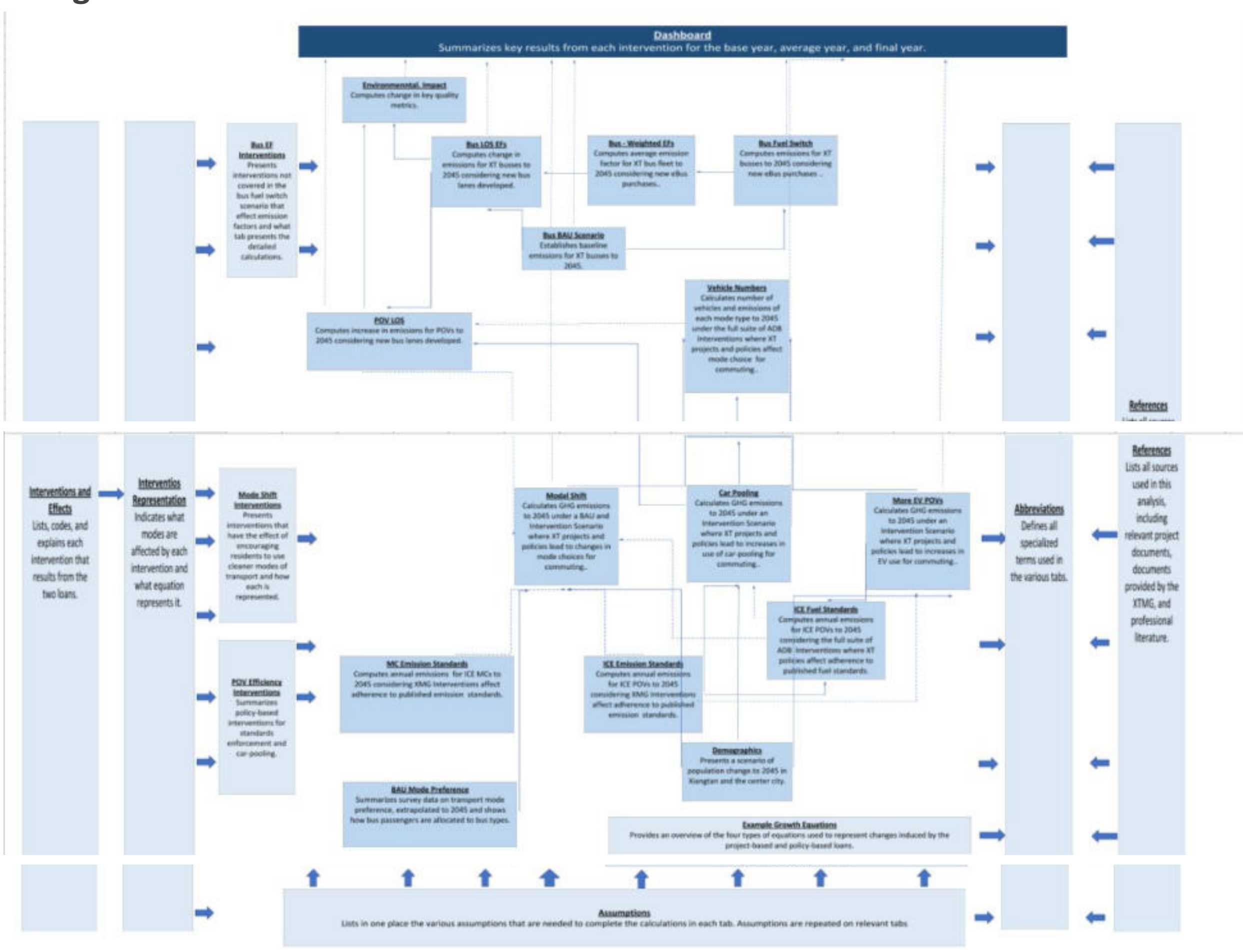
5. Current emission control regulations require that all vehicles conform to China-5 criteria pollutant emission standards. Efforts at enforcement will tend to move vehicles now conforming to lower standards to the China-5 level. It is assumed the effect of these efforts can be represented with a Markov transition matrix describing the probability of faster vehicle scrappage than would otherwise occur. Without this enforcement, it is assumed vehicles tend to conform to the standard in place when they were assembled.

6. MC calculations consider only two-wheeled vehicles with four-stroke engines (engine displacement >50cc) and do not include calculations for three-wheeled vehicles, two-stroke engines, or mopeds. Derogation rules are unknown and for the purposes of this analysis derogation is assumed to be not allowed.

2.10. POV LOS

1. We assume that only the traffic on roads directly modified by the bus lane designation is affected by LOS reductions.
2. This ignores any effect of bus lane change on the number of POVs (i.e. mode shift).
3. We assume that traffic load is evenly spread across all roads considered. This ignores the difference in traffic between different road types.
4. We assume that the length of roads in XT does not change during the entire period.
5. We calculate the case assuming the bus lanes are on major arterial roads.
6. We had assumed in the "Bus LOS EFs scenario that traffic flow began in the "Saturated Traffic" LOS. We use that same assumption here.
7. In this case, traffic LOS switches down two levels (symmetric with our assumption of a two level improvement for busses. Thus, traffic flow becomes "Heavy stop-and-go" for automobiles on roads affected by bus lane modifications. For roads not affected by bus lane modifications, LOS changes from carpooling adoption are assumed to increase LOS two levels by 2026. Effects are assumed to apply to all commute trips.

3. Logical Flow



4. User-Defined Parameters

Parameter	Value	Equation(s)	Data Source	Explanation
t_0 *(year)*	2019	*Eq. 1*	XT Health and H	*Year of initial population estimate*

			Comm	
$N(2019)_{XT}$	3,050,000	*Eq. 1* *Eq. 2*	XT City Assessment Report	*Initial population estimate*
r_n *(%)*	3.23%	*Eq. 1*	XT City Assessment Report	*Natural population growth rate*
r_{XTH} *(person/yr)*	12,500	*Eq. 2*	XT Health and H Comm	*Annual population growth rate estimated by XT Health & H Comm. (persons/yr)*
p_{YH+YT} *(%)*	30%	*Eq. 3* *Eq. 11* *Eq. 93* *Eq. 117*	XT City Assessment Report	*Percentage of XT county population living in YH+YT (%)*
$p_W(\%)$	62%	*Eq. 4*	XT City Assessment Report	*Percentage of population in YH+YT that is working age (%)*
$p_F(\%)$	43.8%	*Eq. 5*	World Bank	*Percentage of workforce that is female (%)*
$y_{0,B}(\%)$	19.5%	*Eq. 7* *Eq. 25* *Eq. 89*	XT PMO	*Percentage of commuters travelling by bus in first year of policy period (%)*
ζ_{tpd} $(trips/day)$	3.86	*Eq. 8* *Eq. 26* *Eq. 41* *Eq. 44* *Eq. 51* *Eq. 52* *Eq. 58* *Eq. 68* *Eq. 69* *Eq. 74* *Eq. 75* *Eq. 80* *Eq. 83* *Eq. 86* *Eq. 90* *Eq. 101* *Eq. 103* *Eq. 105* *Eq. 108* *Eq. 111* *Eq. 114* *Eq. 129* *Eq. 132* *Eq. 135* *Eq. 139* *Eq. 143*	General report on XT urban comprehensive transportation system planning (for 2015).	*Average number of one-way trips per commuter per day* Equal to the reported number of daily trips multiplied by 2, assuming each commuter makes two one-way trips per day. Used for all modes.
d_B $(km/trip)$	5.9	*Eq. 9* *Eq. 27* *Eq. 91* *Eq. 115*	General report on XT urban comprehensive transportation system planning	*Average bus trip distance*

			(for 2015).	
vkt_B (km/day)	200.2	*Eq. 10* *Eq. 12* *Eq. 23* *Eq. 92* *Eq. 94*	"Emission calculation 21 Feb_final, Gui'an.xlsx" Traffic Load tab, line 87	*Daily VKT per bus*
LF_B	25	*Eq. 10* *Eq. 92*	Urban Bus Toolkit, World Bank Group	*Average bus load factor* Dimensionless ratio of passenger-kilometers to place-kilometers. For urban services with regular stop spacing it is usually adequate to measure passenger-kilometers by dividing the route length by the number of stops to calculate the average stop distance. Place-kilometers measure the kilometers operated by all the buses on a route times the average capacity of the buses on the route.
ζ_{acd} $(days/yr)$	365	*Eq. 12* *Eq. 23* *Eq. 26* *Eq. 41* *Eq. 44* *Eq. 52* *Eq. 58* *Eq. 68* *Eq. 69* *Eq. 74* *Eq. 75* *Eq. 80* *Eq. 83* *Eq. 86* *Eq. 94* *Eq. 101* *Eq. 103* *Eq. 105* *Eq. 108* *Eq. 111* *Eq. 118* *Eq. 129* *Eq. 132* *Eq. 135* *Eq. 139* *Eq. 143*		*Annual commute days*
$B_{0,eBus}$	143	*Eq. 13* *Eq. 95* *Eq. 119*	XT PMO	*Initial number of eBusses in XT bus fleet* Bus fleet composition for Xiangtan Public Transportation Company, Xiangtan Xiangyun Public Transportation Co., Ltd.
$B_{0,pureNG}$	223	*Eq. 14* *Eq. 95* *Eq. 120*	XT PMO	*Initial number of pure NG busses in XT bus fleet* Bus fleet composition for Xiangtan Public Transportation Company, Xiangtan Xiangyun Public Transportation Co., Ltd.

$B_{0,NG\ Hybrid}$	430	*Eq. 15* *Eq. 95* *Eq. 121*	XT PMO	*Initial number of NG hybrid busses in XT bus fleet* Bus fleet composition for Xiangtan Public Transportation Company, Xiangtan Xiangyun Public Transportation Co., Ltd.
$B_{0,Diesel\ H}$	275	*Eq. 15* *Eq. 95* *Eq. 121*	XT PMO	*Initial number of Diesel hybrid busses in XT bus fleet* Bus fleet composition for Xiangtan Public Transportation Company, Xiangtan Xiangyun Public Transportation Co., Ltd.
$B_{0,Diesel}$	81	*Eq. 15* *Eq. 95* *Eq. 121*	XT PMO	*Initial number of diesel busses in XT bus fleet* Bus fleet composition for Xiangtan Public Transportation Company, Xiangtan Xiangyun Public Transportation Co., Ltd.
EF_{eBus} *($ktCO_2e/km$)*	6.70E-7	*Eq. 17* *Eq. 97* *Eq. 123*	Sustainable Transport Solutions Low-Carbon Buses in the PRC, ADB 2018.	*Distance-based WTW CO_2 EF for eBusses*
EF_{pureNG} *($ktCO_2e/km$)*	1.19E-6	*Eq. 17* *Eq. 97* *Eq. 123*	Sustainable Transport Solutions Low-Carbon Buses in the PRC, ADB 2018.	*Distance-based WTW CO_2 EF for pure NG busses*
$EF_{NG\ Hybrid}$ *($ktCO_2e/km$)*	9.80E-7	*Eq. 17* *Eq. 97* *Eq. 123*	Sustainable Transport Solutions Low-Carbon Buses in the PRC, ADB 2018.	*Distance-based WTW CO_2 EF for NG hybrid busses*
$EF_{Diesel\ H}$ *($ktCO_2e/km$)*	9.00E-7	*Eq. 17* *Eq. 97* *Eq. 123*	Sustainable Transport Solutions Low-Carbon Buses in the PRC, ADB 2018.	*Distance-based WTW CO_2 EF for diesel hybrid busses*
EF_{Diesel} *($ktCO_2e/km$)*	1.10E-6	*Eq. 17* *Eq. 97* *Eq. 123*	Sustainable Transport Solutions Low-Carbon Buses in the PRC, ADB 2018.	*Distance-based WTW CO_2 EF for diesel busses*
$B_{Pr,eBus}$	100	*Eq. 13* *Eq. 14* *Eq. 119* *Eq. 120*	XT PMO	*Additional eBusses provided by XT project-based loan*
$l_{B,mod}\ (km)$	62.8	*Eq. 21*	XT PMO	*Total length of bus lanes with improved*

		Eq. 81		*service (km)*
l_B (km)	3,640	*Eq. 21* *Eq. 81*	XT PMO	*Total length of bus routes (km)*
t_L $(year)$	2026	*Eq. 13* *Eq. 14* *Eq. 21* *Eq. 81* *Eq. 119* *Eq. 120*	XT PMO (2019)	*End of loan period*
$y_{0,ICE}(\%)$	21.97%	*Eq. 25* *Eq. 95*	XT PMO (2019)	*Percentage of commuters travelling by ICE POV at start of loan period*
$y_{0,eV}(\%)$	0.45%	*Eq. 25* *Eq. 99*	XT PMO (2019)	*Percentage of commuters travelling by EV POV at start of loan period*
$y_{0,MC}(\%)$	1.9%	*Eq. 25* *Eq. 100*	XT PMO (2019)	*Percentage of commuters travelling by MC at start of loan period*
$y_{0,bike}(\%)$	5.1%	*Eq. 25*	XT PMO (2019)	*Percentage of commuters travelling by bicycle at start of loan period*
$y_{0,walk}(\%)$	32.6%	*Eq. 25*	XT PMO (2019)	*Percentage of commuters travelling on foot at start of loan period*
$y_{0,eB}(\%)$	18.5%	*Eq. 25* *Eq. 110*	XT PMO (2019)	*Percentage of commuters travelling by eBike at start of loan period*
R	100%	*Eq. 24* *Eq. 25*		*Recurrence Probability* Estimated parameter for modal shift transition matrix reflecting the probability a commuter will remain "loyal" to a given transport mode in the absence of additional ADB-funded interventions.
a	1.0%	*Eq. 24* *Eq. 25*		*Bicycle Transition Probability* Estimated parameter for modal shift transition matrix reflecting the probability a commuter will switch from a different mode to bicycle.
b	4.5%	*Eq. 24* *Eq. 25*		*Bus Transition Probability* Estimated parameter for modal shift transition matrix reflecting the probability a commuter will switch from a different mode to bus.
c	0.3%	*Eq. 24* *Eq. 25*		*EV Transition Probability* Estimated parameter for modal shift transition matrix reflecting the probability a commuter will switch from a different mode to EV POVs.
d	1.0%	*Eq. 24* *Eq. 25*		*Walking Transition Probability* Estimated parameter for modal shift transition matrix reflecting the probability a commuter will switch from a different mode to walking.
e	1.0%	*Eq. 24* *Eq. 25*		*MC Transition Probability* Estimated parameter for modal shift transition matrix reflecting the probability

				a commuter will switch from a different mode to MCs.
f	0.0%	*Eq. 24* *Eq. 25*		*Train Transition Probability* Estimated parameter for modal shift transition matrix reflecting the probability a commuter will switch from a different mode to train.
g	5.0%	*Eq. 24* *Eq. 25*		*eMB Transition Probability* Estimated parameter for modal shift transition matrix reflecting the probability a commuter will switch from a different mode to eBike.
$t_e\ (year)$	2026	*Eq. 25* *Eq. 53* *Eq. 54* *Eq. 63* *Eq. 73* *Eq. 79*	XT PMO (2018)	*First year project and policy based modifications see an effect*
$d_{POV}\ (km/trip)$	11	*Eq. 28*	Kim (2019)	*Average one-way POV trip distance* For single-occupant vehicle
R_{max} (*riders/vehicle*)	6	*Eq. 28* *Eq. 55*		*Average POV capacity* Above maximum capacity, additional passengers results in unsafe conditions
d'_{POV} *(km/trip)*	13.1	*Eq. 28*	XT PMO	*Carpool-adjusted distance travelled per POV trip* *VKT per trip are adjusted to represent the extra distance travelled due to extra stops picking up and leaving off passengers*
$EF_G\ (ktCO_2e/km)$	2.85E-7	*Eq. 29* *Eq. 42* *Eq. 57* *Eq. 102* *Eq. 130*	Kim (2019)	*Distance-based WTW EF for gas ICE POV*
$LF_{0,POV}$	1.2	*Eq. 36* *Eq. 53* *Eq. 54* *Eq. 101* *Eq. 103* *Eq. 105*		*Baseline load factor for POV*
$EF_{eV}\ (ktCO_2e/km)$	1.07E-7	*Eq. 30* *Eq. 52* *Eq. 57* *Eq. 106* *Eq. 136*	Kim (2019)	*Distance-based WTW EF for pure EV*
$d_{MC}\ (km/trip)$	7.3	*Eq. 31* *Eq. 68* *Eq. 69* *Eq. 80* *Eq. 108* *Eq. 139*	Kim (2019)	*Average one-way trip distance for MC*
LF_{MC}	1	*Eq. 31*		*Average load factor for MC*

		Eq. 67 *Eq. 108* *Eq. 138*		
EF_{MC} $(ktCO_2e/km)$	6.10E-8	*Eq. 31* *Eq. 109* *Eq. 140*	Kim (2019)	*Distance-based WTW EF for MCs*
d_{bike} $(km/trip)$	3.5	*Eq. 32*	Kim (2019)	*Average one-way trip distance for bicycles*
LF_{bike}	1	*Eq. 32*		*Average load factor for bicycles*
EF_{bike} $(ktCO_2e/km)$	4.70E-9	*Eq. 32*	Kim (2019)	*Distance-based WTW EF for non-motorized transport*
d_{eB} $(km/trip)$	5.0	*Eq. 33* *Eq. 111* *Eq. 143*	Kim (2019)	*Average one-way trip distance for eBikes*
LF_{eB}	1	*Eq. 33* *Eq. 111* *Eq. 142*		*Average load factor for eBikes*
EF_{eB} $(ktCO_2e/km)$	1.71E-7	*Eq. 33* *Eq. 112* *Eq. 144*	Kim (2019)	*Distance-based WTW EF for eBikes*
$\rho_{0,D}$ $(\%)$	13%	*Eq. 37* *Eq. 103*		*Initial diesel ICE POV market share*
L_D $(\%)$	100%	*Eq. 37*	Stanway (2018); Hao et al. (2011)	*Maximum percentage of existing diesel POVs active in the transportation fleet*
k_D $(\%)$	-50%	*Eq. 37*	Stanway (2018); Hao et al. (2011)	*Logistic growth rate for diesel POV scrappage*
$t_{0,D}$ $(years)$	10	*Eq. 37*	Stanway (2018); Hao et al. (2011)	*Midpoint year for diesel POV scrappage model*
t_b $(year)$	2026	*Eq. 37*	McFadden (2019)	*Year XT ban o sale of new diesel POVs expected to go into effect* Signal of change / Diesel and petrol cars will no longer be sold in Hainan province of China. Beginning March 1st 2019 in the Hainan province of China, internal combustion engine vehicles (ICEs) will no longer be sold. The ban, which includes both petrol and diesel cars, will be the first of its kind in China. China announced they would ban gasoline and diesel-engine cars in the future back in 2017. But, to date, they have not committed to an actual date.
EF_D $(ktCO_2e/km)$	2.80E-7	*Eq. 45* *Eq. 57* *Eq. 104* *Eq. 133*	Kim (2019)	*Distance-based WTW EF for diesel ICE POV*

ζ_{Φ} $(EVs\ per\ pile)$	8	*Eq. 47*	XT Standard	*Public charging pile density requirement* Equivalent to Hunan standard and national standard
ζ_{Ψ} *(EVs per station)*	2000	*Eq. 49*	XT Standard	*Public charging station density requirement* Equivalent to Hunan standard and national standard
L_{eV} (kWh/km)	0.024	*Eq. 50*	Huo et al. (2010)	*Maximum average EV electricity demand* EVs currently use 20 kWh/100km, projected to improve to 12 kWh/100km by 2030.
k_{eV} (%)	-15%	*Eq. 50*		*Logistic growth rate for average EV electricity demand*
$t_{0,eV}$ $(year)$	2030	*Eq. 50*		*Midpoint year for EV electricity demand model*
EF_E $(ktCO_2e/kWh)$	4.62E-7	*Eq. 52*	XT PMO (2018)	*Emission factor for electricity* Hunan-specific grid EF
κ_{CP}	1.103	*Eq. 53*		*Optimal final distribution of passengers*
γ_{CP} (%)	20%	*Eq. 53*		*Annual growth rate of carpooling*
μ_{CP} $(year)$	2033	*Eq. 53*		*Midpoint year for carpooling adoption model*
$\alpha_{POV,REF}$	2.80E-4	*Eq. 59*	Wang et al. (2017)	*Regression coefficient for POV improvement index, REF scenario* Estimated in R programming software from data presented in Wang et al. (2017)
$\beta_{POV,REF}$	-1.144	*Eq. 59*	Wang et al. (2017)	*Regression coefficient for POV improvement index, REF scenario* Estimated in R programming software from data presented in Wang et al. (2017)
$\xi_{POV,REF}$	1,170.00	*Eq. 59*	Wang et al. (2017)	*Regression coefficient for POV improvement index, REF scenario* Estimated in R programming software from data presented in Wang et al. (2017)
$\alpha_{MC,REF}$	7.79E-6	*Eq. 59*	Wang et al. (2017)	*Regression coefficient for MC improvement index, REF scenario* Estimated in R programming software from data presented in Wang et al. (2017)
$\beta_{MC,REF}$	-3.450E-2	*Eq. 59*	Wang et al. (2017)	*Regression coefficient for MC improvement index, REF scenario* Estimated in R programming software from data presented in Wang et al. (2017)
$\xi_{MC,REF}$	38.872	*Eq. 59*	Wang et al. (2017)	*Regression coefficient for MC improvement index, REF scenario* Estimated in R programming software from data presented in Wang et al. (2017)

$\alpha_{POV,EEI}$	2.58E-4	*Eq. 60*	Wang et al. (2017)	*Regression coefficient for POV improvement index, EEI scenario* Estimated in R programming software from data presented in Wang et al. (2017)
$\beta_{POV,EEI}$	-1.06	*Eq. 60*	Wang et al. (2017)	*Regression coefficient for POV improvement index, EEI scenario* Estimated in R programming software from data presented in Wang et al. (2017)
$\xi_{POV,EEI}$	1,088	*Eq. 60*	Wang et al. (2017)	*Regression coefficient for POV improvement index, EEI scenario* Estimated in R programming software from data presented in Wang et al. (2017)
$\alpha_{MC,EEI}$	-3.51E-6	*Eq. 60*	Wang et al. (2017)	*Regression coefficient for MC improvement index, EEI scenario* Estimated in R programming software from data presented in Wang et al. (2017)
$\beta_{MC,EEI}$	9.73E-3	*Eq. 60*	Wang et al. (2017)	*Regression coefficient for MC improvement index, EEI scenario* Estimated in R programming software from data presented in Wang et al. (2017)
$\xi_{MC,EEI}$	-4.392	*Eq. 60*	Wang et al. (2017)	*Regression coefficient for MC improvement index, EEI scenario* Estimated in R programming software from data presented in Wang et al. (2017)
$e_{0,POV}$ (L/km)	0.082	*Eq. 61* *Eq. 62*	Hoffman et al. (2016)	*Baseline fuel demand of average POV*
$e_{0,MC}$ (L/km)	0.024	*Eq. 61* *Eq. 62*	Wang et al. (2017)	*Baseline fuel demand of average MC*
κ_{EEI} (%)	100%	*Eq. 63*		*Optimal final conformance to EEI scenario* 100% conformance implies XT fleet achieves fuel efficiency improvements equivalent to EEI scenario in Wang et al. (2017)
γ_{EEI} (%)	50%	*Eq. 63*		*Annual improvement in conformance*
μ_{EEI} $(year)$	2036	*Eq. 63*		*Year of maximum growth in conformance* Inflection point (midpoint) of the logistic growth model for EEI scenario conformance
ε_F $(ktCO_2/L)$	2.96E-6	*Eq. 68* *Eq. 69*	ADB	*Emission intensity for transportation fuel* Emission factor based on energy consumption
κ_{POV} (%)	100%	*Eq. 70*	Hao et al. (2011)	*Maximum POV survival percentage* 100% the year standard goes into effect
γ_{POV} (%)	-50%	*Eq. 70*	Hao et al. (2011)	*Logistic growth rate for POV scrappage model* Larger (more negative) value implies

				earlier retirement of older vehicles built to lower emission standards
μ_{POV} $(years)$	10	*Eq. 70*	Hao et al. (2011)	*Midpoint year of POV scrappage model* Inflection point of POV scrappage model
t_{C-I}	1999	*Eq. 70*	Raza et al. (2018)	*Year China I vehicle emission standards go into effect*
t_{C-II}	2005	*Eq. 70*	Raza et al. (2018)	*Year China II vehicle emission standards go into effect*
t_{C-III}	2008	*Eq. 70*	Raza et al. (2018)	*Year China III vehicle emission standards go into effect*
t_{C-IV}	2015	*Eq. 70*	Raza et al. (2018)	*Year China IV vehicle emission standards go into effect*
t_{C-5}	2017	*Eq. 70*	Raza et al. (2018)	*Year China 5 vehicle emission standards go into effect*
t_{C-6a}	2020	*Eq. 70*	Raza et al. (2018)	*Year China 6-a vehicle emission standards go into effect*
t_{C-6b}	2023	*Eq. 70*	Raza et al. (2018)	*Year China 6-b vehicle emission standards go into effect*
$R_{NC}(\%)$	95%	*Eq. 72*		*Persistence of non-conforming vehicles* Estimated parameter for POV emission standard transition matrix describing the probability that a vehicle *not* conforming to the highest emission standard will remain in the POV fleet
$R_S(\%)$	5%	*Eq. 72*		*POV Scrappage Rate* Estimated parameter for POV emission standard transition matrix describing the probability a vehicle will be "scrapped" independent of ADB-funded policy interventions.
$x_{III}(\%)$	10%	*Eq. 72*		*China-III Transition Probability* Estimated parameter for POV emission standard transition matrix describing the probability a vehicle adhering to China-II standards will be replaced with a vehicle adhering to China-III standards.
$x_{IV}(\%)$	10%	*Eq. 72*		*China-IV Transition Probability* Estimated parameter for POV emission standard transition matrix describing the probability a vehicle adhering to China-III standards will be replaced with a vehicle adhering to China-IV standards.
$x_5(\%)$	10%	*Eq. 72*		*China-5 Transition Probability* Estimated parameter for POV emission standard transition matrix describing the probability a vehicle adhering to China-IV

				standards will be replaced with a vehicle adhering to China-5 standards.
$x_{6-a}(\%)$	10%	*Eq. 72*		*China 6-a Transition Probability* Estimated parameter for POV emission standard transition matrix describing the probability a vehicle adhering to China-5 standards will be replaced with a vehicle adhering to China 6-a standards.
$x_{6-b}(\%)$	10%	*Eq. 72*		*China 6-b Transition Probability* Estimated parameter for POV emission standard transition matrix describing the probability a vehicle adhering to China 6-a standards will be replaced with a vehicle adhering to China 6-b standards.
κ_{MC} (%)	100%	*Eq. 76*	Hao et al. (2011)	*Maximum MC survival percentage* 100% the year standard goes into effect
γ_{MC} (%)	-70%	*Eq. 76*	Hao et al. (2011)	*Logistic growth rate for MC scrappage model* Larger (more negative) value implies earlier retirement of older vehicles built to lower emission standards
μ_{MC} $(year)$	7	*Eq. 76*	Hao et al. (2011)	*Midpoint year of MC scrappage model* Inflection point of MC scrappage model
$m_{III}(\%)$	0%	*Eq. 78*		*China-III Transition Probability* Estimated parameter for MC emission standard transition matrix describing the probability a vehicle adhering to China-II standards will be replaced with a vehicle adhering to China-III standards.
$m_{IV}(\%)$	0%	*Eq. 78*		*China-IV Transition Probability* Estimated parameter for MC emission standard transition matrix describing the probability a vehicle adhering to China-III standards will be replaced with a vehicle adhering to China-IV standards.
$m_5(\%)$	0%	*Eq. 78*		*China-5 Transition Probability* Estimated parameter for MC emission standard transition matrix describing the probability a vehicle adhering to China-IV standards will be replaced with a vehicle adhering to China-5 standards.
l_{YH+YT} (km)	612	*Eq. 81*	XT PMO (2018)	*Length of urban roads in YH+YT* Selecting this value as the denominator in the fraction of POV service affected by LOS reduction implies POV traffic from bus lanes will be redistributed throughout urban roads in YH+YT only
l_{XT} (km)	7,819	*Eq. 81*	XT PMO (2018)	*Length of roadways in XT* Selecting this value as the denominator in

				the fraction of POV service affected by LOS reduction implies POV traffic from bus lanes will be redistributed throughout all of XT
$EF_{G,MA,SG}$ $(ktCO_2e/km)$	4.20E-7	*Eq. 84*	Sun et al. (2014)	*Emission factor for gas ICE POVs travelling on major arterials in stop-and-go traffic* Assumed to represent POVs experiencing reduced LOS. LOS reduction of two levels (from "saturated traffic") chosen to mirror assumed LOS improvement for busses
$EF_{G,MA,FF}$ $(ktCO_2e/km)$	1.60E-7	*Eq. 87*	Sun et al. (2014)	*Emission factor for gas ICE POVs travelling on major arterials in free flow traffic* Assumed to represent POVs experiencing improved LOS due to carpooling. LOS improvement of two levels (from "saturated traffic") chosen to mimic assumed LOS improvement for busses
$EF_{G,MA,ST}$ $(ktCO_2e/km)$	2.21E-7	*Eq. 84* *Eq. 87*	Sun et al. (2014)	*Emission factor for gas ICE POVs travelling on major arterials in saturated traffic* Assumed to represent POVs and busses before lane modifications

5. Calculations

The following sections describe methods used in estimating energy and GHG impacts of policy-based actions for the promotion of green building standards in Yuhu and Yuetang Districts. Formulas in the following sections are represented in the "Summary Equations" tab of the spreadsheet titled "Transport Emissions Calculations - Xiangtan ADB Output 1, 11 May 2020". The results of these calculations have been validated against earlier calculations performed in other tabs of the same spreadsheet, and a thorough dimensional analysis of all tabs of the spreadsheet was conducted May 12, 2020 to confirm dimensional agreement of all calculations.

5.1. Demographics

Annual population estimates for XT and YH+YT serve as the basis for all subsequent estimates of transport demand throughout the loan period. 2015 population estimates and annual population growth, estimated with either the "natural population growth rate" (Equation 1) or linear population growth (Equation 2) method. Population of YH and YT is extrapolated from the XT population by assuming the proportion of XT county residents living in YH and YT will remain constant throughout the loan period. Working age population is extrapolated from the population of YH and YT by assuming the proportion of the population that is working age will remain constant throughout the loan period. The ratio of male to female workers is used to estimate the total number of male and female workers each year.

Note: Equation 1, Equation 5, and Equation 6 are <u>not</u> directly used in subsequent calculations. Final reported estimates assume linear population growth (Equation 2).

$$N(i)_{XT} = N(i-1)_{XT} * (1 + r_n) \qquad for\ i > t_0 \qquad \text{Equation 1}$$

$$N(i)_{XT} = N(i-1)_{XT} + r_{XTH} \qquad \text{Equation 2}$$

$$N(i)_{YH+YT} = N(i) * p_{YH+YT} \qquad \text{Equation 3}$$

$$N(i)_{W} = N(i)_{YH+YT} * p_{W} \qquad \text{Equation 4}$$

$$N(i)_{F} = N(i)_{W} * p_{F} \qquad \text{Equation 5}$$

$$N(i)_{M} = N(i)_{W} - N(i)_{F} \qquad \text{Equation 6}$$

Where:

$t_0 = year\ of\ initial\ population\ estimate$
$N(i)_{XT} = population\ of\ XT\ county\ in\ year\ i$
$N(i)_{YH+YT} = population\ of\ YH\ +\ YT\ in\ year\ i$
$N(i)_{W} = working\ age\ population\ in\ YH + YT\ in\ year\ i$
$N(i)_{F} = number\ of\ female\ workers\ in\ YH + YT\ in\ year\ i$
$N(i)_{M} = number\ of\ male\ workers\ in\ YH + YT\ in\ year\ i$
$r_n = natural\ population\ growth\ rate\ (\%)$
$r_{XTH} = annual\ population\ growth\ rate\ estimated\ by\ XT\ Health\ \&\ H\ Comm.\ (persons/yr)$
$p_{YH+YT} = percentage\ of\ XT\ county\ population\ living\ in\ YH + YT\ (\%)$
$p_{W} = percentage\ of\ population\ in\ YH + YT\ that\ is\ working\ age\ (\%)$
$p_{F} = percentage\ of\ YH + YT\ workforce\ that\ is\ female\ (\%)$

5.2. Bus Interventions

5.2.1. Bus Fuel Switch

Information for the XT bus fleet composition is taken from data provided by the XT PMO for two bus companies currently serving metropolitan XT. Annual population estimates for YH and YT and BAU mode preference are used to estimate riders per day for each year of the loan period. The number of daily commuters is multiplied by average number of one-way trips per day per commuter and average one-way trip distance to estimate total daily VKT for all busses each year. Total daily VKT for all busses is then divided by average daily VKT per bus in XT and average bus LF to estimate need for busses in YH and YT each year during the loan period. Bus need is then extrapolated to all of XT.

Annual emission impacts of project-based interventions to replace a portion of the XT bus fleet with eBusses are estimated by calculating weighted distance-based WTW bus EFs for the entire XT bus fleet. Estimates assume ADB-funded eBusses will replace existing Pure NG busses at the end of the project period, as these busses have the highest WTW EF. Otherwise, numbers of busses of each type are assumed to increase to meet projected population growth (absent any mode shift). Load factors for busses are calculated by dividing passenger-kilometers (kilometers travelled per passenger, equal to the occupancy between any two stops multiplied by the distance between stops) by place-kilometers (equal to the kilometers travelled by each bus multiplied by the average occupancy) (World Bank Group).

Note: Equation 11 is <u>not</u> directly used in subsequent calculations. Estimates in this tab do <u>not</u> incorporate effects of population growth (Section 5.1.), bus LOS improvements (Section 5.2.2.), or mode shift (Section 5.3.1.).

$$N(i)_B = N(i)_W * y_{0,B} \quad \text{Equation 7}$$

$$\tau(i)_B = N(i)_B * \zeta_{tpd} \quad \text{Equation 8}$$

$$VKT(i)_B = \tau(i)_B * d_B \quad \text{Equation 9}$$

$$B(i)_{YH+YT} = \frac{VKT(i)_B}{vkt_B * LF_B} \quad \text{Equation 10}$$

$$B(i)_{XT} = B(i)_{YH+YT} * \frac{1}{p_{YH+YT}} \quad \text{Equation 11}$$

$$D(i)_B = B(i)_{YH+YT} * vkt_B * \zeta_{acd} \quad \text{Equation 12}$$

$$\rho(i)_{eBus} = \frac{B_{0,eBus} + B_{Pr,eBus}}{\sum_j B_{0,j}} \quad for\ i \geq t_L,\ \rho(i)_{eBus} = \rho_{0,eBus}\ otherwise \quad \text{Equation 13}$$

$$\rho(i)_{pureNG} = \frac{B_{0,pureNG} - B_{Pr,eBus}}{\sum_j B_{0,j}} \quad for\ i \geq t_L,\ \rho(i)_{pureNG} = \rho_{0,pureNG}\ otherwise \quad \text{Equation 14}$$

$$\rho(i)_j = \frac{B_{0,j}}{\sum_j B_{0,j}} \quad for\ j \neq eBus,\ pureNG \quad \text{Equation 15}$$

$$B(i)_j = B(i)_{YH+YT} * \rho(i)_j \quad \text{Equation 16}$$

$$\overline{EF}(i)_B = \frac{\sum_j B(i)_j * EF_j}{\sum_j B(i)_j} \quad \text{Equation 17}$$

$$CO_{2,B}(i) = D(i)_B * \overline{EF}(i)_B \quad \text{Equation 18}$$

Where:

$N(i)_B$ = number of commuters travelling by bus in year i
$y_{0,B}$ = percentage of commuters travelling by bus in first year of policy period (%)
$\tau(i)_B$ = total number of bus trips per day in year i (trips/day)
ζ_{tpd} = average number of one − way trips per commuter per day (trips/day/person)
$VKT(i)_B$ = total daily VKT of all busses in year i (km/day)
d_B = average bus trip distance (km/trip)
$B(i)_{YH+YT}$ = annual demand for busses in YH + YT in year i (busses)
vkt_B = daily VKT per bus (km/day)
LF_B = average bus load factor
$B(i)_{XT}$ = annual demand for busses in XT in year i (busses)
$D(i)_B$ = total annual distance travelled by all busses in year i (km/yr)
ζ_{acd} = annual commute days (days/yr)
$B(i)_j$ = total number of busses of type j in operation in year i
$B_{0,j}$ = initial number of busses of type j at start of loan period
$\rho_{0,j}$ = initial fraction of bus type j in XT bus fleet (%)
$\rho(i)_j$ = fraction of bus type j in XT bus fleet in year i (%)
$CO_{2,j}(i)$ = annual CO_2 emissions from all busses of type j in year i ($ktCO_2e/yr$)
EF_j = distance − based WTW CO_2 emission factor for bus type j ($ktCO_2e/km$)
$CO_{2,B}(i)$ = annual CO_2 emissions of XT bus fleet in year i ($ktCO_2e/yr$)
$\overline{EF}(i)_B$ = weighted emission factor for XT bus fleet in year i ($ktCO_2e/km$)
$B_{Pr,eBus}$ = additional eBusses provided by XT project − based loan
t_L = end of loan period (year)

5.2.2. Bus LOS EFs

The effect of changes in bus operating speeds on emissions is extrapolated from data collected for passenger cars meeting China 4 standards for five LOS (free flow, heavy traffic, saturated traffic, stop-and-go, heavy stop-and-go) on four major road types (expressway, major arterial, minor arterial, branch) (see Appendix, Table A19). Assuming the average baseline LOS corresponds to "saturated traffic" (>20-30 kph) and project-based modifications will only affect bus operations on major arterials, automobile EFs under different operating conditions are standardized relative to the EF for automobiles in "saturated traffic" on major arterials to characterize the relative change in EF resulting from LOS changes. Assuming project-based modifications will improve average bus LOS on major arterials by two levels (from "saturated traffic" to "free flow"), baseline EFs for each bus type (assumed to correspond to baseline conditions of saturated traffic on major arterials) are multiplied by standardized EFs for automobiles to estimate adjusted EFs for busses of each fuel type operating at different LOS.

The fraction of bus operations affected by LOS improvements is calculated as the proportion of total length of affected busways multiplied by total annual kilometers traveled by all busses. The fraction of bus operations affected is used to estimate the number of busses of each type operating at improved LOS each year, based on total bus numbers estimated in Section 5.2.1 Bus Fuel Switch (incorporating additional ADB-funded eBusses) and assuming all bus types will be evenly impacted by LOS improvements. Annual VKT of busses operating at improved LOS and scaled EFs for each fuel type are used to calculate total emissions from affected busses, which are compared to expected baseline emissions from affected busses to determine total annual emission reductions.

Note: Estimates in this tab do <u>not</u> incorporate effects of mode shift (Section 5.3.1.) or population growth (Section 5.1.) and resulting increased demand for busses because it is assumed that, while the total number of busses in operation is expected to increase over the lifetime of the loan, the number of busses and bus routes that can benefit from road improvements completed as part of the project-based component is limited by road capacity and will not scale with population growth. Estimates in this tab <u>do</u> incorporate effects of bus fuel switch (Section 5.2.1.).

$$\widehat{EF}_{G,m,n} = \frac{EF_{G,m,n}}{EF_{G,MA,ST}}$$ *Equation 19*

$$EF_{j,m,n} = \widehat{EF}_{G,m,n} * EF_{j,MA,ST}$$ *Equation 20*

$$p(i)_n = \frac{l_{B,mod}}{l_B} \quad for\ t \geq t_L,\ 0\ otherwise$$ *Equation 21*

$$B(i)_{j,n} = B(i)_j * p(i)_n$$ *Equation 22*

$$\Delta CO_2(i) = \sum_j \sum_m \sum_n (B(i)_{j,n} * (EF_{j,m,n} - EF_{j,MA,ST})) * vkt_B * \zeta_{acd}$$

Equation 23

Where:

$\widehat{EF}_{G,m,n}$ = standardized EF for gas ICE POV on road type m for LOS n (%)
$EF_{G,m,n}$ = EF for gas ICE POV on road type m for LOS n ($ktCO_2e/km$) (see Appendix Table A19)
$EF_{G,MA,ST}$ = EF for gas ICE POV at BAU LOS and road type (major arterial, saturated traffic) ($ktCO_2e/km$)
$EF_{j,m,n}$ = scaled EF for bus type j operating on road type m at improved LOS n ($ktCO_2e/km$)
$EF_{j,MA,ST}$ = EF for bus type j calculated for BAU scenario (major arterial, saturated traffic) ($ktCO_2e/km$)
$p(i)_n$ = fraction of annual bus kilometers travelled at improved LOS n in year i (%)
$l_{B,mod}$ = total length of bus lanes with improved service (km)
l_B = total length of bus routes (km)
$B(i)_{j,n}$ = total number of busses of type j operating at improved LOS n in year i
$\Delta CO_{2,j}(i)$ = annual CO_2 emission reduction attributed to improved bus LOS in year i ($ktCO_2e/yr$)

5.3. Mode Shift Interventions

5.3.1. Modal Shift

Impacts of policies on commuter mode shifts are represented with a Markov transition matrix, which describes the probability of moving from one state (commuter mode in year *i*) to another state (commuter mode in year *i*+1) in any given year. The effects of policy decisions are modeled by adjusting the "recurrence probability" (probability of choosing the same mode in year *i*+1) and "random change probability" (probability of switching to one of the other modes) for each commuter transport mode. The resulting change in the relative numbers (percentages) of commuters using each transport mode are calculated year-by-year by powering the transition matrix. From workforce population projections and total estimated commuter trips per year, annual emissions from each mode are estimated from the percentage of commuters using each mode in the BAU and policy scenarios, average load factors for each mode, average trip distance for each mode, and average distance-based WTW EFs for each mode. No emissions are attributed to train commute trips (assumed to be zero) or walking commute trips (assumed to produce no emissions).

Note: Estimates in this tab do incorporate population growth (Section 5.1.) and can incorporate bus fuel switch (Section 5.2.1.), but do not include bus LOS improvements (Section 5.2.2.), changes in POV or MC operating efficiency (Section 5.4), or increasing EV POV market share/ diesel POV scrappage (Section 5.3.2.). ICE POV emission estimates could be improved by estimating gas and diesel POV market shares and applying appropriate distance-based WTW EFs for each vehicle type (see Section 5.3.2.). Equation 28 was added May 15, 2020 as an alternative method of estimating average trip distance adjusted for relative adoption of carpooling, as indicated by average LF.

$$P(X_{i+1}|X_i) = [p_{qr}] \quad for\ p_{qr} \geq 0,\ where\ \sum_r p_{qr} = \sum_r P(X_{i+1} = r|X_i = q) = 1$$ *Equation 24*

$$[y(i)] = [y_0]\ x\ [p_{qr}]^{(t-t_e)} \qquad for\ t \geq t_e,\ [y_0]\ otherwise$$ *Equation 25*

$$\tau(i) = N(i)_W * \zeta_{tpd} * \zeta_{acd}$$ *Equation 26*

$$CO_{2,B}(i) = \frac{\tau(i) * y(i)_B}{LF(i)_B} * d(i)_B * \overline{EF}(i)_B$$
Equation 27

$$d(i)_{POV} = \frac{LF(i)_{POV}}{R_{mzx}} * d_{POV} + (1 - \frac{LF(i)_{POV}}{R_{max}}) * d'_{POV}$$ *Equation 28*

$$CO_{2,ICE}(i) = \frac{\tau(i) * y(i)_{ICE}}{LF(i)_{POV}} * d(i)_{POV} * EF_G$$ *Equation 29*

$$CO_{2,eV}(i) = \frac{\tau(i) * y(i)_{eV}}{LF(i)_{POV}} * d(i)_{POV} * EF_{eV}$$ *Equation 30*

$$CO_{2,MC}(i) = \frac{\tau(i) * y(i)_{MC}}{LF(i)_{MC}} * d(i)_{MC} * EF_{MC}$$ *Equation 31*

$$CO_{2,bike}(i) = \frac{\tau(i) * y(i)_{bike}}{LF(i)_{bike}} * d(i)_{bike} * EF_{bike}$$ *Equation 32*

$$CO_{2,eB}(i) = \frac{\tau(i) * y(i)_{eB}}{LF(i)_{eB}} * d(i)_{eB} * EF_{eB}$$ *Equation 33*

Where:

$P(X_{i+1}|X_i)$ = *Markov transition matrix containing probabilities of moving from one mode to another in year* $i+1$
p_{qr} = *probability of moving from mode q in year i to mode r in year* $i+1$ (%)
$[y(i)]$ = *vector containing percentage of commuters using each mode type in year i*
$[y_0]$ = *vector containing baseline percentage of commuters using each mode type (from ADB survey)*
t_e = *first year project and policy based modifications see an effect*
$\tau(i)$ = *number of one − way commuter trips per year (trips/yr)*
$CO_{2,ICE}(i)$ = *annual* CO_2 *emissions from gas and diesel ICE POVs in year i* ($ktCO_2e/yr$)
$LF_{0,POV}$ = *baseline load factor for POV*
$y(i)_{ICE}$ = *percentage of commuters travelling by ICE POV in year i* (%)
R_{max} = *average POV capacity (riders/vehicle)*
d_{POV} = *average one − way POV trip distance (no carpooling) (km/trip)*
d'_{POV} = *average one − way POV trip distance (with carpooling) (km/trip)*
$d(i)_{POV}$ = *average one − way POV trip distance in year i (adjusted for carpooling) (km/trip)*
EF_G = *distance − based WTW EF for gas ICE POV* ($ktCO_2e/km$)
$CO_{2,eV}(i)$ = *annual* CO_2 *emissions from EV POVs in year i* ($ktCO_2e/yr$)
$y(i)_{eV}$ = *percentage of commuters travelling by EV POV in year i* (%)
EF_{eV} = *distance − based WTW EF for pure EV* ($ktCO_2e/km$)
$CO_{2,MC}(i)$ = *annual* CO_2 *emissions from all MCs in year i* ($ktCO_2e/yr$)
$d(i)_{MC}$ = *average one − way trip distance for MC (km/trip)*
$LF(i)_{MC}$ = *average load factor for MC*
EF_{MC} = *distance − based WTW EF for MCs* ($ktCO_2e/km$)
$CO_{2,bike}(i)$ = *annual* CO_2 *emissions from all bicycles in year i* ($ktCO_2e/yr$)
EF_{bike} = *distance − based WTW EF for bicycles* ($ktCO_2e/km$)
$d(i)_{bike}$ = *average one − way trip distance for bicycles (km/trip)*
$LF(i)_{bike}$ = *average load factor for bicycles*
$CO_{2,eB}(i)$ = *annual* CO_2 *emissions from all eBikes in year i* ($ktCO_2e/yr$)
EF_{eB} = *distance − based WTW EF for eBikes* ($ktCO_2e/km$)
$d(i)_{eB}$ = *average one − way trip distance for eBikes (km/trip)*
$LF(i)_{eB}$ = *average load factor for eBike*

5.3.2 More EV POVs

Impacts of increasing EV market penetration on charging station requirements, total electricity demand, and associated emissions are modeled with and without assumptions of improving EV efficiency (measured as kWh/100km), as predicted by Huo et al. (2010). In this scenario, the total number of POVs is expected to scale with population over the lifetime of the loan, with the relative proportion of EV and ICE POVs shifting to reflect annual changes in POV mode preference described in the modal shift scenario (Section 5.3.1.). Annual emissions from EVs are calculated using both a constant EF of electricity from the XT electricity grid and a constant distance-based WTW EF for pure EVs calculated for a similar ADB-funded project in Gui'an (Kim 2019).

A "Diesel Scrappage Equation" based on a logistic decay formula is used to model declining market share of diesel POVs due to enforcement of existing emission standards and a ban on the sale of new diesel vehicles, expected to begin in 2026. Although official bans on diesel cars have not been finalized, Chinese officials signaled plans as early as 2017 to ban both gasoline and diesel ICE cars in the future (McFadden 2019). Annual emissions from POVs are calculated by estimating total demand for POVs (ICE and EV) each year based on annual estimates of working-age population, BAU mode preference for POVs (assuming total percentage of commuters using POVs remains constant), and a constant load factor (no carpooling). Annual POV market share estimates for pure EV, gas ICE, and diesel ICE POVs are used to estimate the total number of POVs of each type on the road each year. Constant distance-based WTW EFs for each vehicle type are then used to estimate total annual emissions from each vehicle type.

Note: Estimates in this tab <u>do</u> include effects of population growth (Section 5.1.), or modal shift from ICE POVs to EV POVs (Section 5.2.1.) but do <u>not</u> include modal shift between POVs and other modes, effects of carpooling (Section 5.4.1.), additional enforcement of ICE fuel or emission standards (Sections 5.4.2. - 5.4.3.) or impacts to POV LOS (Section 5.4.5.).

$$N(i)_{ICE} = N(i)_W * y(i)_{ICE}$$ *Equation 34*

$$N(i)_{eV} = N(i)_W * y(i)_{eV}$$ *Equation 35*

$$V(i)_{POV} = \frac{N(i)_{ICE} + N(i)_{eV}}{LF_{0,POV}}$$ *Equation 36*

$$\rho(i)_D = \rho_{0,D} * \frac{L_D}{1 + exp(k_D * (t_{0,D} - (t - t_b))} \quad for\ t \geq t_b,\ \rho_{0,D}\ otherwise$$ *Equation 37*

$$\rho(i)_{eV} = \frac{N(i)_{eV}}{N(i)_{eV} + N(i)_{ICE}}$$ *Equation 38*

$$\rho(i)_G = 1 - (\rho(i)_D + \rho(i)_{eV})$$ *Equation 49*

$$V(i)_G = V(i)_G * \rho(i)_G$$ *Equation 40*

$$D(i)_G = V(i)_G * d(i)_{POV} * \zeta_{tpd} * \zeta_{acd}$$ *Equation 41*

$$CO_{2,G}(i) = D(i)_G * EF_G$$ *Equation 42*

$$V(i)_D = V(i)_{POV} * \rho(i)_D$$ *Equation 43*

$$D(i)_D = V(i)_D * d(i)_{POV} * \zeta_{tpd} * \zeta_{acd}$$ *Equation 44*

$$CO_{2,D}(i) = D(i)_D * EF_D$$ *Equation 45*

$$V(i)_{eV} = POV(i) * \rho(i)_{eV}$$ *Equation 46*

$$\Phi(i) = \frac{POV(i)_{eV}}{\zeta_\Phi}$$ *Equation 47*

$$\chi(i) = POV(i)_{eV} \quad \text{Equation 48}$$

$$\Psi(i) = \frac{POV(i)_{eV}}{\zeta_{\Psi}} \quad \text{Equation 49}$$

$$e(i)_{eV} = \frac{L_{eV}}{1+exp(k_{eV}*(t_{0,eV}-t))} \quad \text{Equation 50}$$

$$E(i)_{eV} = V(i)_{eV} * d(i)_{POV} * \zeta_{tpd} * \zeta_{acd} * e(i)_{eV} \quad \text{Equation 51}$$

$$CO_{2,eV}(i) = V(i)_{eV} * d(i)_{POV} * \zeta_{tpd} * \zeta_{acd} * EF_{eV} \quad or \quad CO_{2,eV}(i) = E(i)_{eV} * EF_{E} \quad \text{Equation 52}$$

Where:

$N(i)_{ICE}$ = number of commuters travelling by ICE POV in year i
$N(i)_{eV}$ = number of commuters travelling by EV POV in year i
$V(i)_{POV}$ = number of POVs in XT fleet in year i
$\rho(i)_D$ = diesel ICE POV market share in year i (%)
$\rho_{0,D}$ = initial diesel ICE POV market share in year t_b (%)
L_D = maximum percentage of existing diesel POVs active in the transportation fleet (%)
k_D = logistic growth rate for diesel POV scrappage (%)
$t_{0,D}$ = midpoint year for diesel POV scrappage model
t_b = year XT ban on sale of new diesel POVs goes into effect
$\rho(i)_{eV}$ = EV POV market share in year i (%)
$\rho(i)_G$ = gas ICE POV market share in year i (%)
$V(i)_G$ = gas ICE POVs in XT fleet in year i
$D(i)_G$ = total annual distance travelled by gas ICE POVs in year i (km/yr)
$CO_{2,G}(i)$ = annual CO_2 emissions from gas ICE POVs in year i ($ktCO_2e/yr$)
$V(i)_D$ = diesel ICE POVs in XT fleet in year i
$D(i)_D$ = total annual distance travelled by diesel ICE POVs in year i (km/yr)
$CO_{2,D}(i)$ = annual CO_2 emissions from diesel ICE POVs in year i ($ktCO_2e/yr$)
EF_D = distance − based WTW EF for diesel ICE POV ($ktCO_2e/km$)
$V(i)_{eV}$ = EV POVs in XT fleet in year i
$\Phi(i)$ = number of public charging piles in year i
$\chi(i)$ = number of private charging piles in year i
$\Psi(i)$ = number of public charging stations in year i
ζ_{Φ} = public charging pile density requirement (EVs per pile)
ζ_{Ψ} = public charging station density requirement (EVs per station)
$e(i)_{eV}$ = electricity demand of average EV in transportation fleet in year i (kWh/km)
L_{eV} = maximum average EV electricity demand (kWh/km)
k_{eV} = logistic growth rate for average EV electricity demand (%)
$t_{0,eV}$ = midpoint year for EV electricity demand model
$E(i)_{eV}$ = total annual electricity demand for EVs in year i (kWh)
$CO_{2,eV}(i)$ = annual CO_2 emissions from EV POVs in year i (ktCO2e/yr)
EF_E = emission factor for electricity ($ktCO_2e/kWh$)

5.4. POV Efficiency Interventions

5.4.1. Carpooling

Policies to encourage carpooling are represented with a logistic growth model assuming a gradual increase in POV load factor (the number of people occupying a particular transit unit per trip) as carpooling becomes more prevalent throughout the lifetime of the loan due to ADB-funded interventions. Average load factor is used to

calculate the percentage of commuters using ride-sharing by assuming vehicle occupancy follows a Poisson distribution, taking on values from 1.0 (single-occupant POV) to the assumed vehicle saturation point, equal to the average vehicle capacity. Emission impacts are calculated by estimating the marginal difference in POV need between the "optimal carpooling and ridesharing scenario" and BAU POV demand (constant LF), assuming no additional mode shift. Average POV trip distance in the carpooling scenario is adjusted to account for the increased distance travelled to pick up and drop off additional passengers. Emission reductions achieved by carpooling are estimated by calculating a distance-based WTW weighted EF for the POV fleet in a scenario with no change in the relative market share of EVs, diesel ICE POVs, and gas ICE POVs, and a scenario with EVs steadily increasing market share while diesel ICE POVs steadily lose market share (see Section 5.3.2. More EV POVs). All calculations assume constant distance-based WTW EFs for each vehicle type.

Note: Estimates in this tab do include effects of population growth (Section 5.1.), and can include impacts of changing gas, diesel, and EV POV market share (Section 5.3.2.), but do not include other forms of mode shift (Section 5.3.1.), additional enforcement of ICE fuel or emissions standards (Section 5.4.2. - 5.4.3.), or changes in POV LOS (Section 5.4.5.). Equation 55 was updated May 12, 2020 from earlier versions of the spreadsheet to reflect a constant BAU LF equal to the baseline POV LF specified in Section 4. User-Defined Parameters. Equation 58 was updated May 16, 2020 from earlier versions of the spreadsheet to reflect annually-updated average POV trip distance based on relative adoption of carpooling.

$$\lambda(i) = \frac{\kappa_{CP}}{1+exp(\gamma_{CP}*(\mu_{CP}-t))} \quad for\ t \geq t_e,\ \lambda(i) = LF_{0,POV} - 1.00\ otherwise \tag{Equation 53}$$

$$LF(i)_{POV} = 1 + \lambda(i) \quad for\ t \geq t_e,\ LF_{0,POV}\ otherwise \tag{Equation 54}$$

$$\sigma(i)_R = \frac{(\lambda(i)*R)*exp(-\lambda(i))}{R!} \quad for\ R = [1, 2, 3...R_{max}] \tag{Equation 55}$$

$$V'(i)_{POV} = \frac{N(i)_W*(y(i)_{ICE}+y(i)_{eV})}{LF(i)_{POV}} \tag{Equation 56}$$

$$\overline{EF}(i)_{POV} = \rho(i)_D * EF_D + \rho(i)_G * EF_G + \rho(i)_{eV} * EF_{eV} \tag{Equation 57}$$

$$\Delta CO_{2,POV}(i) = (V'(i)_{POV} - V(i)_{POV}) * d(i)_{POV} * \zeta_{tpd} * \zeta_{acd} * \overline{EF}(i)_{POV} \tag{Equation 58}$$

Where:

$\lambda(i) = average\ number\ of\ additional\ passengers\ (in\ addition\ to\ driver)\ in\ POVs\ in\ year\ i$
$\kappa_{CP} = optimal\ final\ distribution\ of\ passengers$
$\gamma_{CP} = annual\ growth\ rate\ of\ carpooling\ (\%)$
$\mu_{CP} = midpoint\ year\ for\ carpooling\ adoption\ model\ (year)$
$LF(i)_{POV} = average\ LF\ for\ POVs\ in\ year\ i$
$\sigma(i)_R = percentage\ of\ POVs\ with\ R\ riders\ (including\ driver)\ in\ year\ i\ (\%)$
$V'(i)_{POV} = annual\ POV\ demand\ in\ year\ i,\ adjusted\ for\ carpooling\ (vehicles)$
$\overline{EF}(i)_{POV} = distance-based\ WTW\ weighted\ EF\ for\ POV\ fleet\ in\ year\ i\ (ktCO_2e/km)$
$\Delta CO_{2,POV}(i) = emission\ reduction\ attributed\ to\ carpooling\ in\ year\ i\ (ktCO_2e/yr)$

5.4.2. ICE Fuel Standards

Impacts of policy measures to enforce more efficient ICE POV operating standards (lower L/100 km fuel use) are modeled after scenarios proposed by Wang et al. (2017), developed with the Transportation Mode-Technology-Energy-CO_2 (TMOTEC) model based on discrete choice method and general transport cost simulation. The REF (reference) scenario presented by Wang et al. (2017) is intended to represent China's transport sector up to 2050 with a consideration of current policies and an assumed rate of decline in average fuel demand rate for each vehicle type over time, represented with an "improvement index" equal to the percentage of average 2010 fuel demand (L/100 km) for the mode in question. The EEI (energy efficiency improvement) scenario is based on the REF scenario with stronger influence of policies to improve future energy efficiency, resulting in a faster increase in energy efficiency (steeper decline in "improvement index" over time) (see Appendix, Table A9).

Regression coefficients for improvement indices are estimated from Table A-6 and Table A-9 from Wang et al. using the LM program (R Core Team 2012) to interpolate and extrapolate annual improvement indices for the lifetime of the loan for cars and MCs in both the REF and EEI scenarios. Average fuel use is then estimated as the product of annual improvement index for the mode and average fuel use in 2010 for each mode. BAU emissions are calculated by either assuming a constant average fuel demand or a gradually declining average fuel demand reflected in the REF scenario. Assuming the EEI scenario represents the most ambitious efficiency improvements XT policies could achieve, a logistic growth model is used to develop a convergence scenario describing XT annual progress towards conformance to the EEI scenario.

In each scenario, annual gas ICE POV, diesel ICE POV, and EV POV demand is estimated from the working age population (Section 5.1.) and the diesel retirement-EV adoption scenario described in Section 5.3.2., ignoring any additional modal shift or carpooling adoption. Average annual fuel use by ICE POVs and MCs in the REF scenario and policy scenario is estimated from the expected number of vehicles and annual VKT per vehicle. Annual VKT of all vehicles and average fuel use per VKT is used to estimate total annual fuel use in both scenarios, and a constant EF for gasoline and diesel is used to estimate annual emissions in both scenarios.

Note: Estimates in this tab do include effects of population growth (Section 5.1.) and increasing EV POV market share (Section 5.2.2.) but do not include any other forms of mode shift (Section 5.2.1.), effects of carpooling (5.4.1.), additional enforcement of ICE or MC emission standards (Section 5.4.3. - 5.4.4.), or changes to POV LOS (Section 5.4.5.). Equation 68 and Equation 69 were updated from previous versions of the spreadsheet to account for differences in POV and MC average trip distances reflected in Sections 5.3.1. - 5.3.2. Estimates could be further improved by incorporating data on current average fuel demand for ICE POVs and MCs to calibrate the conformance model for the policy scenario.

$$\eta(i)_{q,REF} = \alpha_{q,REF} * t^2 + \beta_{q,REF} * t + \xi_{q,REF} \quad \text{Equation 59}$$

$$\eta(i)_{q,EEI} = \alpha_{q,EEI} * t^2 + \beta_{q,EEI} * t + \xi_{q,EEI} \quad \text{Equation 60}$$

$$e(i)_{q,REF} = e_{0,q} * \eta(i)_{q,REF} \quad \text{or} \quad e(i)_{q,REF} = e_{0,q} \quad \text{Equation 61}$$

$$e(i)_{q,EEI} = e_{o,q} * \eta(i)_{q,EEI} \quad \text{Equation 62}$$

$$\vartheta(i) = \frac{\kappa_{EEI}}{1+exp(\gamma_{EEI}*(\mu_{EEI}-t))} \quad for\ t \geq t_e,\ 0\ otherwise \quad \text{Equation 63}$$

$$e(i)_q = (1-\vartheta(i)) * e(i)_{q,REF} + \vartheta(i) * e(i)_{q,EEI}$$

Equation 64

$$V(i)_G = \frac{N(i)_W*(y(i)_{ICE}+y(i)_{eV})}{LF(i)_{POV}} * \rho(i)_G \quad \text{Equation 65}$$

$$V(i)_D = \frac{N(i)_W*(y(i)_{ICE}+y(i)_{eV})}{LF(i)_{POV}} * \rho(i)_D \quad \text{Equation 66}$$

$$V(i)_{MC} = \frac{y(i)_{MC}*N(i)_W}{LF(i)_{MC}} \quad \text{Equation 67}$$

$$CO_{2,REF}(i) = \sum_q (V(i)_q * e(i)_{q,REF} * d(i)_q) * \zeta_{tpd} * \zeta_{acd} * \varepsilon_F \quad \text{Equation 68}$$

$$\Delta CO_2(i) = \sum_q (V(i)_q * e(i)_q * d(i)_q) * \zeta_{tpd} * \zeta_{acd} * \varepsilon_F - CO_{2,REF}(i) \quad \text{Equation 69}$$

Where:

$\eta(i)_{q,REF}$ = *improvement index for mode q in year i, REF scenario* (%)

$\alpha_{q,REF}$ = *regression coefficient for improvement index for mode q, REF scenario*

$\beta_{q,REF}$ = *regression coefficient for improvement index for mode q, REF scenario*
$\xi_{q,REF}$ = *regression coefficient for improvement index for mode q, REF scenario*
$\eta(i)_{q,EEI}$ = *improvement index for mode q in year i, EEI scenario* (%)
$\alpha_{q,EEI}$ = *regression coefficient for improvement index for mode q, EEI scenario*
$\beta_{q,EEI}$ = *regression coefficient for improvement index for mode q, EEI scenario*
$\xi_{q,EEI}$ = *regression coefficient for improvement index for mode q, EEI scenario*
$e(i)_{q,REF}$ = *fuel demand of average vehicle for mode q in year i, REF scenario* (L/km)
$e_{0,q}$ = *baseline fuel demand of average vehicle for mode q* (L/km)
$e(i)_{q,EEI}$ = *fuel demand of average vehicle for mode q in year i, EEI scenario* (L/km)
$\vartheta(i)$ = *percentage conformance to EEI scenario in XT policy scenario in year i* (%)
κ_{EEI} = *optimal final conformance to EEI scenario* (%)
γ_{EEI} = *annual improvement in conformance* (%)
μ_{EEI} = *year of maximum growth in conformance* (*year*)
$e(i)_q$ = *fuel demand of average vehicle for mode q in year i, XT policy scenario* (L/km)
$V(i)_q$ = *annual vehicle demand for mode q in year i* (*vehicles*)
$CO_{2,REF}(i)$ = *annual* CO_2 *emissions from POVs and MCs in year i, REF scenario* ($ktCO_2e/yr$)
ε_F = *emission intensity for transportation fuel* ($ktCO_2e/L$)
$\Delta CO_2(i)$ = *annual* CO_2 *emission reduction from POVs and MCs attributed to XT policy in year i* ($ktCO_2e/yr$)

5.4.3. ICE Emission Standards

Policies to enforce criteria pollutant emission standards for ICE POVs are expected to indirectly reduce GHG concentrations by reducing emission of GHG precursors. For gas ICE POVs, enforcement of China-5 standards as a minimum conformance level will increase stringency for four standards (CO, HC, NO_x, PM) (see Appendix, Table A12). For diesel POVs, enforcement of China-5 standards will increase stringency for five standards (CO, HC+NO_x, NO_x, PM, PN).

Vehicle survival rates are estimated with a logistic replacement model to determine the percentage of vehicles manufactured to a given standard remaining on the road each year, based on the standard in place when the vehicles were manufactured. Survival rates, total POV demand (with or without carpooling, see Section 5.4.1.), and POV market shares (assuming diesel POV scrappage and increasing market share of EVs, see Section 5.3.2.) are then used to estimate the number of vehicles and proportion of the XT POV fleet operating at each standard level each year. Impacts of policies to enforce standards are represented with a Markov transition matrix describing the probability of accelerated vehicle scrappage and replacement rates in response to ADB-funded enforcement policies, resulting in greater conformance to more efficient average operating standards across the XT POV fleet.

Annual emissions of each criteria pollutant in the BAU and policy scenarios are calculated by multiplying the number of POVs operating at each standard by the gas ICE POV market share (with or without diesel scrappage and increasing EV market share, see Section 5.3.2.) to estimate the number of gas ICE POVs operating at each standard each year. The number of gas ICE POVs is then multiplied by the expected average POV trip distance, adjusted for carpooling rates, and the emission rate specified by the appropriate regulatory regime. Expected emissions of each pollutant from vehicles meeting each standard are then summed over all POVs in operation each year. The same approach is applied to emissions from diesel ICE POVs.

Note: Estimates in this tab <u>do</u> incorporate effects of population growth (Section 5.1.), and <u>can</u> incorporate effects of increasing EV POV market share (Section 5.3.2.), and carpooling (Section 5.4.1.). Estimates in this tab do <u>not</u> include other forms of mode shift (Section 5.3.1.), greater enforcement of ICE fuel standards (Section 5.4.2.), or changes to POV LOS (Section 5.4.5.). Estimates could be improved by adjusting scrappage models to begin vehicle scrappage timeline (t) for standard S the year standard S+1 goes into effect. Estimates were updated May 12, 2020 after dimensional analysis of all spreadsheet formulas revealed a unit conversion error resulting in an underestimate of annual emission of four criteria pollutants (CO, HC, NO_x, PM). Neither relative emission reductions achieved by the policy nor subsequent calculations were affected by the change. Equation 74 and Equation 75 were updated May

17, 2020 to use average POV trip distance, adjusted for carpooling rates, rather than annual VKT per POV. GHG precursor emissions estimated in this section are not reflected in final GHG estimates and do not directly influence GHG calculations in any other sections.

$$\omega(i)_{POV,S} = \frac{\kappa_{POV}}{1+exp(\gamma_{POV}*(\mu_{POV}-(t-t_S))} \quad \textit{Equation 70}$$

$$V(i)_{POV,S,BAU} = \frac{V(i)_{POV}*\omega(i)_{POV,S}}{\sum_s \omega(i)_{POV,S}} \quad or \quad V(i)_{POV,S,BAU} = \frac{V'(i)_{POV}*\omega(i)_{POV,S}}{\sum_S \omega(i)_{POV,S}} \quad \textit{Equation 71}$$

$$P(S_{i+1}|S_i) = [p_{uv}] \quad for\ p_{uv} \geq 0,\ where\ \sum_v p_{uv} = \sum_v P(S_{i+1} = v|S_i = u) = 1 \quad \textit{Equation 72}$$

$$[V(i)_{POV}] = [a]\ x\ [p_{uv}]^{(t-t_e)} \quad for\ t \geq t_e,\ [V(i)_{POV,BAU}]\ otherwise \quad \textit{Equation 73}$$

$$\Upsilon(i)_{G,P} = \sum_S (V(i)_{POV,S} * \nu_{G,P,S}) * d(i)_{POV} * \zeta_{tpd} * \zeta_{acd} * \rho(i)_G \quad \textit{Equation 74}$$

$$\Upsilon(i)_{D,P} = \sum_S (V(i)_{POV,S} * \nu_{D,P,S}) * d(i)_{POV} * \zeta_{tpd} * \zeta_{acd} * \rho(i)_D \quad \textit{Equation 75}$$

Where:

$\omega(i)_{POV,S}$ = percentage of POVs built to standard S surviving in year i (%)
κ_{POV} = maximum POV survival percentage (%)
γ_{POV} = logistic growth rate for POV scrappage model (%)
μ_{POV} = midpoint year of POV scrappage model (years after standard S goes into effect)
t_S = year standard S goes into effect (year)
$V(i)_{POV,S,BAU}$ = number of POVs in XT fleet operating at standard S in year i (without XT policy)
$P(S_{i+1}|S_i)$ = policy − driven transition matrix, probabilities of moving from one standard to another in year i + 1
p_{uv} = probability of replacing POV satisfying standard u (lower) to with POV satisfying standard v (higher) (%)
$[V(i)_{POV}]$ = vector containing number of POVs satisfying each emission standard in year i
$[a]$ = vector containing baseline number of POVs in XT fleet built to each standard
$\Upsilon(i)_{G,P}$ = annual emissions of pollutant P from all gas ICE POVs in year i, (10^{21}) for P = PN, (kt) otherwise
$\nu_{G,P,S}$ = emission rate of pollutant P for gas ICE POVs operating at standard S (see Appendix, Table A16)
$\Upsilon(i)_{D,P}$ = annual emissions of pollutant P from all diesel ICE POVs in year i, (10^{21}) for P = PN, (kt) otherwise
$\nu_{D,P,S}$ = emission rate of pollutant P for diesel ICE POVs operating at standard S (see Appendix, Table A16)

5.4.4. MC Emission Standards

Policies to enforce criteria pollutant emission standards for gasoline-powered motorcycles are expected to reduce GHG precursors by reducing emissions of three pollutants (CO, total HC, NO_x). Vehicle survival rates are estimated with a logistic replacement model to determine the percentage of vehicles and proportion of XT motorcycle fleet manufactured to a given standard remaining on the road each year, based on the standard in place when the vehicles were manufactured. Survival rates and total MC demand (assuming constant ratio of POV commuters to MC commuters) are used to estimate the proportion of the XT MC fleet operating at each standard level each year.

Impacts of policies to enforce standards are represented with a Markov transition matrix describing the probability of accelerated vehicle scrappage and replacement rates in response to ADB-funded enforcement policies. Annual emissions of each criteria pollutant in the BAU and policy scenarios are calculated by multiplying the number of MCs operating at each standard by the expected annual VKT per MC and the emission rate specified by the appropriate regulatory regime. Expected emissions of each pollutant from vehicles meeting each standard are then summed over all MCs in operation each year.

Note: Estimates in this tab do incorporate effects of population growth (Section 5.1.), but do not include effects of mode shift (Section 5.3.2.) or additional enforcement of ICE fuel standards (Section 5.4.2.). Equation 80 was updated May 17, 2020 from earlier versions of the spreadsheet to use MC average trip distances reflected in Sections 5.3.1. - 5.3.2, rather than annual VKT per MC. Estimates were updated May 12, 2020 after dimensional analysis of all spreadsheet formulas revealed a unit conversion error resulting in an underestimate of annual emission of four criteria pollutants (CO, total HC, NO_x). Neither relative emission reductions achieved by the policy nor subsequent calculations were affected by the change. Estimates could be further improved by adjusting scrappage models to begin vehicle scrappage timeline (t) for standard S the year standard S+1 goes into effect. GHG precursor emissions estimated in this section are not reflected in final GHG estimates and do not directly influence GHG calculations in any other sections.

$$\omega(i)_{MC,S} = \frac{\kappa_{MC}}{1+exp(\gamma_{MC}*(\mu_{MC}-(t-t_S))}$$ *Equation 76*

$$V(i)_{MC,S,BAU} = \frac{V(i)_{MC}*\omega(i)_{MC,S}}{\sum_s \omega(i)_{MC,S}}$$ *Equation 77*

$$P(S_{i+1}|S_i) = [p_{uv}] \quad for\ p_{uv} \geq 0,\ where\ \sum_v p_{uv} = \sum_v P(S_{i+1} = v|S_i = u) = 1$$ *Equation 78*

$$[V(i)_{MC}] = [a]\ x\ [p_{uv}]^{(t-t_e)} \quad for\ t \geq t_e,\ [V(i)_{MC,BAU}]\ otherwise$$ *Equation 79*

$$\Upsilon(i)_{MC,P} = \sum_S (V(i)_{MC,S} * \nu_{MC,P,S}) * d(i)_{MC} * \zeta_{tpd} * \zeta_{acd}$$ *Equation 80*

Where:

$\omega(i)_{MC,S}$ = percentage of MCs built to standard S surviving in year i (%)
κ_{MC} = maximum MC survival percentage (%)
γ_{MC} = logistic growth rate for MC scrappage model (%)
μ_{MC} = midpoint year of MC scrappage model (years after standard S goes into effect)
t_S = years after standard S goes into effect
$V(i)_{MC,S,BAU}$ = number of MCs in XT fleet operating at standard S in year i (without XT policy)
$P(S_{i+1}|S_i)$ = policy − driven transition matrix, probabilities of moving from one standard to another in year i + 1
p_{uv} = probability of moving from standard u (lower) to standard v (higher) in year i + 1 (%)
$[V(i)_{MC}]$ = vector containing number of MCs built to each standard in year i
$[a]$ = vector containing baseline number of MCs in XT fleet built to each standard
$\Upsilon(i)_{MC,P}$ = annual emissions of pollutant P from all MCs in year i (kt)
$\nu_{MC,P,S}$ = emission rate of pollutant P for MCs operating at standard S (kt/km) (see Appendix Table A18)

5.4.5. POV LOS

The effect of changes in POV operating speeds on emissions is extrapolated from data collected for passenger cars meeting China 4 emission standards for five LOS (free flow, heavy traffic, saturated traffic, stop-and-go, heavy stop-and-go) on four major road types (expressway, major arterial, minor arterial, branch). Following assumptions of impacts to bus LOS from bus priority lane designation, it is assumed that project-based modifications to designate bus priority lanes will reduce average POV LOS on affected roadways from "saturated traffic" to "heavy stop-and-go" by reducing the number of lanes available for POV traffic. The fraction of POVs affected by LOS changes is assumed to be proportional to the fraction of roadways (total length of urban roadways or total length of roadways in XT) affected by project-based modifications. The fraction of POVs affected by LOS changes is used to estimate the number of POVs affected based on total annual POV estimates (with or without carpooling, see Section 5.4.1.) and ignoring any additional mode shift. Annual VKT of POVs operating at reduced LOS and scaled EFs for each fuel type are used to calculate total emissions from affected POVs, which are compared to expected baseline emissions from affected POVs to determine total annual emission changes.

Effects of carpooling on POV LOS are estimated by assuming the fraction of car travel in XT affected by LOS improvement is proportional to total POV demand reduction achieved by carpooling (see Section 5.4.1.). Only traffic on roads not directly modified by bus lane designation are considered for LOS improvement from carpooling, and it is assumed that affected traffic is on major arterial roads. Traffic LOS is assumed to increase two levels from "saturated traffic" to "free-flow."

Note: Estimates in this tab do include effects of population growth (Section 5.1.), and can include effects of carpooling (Section 5.4.1.), but do not account for changing gas, diesel, and EV market share (Section 5.3.2.), other forms of mode shift (Section 5.3.1.), or additional enforcement of ICE fuel or emissions standards (Section 5.4.2. - 5.4.3.). Estimates could further be improved by differentiating between gas, diesel, and EV POVs, and calculated scaled EFs for each vehicle type at different LOS using the same approach applied to busses (see Section 5.2.2.). Further improvements could apply the same approach to other vehicle types sharing the same roadways (MCs, eBikes) to estimate emission changes for these vehicle types. Equation 82, Equation 83, and Equation 86 were updated May 11, 2020 from earlier versions of the spreadsheet to adjust POV demand and average trip distance for carpooling scenarios. Equation 83 and Equation 86 were updated May 11, 2020 to include factors for two-way daily commute trips and total commute days per year. While the percentage of roadways in XT affected is calculated in Equation 81, only the length of urban roads in YH+YT is used in subsequent calculations to be consistent with vehicle estimates reflecting POV demand in YH+YT only.

$$p(i)_{BL} = \frac{l_{B,mod}}{l_{YH+YT}} \quad \text{or} \quad p(i)_{BL} = \frac{l_{B,mod}}{l_{XT}} \quad for\ t \geq t_L,\ 0\ otherwise$$ *Equation 81*

$$V(i)_{POV,MA,SG} = V(i)_{POV} * p(i)_{BL} \quad \text{or} \quad V(i)_{POV,MA,SG} = V'(i)_{POV} * p(i)_{BL}$$ *Equation 82*

$$D(i)_{POV,MA,SG} = V(i)_{POV,MA,SG} * d(i)_{POV} * \zeta_{tpd} * \zeta_{acd}$$ *Equation 83*

$$\Delta CO_{2,-LOS}(i) = D(i)_{POV,MA,SG} * (EF_{G,MA,SG} - EF_{G,MA,ST})$$ *Equation 84*

$$V(i)_{POV,MA,FF} = V'(i)_{POV} * (1 - p_{BL})$$ *Equation 85*

$$D(i)_{POV,MA,FF} = V(i)_{POV,MA,FF} * d(i)_{POV} * \zeta_{tpd} * \zeta_{acd}$$ *Equation 86*

$$\Delta CO_{2,+LOS}(i) = D(i)_{POV,MA,FF} * (EF_{G,MA,FF} - EF_{G,MA,ST})$$ *Equation 87*

$$\Delta CO_{2,LOS}(i) = \Delta CO_{2,+LOS}(i) + \Delta CO_{2,-LOS}(i)$$ *Equation 88*

Where:

p_{BL} = *percentage of roadways affected by bus lane modifications* (%)
l_{YH+YT} = *length of urban roads in* $YH + YT$ (*km*)
l_{XT} = *length of roadways in XT* (*km*)
$V(i)_{POV,MA,SG}$ = *POVs affected by LOS change to stop and go traffic on major arterials in year i*
$D(i)_{POV,MA,SG}$ = *annual VKT of POVs in stop and go traffic on major arterials in year i* (*km/yr*)
$\Delta CO_{2,-LOS}(i)$ = CO_2 *emission change from reduced POV LOS in year i* ($ktCO_2e/yr$)
$EF_{G,MA,SG}$ = *emission factor for gas ICE POVs travelling on major arterials in stop and go traffic* ($ktCO_2e/km$)
$V(i)_{POV,MA,FF}$ = *POVs affected by LOS change to free flow traffic on major arterials in year i*
$D(i)_{POV,MA,FF}$ = *annual VKT of POVs in free flow traffic on major arterials in year i* (*km/yr*)
$\Delta CO_{2,+LOS}(i)$ = CO_2 *emission change from improved POV LOS in year i* ($ktCO_2e/yr$)
$EF_{G,MA,FF}$ = *emission factor for gas ICE POVs travelling on major arterials in free flow traffic* ($ktCO_2e/km$)
$\Delta CO_{2,LOS}(i)$ = *net* CO_2 *emission change from POV LOS changes in year i* ($ktCO_2e/yr$)

5.4.6. Summary Data

5.4.6.1. BAU Scenario

5.4.6.1.1. BAU Bus Emissions

BAU bus emissions are calculated using the procedure described in section 5.2.1 Bus Fuel Switch, assuming constant bus fleet composition and constant weighted EF throughout the loan period. Ridership throughout the loan period accounts for population growth only, and assumes no additional mode shift or change in bus fleet composition and characteristics.

This scenario does include effects of population growth (Section 5.1.) but does not include effects of bus fuel switch (Section 5.2.1.), changes to bus LOS (Section 5.2.2.), or modal shift (Section 5.3.1.).

$$N(i)_B = N(i)_W * y_{0,B} \quad \text{Equation 89}$$

$$\tau(i)_B = N(i)_B * \zeta_{tpd} \quad \text{Equation 90}$$

$$VKT(i)_B = \tau(i)_B * d_B \quad \text{Equation 91}$$

$$B(i)_{YH+YT} = \frac{VKT(i)_B}{vkt_B * LF_B} \quad \text{Equation 92}$$

$$B(i)_{XT} = B(i)_{YH+YT} * \frac{1}{p_{YH+YT}} \quad \text{Equation 93}$$

$$D(i)_B = B(i)_{YH+YT} * vkt_B * \zeta_{acd} \quad \text{Equation 94}$$

$$\rho_{0,j} = \frac{B_{0,j}}{\sum_j B_{0,j}} \quad \text{Equation 95}$$

$$B(i)_j = \rho_{0,j} * B(i)_{YH+YT} \quad \text{Equation 96}$$

$$\overline{EF}(i)_B = \frac{\sum_j B(i)_j * EF_j}{\sum_j B(i)_j} \quad \text{Equation 97}$$

$$CO_{2,B}(i) = D(i)_B * \overline{EF}(i)_B \quad \text{Equation 98}$$

5.4.6.1.2. BAU Auto-Gas Emissions

BAU automobile (POV) emissions assume gas ICE POV operating conditions would remain constant throughout the loan period in the absence of ADB-funded policy interventions, with no improvement in fuel efficiency, emissions factors, or carpooling, and no additional adoption of EVs throughout the loan period. The total number of annual commuters using ICE POVs is estimated from the working-age population and percentage of commuters using ICE POVs in 2019. Total distance travelled by gas ICE POVs is estimated by first calculating the total number of POVs as the sum of ICE POVs and EV POVs, and multiplying by the POV market share of gas ICE POVs. The total number of gas ICE POVs is multiplied by average number of one-way trips per commuter per day and annual number of commute days, then divided by the average POV LF to determine total distance travelled by gas ICE POVs per year. This distance is multiplied by the distance-based WTW EF for gas ICE POVs to estimate total annual emissions. Load factors for cars (ICE and EV) are set according to published values.

This scenario does account for population growth (Section 5.1.), but does not include modal shift (Section 5.3.1.), EV adoption and diesel POV scrappage (Section 5.3.2.), adoption of carpooling and ridesharing (Section 5.4.1.), additional enforcement of ICE fuel and emission standards (Sections 5.4.2 - 5.4.3.), or changes to POV LOS (Section

5.4.5.). Equation 101 was updated May 20, 2020 from earlier versions of the spreadsheet to use average POV trip distance adjusted for carpooling rates.

$$N(i)_{ICE} = N(i)_W * y_{0,ICE} \quad \text{Equation 99}$$

$$N(i)_{eV} = N(i)_W * y_{0,eV} \quad \text{Equation 100}$$

$$D(i)_G = \frac{(N(i)_{ICE} + N(i)_{eV}) * \rho_{0,G} * d(i)_{POV} * \zeta_{tpd} * \zeta_{acd}}{LF_{0,POV}} \quad \text{Equation 101}$$

$$CO_{2,G}(i) = D(i)_G * EF_G \quad \text{Equation 102}$$

Where:

$y_{0,ICE}$ = percentage of commuters travelling by ICE POV in first year of policy period (%)
$y_{0,eV}$ = percentage of commuters travelling by EV POV in first year of policy period (%)
$\rho_{0,G}$ = gas ICE POV market share in first year of policy period (%)

5.4.6.1.3. BAU Auto-Diesel Emissions

BAU automobile (POV) emissions assume no additional adoption of EVs throughout the loan period, no change in POV market share of EV, diesel ICE, and gas ICE POVs (i.e. constant *y(i)* and $\rho(i)$), no improvements in ICE WTW distance-based EFs, and no modifications to LF through carpooling and ridesharing. The same procedure described in Section 5.1.3. is applied to diesel ICE POVs using the estimated baseline diesel POV market share and distance-based WTW EF.

This scenario <u>does</u> account for population growth (Section 5.1.), but does <u>not</u> include modal shift (Section 5.3.1.), EV adoption and diesel POV scrappage (Section 5.3.2.), adoption of carpooling and ridesharing (Section 5.4.1.), additional enforcement of ICE fuel and emission standards (Sections 5.4.2 - 5.4.3.), or changes to POV LOS (Section 5.4.5.). Equation 103 was updated May 20, 2020 from earlier versions of the spreadsheet to use average POV trip distance adjusted for carpooling rates.

$$D(i)_D = \frac{(N(i)_{ICE} + N(i)_{eV}) * \rho_{0,D} * d(i)_{POV} * \zeta_{tpd} * \zeta_{acd}}{LF_{0,POV}} \quad \text{Equation 103}$$

$$CO_{2,D}(i) = D(i)_D * EF_D \quad \text{Equation 104}$$

5.4.6.1.4. BAU Auto-EV Emissions

BAU automobile (POV) emissions assume no additional adoption of EVs throughout the loan period, no change in POV market share of EV, diesel ICE, and gas ICE POVs (i.e. constant *y(i)* and $\rho(i)$), no improvements in EV energy efficiency, and no modifications to LF through carpooling and ridesharing. Total number of annual commuters using EV POVs is estimated from the working-age population and percentage of commuters using EV POVs. The total number of EV POVs is multiplied by average number of one-way trips per commuter per day and annual number of commute days, then divided by the average POV LF to determine total distance travelled by EV POVs per year. This distance is multiplied by the distance-based WTW EF for EV POVs to estimate total annual emissions.

This scenario <u>does</u> account for population growth (Section 5.1.), but does <u>not</u> include modal shift (Section 5.3.1.), EV adoption, diesel POV scrappage, and EV energy efficiency improvements over time (Section 5.3.2.), adoption of carpooling and ridesharing (Section 5.4.1.), or changes to POV LOS (Section 5.4.5.). Equation 105 was updated May 20, 2020 from earlier versions of the spreadsheet to use average POV trip distance adjusted for carpooling rates.

$$D(i)_{eV} = \frac{N(i)_{eV} * d(i)_{POV} * \zeta_{tpd} * \zeta_{acd}}{LF_{0,POV}} \quad \text{Equation 105}$$

$$CO_{2,eV}(i) = D(i)_{eV} * EF_{eV} \quad \text{Equation 106}$$

5.4.6.1.5. BAU MC Emissions

Total number of annual commuters using MCs is estimated from the working-age population and percentage of commuters using MCs. The total number of MCs is multiplied by average number of one-way trips per commuter per day and annual number of commute days, then divided by the average MC LF to determine total distance travelled by MCs per year. This distance is multiplied by the distance-based WTW EF for MCs to estimate total annual emissions.

This scenario does account for population growth (Section 5.1.), but does not include modal shift (Section 5.3.1.), additional enforcement of ICE fuel standards (Section 5.4.2.), or enforcement of MC emission standards (Section 5.4.3.).

$$N(i)_{MC} = N(i)_W * y_{0,MC} \quad \text{Equation 107}$$

$$D(i)_{MC} = \frac{N(i)_{MC} * d_{MC} * \zeta_{tpd} * \zeta_{acd}}{LF_{MC}} \quad \text{Equation 108}$$

$$CO_{2,MC}(i) = D(i)_{MC} * EF_{MC} \quad \text{Equation 109}$$

Where:

$N(i)_{MC}$ = *number of commuters travelling by MC in year i*

$y_{0,MC}$ = *percentage of commuters travelling by MC in first year of policy period* (%)

$D(i)_{MC}$ = *total annual distance travelled by MCs in year i* (*km/yr*)

5.4.6.1.7. BAU eBike Emissions

Total number of annual commuters using eBikes is estimated from the working-age population and percentage of commuters using eBikes. The total number of eBikes is multiplied by average number of one-way trips per commuter per day and annual number of commute days, then divided by the average eBike LF to determine total distance travelled by eBikes per year. This distance is multiplied by the distance-based WTW EF for eBikes to estimate total annual emissions.

This scenario does account for population growth (Section 5.1.), but does not include modal shift (Section 5.3.1.).

$$N(i)_{eB} = N(i)_W * y_{0,eB} \quad \text{Equation 110}$$

$$D(i)_{eB} = \frac{N(i)_{eB} * d_{eB} * \zeta_{tpd} * \zeta_{acd}}{LF_{eB}} \quad \text{Equation 111}$$

$$CO_{2,eB}(i) = D(i)_{eB} * EF_{eB} \quad \text{Equation 112}$$

Where:

$N(i)_{eB}$ = *number of commuters travelling by eBike in year i*

$y_{0,eB}$ = *percentage of commuters travelling by eBike in first year of policy period* (%)

$D(i)_{eB}$ = *total annual distance travelled by eBikes in year i* (*km/yr*)

5.4.6.2. Effects of Bus Interventions

5.4.6.2.1. Mode Shift and eBus Impact

Emissions resulting from modal shift to busses along with replacement of a portion of the bus fleet with eBusses are estimated by calculating expected ridership each year from working-age population and annually-updated mode preference. Passenger trips per day, total daily VKT for all busses, and total number of busses needed each year in YH and YT as well as XT county are calculated as described in Section 5.1.2 BAU Bus Emissions. Number of busses of each type and weighted bus EFs are calculated as described in section 5.2.1 Bus Fuel Switch, assuming

bus fleet composition remains constant after the introduction of ADB-funded eBusses at the end of the loan period. Total annual emissions from busses resulting from both modal shift and fuel switch policies are calculated by multiplying total annual VKT for all busses by the annually-updated weighted EF of the XT bus fleet.

This scenario <u>does</u> account for population growth (Section 5.1.), bus fuel switch (Section 5.2.1.), and a "light touch" policy resulting in 0.8% average annual modal shift toward busses over the lifetime of the loan (Section 5.3.1.). This scenario does <u>not</u> account for changes in bus LOS (Section 5.2.2.).

$$N(i)_B = N(i)_W * y(i)_B \quad \text{Equation 113}$$

$$\tau(i)_B = N(i)_B * \zeta_{tpd} \quad \text{Equation 114}$$

$$VKT(i)_B = \tau(i)_B * d_B \quad \text{Equation 115}$$

$$B(i)_{YH+YT} = \frac{VKT(i)_B}{vkt_B * LF_B} \quad \text{Equation 116}$$

$$B(i)_{XT} = B(i)_{YH+YT} * \frac{1}{p_{YH+YT}} \quad \text{Equation 117}$$

$$D(i)_B = B(i)_{YH+YT} * vkt_B * \zeta_{acd} \quad \text{Equation 118}$$

$$\rho(i)_{eBus} = \frac{B_{0,eBus} + B_{Pr,eBus}}{\sum_j B_{0,j}} \quad for\ i \geq t_L,\ \rho(i)_{eBus} = \rho_{0,eBus}\ otherwise \quad \text{Equation 119}$$

$$\rho(i)_{pureNG} = \frac{B_{0,pureNG} - B_{Pr,eBus}}{\sum_j B_{0,j}} \quad for\ i \geq t_L,\ \rho(i)_{pureNG} = \rho_{0,pureNG}\ otherwise \quad \text{Equation 120}$$

$$\rho(i)_j = \frac{B_{0,j}}{\sum_j B_{0,j}} \quad for\ j \neq eBus,\ pureNG \quad \text{Equation 121}$$

$$B(i)_j = B(i)_{YH+YT} * \rho(i)_j \quad \text{Equation 122}$$

$$\overline{EF}(i)_B = \frac{\sum_j B(i)_j * EF_j}{\sum_j B(i)_j} \quad \text{Equation 123}$$

$$CO_{2,B}(i) = D(i)_B * \overline{EF}(i)_B \quad \text{Equation 124}$$

Where:

$y(i)_B$ = percentage of commuters travelling by bus in year i (%)

5.4.6.2.2. Bus LOS Impact

See Section 5.2.2. Bus LOS EFs.

5.4.6.3. Intervention Scenario

5.4.6.3.1. Mode Shift, More EVs, Carpooling

Auto-Gas Impacts

Emissions resulting from modal shift away from gas ICE POVs are estimated by calculating expected number of gas ICE POVs and total annual VKT by gas ICE POVs from annual working-age population and annually-updated mode preference, assuming a steadily declining market share of diesel ICE POVs (see Section 5.3.2.) and an increasing LF

due to increased adoption of carpooling (see Section 5.4.1.). Emissions are calculated using total annual demand for gas ICE POVs, a constant average trip distance, and a constant distance-based WTW EF.

This scenario <u>*does*</u> *account for population growth (Section 5.1.), a "light touch" policy resulting in 0.8% average annual modal shift away from ICE POVs over the lifetime of the loan (Section 5.3.1.), increased EV POV market share (Section 5.3.2.), and reduced POV demand due to increased adoption of carpooling and ridesharing (Section 5.4.1.). This scenario does* <u>*not*</u> *include additional enforcement of ICE fuel standards and emission standards (Sections 5.4.2. - 5.4.3.), or changes to POV LOS (Section 5.4.5.). Equation 129 was updated May 11, 2020 from earlier versions of the spreadsheet to reflect increased average trip distance due to carpooling adoption (Section 5.4.1.).*

$$N(i)_{ICE} = N(i)_W * y(i)_{ICE}$$ *Equation 125*

$$N(i)_{eV} = N(i)_W * y(i)_{eV}$$ *Equation 126*

$$V'(i)_{POV} = \frac{N(i)_{ICE}+N(i)_{eV}}{LF(i)_{POV}}$$ *Equation 127*

$$V(i)_G = V'(i)_{POV} * \rho(i)_G$$ *Equation 128*

$$D(i)_G = V(i)_G * d(i)_{POV} * \zeta_{tpd} * \zeta_{acd}$$ *Equation 129*

$$CO_{2,G}(i) = D(i)_G * EF_G$$ *Equation 130*

Auto-Diesel Impacts

Emissions resulting from modal shift away from diesel ICE POVs are estimated by calculating expected number of diesel ICE POVs and total annual VKT by diesel ICE POVs from annual working-age population and annually-updated mode preference, assuming a steadily declining market share of diesel ICE POVs (see Section 5.3.2. More EV POVs) and an increasing LF due to increased adoption of carpooling (see Section 5.4.1. Carpooling). Emissions are calculated using total annual VKT by diesel ICE POVs and a constant distance-based WTW EF.

This scenario <u>*does*</u> *account for population growth (Section 5.1.), a "light touch" policy resulting in 0.8% average annual modal shift away from ICE POVs over the lifetime of the loan (Section 5.3.1.), increased EV POV market share and a ban on sale of new diesel POVs beginning in 2026 (Section 5.3.2.), and reduced POV demand due to increased adoption of carpooling and ridesharing (Section 5.4.1.). This scenario does* <u>*not*</u> *include additional enforcement of ICE fuel standards and emission standards (Sections 5.4.2. - 5.4.3.), or changes to POV LOS (Section 5.4.5.). Equation 132 was updated May 11, 2020 from earlier versions of the spreadsheet to include increased average trip distance due to carpooling adoption (Section 5.4.1.).*

$$V(i)_D = V'(i)_{POV} * \rho(i)_D$$ *Equation 131*

$$D(i)_D = V(i)_D * d(i)_{POV} * \zeta_{tpd} * \zeta_{acd}$$ *Equation 132*

$$CO_{2,D}(i) = D(i)_D * EF_D$$ *Equation 133*

Auto-EV Impacts

Emissions resulting from modal shift to EV POVs are estimated by calculating expected number of EV POVs and total annual VKT by EV POVs from annual working-age population and annually-updated mode preference, assuming a steadily declining market share of diesel ICE POVs (see Section 5.3.2. More EV POVs) and an increasing LF due to increased adoption of carpooling (see Section 5.4.1. Carpooling). Emissions are calculated using total annual VKT by EV POVs and a constant distance-based WTW EF.

This scenario <u>*does*</u> *account for population growth (Section 5.1.), a "light touch" policy resulting in 0.3% average annual modal shift toward EV POVs over the lifetime of the loan (Section 5.3.1.), increased EV POV market share*

(Section 5.3.2.), and reduced POV demand due to increased adoption of carpooling and ridesharing (Section 5.4.1.). This scenario does not include EV energy efficiency improvements over time (Sections 5.4.2. - 5.4.3.), or changes to POV LOS (Section 5.4.5.). Equation 135 was updated May 11, 2020 from earlier versions of the spreadsheet to include increased average trip distance due to carpooling (Section 5.4.1.).

$$V(i)_{eV} = V'(i)_{eV} * \rho(i)_{eV}$$ *Equation 134*

$$D(i)_{eV} = V(i)_{eV} * d(i)_{POV} * \zeta_{tpd} * \zeta_{acd}$$ *Equation 135*

$$CO_{2,eV}(i) = D(i)_{eV} * EF_{eV}$$ *Equation 136*

MC Impacts

Emissions resulting from changes in commuter preference for MCs are estimated by calculating expected number of MCs and total annual VKT by MCs from annual working-age population and annually-updated mode preference. Emissions are calculated using total annual VKT by MCs and a constant distance-based WTW EF.

This scenario does account for population growth (Section 5.1.), and a "light touch" policy resulting in 0.1% average annual modal shift towards MCs (Section 5.3.1.). This scenario does not include additional enforcement of ICE fuel standards (Section 5.4.2.) or MC emission standards (Section 5.4.4.).

$$N(i)_{MC} = N(i)_{W} * y(i)_{MC}$$ *Equation 137*

$$V(i)_{MC} = \frac{N(i)_{MC}}{LF_{MC}}$$ *Equation 138*

$$D(i)_{MC} = V(i)_{MC} * d_{MC} * \zeta_{tpd} * \zeta_{acd}$$ *Equation 139*

$$CO_{2,MC}(i) = D(i)_{MC} * EF_{MC}$$ *Equation 140*

eBike Impacts

Emissions resulting from changes in commuter preference for eBikes are estimated by calculating expected number of eBikes and total annual VKT by eBikes from annual working-age population and annually-updated mode preference. Emissions are calculated using total annual VKT by eBikes and a constant distance-based WTW EF.

This scenario does account for population growth (Section 5.1.) and a "light touch" policy resulting in 0.3% average annual modal shift toward eBikes over the lifetime of the loan (Section 5.3.1.).

$$N(i)_{eB} = N(i)_{W} * y(i)_{eB}$$ *Equation 141*

$$V(i)_{eB} = \frac{N(i)_{eB}}{LF_{eB}}$$ *Equation 142*

$$D(i)_{eB} = eB(i) * d_{eB} * \zeta_{tpd} * \zeta_{acd}$$ *Equation 143*

$$CO_{2,eB}(i) = D(i)_{eB} * EF_{eB}$$ *Equation 144*

5.4.6.3.2. Improved km/l

Emission reductions are calculated relative to a BAU scenario in which ICE POV and MC fuel demand (L/100km) remain constant at 2019 estimated values, as described in Section 5.4.6.1., and a policy scenario with no additional mode shift, changes in POV market share, or carpooling (see Section 5.4.2 ICE Fuel Standards).

5.4.6.3.3. POV LOS

See Section 5.4.5. POV LOS. Emission reductions are calculated relative to a BAU scenario in which ICE POV and MC fuel demand (L/100km) remain constant at 2019 estimated values, and both BAU and policy scenarios estimate POVs affected by LOS changes based on scenarios with increased adoption of carpooling. All emission changes from changes to POV LOS are attributed to Gas ICE POVs.

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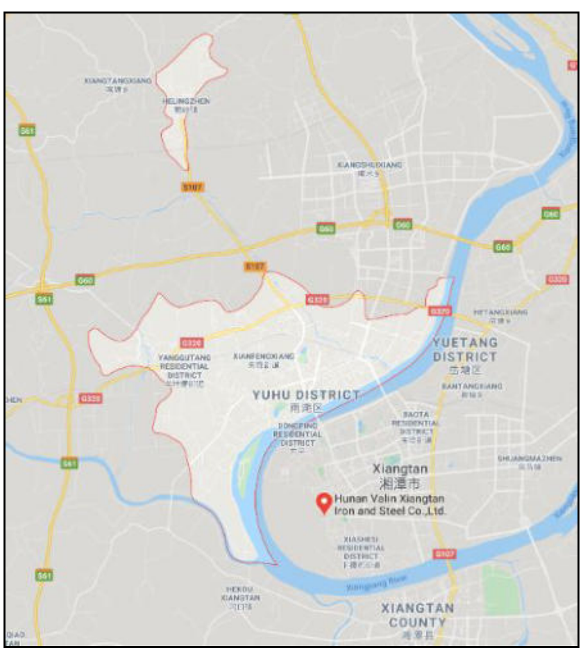
Appendix

A1. ABBREVIATIONS AND ACRONYMS

Abbreviation	Definition
ADB	Asian Development Bank
BAU	Business as usual
CH4	Methane
C-III	China three emission standards
C-IV	China four emission standards
C-V	China five emission standards
CO	Carbon monoxide
CO2	Carbon dioxide
CO2e	Carbon dioxide equivalent
DCFC	Direct current fast charger
Diesel H	Diesel hybrid
eBike	Electric bike
EEI	Energy Efficiency Increase scenario (fuel standards tab)
EF	Emission factor
eMB	Electric motor-bike
EV	Electric vehicle
GDI	Gasoline direct injection
GHG	Greenhouse gas
GVWR	Gross vehicle weight rating
GWP	Global warming potential
HC	Hydrocarbon (emissions)
HCC	High hydrogen content
Health & H Comm	XT Municipal Government Committee responsible for health
HEV	Hybrid electric vehicle
ICE	Internal combustion engine
ICEV	Internal combustion engine vehicle
IPCC	Intergovernmental Panel on Climate Change
kWh	Kilowatt-hours
LDV	Light duty vehicle
LF	Load factor
LC	Low carbon
LOS	Level of service
MC Scenario	(scenario/fuel standards)
MC	Motorcycles
MEE	Ministry of Ecology and Environment
MJ	MegaJoule
MOU	Memorandum of understanding
Mt	Million tons
Mt	Metric tonnes
N20	Nitrous oxide
NEV	New Energy Vehicle (almost always EV but may be hydrogen or other)
NG	Natural gas
NMHC	Non-methane hydrocarbon

NO_3	Nitrate
NO_x	Nitrogen oxides
O_3	Ozone
PHEV	Plug-in hybrid electric vehicle
Pkg	Parking
PM	Particulate matter
PN	Particulate number
Pop'n	Population
POV	Personally operated vehicle
RF	Radiative forcing
REF	Reference scenario for improvement in fuel use
Stds	Standards
t CO_2e/yr	Tons of carbon dioxide equivalent emissions per year
TAR	Third Assessment Report (published in 2001 by IPCC)
TMOTEC	Transportation Mode-Technology-Energy CO_2 model
Ttl Kt CO_2e/yr	Total kilotons of carbon dioxide equivalent emissions per year
Tr1	Tranche 1
Tr2	Tranche 2
VKT	Vehicle kilometers traveled
VMT	Vehicle miles traveled
WTW	Well-to-wheels emissions (Includes fuel source emissions & those produced by fuel use)
XPTC	Xiangtan public transportation company
XT	Xiangtan
XTMG/XMG	Xiangtan municipal government
XXPT	Xiangtan Xiangyun Public Transportation Co., Ltd.
YT	Yuetang District
YT+YH	Yuetang District plus Yuhu District = downtown or center city Xiangtan
YH	Yuhu District



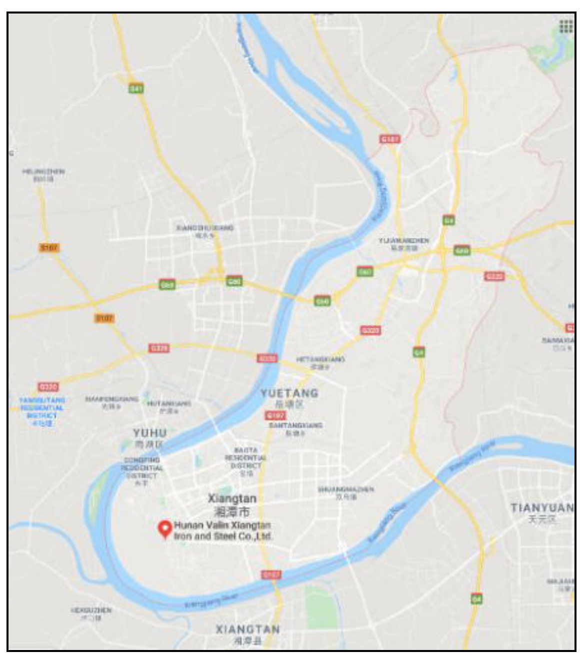


Figure A1: Yuhu District (outlined in red)

Figure A2: Yuetang District (outlined in purple)

Table A1. Project-Based Interventions

Code	Interventions	Details and Effects on Mode Use and Characteristics
01-Pr01	Installation of 791 e-charging piles in 31 locations	EV access to charging piles improved, purchase and use of EV encouraged, change in fleet balance
01-Pr02	Reprogramming traffic signals for bus priority	Private vehicle travel times and emissions increase, making alternative transit modes more attractive
01-Pr03	Lane modification of 31.3km median and 31.5km peak-hr curbside bus priority system in main trunk roads	Bus fleet operates at higher average velocity with fewer stops and starts, which leads to lower EF
01-Pr04	Bus-designated traffic light management	Bus fleet operates at higher average velocity with fewer stops and starts, which leads to lower EF
01-Pr05	Upgrading 258 bus stops equipped with digital signage	Expanded bus routes and more bus boarding opportunities, more info. encourages greater use of busses
01-Pr06	70 pairs of bus stops in structural trunk roads	Expanded bus routes and more bus boarding opportunities encourages greater use of busses
01-Pr07	59 pairs of bus stops in trunk roads	Expanded bus routes and more bus boarding opportunities encourages greater use of busses
01-Pr08	Procurement of 100 e-buses	Bus fleet operates with lower EF
01-Pr09	Procurement of 0 natural gas and battery hybrid buses	Bus fleet operates with lower EF
01-Pr10	Installation of 791 e-charging piles in 31 locations	Support for increased numbers of eBusses and more efficient operation
01-Pr11	Reprogramming traffic signals for bus priority	Bus fleet operates at higher average velocity with fewer stops and starts, which leads to lower EF
01-Pr12	Expanding sensing systems (Green Wave)	Bus fleet operates at higher average velocity with fewer stops and starts, which leads to lower EF
01-Pr13	Upgrading bus dispatching platform	Bus fleet operates at higher LF with fewer stops and starts, which leads to lower EF
01-Pr14	Upgrading 63.4 km cycling ways	Improved bicycle lanes encourage bicycle ridership
01-Pr15	Addition of 63.4km/260,100m2 of cycling ways	New bicycle lanes widen regions that encourage bicycle ridership
01-Pr16	Upgrading over 60km of pedestrian walkways	Capacity and attractiveness of walkways increases, encouraging walking
01-Pr17	Installation of 48 Safe Islands	Concern about pedestrian safety decreases, walking is encouraged

01-Pr18	253,600m2 of pedestrian walkways	Options for walking as a transport option broaden geographic scope, other mode use decreases
01-Pr19	Removal of access barrier at 5,000 locations	Opportunities for walking as a transit mode increase
01-Pr20	6.143km paved with absorbent bricks	The number of days when walking is an option increases since sidewalk flooding is less of a deterrent
01-Pr21	24-hour operation of pedestrian crossing lights	Concern about pedestrian safety decreases, walking is encouraged
01-Pr22	Improvement of accessibility and mode change at Xiangtan Railway Sta. and Xiangtan Train Sta.	Greater use of train-to-bus and bus-to-train commute option, reduction in ICE use, change in fleet balance

Table A2. Policy-Based Interventions (Tranche 1)

Code	Interventions	Details and Effects on Mode Use and Characteristics
01-Tr1g	Pkg. fees, differentiated pkg. zoning, smart pkg. facilities, and inst. setup for pkg. policy & mgmt.	Higher parking fees for ICE vehicles lead to decreased incentive for purchase or use
		Fewer parking spaces for ICE vehicles lead to decreased incentive for purchase or use
		Greater enforcement of parking fines for expired parking or parking in EV spaces lead to preference of EV over ICE
		More parking spaces for EVs lead to preference of EV over ICE, change in fleet balance
		Preferential location of EV parking spaces lead to preference of EV over ICE, change in fleet balance
		Easier to locate parking spaces lead to preference of EV over ICE, change in fleet balance
		EV access to charging piles improved, purchase and use of EV encouraged, change in fleet balance
		Smart parking apps allow drivers to find spaces faster and "circle" in search of spaces less.
		Smart parking facilities (intelligent parking lots) can fit more vehicles into existing parking lot space.
01-Tr1i	Measures to promote Car Sharing	Greater use of ride sharing, reduced number of private vehicles on the road
01-Tr1j	Xiangtan Action Plan on Clean energy vehicle promotion	Greater purchase and use of EVs

01-Tr1k	Motorized vehicle air emission management action plan	Existing ICE vehicles operate at lower EF through greater enforcement of requirements
		New ICE vehicles added to fleet (public, private, taxis) operate at lower EF
		Increased cost of purchase and operation of ICE vehicles leads to fewer ICE vehicles on the road and mode switch
01-Tr1a	Implementation Note on bus priority lanes and operation	Bus fleet operates at higher average speed with fewer stops and starts, which leads to lower EF
01-Tr1b	Xiangtan Notice on market-driven public bus operation program	New fare structure encourages greater use of public busses and higher load factors
01-Tr1c	Sustainable urban road guidelines on comprehensive road	Bus priority lanes are enabled on existing trunk roads, busses operate at lower EF and usage encouraged
01-Tr1d	High-level implementation plans on non-motorized transport system	Improved bicycle lanes are encouraged, bicycle ridership encouraged
01-Tr1e	Bicycle Program Management Rules	More places to park bicycles are available, bicycle ridership encouraged
01-Tr1f	Regulations on electric moto-bikes	Use of electric moto-bikes is discouraged, change in fleet balance
01-Tr1h	Promotion of enabling facilities and design features for Multi-modal hubs	Greater use of train-to-bus and bus-to-train commute option, reduction in ICE use, change in fleet balance

Table A3. Policy-Based Interventions (Tranche 2)

Code	Interventions	Details and Effects on Mode Use and Characteristics
01-Tr2g	Parking facilities Design Standards for motorized and non-motorized vehicles	Fewer parking spaces for ICE vehicles, use of ICE discouraged, change in fleet balance
		More parking spaces for EVs, purchase and use of EVs encouraged
		Preferential location of EV parking spaces, purchase and use of EVs encouraged
		EV access to charging piles improved, purchase and use of EVs encouraged
01-Tr2k	Diesel vehicle emission standards	New ICE diesel vehicles added to fleet (public, private, taxis) are cleaner, EF lower
		Existing ICE diesel vehicles operate cleaner through stricter requirements, EF lower

		Increased cost of purchase and operation of ICE diesel vehicles leads to fewer on the road
01-Tr2a	Revised design standards on bus priority lanes with integration of designated bus traffic lights	Bus fleet operates at higher average velocity with fewer stops and starts, higher LF, lower EF
		Green Wave system implemented and bus speeds increase, with fewer starts and stops, higher LF, lower EF
01-Tr2b	Xiangtan Notice on Metro-express & neighborhood bus operation pgms. with market-based fees	New fare structure and expanded extra-urban coverage encourages greater use of public busses, higher LF
01-Trc2c	Integrated urban road design standards for bus priority system developed	Use of bus priority lanes expands to more roads, higher LF, mode switch encouraged
01-Tr2j	Xiangtan notice on electric bus management and disposal rules	eBusses allowed to operate for more miles per year and more years, improving economics, lower fares
01-Tr2d1	Design standards for safe cycling ways developed	More and improved bicycle lanes are constructed, bicycle ridership encouraged
01-Tr2e	Xiangtan Notice on Implementation Plan on expansion of bicycle facilities in pub. & comm. areas	More public bicycles are available, bicycle ridership encouraged
01-Tr2d2	Design standards for safe, inclusive, resilient pedestrian walkways developed	More use of walking as a transport option is encouraged, other mode use decreases
01-Tr2f	Xiangtan Notice on moto-bikes free zones introduced, published and under implementation	Use of electric moto-bikes is discouraged or forbidden, change in fleet balance
01-Tr2h	Design standards for easy transfer at multimodal hubs	Greater use of train-to-bus and bus-to-train commute option (at additional stations)

Table A4. Population Data from Xiangtan CIty GHG Assessment Report

Districts & Counties	Population	Population per Household	Urbanization Rate
Yuetang District	350,500	2.84	100%
Yuhu District	520,500	2.86	100%
Shaoshan City	118,200	3.30	32.74%
Xiangxiang City	924,100	2.96	28.91%
Xiangtan County	979,600	3.23	17.20%
Amount/Average	2,892,900	3.02	46.51%

Table A5. Historical Population Statistics for XT County (2005-2015) (Source: Total Urban population and projection for the next 20 years [XH&HC, 24 Oct 2019])

Year	2005	2015

Total population	2,841,034	2,892,965
Natural population growth rate	3.23%	3.88%
Family planning rate	96.2%	

The rate of natural increase refers to the difference between the number of live births and the number of deaths occurring in a year, divided by the mid-year population of that year, multiplied by a factor (usually 1,000). It is equal to the difference between the crude birth rate and the crude death rate. This measure of the population change excludes the effects of migration (United Nations 1991).

Table A6. Planning Table of Urban Scale Structure

Scale Rank	Urban Scale	Urban Name	Pop. Size	Urban Number
First Class	> 1 Million	Xiangtan Central Area	1,100,000	1

Table A7. Urban Development Statistics

Year	Urbanization Rate	Urban Residential Population
1978	16.45%	23300
2017	62%	1,860,000

Table A8. Modal Shift Transition Matrix

	Bus	*Train*	*Car (ICE)*	*Car (EV)*	*MC*	*Bicycle*	*Walk*	*eMotoBike*
Bus	*R*							
Train		*R*						
Car (ICE)	*b*		*R-(a+b+c+d +e+f)*	*c*		*a*	*d*	*e*
Car (EV)				*R*				
MC	*b/6*				*R-e/3*			*b/6*
Bicycle						*R*		
Walk							*R*	
eMotoBike	*g*		*g*	*g*	*g*	*g*		*R*

Table A9. Tables A.6 and A.9 from Wang, Ou, and Zhang (2017)

Table A-6	REF Scenario for energy efficiency improvement to 2050.										
	Year										
	L/ 100 km	2010	2015	2020	2025	2030	2035	2040	2045	2050	
MC	2.5	100.0%	98.5%	97.0%	95.6%	94.2%	92.8%	91.4%	90.0%	88.7%	
Car	9.75	100.0%	90.4%	81.7%	75.8%	70.2%	67.5%	64.8%	64.2%	63.5%	
Table A-9	EEI Scenario for energy efficiency improvement to 2050.										
MC	2.5	100.0%	98.5%	97.0%	93.7%	91.4%	89.1%	86.9%	84.8%	82.7%	
Car	9.75	100.0%	90.4%	81.7%	73.1%	67.1%	63.2%	59.5%	57.4%	55.4%	

Table A10. Standards Applicable to Automobile Exhaust

Applicable Standards and Inception Dates							
Motorcycle				1	2		
				Jan '10	July '18		
Car + LV						US Tier 2	
Emission	Euro1	Euro2	Euro3	Euro4	Euro5	Euro6	Euro RDE
	C-I	C-II	C-III	C-IV	C5	C6a	C6b
	Jul '99	Jul-'05	Sep '08	Dec '15	Jan '17 gas	July '20	July '23
					Jan '18 diesel		
Durability			80k	100k	160k	160k	200k
Efficiency	L/100km	Phase I	Phase II	Phase III		Phase IV	
			-10%	2012			
	2002	Jul-05	Jul-08	2015		2020	
	9.11		8.6	6.9		5	
ZEV					2018	2019	2020
					8%	10%	12%

Table A11. Emission Standards for Criteria Pollutants for Gasoline-Powered Vehicles

Vehicle Emission Standards for Gasoline Engine Vehicles											
Stage	Veh. type	Level	Mass (kg)	CO (g/km)	HC	NMHC	HC+NOx	NOx	N20	PM	PN/km
China -III	1		All	2.30	0.20	-	-	0.15	-	-	-
	2	I	<1305	2.30	0.20	-	-	0.15	-	-	-
		II	1305 - 1760	4.17	0.25	-	-	0.18	-	-	-
		III	>1760	5.22	0.29	-	-	0.21	-	-	-
China-IV	1		All	1.00	0.10	-	-	0.08	-	-	-
	2	I	<1305	1.00	0.10	-	-	0.08	-	-	-
		II	1305 - 1760	1.81	0.13	-	-	0.1	-	-	-
		III	>1760	2.27	0.16	-	-	0.11	-	-	-
China-5	1		All	1.00	0.10	-	-	0.06	-	0.0045	-
	2	I	<1305	1.00	0.10	-	-	0.06	-	0.0045	-
		II	1305 - 1760	1.81	0.13	-	-	0.075	-	0.0045	-

		III	>1760	2.27	0.16	-	-	0.082	-	0.0045	-
China 6-a	1		All	0.7	0.1	0.068	-	0.06	0.02	0.0045	6.0x10^11
	2	I	<1305	0.7	0.1	0.068	-	0.06	0.02	0.0045	6.0x10^11
		II	1305 - 1760	0.88	0.13	0.09	-	0.075	0.025	0.0045	6.0x10^11
		III	>1760	1	0.16	0.108	-	0.082	0.03	0.0045	6.0x10^11
China 6-b	1		All	0.5	0.05	0.035	-	0.035	0.02	0.0030	6.0x10^11
	2	I	<1305	0.5	0.05	0.035	-	0.035	0.02	0.0030	6.0x10^11
		II	1305 - 1760	0.63	0.065	0.045	-	0.045	0.025	0.0030	6.0x10^11
		III	>1760	074	0.08	0.055	-	0.05	0.03	0.0030	6.0x10^11

Table A12. Emission Standards for Criteria Pollutants for Diesel-Powered Vehicles

Vehicle Emission Standards for Diesel Engine Vehicles											
Stage	Veh. type	Level	Mass (kg)	CO (g/km)	HC	NMHC	HC+NOx	NOx	N20	PM	PN/km
China -III	1		All	0.64	-	-	0.56	0.50	-	0.050	-
	2	I	<1305	0.64	-	-	0.56	0.50	-	0.050	-
		II	1305 - 1760	0.80	-	-	0.72	0.65	-	0.07	-
		III	>1760	0.95	-	-	0.86	0.78	-	0.100	-
China-IV	1		All	0.50	-	-	0.30	0.25	-	0.025	-
	2	I	<1305	0.50	-	-	0.30	0.25	-	0.025	-
		II	1305 - 1760	0.63	-	-	0.39	0.33	-	0.04	-
		III	>1760	0.74	-	-	0.46	0.39	-	0.060	-
China-5	1		All	0.50	-	-	0.23	0.18	-	0.0045	6.0x10^11
	2	I	<1305	0.50	-	-	0.23	0.18	-	0.0045	6.0x10^11
		II	1305 - 1760	0.63	-	-	0.295	0.235	-	0.0045	6.0x10^11
		III	>1760	0.74	-	-	0.35	0.28	-	0.0045	6.0x10^11
China 6-a	1		All	0.7	0.1	0.068		0.06	0.02	0.0045	6.0x10^11
	2	I	<1305	0.7	0.1	0.068		0.06	0.02	0.0045	6.0x10^11
		II	1305 - 1760	0.88	0.13	0.09		0.075	0.025	0.0045	6.0x10^11
		III	>1760	1	0.16	0.108		0.082	0.03	0.0045	6.0x10^11

China 6-b	1		All	0.5	0.05	0.035		0.035	0.02	0.003	6.0x10^11
	2	I	<1305	0.5	0.05	0.035		0.035	0.02	0.003	6.0x10^11
		II	1305 - 1760	0.63	0.065	0.045		0.045	0.025	0.003	6.0x10^11
		III	>1760	0.74	0.08	0.055		0.05	0.03	0.003	6.0x10^11
Source: https://www.transportpolicy.net/standard/china-light-duty-emissions/											
Type 1 vehicles: M1 vehicles for no more than 6 passengers including driver, and GVWR ≤ 2.5 tons.											
Type 2 vehicles: Other light-duty vehicles (including N1 light commercial vehicles) further divided into three classes based on the reference mass.											

Table A13. Relation between criteria air pollutants from vehicle exhaust and greenhouse gasses and other radiative forcing agents

Although the radiative forcing concept is useful to understand the climate change impact potential of a pollution type, RF is not a direct metric of the impact of a unit amount of emissions, rather it represents the integrated impact of all such emissions.							
Source: IPCC TAR, Ch 6, Table 6.7							
Formula	Molecule/ Component	Precursor to:	RF Agent	GWP (TAR)		RF Agent	GWP (TAR)
CO	Carbon Monoxide	CO2, CH4, O3		1 to 3		CO2	1
HC	Hydrocarbons	CO2, CH4, O3		Use CH4 value		CH4	23
NOx	Nitrogen Oxides	Nitrate (NO3), CH4, O3		~5		O3	Troposphere (+ve) to stratosphere (-ve)
PM	Particulate Matter		Yes		as aerosol	NO3	
PN	Particulate Number		Yes, as PM		as aerosol	PM	Black carbon (+ve) and organic carbon (-ve)

Table A14. Maximum exhaust concentration for each criteria pollutant under each regulatory regime, spark ignition (gasoline) vehicles

		July '99	July '05	Sept '08	Dec '15	Jan '18	July '20	July '23
	Pollutant	China I	China -II	China -III	China-IV	China-5	China 6-a	China 6-b
(g/km)	CO	2.72	2.2	2.3	1.0	1.0	0.7	0.5
	HC	-	-	0.2	0.1	0.1	0.1	0.05
	NOx	-	-	0.15	0.08	0.06	0.06	0.035
	PM	-	-	-	-	0.0045	0.0045	0.003
#/km	PN	-	-	-	-	-	6.0x10^11	6.0x10^11

Table A15. Maximum exhaust concentration for each criteria pollutant under each regulatory regime, compression ignition (diesel) vehicles

		July '99	July '05	Sept '08	Dec '15	Jan '18	July '20	July '23

	Pollutant	China I	China -II	China -III	China-IV	China-5	China 6-a	China 6-b
(g/km)	CO	2.72	1.00	0.64	0.5	0.5	0.7	0.5
	HC	-	-	-	-	-	0.1	0.05
	HC+NOx	0.97	0.7	0.56	0.3	0.21	-	-
	NOx	-	-	0.5	0.25	0.18	0.06	0.035
	PM	-	-	0.05	0.025	0.0045	0.0045	0.003
#/km	PN	-	-	-	-	6.0x10^11	6.0x10^11	6.0x10^11

Table A16. Assumed exhaust concentration for each criteria pollutant under each regulatory regime.

Spark ignition (gasoline) vehicles			(g/km)			(#/km)
	Pollutant	CO	HC	NOx	PM	PN
Jul '99	China I	2.72	0.97	0.97	0.14	1.20E+12
Jul-'05	China -II	2.2	0.7	0.7	0.8	1.20E+12
Sep '08	China -III	2.3	0.2	0.15	0.05	1.20E+12
Dec '15	China-IV	1.0	0.1	0.08	0.025	1.20E+12
Jan '17	China-5	1.0	0.1	0.06	0.0045	1.20E+12
July '20	China 6-a	0.7	0.1	0.06	0.0045	600000000000
July '23	China 6-b	0.5	0.05	0.035	0.003	600000000000
Compression Ignition (Diesel Vehicles)						
	Pollutant	CO	HC	NOx	PM	PN
Jul '99	China I	2.72	0.97	0.97	0.14	1.20E+12
Jul-'05	China -II	1.00	0.7	0.7	0.8	1.20E+12
Sep '08	China -III	0.64	0.56	0.5	0.05	1.20E+12
Dec '15	China-IV	0.5	0.3	0.25	0.025	1.20E+12
Jan '18	China-5	0.5	0.21	0.18	0.0045	600000000000
July '20	China 6-a	0.7	0.1	0.06	0.0045	600000000000
July '23	China 6-b	0.5	0.05	0.035	0.003	600000000000

Table A17. Technical Standards for Motorcycles

Technical Standards for Motorcycles								
Year began	Engine Size	(g/km)				Driving Cycle	Cold Start	Durability
	(cc)	CO	HC	NOx	HC + NOx			(km)
Two-Wheeler with Two-Stroke Engine								
2003	<50 (moped)	6	–	–	3	ECE R47	No	6,000
	≥50	8	4	0.1	–	ECE R40	No	6,000
2004	≥50	5.5	1.2	0.3	–	ECE R40	No	10,000

2005	≥50 (moped) [s.b <50]	1	–	–	1.2	ECE R47	No	10,000
Two-Wheeler with Four-Stroke Engine								
2003	<50 (moped)	6	–	–	3	ECE R47	No	6,000
	≥50	13	3	0.3	–	ECE R40	No	6,000
2004	≥50	5.5	1.2	0.3	–	ECE R40	No	10,000
2005	<50 (moped)	1	–	–	1.2	ECE R47	No	10,000
2008	<50	1	–	–	1.2	ECE R47	Yes	10,000
	50-150	2	0.8	0.15	–	ECE R40	Yes	18,000
								30,000
	≥150	2	0.3	0.15	–	ECE R40 + EUDC	Yes	18,000
								30,000

Table A18. Assumed exhaust concentration for each criteria pollutant under each regulatory regime, motorcycles

Spark ignition (gasoline) motorcycles						
		Pollutant (g/km)				
Four-stroke engines only		CO	Total HC	NMHC	NOx	
2003	China I	13	4	--	0.3	
Jul-'05	China -II	5.5	1.2	--	0.3	
Sep '08	China -III	2	0.8	--	0.15	
2020	China-IV	1.1400	0.1700	--	0.0900	Euro 4
2025?	China-5	1.0000	0.1000	0.0680	0.0600	Euro 5

Table A19. Effect of change in Operating Speed on Emissions

Road type	Level of service (LOS)	CO2 emission factor in g/vkm			
		China 1	China 2	China 3	China 4
Expressway	Free flow	146	143	137	133
	Heavy traffic	151	148	141	138
	Saturated traffic	171	168	160	157
	Stop-and-go	226	222	212	207
	Heavy stop-and-go	389	381	364	356
Major Arterial	Free flow	175	171	164	160
	Heavy traffic	207	202	193	189
	Saturated traffic	242	237	226	221
	Stop-and-go	299	293	280	274
	Heavy stop-and-go	459	450	430	420
Minor Arterial	Free flow	194	191	182	178
	Heavy traffic	219	215	205	200

	Saturated traffic	276	271	259	253
	Stop-and-go	368	361	345	337
	Heavy stop-and-go	616	603	577	563
Branch	Free flow	170	167	159	156
	Heavy traffic	224	219	210	205
	Saturated traffic	270	265	253	247
	Stop-and-go	376	368	352	344
	Heavy stop-and-go	715	700	669	653

Table A20. POV Emission Standard Transition Matrix

	China-I	China-II	China-III	China-IV	China-5	China 6-a	China 6-b	Scrap
China-I	*R(NC)-x(III)-x(IV)-x(5)-x(6a)-x(6b)*	*(1-R(NC)-R(S))/6*	*(1-R(NC)-R(S))/6 + x(III)*	*(1-R(NC)-R(S))/6 + x(IV)*	*(1-R(NC)-R(S))/6 + x(5)*	*(1-R(NC)-R(S))/6 + x(6a)*	*(1-R(NC)-R(S))/6 + x(6b)*	*R(S)*
China-II		*R(NC)-x(III) -x(IV)-x(5)-x(6a)-x(6b)*	*(1-R(NC)-R(S))/5 + x(III)*	*(1-R(NC)-R(S))/5 + x(IV)*	*(1-R(NC)-R(S))/5 + x(5)*	*(1-R(NC)-R(S))/5 + x(6a)*	*(1-R(NC)-R(S))/5 + x(6b)*	*R(S)*
China-III			*R(NC)-x(IV)-x(5)-x(6a)-x(6b)*	*(1-R(NC)-R(S))/4 + x(IV)*	*(1-R(NC)-R(S))/4 + x(5)*	*(1-R(NC)-R(S))/4 + x(6a)*	*(1-R(NC)-R(S))/4 + x(6b)*	*R(S)*
China-IV				*R(NC)-x(5)-x(6a)-x(6b)*	*(1-R(NC)-R(S))/3 + x(5)*	*(1-R(NC)-R(S))/3 + x(6a)*	*(1-R(NC)-R(S))/3 + x(6b)*	*R(S)*
China-5					*R(NC)-x(6a)-x(6b)*	*(1-R(NC)-R(S))/2 + x(6a)*	*(1-R(NC)-R(S))/2 + x(6b)*	*R(S)*
China 6-a						*R(NC)- x(6b)*	*(1-R(NC)-R(S)) + x(6b)*	*R(S)*
Chian 6-b							*1-R(S)*	*R(S)*
Scrappage								*1*

Table A21. MC Emission Standard Transition Matrix

	China-I	China-II	China-III	China-IV	China-5	Scrap
China-I	*R(NC)-m(III)-m(IV)-m(5)*	*(1-R(NC)-R(S))/4*	*(1-R(NC)-R(S))/4*	*(1-R(NC)-R(S))/4*	*(1-R(NC)-R(S))/4*	*R(S)*
China-II		*R(NC)-m(III)-m(IV)-m(5)*	*(1-R(NC)-R(S))/3 + m(III)*	*(1-R(NC)-R(S))/3 + m(IV)*	*(1-R(NC)-R(S))/3 + m(5)*	*R(S)*
China-III			*R(NC)-m(IV)-m(5)*	*(1-R(NC)-R(S))/2 + m(IV)*	*(1-R(NC)-R(S))/2 + m(5)*	*R(S)*
China-IV				*R(NC)-m(5)*	*1-R(NC)-R(S) + m(5)*	*R(S)*
China-5					*1-R(S)*	*R(S)*

Scrappage						*1*