Simple Calculator of Project Effects for BRT (BRT SCOPE)

Documentation

Acknowledgements

Lead Author:

Madeline Liberman, Associate for Monitoring and Evaluation, ITDP Global
Correspondence: madeline.liberman@itdp.org

Supporting Authors:

Saba Akber, Monitoring and Evaluations Intern (former), ITDP Global
D. Taylor Reich, Data Science Manager, ITDP Global
Alyssa Wiegers, Research Intern (former), ITDP Global

Reviewers:

Claire Birungi, ITDP Africa
Manuel Blanco, ITDP Global
Leonardo Canon Rubiano, World Bank
Alfisahr Ferdian, ITDP Indonesia
Jake Fritz, Felsburg Holt & Ullevig
Brian Garcia, Soka University
Karen Graham, Build Consulting / ITDP HQ
Deng Han, ITDP China
Walter Hook, BRT Planning International, LLC
Ki-Joon Kim, ITDP China
Jacob Mason, ITDP Global
Aditya Rane, ITDP India
Rhys Rea-Tucker, Capital Metro (Austin, TX)
Beatriz Rodrigues, ITDP Brazil
Vaishali Singh, ITDP India
Leonardo Veiga, ITDP Brazil

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1. Introduction to SCOPE

This documentation describes the bus rapid transit (BRT) module of the ITDP Simple Calculators of Project Effects (The SCOPE Tools), formerly known as the Transport Emission Evaluation Models for Projects (TEEMP). These tools offer preliminary evaluations of climate and air quality impacts of sustainable transportation infrastructure or policies. They are meant to be simple to use, with little required data and high-quality default inputs.

The SCOPE tools are meant for two audiences. First, the tools can assist organizations that fund the implementation of urban transport projects, by helping estimate the carbon mitigation impacts of potential projects. Second, the tools may also be used in transportation planning at the local, provincial, or national level, whether by mayors, transportation planners, or advocates, in order to understand the carbon mitigation and air pollution reduction impacts of such interventions.

The SCOPE tools can be used both when a project is in the concept stage, relying on default assumptions to provide a first-order estimate of impact, and after a project has been implemented, replacing those assumptions with observed data for a more precise estimation. However, the tools are most useful at preliminary phases in a project's development, before details of implementation have been finalized, to compare between alternatives at the high level. For example, these models can be used to compare between a BRT line and a highway, or between two different BRT lines in different parts of the city. Once a project has progressed from the planning to the design phase, such as by choosing the station locations and route alignment, more detailed models may be necessary.

The BRT module of the SCOPE tools enables users to estimate the impacts that a bus rapid transit system might have on greenhouse gas (GHG) and other air pollutant emissions. It estimates the emissions reduced by a BRT through the year 2050. The tool uses simplified predictions of ridership and modal shift; it is based on data from past case studies and recent literature. The results are meant to prioritize accuracy rather than precision – that is, to give a correct approximation of the actual impact on emissions, rather than an estimate that is specific but incorrect. It is not meant to be a substitute for a geospatial four-step ridership model; rather, it is meant to be used when a four-step model is not feasible.

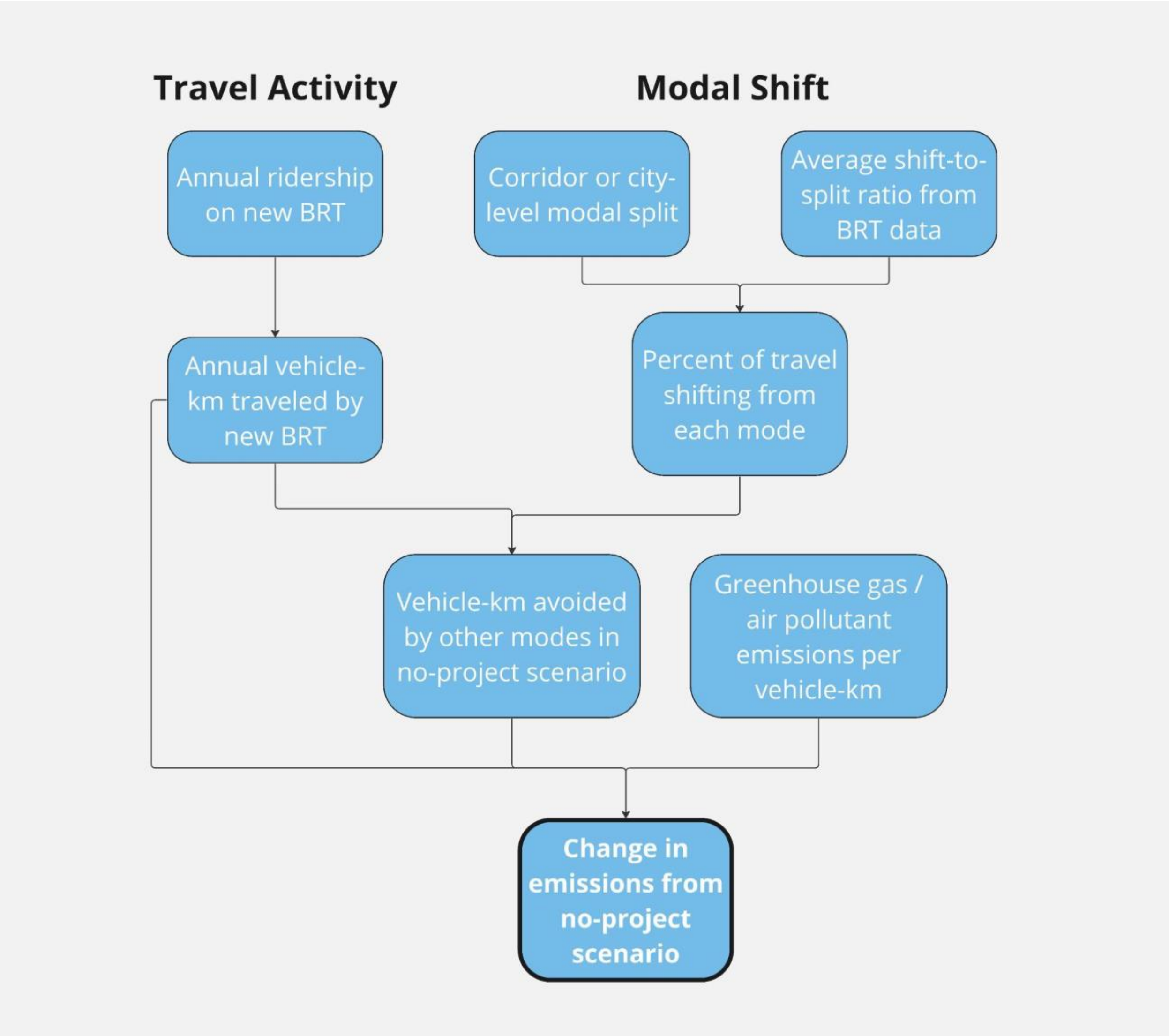
2. Summary of Methodology

The BRT SCOPE tool has three main methodological steps. First, the model predicts travel activity on a future BRT project based on user inputs. Second, the model predicts the amount of travel activity avoided from other modes of transport due to BRT riders shifting away from another mode. Finally, the model calculates the emissions avoided from that travel activity, as well as the emissions generated by the new BRT project, reporting the total in terms of annual greenhouse gas and air pollutant emissions avoided. In other words, the model calculates the difference between the emissions generated in a “no-build” scenario and the emissions generated by the new project.

For more details about each of these steps, see the following sections:

1. Ridership Predictions
2. Modal Shift Predictions
3. All Emissions Calculations

Flow Chart of SCOPE Tool Logic



3. Using the BRT SCOPE Tool

The BRT SCOPE tool is an Excel spreadsheet that can be used to calculate the emissions reduced in any of three different scenarios: adding a new BRT line, extending a BRT line, or upgrading an existing BRT line. Broadly, the tool calculates a reduction in emissions by estimating how many riders of the future BRT line will have shifted from other, higher-polluting modes of transport.

The tool is color-coded as follows:

Required user input	Optional user input; default values are given	Input value is invalid	Calculations/ supporting data; do not edit	**Outputs**

This color coding applies both to the spreadsheet tabs as well as cells within each tab. Across the entire spreadsheet, only tabs with yellow or blue labels have cells that can be edited. Tabs with gray labels are view-only, and display the model's calculations. Within a tab, only yellow or blue boxes may be edited.

For every default input, the user may input custom factors based on city- or project-level data. This is encouraged, as it will improve the precision of the results. If the user provides a custom factor in a blue cell, it will override the default value. Some default factors are shown within the 'Main Inputs' tab, but most are provided in supporting data tabs. Many of these defaults can be overridden in the 'Custom Factors' tab.

To predict the impacts of a new or upgraded BRT corridor, first read the 'Introduction' tab for important instructions, then complete the 'Main Inputs' tab from top to bottom.

The purpose of each tab is described below. Click on the tab name to view more information.

Section	**Tab name**	**Purpose of tab**
User Inputs	Main Inputs	Entry of required user data. This tab must be filled out top-to-bottom to predict the impacts of a BRT corridor. This tab also provides key performance indicators of the future BRT.

	Custom Factors	Entry of additional custom factors to override default inputs. The custom factors can improve the results by adding geographic specificity, as the model defaults are at the region or country level, and cities may vary widely within a country based on factors that are outside of the model's scope.
Results	Results	Complete set of outputs, including GHG and other air pollutant emissions avoided by adding BRT.
Calculations	Ridership Predictions	Uses the model in 'Ridership Model' to calculate predicted BRT ridership in each year in the future based on user inputs, and converts to vehicle-kilometers that would have been traveled by other modes in the absence of the BRT.
	All Emissions Calculations	Calculates the estimated change in emissions from all pollutants, using custom or default emissions factors from the Emissions Factor tabs.
	Custom Emissions Calculations	Calculates the estimated change in emissions from all pollutants, using the custom emissions factors provided.
	Ridership Model	Includes data on various BRT lines evaluated by ITDP around the world, and uses this data to create two multivariate regressions to predict ridership.
	Modal Shift Predictions	Calculates the predicted default shift from other modes to BRT, based on the test city's existing modal split and on modal shift data from past BRT impact evaluations.
Supporting Data	CO_2 Emissions Factors - default	Includes default emissions factors for CO_2 for each mode.
	CO Emissions Factors - default	Includes default emissions factors for CO for each mode.
	NO_x Emissions Factors - default	Includes default emissions factors for NO_x for each mode.

	PM2.5 Emissions Factors - default	Includes default emissions factors for PM2.5 for each mode.
	Level1 Custom Emissions Factors	Includes emissions factors for each vehicle type, fuel type, and emissions standard from the European Environment Agency for user's custom fleet breakdown.
	Non-tailpipe Emissions Factors	Includes emissions factors for road abrasion, tire wear, and brake wear from the European Environment Agency and the National Atmospheric Emissions Inventory.
	Electricity Grid Factors	Includes default electricity grid emissions factors by region.
	Modal Split	Includes default data on modal split in by world region and year. If a current, custom modal split is entered for the test city, this tab also projects the modal split for future years.
	Occupancy Factors	Includes default occupancy factors for each vehicle type.
	Trip Length	Includes default trip lengths for each mode.
	Population Growth Rates	Includes default data on urban population growth by country and year.
	Country Mapping	Lists countries of the world and the region that they are associated with in *The Compact City Scenario - Electrified* (ITDP and UC Davis, 2021).

3.1. Light Rail and Metro Systems

The BRT SCOPE may also be used to roughly estimate the impacts of adding a new metro or light rail system. However, there are several limitations of the tool when used in this way:

- The default modal shift predictions are based on data from BRTs and have not been calibrated for light rail or metro systems.
- The default ridership demand models are based on data from BRTs and have not been calibrated for light rail or metro systems.

- Ridership Option 2 requires the BRT Standard Score as an input, which is not relevant to metro or most light rail systems.
- When entering the fleet size, the model assumes that the unit of the fleet is a single bus, while the unit of a metro fleet is a higher-occupancy train.
- The default electricity intensity is based on data from BRTs and has not been calibrated for light rail or metro systems.

Users should therefore apply the following settings to the tool:

1. In the Main Inputs tab, enter the number of trains in the fleet. Ignore any warnings about a high occupancy rate.
2. In the Main Inputs tab, choose one of the custom emissions factors options.
3. If possible, custom-enter the future demand of the system using Ridership Option 3. If this data is not available, then Option 1 should be used, and **not** Option 2.
4. If possible, custom-enter the modal shift in the Custom Factors tab, based on data from similar metro projects.
5. Custom-enter your fleet breakdown or emissions factors directly in the Custom Factors tab. Custom-enter the electricity intensity of the BRT to a value that is appropriate for metro systems.

However, the model has not been tested on light rail or metro systems and the results may be less accurate.

4. User Inputs

4.1. Main Inputs

The 'Main Inputs' tab provides all necessary information for the user, including all the required user inputs and summaries of the key outputs. It is not necessary to view any of the other tabs, although interested users may do so.

4.1.1. City Characteristics

Summary of Key Inputs and Default Values

Sheet cells	Input Description	Default data and assumptions/limitations
H11	**Country Name**	The country name is The world regions are defined in 'Country Mapping', and come from *The Compact City Scenario - Electrified* report (ITDP and UC Davis, 2021).
E18:E2	**Annual Population**	UN World Urbanization Prospects (United Nations,

0	**Growth Rate**	2018) Assumes that the growth rate of all cities in the country is the same.
H18	**Working Days in a Year** The default value is 260.	EspoCRM Working Time calculator (EspoCRM, 2022) Assumes that no trips are taken on weekends, likely resulting in a conservative estimation.
E29:E44	**Modal Split of Passenger-KM Traveled in City in Start Year**	All regions except Africa from *The Compact City Scenario - Electrified* report (ITDP and UC Davis, 2021). Modal splits for North, Sub-Saharan, and South Africa from the *Compact Cities Electrified: Africa* data (unpublished, 2024). The defaults assume the same modal split for all cities within a region. The default modal split for cities in the Other EUR/Asia and Other Americas categories may be less accurate than other regions, as these regions contain more disparate and dissimilar countries than the other regional groupings.

4.1.2. BRT Characteristics

Enter information about the future BRT project and the current BRT (if upgrading). The tool can be used for a BRT upgrade that leads to a change in the frequency, powertrain, and/or fuel source of the fleet. Because this is a project-level model, the model will only calculate the emissions impacts of the section of BRT that is added or upgraded. The model may be used to estimate the impacts of a future or past project (no earlier than 2020, due to data availability).

4.1.3. Ridership Inputs

The SCOPE tool uses information on future BRT demand to predict the number of trips by high-polluting modes that are avoided when a BRT line is added or improved. The BRT model provides 3 options for predicting ridership on a future BRT line, based on the data that the user has available. Option 1 requires the least input data, and can be used even when only minimal context is available, at the very earliest stages of planning. Option 2 requires data describing current public transport ridership on the corridor where the BRT is proposed. Finally, Option 3 can be used in *ex-post* cases in which the BRT is built and ridership can actually be measured, or in cases where a more detailed model has provided ridership estimates. If the project will upgrade a BRT, only options 1 and 3 are available.

In these options, "current corridor ridership" refers to the current ridership of local bus, minibus, and BRT lines (if applicable) *on the section of the corridor(s) where the project will be implemented.* The model assumes that the future BRT will replace any existing local bus or minibus routes. Currently, the model does not include feeder buses or feeder bus ridership.

The user must fill in only ONE option.

4.1.3.a. Option 1: I have no data on current corridor ridership or future BRT ridership

The user enters data on the average population density surrounding the BRT corridor. This is used with the frequency inputs from the BRT Characteristics section to calculate the People Near Transit (PNT) and predict the future corridor ridership, based on the relationship between the PNT, frequency, and average weekday ridership that we establish from data on existing BRT lines (see Ridership Model).

Summary of Key Inputs and Default Values

Sheet cells	Input description	Default data and assumptions/limitations
F136:F138	**Average population density within 1 km radius of BRT stations**	The default value for all years is the 2020 country-level weighted urban population density from the Compact Electrified data. Assumes that 1 km circular buffer is approximately the same area as an 800-meter isochrone walkshed (e.g., the walkable area).

4.1.3.b. Option 2: I have data on current corridor ridership, but not future BRT ridership

The user enters the current corridor ridership (broken down by local bus, minibus, and BRT where applicable) based on an independent calculation (ideally, using boarding and alighting or frequency and occupancy surveys). This is used to predict the change in corridor ridership per kilometer in the future BRT scenario, based on the relationship between the BRT score and change in corridor ridership per kilometer established from data on existing BRT lines (see Ridership Model). **If the user has the data for Option 2, it is recommended over Option 1** (see Ridership Model for more information).

The BRT Score is an evaluation of the quality of a BRT corridor, on a scale of 0 to 100 points, based on ITDP's BRT Standard. Estimate the future BRT score to the best of your ability. If you do not have enough information to fill out the entire BRT Standard Scorecard, you may enter just the ranking (Basic, Bronze, Silver, or Gold). This will automatically be converted to the median value of the BRT Standard scores that fall into each ranking category. The conversion of scores to rankings is as follows:

20-54.9 points: Basic (median = 37.5)
55-69.9 points: Bronze (median = 62.5)
70-84.9 points: Silver (median = 77.5)
85-100 points: Gold (median = 92.5)

4.1.3.c. Option 3: I have data on current corridor ridership and future BRT ridership

In this scenario, the user enters the current corridor ridership (broken down by local bus, minibus, and BRT where applicable) and the future BRT ridership, both based on independent calculations (for current ridership, ideally using boarding and alighting or frequency and occupancy surveys).

For future average weekday BRT ridership, estimate the average number of unique weekday trips on the post-project BRT corridor, when it is first implemented (as soon as the ridership has stabilized) and in 2030 and 2050. Include population growth.

4.2. Custom Factors

In this tab, users can enter more precise, customized information to replace the model defaults. The custom factors can improve the results by adding geographic specificity, as the model defaults are at the region or country level, and cities may vary widely within a country based on factors that are outside of the model's purview. Users can enter custom data for the following model inputs. Addition of each custom factor is independent, so users may choose to enter custom data for any one or more of these factors without entering data for the others.

4.2.1. Custom percent of BRT users shifting from mode in test city

If a user already knows the shift from other modes to BRT (from a separate calculation or if using the model *ex-post*), they may enter a custom modal shift directly, overriding the default calculation based on the modal split. These values will be applied directly to the predicted ridership to estimate the travel activity by private motorized modes that will be avoided by shifting to BRT.

4.2.2. Custom modal split on project corridor over time

The custom modal split on the project corridor is used to improve estimates of the modal shift to BRT. See the Modal Shift Predictions section for more information.

4.2.3. Custom Trip Length along corridor (km/trip)

The custom trip length is used to convert the change in trips on each mode to the change in passenger-kilometers traveled on each mode in the Ridership Predictions tab. See "Trip Length" for more information.

4.2.4. Split of Vehicle Powertrains/Fuel Types

For the first custom emissions factors option, the user enters the breakdown of the citywide vehicle fleet using each powertrain/fuel type in 2020, 2030, and 2050.

4.2.5. ICE Fleet Split of Fuel Standards

The breakdown of all ICE vehicles by the fuel standard that they use, in 2020, 2030, and 2050. This is multiplied by the split of vehicle fuel types in the Custom Emissions Calculations tab, giving a percentage of the total fleet of each vehicle that uses each fuel type and emissions standard.

4.2.6. Custom CO2eq/CO/NOx/PM2.5 Emissions Factors

An option to enter entirely customized emissions factors in grams per VKT. This allows users to include their own estimates of emissions per fuel type/emissions standard, and/or to enter emissions based on a non-Euro fuel standard.

4.2.7. Custom Electricity Grid Factors

Users may enter a custom emissions intensity per unit of electricity generated, if the local electricity grid in the project location is significantly different from the default. This is not required for the custom emissions factor calculation.

4.2.8. Custom EV Energy Intensity

The energy intensity is required for the custom emissions factor calculation in order to convert to emissions per kilometer driven by a vehicle.

5. Results

The predicted change in emissions in each year is reported from the 'Ridership and Emissions Predictions' tab with two significant figures, which is the assumed maximum precision of the input measurements. The emissions are also reported cumulatively as the total emitted up to each year.

6. Calculations

6.1. Ridership Predictions

This tab uses the ridership inputs from the 'Main Inputs' tab to calculate ridership on the future BRT line. The future ridership is then broken down by the modes that BRT riders used previously.

Summary of Key Calculations and Assumptions

Sheet rows/cells	Calculation Description	Assumptions/limitations
15, 30	**People Near Transit** For ridership option 1, roughly calculates the number of people within 1km of the BRT line, based on the population densities entered in the Introduction tab.	It is assumed that the area that can be accessed by walking within a 1km radius of each stop (also known as the walkshed) is approximately 800m. It is also assumed that BRT stops are less than 800m away from each other. The calculation of the area near the BRT line simplifies its shape to a rectangle with two semi-circles on either end. 
24, 33	**Option 1 ridership calculation** To estimate the future ridership through 2050 without any ridership data, the average population density near the BRT stops in each year is multiplied by the total area within 800m of the BRT (see above). This value (the number of people near transit, or PNT) is entered into a linear regression equation, along with the	In rows 20 and 32, the ridership is reduced in the first two years, assuming that demand increases linearly for the first two years and stabilizes by the third year. See "Ridership Model" for the Option 1 Model assumptions.

	frequency, to predict the average weekday ridership along the corridor (see “Ridership Model”). Finally, the ridership in each year is multiplied by the percentage of population growth and the number of working days in a year.	
41	**Option 2 ridership calculation** To estimate the future ridership through 2050 with a value for the current corridor ridership, the BRT score and current ridership are entered into a regression equation to predict the annual change in ridership along the corridor pre- and post-BRT (see “Ridership Model”). This change in ridership is then added to the current ridership for the first three years that the BRT is open. Finally, the ridership in each year is multiplied by the percentage of population growth and the number of working days in a year.	The ridership is predicted to increase linearly for the first two years only and stabilize by the third year. See “Ridership Model” for the Option 2 Model assumptions.
48	**Option 3 custom ridership projection** In this scenario, the user’s predicted future BRT ridership in 2030 and 2050 is interpolated to find the ridership in each year, then multiplied by the number of working days in a year.	The user’s independently-calculated ridership predictions are assumed to include population growth. It is assumed that ridership will change linearly between each data point for 2020, 2030, and 2050.
85:188	**Change in passenger trips per year by mode in future BRT scenario** The predicted total ridership of the future BRT is multiplied by the predicted percentage of riders shifting from other modes to calculate the trips by other modes avoided in the future BRT scenario (the default mode shift values are calculated within the ‘Modal Shift’ tab).	See “Modal Shift Predictions”
190:214	**Change in PKT per year by mode in future BRT scenario**	See “Trip Length”

	The number of trips for each mode is multiplied by the mode-specific average trip length to calculate the passenger-kilometers that would have been traveled by each mode in the absence of the BRT.	
216:235	**Change in VKT per year by mode in future BRT scenario** The PKT for each mode is divided by the average occupancy rate of that mode to calculate the vehicle-kilometers that would have been traveled by each mode in the absence of the BRT.	See “Occupancy Factors”

6.2. All Emissions Calculations

This tab calculates the change in emissions due to the change in travel activity estimated in the previous tab. The VKT avoided from each mode due to shifting to the BRT is multiplied by the default emissions per VKT of that mode and converted to tonnes to calculate the total tonnes of CO_2, CO, NO_x, and PM2.5 avoided. The emissions produced by the BRT are added to the reduction in emissions due to VKT avoided from other modes to calculate the total change in emissions from the no-build scenario. Non-tailpipe air pollutant emissions are estimated based on data from the European Environmental Agency (see “Non-tailpipe Emissions Factors”).

This tab also reports the change in emissions using custom emissions factors, based on other back-end calculations in the Custom Emissions Calculations tab.

6.3. Custom Emissions Calculations

This tab calculates emissions from the estimated change in travel activity on the corridor using custom emissions factors. Some rows are hidden for ease of navigation.

In the first section, emissions are calculated based on the Level 1 Custom Emissions Factors. The user-provided fleet breakdown of vehicle fuel types and emissions standards is interpolated to each year between the start of the project and 2050. To obtain the emissions from ICE vehicles, the shares of each fuel type and of each emissions standard are multiplied to obtain the percentage of each ICE vehicle fleet that has a particular emissions standard. Next, these percentages are multiplied by the total estimated travel activity from that fleet to obtain the total change in emissions from the no-project scenario. We assume that the share of a vehicle/fuel type in the fleet is proportional to the share of travel activity in the city that comes from that vehicle/fuel type.

In the second section, emissions are calculated based on the Level 2 Custom Emissions Factors. The user-provided emissions factors for each vehicle category are simply multiplied by the travel activity for that category.

6.4. Modal Shift Predictions

This tab calculates the predicted default shift from other modes to BRT, based on the test city's existing modal split and on modal shift data from past BRT impact evaluations.

Rows	Calculation Description	Assumptions and Limitations
3:14	**Percent of BRT riders shifting from mode in BRT case studies** Reported modal shift percentages from BRT impact evaluations in 11 cities across the world.	Data is limited, as modal shift percentages could only be obtained for a small number of cities. If users are aware of additional modal shift data for BRTs, please reach out to madeline.liberman@itdp.org.
17:28	**Modal Split in Case Study Cities Before BRT** The percent of passenger-kilometers traveled by each mode in the BRT case study cities, before the case study BRT was added.	Assumptions for specific data points can be found in the Notes column of the table.
30:58	**Modal Shift Divided by Modal Split (proportion of riders of each mode who switched to BRT)** Each modal shift percentage is divided by the initial modal share, in order to normalize the case study modal shift values based on each mode's prevalence in the city. These values are then normalized by the sum for each city, so that the cities are comparable. The average is taken; this average ratio of the modal shift to modal split in BRT case studies will be used to predict modal shift.	Assumes that the ratio of modal shift to modal split is constant across cities and over time.
60:97	**Ridership Option 1: Default percent of BRT users**	It is assumed that EV

	shifting from mode in test city If Ridership Option 1 is selected, the share of each mode in each year in the new BRT city is multiplied by the average ratio of modal shift to modal split calculated in the previous section.	versions of each mode will have the same mode shift as ICE versions. E-bicycles are also assumed to have the same ratio of modal shift to modal split as pedal bicycles.
99:104	**Ridership Option 2 and 3: Default percent of BRT users shifting from mode other than bus in test region** The same methodology from the previous sections is used for all modes except the current large (non-BRT) bus, minibus, and BRT (if applicable) on the corridor, as the shift from these modes to BRT is obtained from the current ridership. The modal shift values for all modes except large (non-BRT) buses and BRTs are normalized to equal the percentage of BRT riders who shifted from the local bus, so that the modal shift percentages add up to 100% for each year.	The modal shift from large bus and minibus to BRT is assumed to be equal to the ratio of the current ridership of those modes to total BRT ridership. The tool assumes that all current large bus or minibus riders on the corridor will shift to the new BRT; however, this may be an overestimate, as some of these riders may not choose to use the new BRT due to changes in service. If there is existing BRT service on the corridor, the tool assumes that none of these riders will shift to the new BRT. However, this can be adjusted in the Custom Factors tab.

6.5. Ridership Model

This tab includes data on various BRT lines evaluated by ITDP around the world, and uses this data to create a model of BRT ridership that can make ridership predictions based on the user's available ridership data. Two models are included: one for ridership option 1 (where the user inputs population density around the BRT), with a sample size of 19, and one for ridership option 2 (where the user enters the current corridor ridership and the BRT Score), with a sample size of 8.

For Option 1, the average weekday ridership of the BRT line is the dependent variable, and People Near Transit and peak frequency are the independent variables. These variables were chosen by reviewing literature on BRT ridership regression models. Islam et. al (2018) and Umlauf et. al (2016) emphasize the impact of external, geographic factors, such as population density, on BRT ridership. Therefore, the People Near Transit (PNT) variable was chosen as the independent variable. This value is equal to the average population density within 800 meters (assumed to be the maximum convenient distance to the BRT) of the BRT stations, multiplied by the total area within 800 meters of those stations. The PNT variable was found to have a high positive correlation with total average weekday ridership (0.72). We also chose peak frequency as an independent variable. Frequency is one of the common predictors of ridership changes in a traditional four-step model (National Academies of Sciences, Engineering, and Medicine 2007), and it was found to have a high correlation of 0.83 with total average weekday ridership.

To obtain the data for PNT, 800-meter buffers were created around the stations of 19 BRT lines across the world. The average population density within the dissolved buffers was calculated in Python using the 2020 Global Human Settlement Layer, and then multiplied by the area of each buffer. The data on average weekday ridership was obtained from BRT impact evaluations, when available (see the Sources column), or from the Global BRT Dataset. All peak frequency data was obtained from the Global BRT dataset.

A multiple linear regression was performed in Python using the OLS function in the statsmodels package, version 0.14.1. No constant was calculated, as it is assumed that if the PNT and frequency are equal to 0, ridership would also equal 0. The adjusted R^2 was 0.836, meaning that the model has a high degree of explanatory power. Both variables had p-values of less than 0.05.

Option 1 Ridership Model Results

Regression Statistics

R-squared	0.86
Adjusted R-squared	0.84
Observations	19

	Coefficient	**Standard Error**	**P-value**
People Near Transit	0.24	0.09	0.020
Frequency	1567.69	377.30	0.001

For Option 2, the dependent variable is the change in average weekday ridership between the large bus, pre-BRT, and the BRT line, per kilometer. The independent variables are the BRT Score (in points) and the current weekday ridership on the corridor. These variables were chosen based on the assumption that the previous corridor ridership provides a general estimate of the base ridership of the future BRT, and that the rest of the BRT ridership estimate can be calculated by accounting for the BRT service quality. Ko et. al (2019) found in a global study of BRT lines that measurements of internal service characteristics, such as the presence of integrated fare collection and real-time information systems, were significantly associated with ridership of the BRT. Such service characteristics are accounted for in the BRT Score; therefore, the BRT Score may offer a simplified metric for measuring BRT quality without the need for multiple, detailed inputs about the quality of the future BRT. This is supported by our data. Among the 8 BRT corridors for which data on the change in ridership was available, there was a correlation of 0.44 between the total BRT score and the average weekday ridership per kilometer of the BRT. There was an extremely high correlation between the pre-BRT and BRT corridor ridership per kilometer (0.98).

The BRT scores for each BRT line were obtained from ITDP's published BRT Rankings (ITDP, 2024). The data on pre-BRT corridor ridership and change in average weekday ridership come from impact evaluations of these BRT lines, which reported either the corridor ridership before and after the BRT line was added, or the percent change in ridership. The change in ridership was normalized by the length of each BRT line. Because few BRTs have been studied in such in-depth evaluations, the sample size of this regression was more limited than the regression for Option 1.[1]

The second linear regression had an adjusted R^2 value of 0.81; while it is slightly lower than the R^2 value of the Option 1 regression, this may be due to the reduced sample size of the Option 2 regression. Like the first regression, the correlations were positive, meaning that as the BRT score and the pre-project corridor ridership increase, the change in average weekday ridership when a BRT is added also grows.

Option 2 Ridership Model Results

Regression Statistics

R-squared	0.86
Adjusted R-squared	0.81
Observations	8

	Coefficient	**Standard Error**	**P-value**

[1] If users are aware of additional data on the change in ridership on corridors that have replaced local buses with BRT, please reach out to madeline.liberman@itdp.org.

Constant	-1475.03	688.44	0.076
Average Weekday Bus Ridership Before BRT (per km)	0.054	0.014	0.008
BRT Score	26.99	10.31	0.040

The equations produced by each regression are used in the Ridership and Emissions Predictions tab to predict the future ridership on test BRT lines.

Despite having less data and a lower adjusted R-squared, the Option 2 model was found to make more precise predictions. **This model is therefore recommended over the Option 1 model.**

7. Supporting Data

7.1. Default Emissions Factors

Default CO_2 emissions factors per VKT (including vehicle manufacture, infrastructure construction and maintenance, and tailpipe emissions) can be found in the tab labeled "CO_2 Emissions Factors - default" and are sourced from *The Compact City Scenario: Electrified* (ITDP, 2021). These factors rely on each world region's predicted vehicle fleet compositions from the International Energy Agency (IEA) Mobility Model, using their more conservative Stated Policy Scenario (STEPS) (IEA, 2021). The 2021 *Compact Electrified* report does not include separate emissions factors for ICE and electric BRT; to obtain these factors for all regions, we calculated the ratio of BRT to standard bus emissions in ITDP's *Compact Cities Electrified: India* roadmap (Fulton and Reich, 2023). This ratio was 1.342 for ICE powertrains and approximately equal for EVs. The *Compact Electrified* GHG emissions factors also do not include hybrid powertrains for BRT. We therefore used the European Environment Agency's (EEA) emissions factor for large hybrid diesel buses (European Environment Agency 2023).

Default emissions factors for other air pollutants can be found in the tabs labeled "[pollutant] Emissions Factors - default" and are sourced from the International Council on Clean Transportation (ICCT) Roadmap model, version 2.2 (The ICCT, 2023). The ICCT's air pollutant emissions factors also account for the predicted fleet composition in different world regions. However, they only include vehicle tailpipe emissions, therefore excluding emissions from brake, tire, and road wear. We therefore added in non-tailpipe PM2.5 emissions factors, sourced from EEA (see "Non-Tailpipe Emissions Factors"). The default hybrid BRT emissions factors for air pollutants are also obtained from EEA.

7.2. Level1 Custom Emissions Factors

This tab includes emissions factors for different Euro fuel standards, for use in the Level 1 custom emissions calculations. It includes Tier 2 emissions factors per VKT for each vehicle type, ICE fuel type, and emissions standard, obtained from the European Environment Agency (Ntziachristos and Samaras, 2023). The Tier 2 emissions factors are not differentiated by vehicle speed.

CO_2-equivalent emissions factors were derived by multiplying a vehicle's reported fuel consumption by its emissions factor in grams CO_2-e per gram of fuel. Some combinations of vehicle types, fuel types, and fuel standards may not have emissions factors, depending on the age of the technology.

For passenger cars, we used emissions factors for the medium size class. For ⅔-wheelers, we used 4-stroke <250cc vehicles to represent the vehicle class for CO_2 emissions. This category was not available for other air pollutants, so the 4-stroke motorcycle category was used. These emissions factors may not be accurate if a city's 2- and 3-wheelers are not of those vehicle types.

7.3. Non-tailpipe Emissions Factors

The tab includes PM2.5 emissions factors from non-tailpipe sources, including brake and tire wear and road abrasion. The dataset used comes from the European Environment Agency (2023). All emissions factors are for urban driving (assuming a speed of <40kph). For minibuses, the "Light Goods Vehicle (LGV)" factors from NAEI were used. For 2/3-wheelers, the "motorcycle (>50 cc 4st)" factors were used. For passenger cars, "medium" size was used. The emissions factors do not account for road dust resuspension.

7.4. Electricity Grid Factors

CO_2e emissions factors for electricity generation by region are included from the 2022 IEA Mobility Model. We do not include estimates of air pollutants emitted from electricity generation (such as coal-powered electricity plants), as we assume that electricity is generated outside of the test city and therefore does not significantly impact local air quality.

7.5. Modal Split

The default modal split is the default percentage of passenger-km traveled by each mode. The modal split is derived from the estimated travel activity in each region, but we assume that it can be applied to the city level as well. The default modal split is assumed to be the same across all cities in the region. These defaults are from the 2021 *Compact Electrified* data for all regions except Africa. Data for subregions of Africa (North, Sub-Saharan, and South) were obtained from ITDP's *Compact Cities Electrified: Africa* report (unpublished, 2024).

We assume by default that the modal share of BRT in the city is 0%. However, this should be changed if the city already has a BRT system in place.

7.6. Occupancy Factors

Default occupancy factors for all modes except BRT are derived from reported passenger- and vehicle-km traveled in *The Compact City Scenario: Electrified* (2021). For BRT, the default occupancy factor is calculated based on the user's inputs for fleet size and speed (assuming that the BRT runs for 16 hours per day) and the predicted or input daily ridership. The occupancy factors for 2- and 3-wheelers have been averaged.

7.7. Trip Length

The average trip lengths for all modes except walking are equal to 70% of the total corridor length by default. This value is obtained from survey results from ITDP's 2013 impact evaluation of the TransOeste corridor; the average BRT trip on this corridor is equal to 71% of the corridor length (Hughes and Leshner, 2013). Rogat et. al's 2015 study of the Ahmedabad BRT similarly provides an average trip length that is equal to 70% of the corridor length. It is assumed that trips shifting from other modes to BRT will be approximately the same length, except for walking trips, which are assumed to be 50% of the corridor length. However, trip lengths may vary drastically across cities, and we encourage users to enter custom trip lengths if available.

The default trip length for taxis and ride-hail cars includes a "deadheading" factor. As stated in the Compact Electrified Technical Annex, deadheading refers to "the empty vehicle travel in shared vehicles necessary to provide passenger transport services" (Fulton et. al, 2021). Trip lengths for taxis and ride-hail cars are increased by 38.5%, based on research from the California Area Research Board. This default is provided in the "Trip Length" tab of the tool, but it can be overridden in the Custom Factors tab.

We assume that trip lengths will stay roughly the same over time given the same length of BRT infrastructure in the no-build scenario, as the city would be likely to sprawl on the outskirts, not changing the existing built fabric.

7.8. Population Growth Rates

Default urban population growth rates are from the United Nations Population Division (2018). These rates are country-level; they are assumed to be the same for all cities in a country.

7.9. Population Density

This tab reports the 2020 weighted average urban population density at the country level, which is drawn from the Compact Electrified country-level dataset. Not all countries have available data.

Default population densities for 2030 and 2050 will be added when available from ITDP's Atlas of Urban Transportation.

8. References

EspoCRM. "How many work days in a year? (2023) Updated." *EspoCRM* 2022. https://www.espocrm.com/blog/how-many-work-days-in-a-year/.

Ntziachristos, L, and Boulter, P. *EMEP/EEA air pollutant emission inventory guidebook 2023*: *1.A.3.b.vi-vii Road transport 2023*. *European Environment Agency* 2023. https://www.eea.europa.eu/publications/emep-eea-guidebook-2023/part-b-sectoral-guidance-chapters/1-energy/1-a-combustion/1-a-3-b-vi/view.

Ntziachristos, L, and Samaras, Z. *EMEP/EEA air pollutant emission inventory guidebook 2023*: *1.A.3.b.i-iv Road transport 2023*. *European Environment Agency* 2023. https://efdb.apps.eea.europa.eu/?source=%7B%22query%22%3A%7B%22bool%22%3A%7B%22must%22%3A%5B%7B%22term%22%3A%7B%22code%22%3A%221.A.3.b.i%20Road%20transport%2C%20passenger%20cars%22%7D%7D%5D%7D%7D%2C%22display_type%22%3A%22tabular%22%7D.

Fulton, L., Ahmad, M.., and Reich, T. "Compact City Scenario: Electrified: High Shift Model and Scenario Documentation Report." *UC Davis / ITDP* 2021. https://docs.google.com/document/d/1NPqRGjb_llW60ayKYit4HC-W9gxK1zGu/edit.

Fulton, L., and Reich, T. "Compact Cities Electrified: India." *UC Davis / ITDP* 2023. https://www.itdp.org/publication/compact-cities-electrified-india-roadmap/.

Hughes, C., and Leshner, E. "Impact Analysis of Transoeste Bus Rapid Transit System in Rio de Janeiro." *ITDP Brazil* 2013. https://itdpdotorg.wpengine.com/wp-content/uploads/2014/07/Transoeste_Analysis_FINAL.pdf.

The ICCT. "Roadmap v2.2 Documentation." *The ICCT* 2023. https://theicct.github.io/roadmap-doc/versions/v2.2/.

IEA. *The IEA Mobility Model: A Comprehensive Transport Modelling Tool Aimed at Improving the Analysis of all the Aspects of Mobility*. *IEA Paris* 2021. https://www.iea.org/areas-of-work/programmes-and-partnerships/the-iea-mobility-model.

Institute for Transportation and Development Policy. "BRT Rankings." 2024. https://itdp.org/library/standards-and-guides/the-bus-rapid-transit-standard/brt-scores-2024/.

Institute for Transportation and Development Policy and UC Davis. "The Compact City Scenario – Electrified." *ITDP* 2021.

Islam M, Brussel M, Grigolon A, et al. "Ridership and the Built-Form Indicators: A Study from Ahmedabad Janmarg Bus Rapid Transit System (BRTS)." *Urban Science* 2018; 2: 95.

Ko J, Kim D, Etezady A. "Determinants of Bus Rapid Transit Ridership: System-Level Analysis." *J Urban Plann Dev* 2019; 145: 04019004.

National Academies of Sciences, Engineering, and Medicine. *Bus Rapid Transit Practitioner's Guide.* The National Academies Press 2007. https://doi.org/10.17226/23172.

Emissions factors detailed by source and fuel. National Atmospheric Emissions Inventory 2021. https://naei.beis.gov.uk/data/ef-all.

Rogat, J., Dhar, S., Joshi, R., Mahadevia, D., & Mendoza, J. C. "Sustainable Transport: BRT experiences from Mexico and India." *Wiley Interdisciplinary Reviews: Energy and Environment* 2015; 4(6): 564–574. https://doi.org/10.1002/wene.162

Umlauf T, Galicia LD, Cheu RL, et al. "Ridership estimation procedure for a transit corridor with new bus rapid transit service." *J of Advced Transportation* 2016; 50: 473–488.

United Nations, Department of Economic and Social Affairs, Population Division. *World Urbanization Prospects: The 2018 Revision, Online Edition. United Nations* 2018. https://population.un.org/wup/Download/.