WORLD RESOURCES INSTITUTE

TECHNICAL NOTE

THE COSTS AND BENEFITS APPRAISAL TOOL FOR TRANSIT BUSES

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EXECUTIVE SUMMARY

The Costs and Benefits Appraisal Tool for Transit Buses ("the Tool") is an updated version of the Costs and Emissions Appraisal Tool for Transit Buses. It aims to inform bus operators and city officials of the costs, emissions, and social benefits associated with bus fleets using different fuel types. The Tool's outputs can help bus operators make the most cost-efficient decisions when making a clean bus upgrade, allow transit agencies to validate information provided by bus operators, and inform city officials of the social benefits of a low-carbon transit fleet. Compared with the previous version, this tool includes more default data on electric bus costs and operational information with wider geographic coverage and more bus types; provides social cost and benefit calculations; and includes simplified cost functions. Users are encouraged to input their own data to reflect their local situations. The Tool is published as a webtool (https://www.wri.org/resources/data-visualizations/costs-and-benefits-appraisal-tool-transit-buses) to increase user friendliness, and allows users to compare basic procurement and business model scenarios.

CONTENTS

Technical notes document the research or analytical methodology underpinning a publication, interactive application, or tool.

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1. INTRODUCTION

1.1 Background

As the need to mitigate air pollution and reduce carbon emissions from the urban transport sector has risen, more cities have begun to adopt low-carbon technologies such as electric buses (e-buses) in their public transit systems. The electric bus stock rose by about 17 percent from 2018 to 2019, and reached 513,000 worldwide in 2019 (IEA 2020). In Western Europe alone, the number of registered e-buses tripled in 2019 (Sustainable Bus 2020). Many European cities have announced bans on using fossil-fueled vehicles in future years (Wappelhorst 2020). Cities in Latin America have accelerated the electrification process following advances in China, Europe, and the United States, with Santiago de Chile running the second-largest electric bus fleet in the world after China (*TST* 2018), followed by Colombia. India also increased its transport electrification ambition through its Faster Adoption and Manufacturing of Hybrid and Electric Vehicles in India (FAME India) Scheme Phase II (DHI 2019). However, city bus operators, especially those from developing economies, need more cost and operational information about the new technologies in order to make more informed decisions during fleet electrification.

General tools exist that provide cost implications for electric vehicles and conventional internal combustion engine (ICE) vehicles, but they usually do not have good coverage of public transit, or of the social or environmental costs in the global South. For example, the Vehicle Cost Calculator developed by the Alternative Fuels Data Center at the U.S. Department of Energy (Hove and Sandalow 2019) and the EV Savings Calculator by the Pacific Gas and Electric Company (PG&E 2020) provide detailed information on vehicle costs, especially those for electric vehicles, but do not contain related information on public transit. The Volpe Center of the U.S. Department of Transportation has developed the Bus Lifecycle Cost Model to provide federal agencies with cost-related knowledge, providing information regarding direct procurement, operation, and maintenance costs (USDOT 2020), but does not focus on the social and environmental side. The AFLEET tool developed by Argonne National Laboratory so far contains the most detailed information for buses, including total cost of ownership calculations and environmental costs and benefits. However, it contains only U.S. data (ANL 2020), which is useful but not ideal for other countries due to differences in technology, routes, operational conditions, and other local circumstances.

World Resources Institute's (WRI's) earlier Costs and Emissions Appraisal Tool for Transit Buses provided suggestions on vehicle upgrade options for transit agencies and bus operators toward a clean energy transition (Cooper et al. 2019). However, during the tool's development, electric buses remained a nascent technology and only a few data points were included. Also, even though emissions generated by the fleets could be quantified, social implications such as the social cost of emissions were not clear yet.

To increase the applicability and user-friendliness of the previous tool, this updated Costs and Benefits Appraisal Tool for Transit Buses ("the Tool") is published as a webtool with several new features:

More electric bus information with wider geographic coverage. The energy consumption and operational efficiency of buses differ across vehicle models. To better capture the variation, different features, including fuel type, bus length, and emission standards, are included in the Tool. Given the heterogeneity of electricity mixes, fuel contents, and price levels across countries, the Tool also adds more country profiles for reference. Currently, the Tool covers information for China, where 99 percent of the world's electric buses were located as of 2018; the European Union (EU), where the second-highest number of e-buses are registered (IEA 2019); and other emerging markets for electric buses such as the United States, Brazil, India, and Mexico. Electric buses in this tool refer mainly to battery electric buses. To a lesser degree, plug-in electric buses as well as the major ICE buses, such as diesel buses and compressed natural gas (CNG) and liquefied natural gas (LNG) buses, are also included in the Tool. Hydrogen fuel-cell buses are not included due to limited real-world applications and data availability.

Social cost and benefit calculations are included. Electric buses can significantly reduce local air pollution and generate social, health, and environmental benefits for city residents.[1] The potential reduction of greenhouse gas (GHG) emissions can also help reduce future climate impacts. The new feature in the Tool includes a monetization of emissions reduced, based on data from van Essen et al. (2019), EPA (n.d.), and Ricke et al. (2018), to reflect the potential social benefits that a cleaner fleet can bring to a city (see Section 3). In addition, the Tool assumes that not all of the external costs have been internalized by policy interference.

Simplified functions with user interaction options. Many of the calculation functions in the Tool have been simplified, mainly to reduce the amount of data required and improve the user experience. Accuracy is not compromised to a great extent as the major cost components are accounted for. A few user interactions—technology comparisons, financing options, and charging infrastructure options—are included to reflect the real-life options that users may face during a fleet upgrade.

The Tool aims to inform bus operators and transit agencies of the total cost of ownership, emissions reductions, and social benefits associated with bus fleet renewals and upgrades. This can help bus operators make the most cost-efficient decisions to reduce air pollution and emissions, and help transit agencies verify information provided by bus operators. The Tool can also help city decision-makers quantify the benefits of emissions reductions from a cleaner urban transit system, and develop reasonable incentives and policies to encourage their adoption.

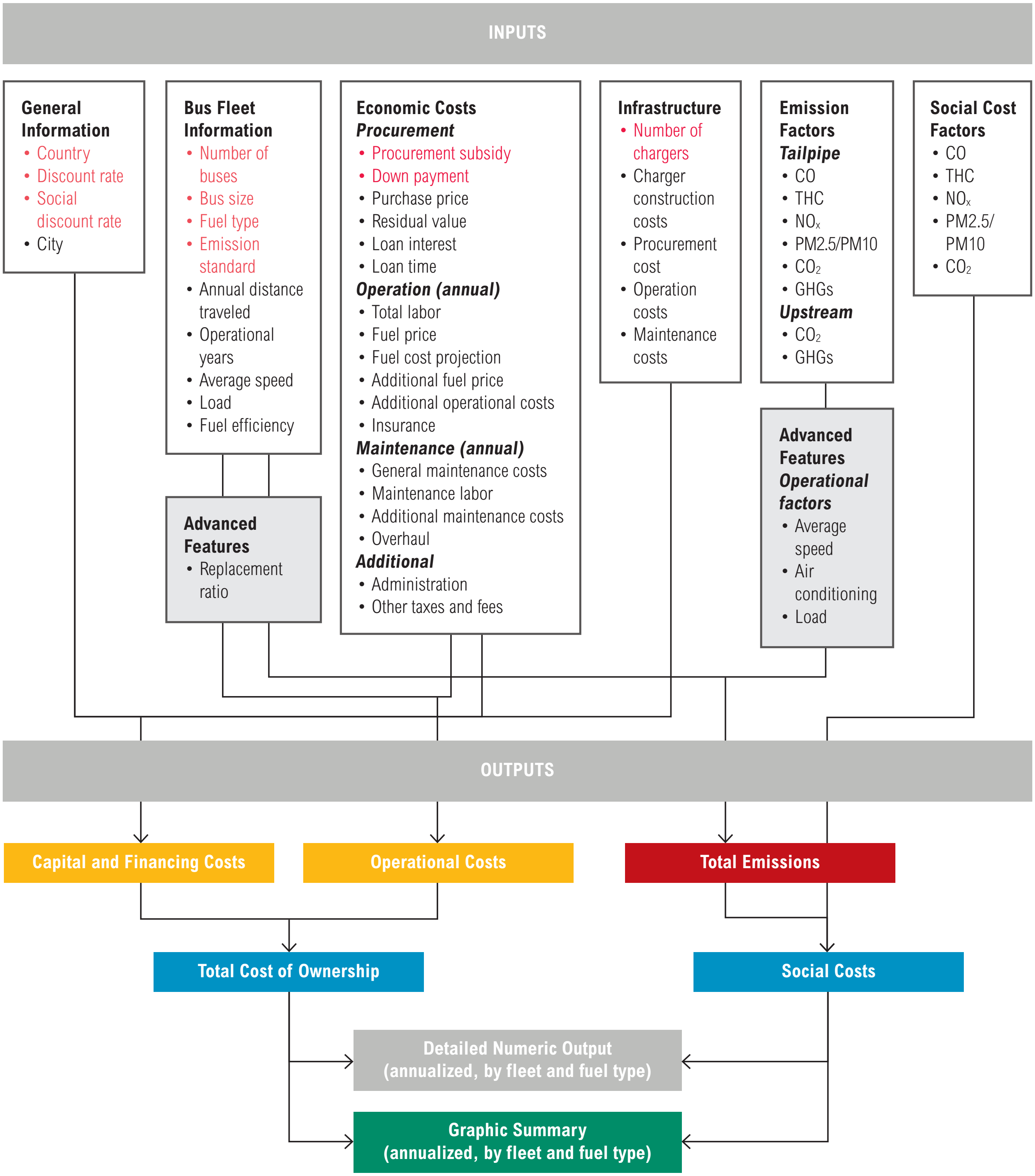
1.2 Definition

The costs and benefits to bus operators of a clean bus technology upgrade can be categorized as direct and indirect. Costs in the Tool refer mainly to direct costs, which include bus procurement and scrappage costs (including capital and finance costs), labor costs of bus operation, fuel costs, maintenance costs, and other costs related to bus operation and maintenance but not included in the previous categories. Direct costs generally differ by bus technology. Indirect costs, including administrative costs, depot and land rental costs, and other compliance costs, normally do not vary much with different bus technologies (Ang-Olson and Mahendra 2011), and are thus set as optional in the Tool. However, due to the mandatory charging needs of electric buses, infrastructure-related costs need to be considered for electric buses, but not necessarily other technologies. Therefore, infrastructure-related costs are included as a stand-alone section in the Tool.

Benefits in this tool refer to direct benefits, which flow from the emissions reduction potential of cleaner bus technologies (e.g., electric buses, ICE buses with higher emissions standards) compared with that of other buses. Thus, benefits are presented as emissions reduced. Indirect benefits include potential reductions in operational and maintenance costs by changing technology and other savings due to changes in use patterns, which are considered cost savings when applicable. Thus, indirect benefits are not included in the benefit outputs of the Tool, but rather reflected in the cost section.

Social costs avoided by emissions reductions are also treated as direct social benefits. Social costs represent the sum of the private (internal) and external costs (Korzhenevych et al. 2014; S. Song 2017). This technical note defines social cost as the cost of externalities. The social cost of traditional bus fleets can include local impacts such as air pollution, noise, congestion, and accidents (Ozbay et al. 2007), and global or regional impacts such as climate change and habitat damage (van Essen et al. 2019). Air pollution and climate impacts are the only two categories calculated in this technical note. Note that in the Tool, we calculate the social cost of air pollutants at the local level (tailpipe, or tank-to-wheel, emissions), and the social cost of carbon emissions at both the local (tailpipe) and global (upstream, or well-to-wheel, emissions) levels. The reason is that the major impact from air pollutants—the impact on local public health—is on the tailpipe side (tank-to-wheel), while local carbon emissions have a global impact, making it meaningful to use the well-to-wheel approach. The general components of costs and benefits are indicated in the structure of the Tool (Figure 1).

Figure 1 | **General Components and Layout of the Tool**



Notes: Variables in red require users' selection or manual input. The Tool provides default values for other variables based on users' selections of country, bus size, and fuel type. Beyond basic analysis, "Advanced Features" (in grey) indicate the costs and emissions variations by operational condition and maturity of technology. Abbreviations: CO: carbon monoxide; THC: total hydrocarbons; NO_x: nitrogen oxides; PM2.5/PM10: particulate matter of 2.5 and 10 micrometers or less in diameter, respectively; CO_2: carbon dioxide; GHGs: greenhouse gases.

Source: Authors.

2. TOOL FUNCTIONALITY AND LAYOUT

2.1 How to Use the Tool

In general, users can explore the Tool in two ways:

- Users select or fill in basic variables → Default data are pulled from the database → Users choose different user interaction options → Results are calculated and compared based on default data
- Users select or fill in basic variables → Default data are pulled from the database → Users update variables with their own data to reflect certain conditions → Users choose different user interaction options, using default data or their own data → Results are calculated and compared based on user input

The basic variables that require user input include the following:

- Country: Drop-down menu with limited options
- City: Drop-down menu with limited options; users can select one of the available cities and use city data from the default database or fill in their own data, or select "general" and use country averages from the default database or fill in their own data
- Bus size: Drop-down menu with limited options; users can select the "general" category to input a bus size not listed
- Fuel type: Drop-down menu with limited options based on default data available, such as diesel and electric
- Emission standard: Drop-down menu with limited options based on default data available
- Number of buses: Requires manual input

Additional variables require user input but are optional to generate results:

- Procurement subsidy
- Down payment
- Number of chargers

The following variables are mandatory for calculations, but because default data are available for them, users are not required to fill in their own information. However, we encourage users to customize the data.

- Operational years
- Annual distance traveled
- Fuel efficiency

For the rest of the mandatory variables in the "General Information" and "Cost Factors" categories, the Tool provides default data that users may use for convenience, but we encourage users to customize the inputs to fit their situations.

Variables in the "Emission Factors" and "Social Cost Factors" categories are automatically filled in based on basic variables selected by users, though these can also be manually edited. We recommend that users use the default data unless local data are available.

2.2 Input Pages

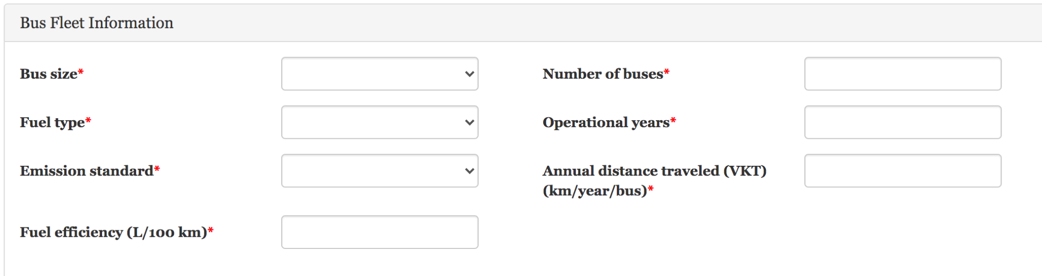
Inputs of the Tool include the following:

- **General information** (see Figure 2): The countries and cities included in the Tool are limited based on the availability of default

Figure 2 | **Input Page for General Country and City Information**

Source: "Costs and Benefits Appraisal Tool for Transit Buses." Webtool. Washington, DC: World Resources Institute.

Figure 3 | Input Page for Bus Fleet Information

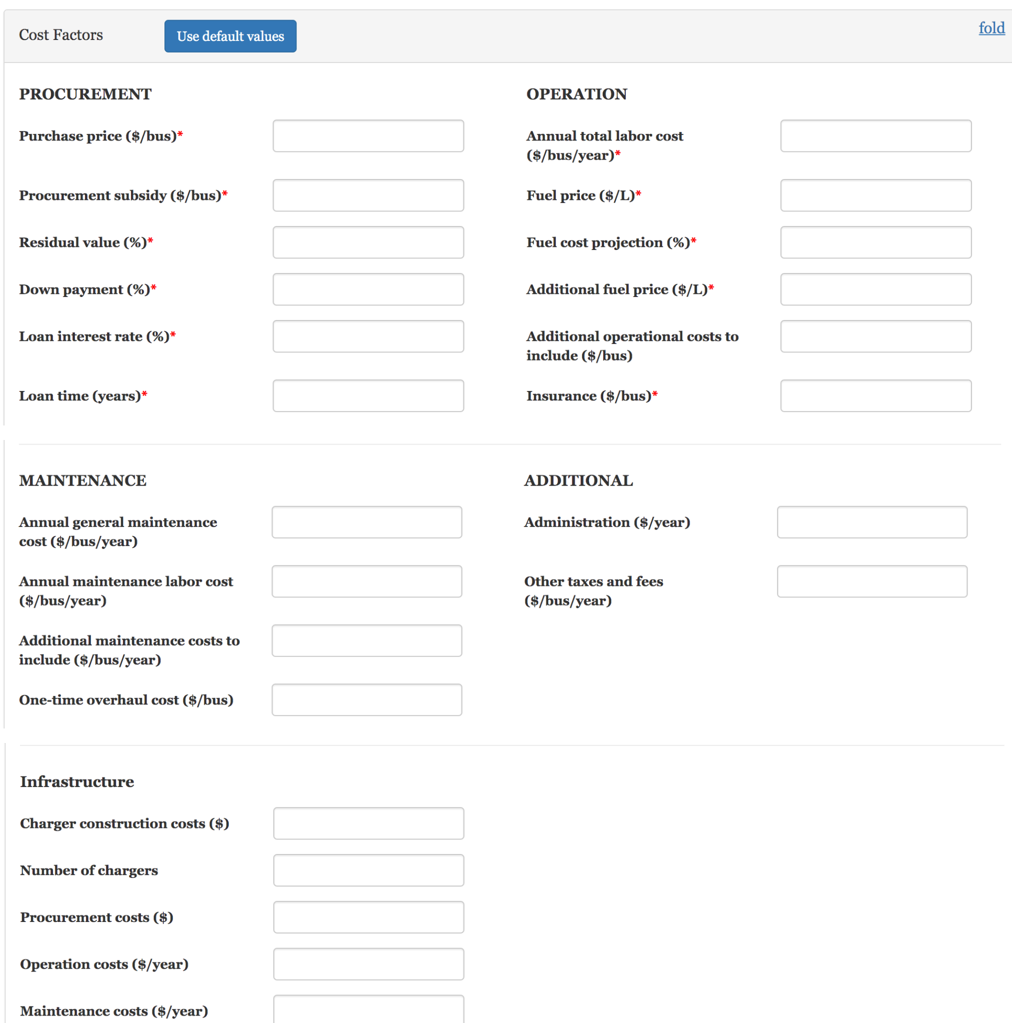

Bus Fleet Information

Bus size*		**Number of buses***	
Fuel type*		**Operational years***	
Emission standard*		**Annual distance traveled (VKT) (km/year/bus)***	
Fuel efficiency (L/100 km)*			

Notes: Abbreviations: L/100 km: liters per 100 kilometers; VKT: vehicle kilometers traveled.

Source: "Costs and Benefits Appraisal Tool for Transit Buses." Webtool. Washington, DC: World Resources Institute.

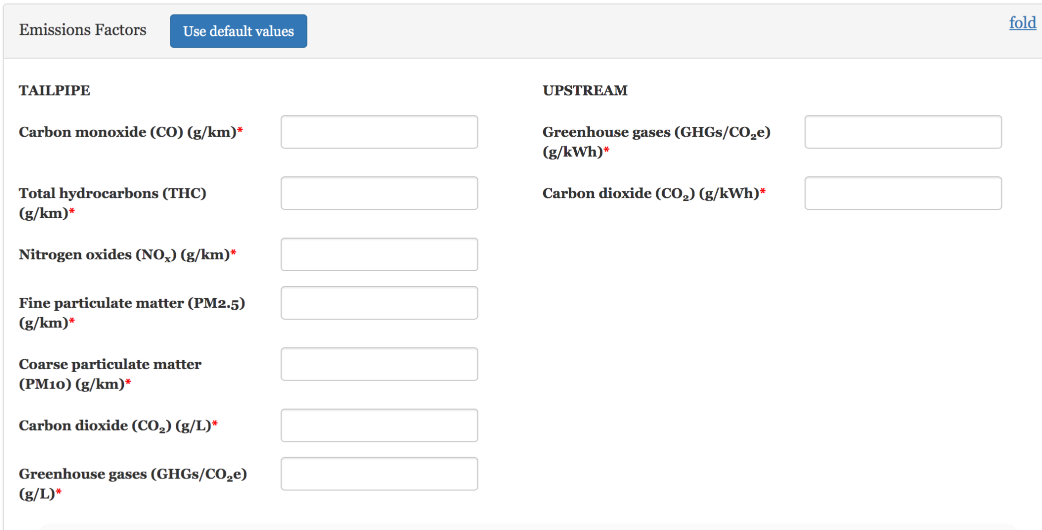
Figure 4 | Input Page for Cost-Related Factors


Cost Factors Use default values fold

PROCUREMENT		**OPERATION**	
Purchase price ($/bus)*		**Annual total labor cost ($/bus/year)***	
Procurement subsidy ($/bus)*		**Fuel price ($/L)***	
Residual value (%)*		**Fuel cost projection (%)***	
Down payment (%)*		**Additional fuel price ($/L)***	
Loan interest rate (%)*		**Additional operational costs to include ($/bus)**	
Loan time (years)*		**Insurance ($/bus)***	
MAINTENANCE		**ADDITIONAL**	
Annual general maintenance cost ($/bus/year)		**Administration ($/year)**	
Annual maintenance labor cost ($/bus/year)		**Other taxes and fees ($/bus/year)**	
Additional maintenance costs to include ($/bus/year)			
One-time overhaul cost ($/bus)			
Infrastructure			
Charger construction costs ($)			
Number of chargers			
Procurement costs ($)			
Operation costs ($/year)			
Maintenance costs ($/year)			

Source: "Costs and Benefits Appraisal Tool for Transit Buses." Webtool. Washington, DC: World Resources Institute.

Figure 5 | **Input Page for Emission Factors**



Notes: Abbreviations: g/km: grams per kilometer; PM2.5/PM10: particulate matter of 2.5 and 10 micrometers or less in diameter, respectively; g/L: grams per liter; CO_2e: carbon dioxide equivalent; g/kWh: grams per kilowatt-hour.

Source: "Costs and Benefits Appraisal Tool for Transit Buses." Webtool. Washington, DC: World Resources Institute.

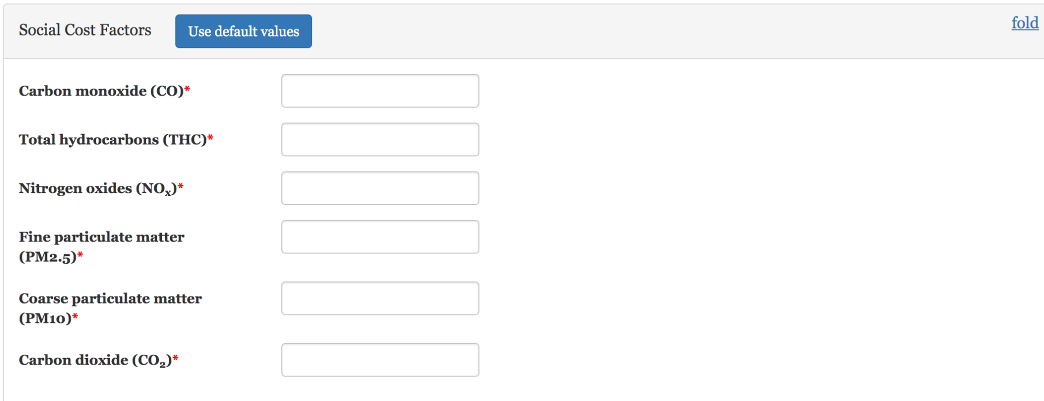
data. Users can refer to regions with similar characteristics if their country or city of interest is not included. Under the drop-down menu for "City," there is an option of "General" that, when selected, populates the remaining fields with the averages of the data collected for the selected country. Users may also enter their own data when selecting "General." Discount rate refers to nominal discount rate, which considers inflation factors. Social discount rate is the discount rate used for social projects and is used in the Tool for social cost and benefit calculations.

- **Bus fleet information** (see Figure 3): The fuel efficiency factor can be identified based on users' selections of basic variables, such as bus length, fuel type, and emission standard. Default fuel efficiency data based on these variables are included in the Tool when available. When such data are not available, the average fuel efficiency factors given by the Tool's underlying sources are used.

- **Costs** are categorized as procurement, operation, and maintenance costs (Figure 4). Although the Tool focuses mainly on the bus itself, charging infrastructure also generates costs in these categories. These may not be included in bus-related costs, so they are addressed in a separate category.

- **Emission factors** include tailpipe emissions (tank-to-wheel) and upstream emissions (well-to-tank). The default data are collected by bus length, fuel type, and emission standard, when such data are available for tailpipe emissions. Upstream emission factors (EFs) are collected for different fuels, including the emission factors for fossil fuel production processes, and grid emission factors, which account for emissions generated by electricity used when operating electric buses. Unlike a conventional well-to-wheel analysis, this tool considers upstream emissions only for greenhouse gases, and does not include upstream emissions for other air pollutants due to different social benefits implications (refer to Section 3.2.3 for more information). Geographic differences are considered by incorporating information from different cities and countries. The pollutants considered include carbon monoxide (CO), total hydrocarbons (THC), nitrogen oxides (NO_x), particulate matter (PM2.5 and PM10[2]), and carbon dioxide (CO_2) or carbon dioxide equivalent (CO_2e),[3] whichever is available or recorded in the sources. Figure 5 shows the specific EFs and their units.

Figure 6 | **Input Page for Social Cost Factors**



Notes: Abbreviations: PM2.5/PM10: particulate matter of 2.5 and 10 micrometers or less in diameter, respectively.

Source: "Costs and Benefits Appraisal Tool for Transit Buses." Webtool. Washington, DC: World Resources Institute.

- **Social cost factors** are collected for each type of air pollutant (Figure 6). They measure the total social cost per unit mass of each pollutant (in US$/tonne) at the national level. Localized social cost factors as default values are included in the Tool. The localization procedure requires national-level income data, such as purchasing power parity (PPP)–adjusted gross domestic product (GDP) per capita.

- **Advanced features** reflect variables that impact fuel efficiency, emission factors (e.g., speed, load), or a bus's total cost of ownership (e.g., replacement ratio). Correction factors for these variables are not included in this tool due to limited data and research available to generate a robust number for different countries. Therefore, the variables are included as advanced features for reference only for users who are interested in exploring how they can impact fuel efficiency, emissions, and costs. Users may choose different combinations of operational factors. When default data are available for these variables for a certain city, related fuel efficiency and emission factors are used. When such data are not available, users cannot get condition-specific data. Some reference numbers are included as notes for each variable, which users can refer to for more information. Users are encouraged to explore different numbers reflecting different operational conditions. The intention behind the advanced features is to give users an idea of other factors that impact fuel efficiency and emission factors.

  - The replacement ratio refers to the number of electric buses—or buses with more advanced technology—it takes to achieve the same level of service as one traditional ICE bus. Ideally, the ratio is 1:1, which means one electric bus can fully replace one ICE bus. However, in reality, especially when the technology is still in its nascent stage or still has operational issues, the ratio can be 1.5–2:1 (Jin 2020). Therefore, we recommend users use 1:1 and 2:1 in different scenarios.

  - Operational factors—speed, load factor, and air conditioning—are discussed in more detail in Section 3.3. The Tool provides some reference values, representing the general impact these factors have on fuel efficiency and emission factors. However, as the numbers are extracted from academic papers, they serve only as a reference, and do not necessarily reflect the operational conditions in the city of interest.

2.3 User Interactions

Three **user interaction options** are also included in the Tool, covering the issues most often faced by bus operators when procuring clean technology buses:

- **Add Fleet**: Bus upgrade options, which compare the costs and emissions implications of a fleet upgrade (similar to the previous tool).
- **Add Cost Factor**: Financing and subsidy options, which allow for a direct subsidy per bus, and other subsidy options given through better financing conditions, which users can simulate by inputting different combinations of factors such as interest rate, loan year, and down payment. Battery leasing is one way to reduce the cost of an electric bus; while this financing option is not explicitly mentioned in the Tool, users can fill in the related cost in the "Additional Operational Costs" box if such a financing option is used or desired.
- **Add Infrastructure**: Charging infrastructure costs are included to reflect the potential business models of charging infrastructure.

After users create a first, baseline-scenario fleet, they can create additional fleets by changing the inputs, and then compare the cost and emission implications of different bus upgrade, financing, and infrastructure business models (Figure 7).

2.3.1 Bus Upgrade Options

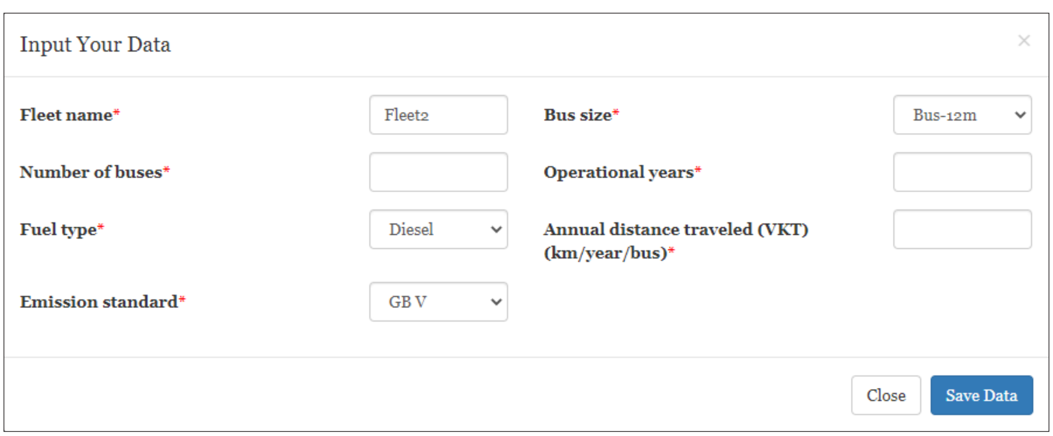
As illustrated in Figure 8, users can change the basic features related to a fleet upgrade and compare the cost and emission implications when switching

Figure 7 | **Compare Fleets**

	Number	Name	Action
☐	1	Fleet1	
☐	2	Fleet2	edit delete
☐	3	Fleet3	edit delete

Source: "Costs and Benefits Appraisal Tool for Transit Buses." Webtool. Washington, DC: World Resources Institute.

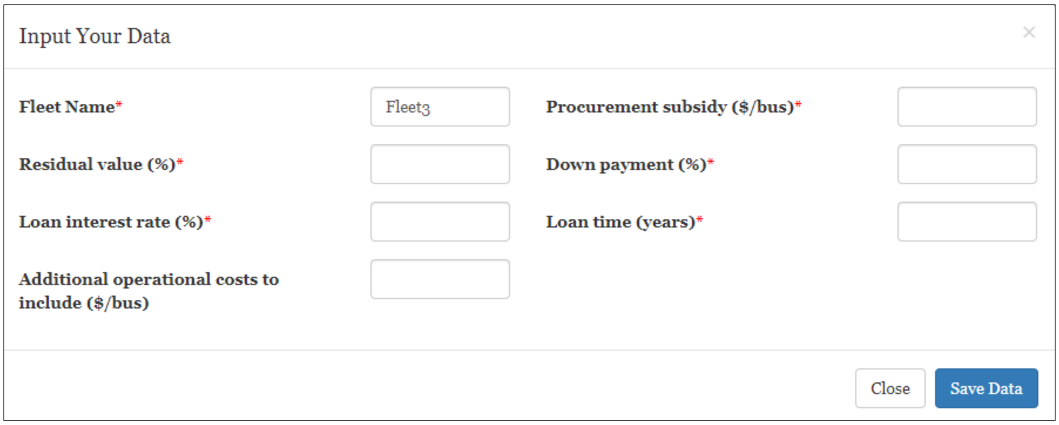
Figure 8 | **Input Page for Bus Features**



Notes: Abbreviations: VKT: vehicle kilometers traveled; km: kilometers; m: meters.

Source: "Costs and Benefits Appraisal Tool for Transit Buses." Webtool. Washington, DC: World Resources Institute.

Figure 9 | **Input Page for Bus Financing Factors**



Source: "Costs and Benefits Appraisal Tool for Transit Buses." Webtool. Washington, DC: World Resources Institute.

bus technologies. By changing these features, procurement cost, fuel efficiency, and emission factor will change accordingly when default data are available. If default data are not available or not applicable to the user's situation, the user is encouraged to input their own data.

Other variables such as number of buses, vehicle kilometers traveled (VKT), and operational years (lifespan) determine the quality of service of the bus fleet. These numbers change according to the choice of technology. For example, electric buses may have a shorter VKT due to battery range and, therefore, more buses and higher operational frequency may be necessary to keep the same level of bus service. Users must input the number of buses needed, VKT, and operational years; the Tool does not automatically calculate them.

2.3.2 Financing and Subsidy Options

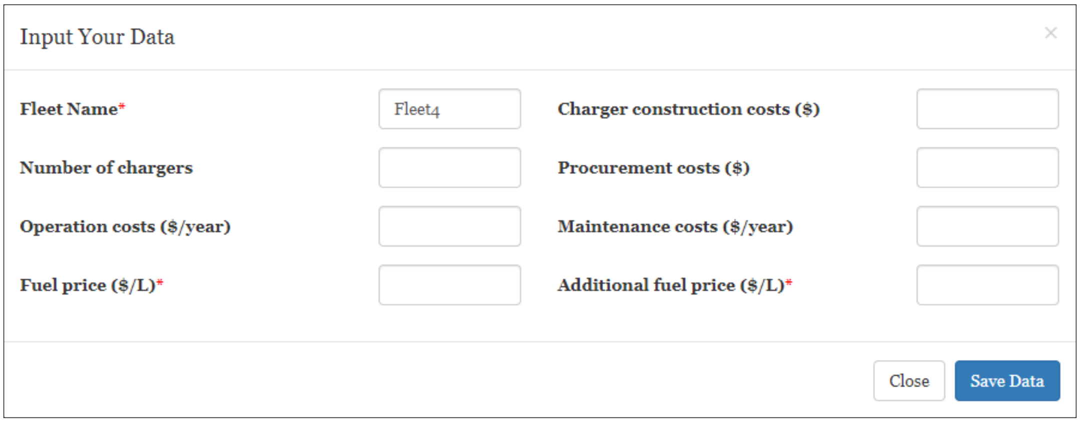
Bus procurement business models vary widely across regions (Moon-Miklaucic et al. 2019). Some involve public funding via financial subsidies, whereas others involve different financing options. This tool offers a simplified way to reflect the core differences between business models and financing options: down payment, procurement subsidy, interest rate, loan time, residual value during bus scrappage, and potential other operational costs due to different financing mechanisms (such as battery leasing cost, which can be considered in "Additional operational costs to include") (see Figure 9). Most innovative ways to finance buses result from adjusting these variables. While this tool does not provide users with the detailed design of a potentially relevant business model, users can still change these numbers and compare the cost differences of various financing options.

2.3.3 Charging Infrastructure Needed/Costs

The costs related to charging infrastructure are complicated (Nelder and Rogers 2019), and the cost implications for bus operators differ by business model. For example, operators may have the opportunity to construct and manage their own chargers, purchase charging services from charger operators, or get a preferential electricity price based on certain incentive policies. To simplify the calculations, the Tool includes only some basic components related to chargers (see Figure 10).

In Figure 10, procurement costs refer to the unit charger costs, if chargers need to be purchased. Construction costs for charging infrastructure in this tool may include labor, materials, utility upgrades, and other costs incurred during the installation process, and should be considered early in the planning process of upgrading to an electric bus fleet (Nelder and Rogers 2019). Operational and maintenance costs are

Figure 10 | **Input Page for Charging Infrastructure**



Source: "Costs and Benefits Appraisal Tool for Transit Buses." Webtool. Washington, DC: World Resources Institute.

annual costs incurred by bus operators. Users can adjust the related costs to reflect specific business models. For example, if the bus operator owns the charging infrastructure, users can put all direct costs into this infrastructure section; if charging services are purchased under contract, users can use operational and maintenance costs in this section to roughly reflect that; if electricity prices or charging service fees are changed under this business model, users can adjust "fuel price" and "additional fuel price" in the cost section.

As is discussed in Section 6, this tool does not intend to tell users how many chargers to construct or where to install them. Such information can be explored using WRI's other tools,[4] such as the Future Mobility Calculator, which takes a city-level macro approach, and a tool that analyzes the impact of charging behaviors on the distribution grid. In this tool, users need to create their own scenarios to conduct an analysis.

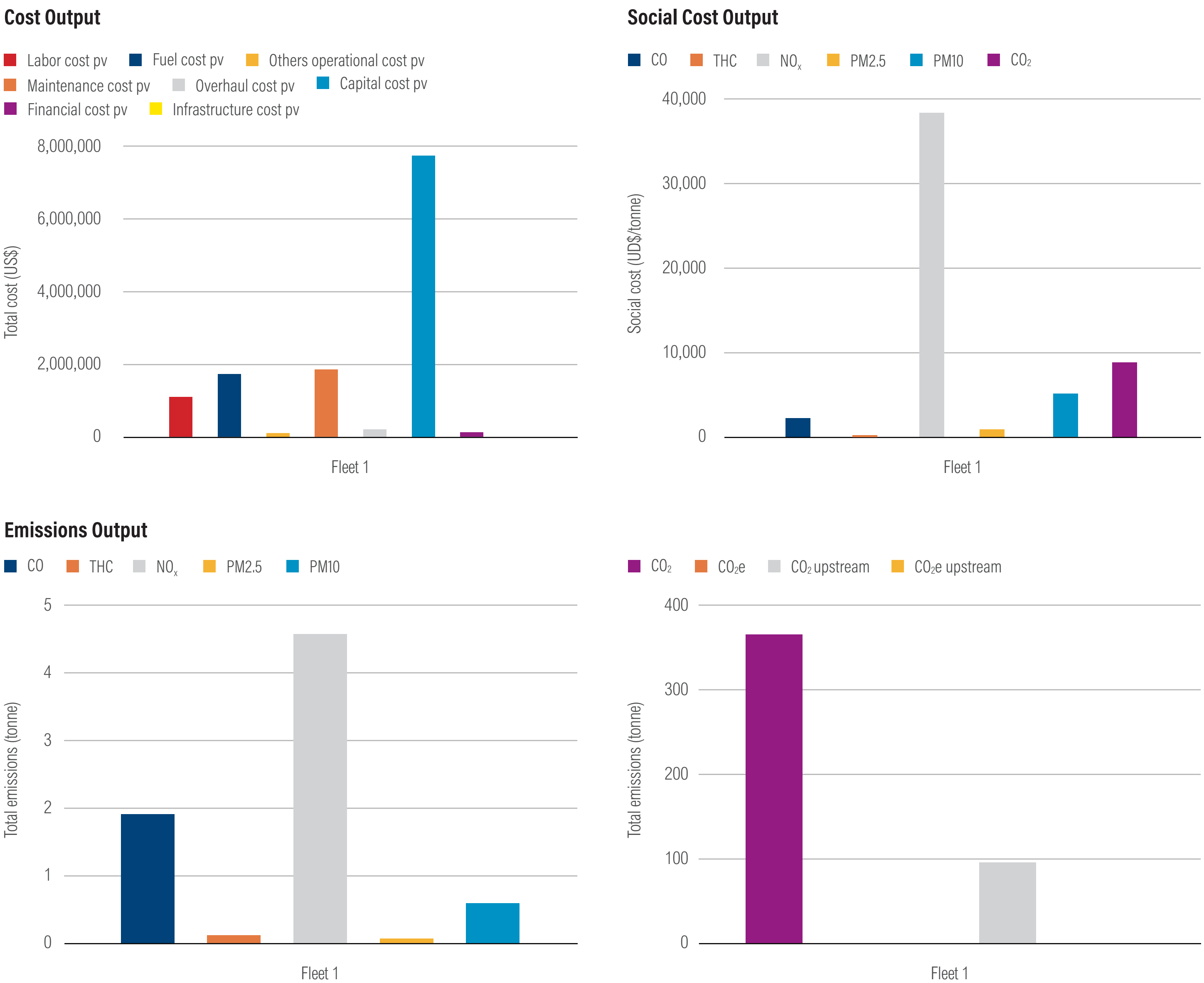
2.4 Outputs and Sample Graphics

Outputs of the Tool can be downloaded into Microsoft Excel and tailored to fit the comparison needs of the user. Some direct output comparisons are also available in sample graphics (Figure 11) after users input information for multiple bus fleets and compare results. It is worth noting that the Tool provides only a few general graphics. Users are encouraged to generate their own graphics.

Some of the Tool's outputs include the following:

- The present value (PV) of the total cost of ownership of a bus fleet in its operational lifespan, annualized cost and unit cost (single bus per kilometer, or km).
- The total emissions of different air pollutants and greenhouse gases in a fleet's operational lifespan, annualized, by unit (single bus per km).
- The PV of lifetime social costs or avoided social costs (social benefits).

Figure 11 | **Sample Output Graphics**



Notes: Abbreviations: Labor cost pv: the present value of labor costs; Fuel cost pv: the present value of fuel costs; Others operational cost pv: the present value of operational costs other than for labor and fuel; Maintenance cost pv: the present value of maintenance costs; Overhaul cost pv: the present value of the cost to overhaul a fleet of buses; Capital cost pv: the present value of capital costs; Financial cost pv: the present value of financial costs; Infrastructure cost pv: the present value of infrastructure costs; CO: carbon monoxide (tailpipe emissions); THC: total hydrocarbons (tailpipe emissions); NO_x: nitrogen oxides (tailpipe emissions); PM2.5: particulate matter of 2.5 micrometers or less in diameter (tailpipe emissions); PM10: particulate matter of 10 micrometers or less in diameter (tailpipe emissions); CO_2: carbon dioxide (tailpipe emissions); CO_2e: carbon dioxide equivalent (tailpipe emissions); CO_2 upstream: carbon dioxide (upstream emissions); CO_2e upstream: carbon dioxide equivalent (upstream emissions).

Source: "Costs and Benefits Appraisal Tool for Transit Buses." Webtool. Washington, DC: World Resources Institute.

3. DATA

3.1 Data Overview

Default data related to costs and emissions calculations were collected mainly by literature review. The authors explored, using keywords, local transport agency websites (e.g., that of the U.S. Department of Transportation), databases of academic journals, and publication archives of transport-related or environment-related research institutions (e.g., International Council on Clean Transportation). A more detailed description of this compiled dataset can be found in the next section. We also conducted a few interviews with transit agencies to gain a better understanding of cost structure, which helps to justify the calculation methodology. The geographic coverage of the dataset of this tool includes China, India, some Latin American countries (Brazil, Colombia, and Chile), the United States, the United Kingdom, some members of the EU (Austria, France, Germany, Norway, Sweden), and Switzerland (Table 1). In general, data identified through this literature review mostly came from the United States, followed by China and the EU.[5] In terms of fuel types, diesel buses, hybrid-electric buses, and battery electric buses have a heavier focus in this tool, compared with buses powered by natural gas (LNG or CNG), liquified petroleum gas (LPG), and biodiesel. Hydrogen fuel cell buses are not included in this tool.

Table 1 | **Summary of Data Categories, Availability, and Geographic Distribution**

	Fuel Efficiency		ICE Bus EF	Grid EF	Financial Cost	Social Cost
	E-bus	ICE bus				
United States	GA	GA	GA	GA		
European Union		GA	GA	GA		
Switzerland						
United Kingdom		GA	GA	GA		
China			GA	GA		
India				GA		
Chile						
Colombia						
Brazil				GA		
Mexico						

GA	Datasets by government agencies
	Over 10 sources
	5-10 sources
	Fewer than 5 sources

Notes: Abbreviations: E-bus: electric bus; ICE: internal combustion engine; EF: emission factor.

Source: Authors.

3.2 General Costs

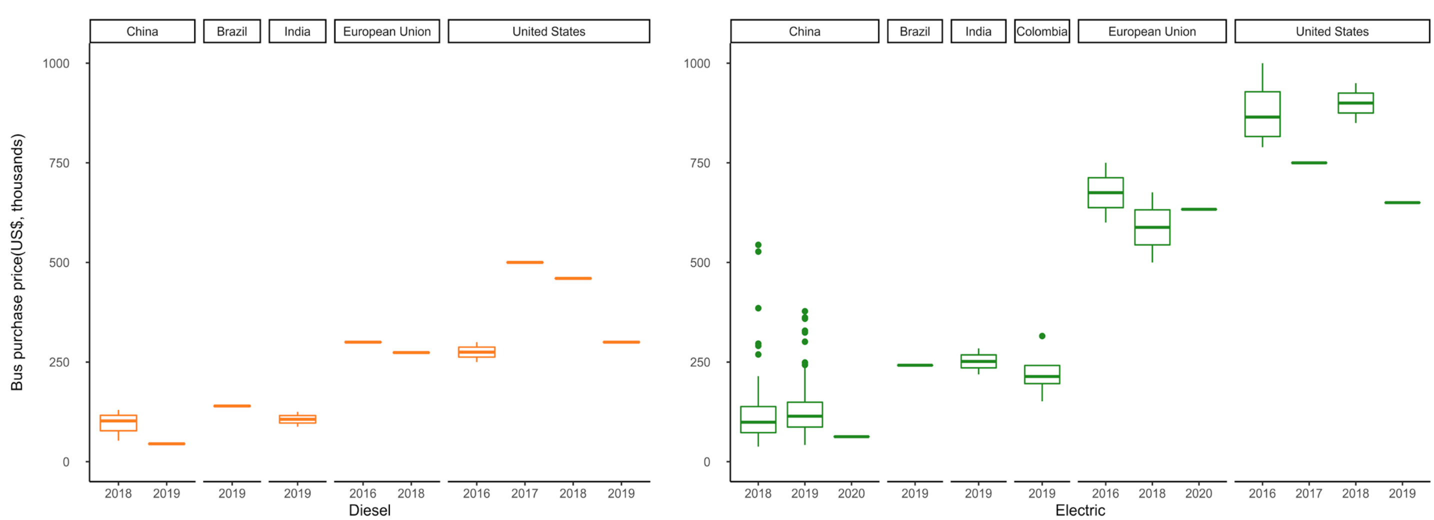
3.2.1 General Costs

- **Procurement costs**

Financial information about existing projects was gleaned mainly from bidding documents in the case of China, and journal articles for other regions. The purchase price of individual buses varies greatly depending on the specifications—such as engine type, chassis make and model, emission control technology, manufacturer, whether production and materials are domestic or imported, time and location of purchase, and the procurement model—which makes it hard to give a precise price for each bus technology. Further analyses are encouraged to assess how these factors impact the actual purchase cost. In this version of the Tool, however, default costs are empirical estimates that reflect the average values of models used in bus fleets around the world.

Figure 12 shows the majority of bus procurement information in the Tool's dataset in different regions. Users are encouraged to use the default data as a reference, and update costs to fit their situations when needed. In this dataset, bus prices in developing countries are generally lower than those in developed countries, especially for electric buses, which can cost three to four times more in the EU and the United States than in China and Latin American countries. However, it is worth noting that due to data availability, the figure does not aim to provide a comprehensive picture of the world's bus market. Other cases and trends may exist but were not captured by the authors by the time the Tool was released. As indicated above, several factors may impact the actual procurement cost, which may not be captured in the graphic. The tool does not analyze how these factors have impacted the procurement cost, but rather provides a general picture using empirical data. Users should use the multi-country information only as a reference.

Figure 12 | **Purchase Prices of Diesel and Electric Buses**



Notes: The lower and upper hinges correspond to the 25th and 75th percentiles. The upper whisker extends from the hinge to the largest value no further than 1.5 * IQR from the hinge (where IQR is the inter-quartile range). The lower whisker extends from the hinge to the smallest value, at most 1.5 * IQR of the hinge. Data beyond the end of the whiskers are "outliers" and are plotted individually.

Sources: Eudy et al. 2014; Eudy and Jeffers 2018; Goswami and Chandra Tripathi 2019; ZEBRA 2019; Dallmann 2019; Potkány et al. 2018; BNEF 2018; USDOT 2016; ChinaBuses 2020; MFC 2020; Lajunen and Lipman 2016; ANL 2020.

Subsidy and financing options

Due to the higher procurement costs of electric buses (Figure 12), public entities and financing institutions around the world use various incentives to encourage their use (Moon-Miklaucic et al. 2019). Two common options are included in this tool: procurement subsidies, which can reduce the upfront costs immediately, and normally depend on the operational range and battery size of the vehicles; and loans, which are a common financing option for bus operators. Different interest rates can reflect innovative financing options and specific costs vary widely. A comprehensive dataset may be informative but cannot help cities when making context-specific electric bus procurement decisions. Therefore, this tool includes only some default information to provide users with a general idea of the potential options; we encourage users to explore their own scenarios.

Operation and maintenance costs

The operation and maintenance (O&M) costs for buses vary greatly by location, operational pattern, and business model. For example, labor costs, and how labor costs are accounted for, are different across cities. Fuel costs depend on local fuel prices, charging times (if electric), fuel efficiency, and operational mileage. Maintenance can be contracted out as a service package or be kept in-house with specialists. Also, the cost of battery replacement, or engine overhaul, depends largely on the operator's contract with the manufacturer, and the operator's decision of whether to replace the whole vehicle at once or just key parts.

Given such cost variations, the Tool captures only the key calculations for O&M but does not include an extensive set of related data. Some default values are included, but only as a reference. Users are encouraged to fill in the information that best represents their situation to get the most applicable results.

3.2.2 Fuel Efficiency

We collected fuel efficiency and emission factors mostly from studies conducting field or road tests, except for data from European countries, which came mainly from lab test results. During road tests, buses are usually operated under controlled conditions, such as at a certain operational speed with a certain passenger load and following a fixed route reflecting local traffic conditions. In this dataset, we classify speed into seven categories, in increments of five kilometers per hour (km/h): (0–5 km/h, 5–10 km/h ... 25–30 km/h, and over 30 km/h). Three levels of load factors are applied—low (<40 percent), medium (40–60 percent), and high (>60 percent)—which indicate the ratio of actual load to the maximum passenger load.

As illustrated in Table 2, the United States has the largest number of fuel efficiency records for all types of buses in the Tool. Data are relatively limited for other

Table 2a | **Number of Records of Fuel Efficiency Data by Fuel and Country**

Country	Diesel	Electric	Hybrid	Gasoline	NG	LPG	Total
Brazil	33	0	25	0	0	0	58
Chile	2	0	1	0	0	0	3
Colombia	1	0	2	0	0	0	3
Mexico	30	0	0	0	0	0	30
China	49	65	15	0	8	0	137
India	8	2	1	0	2	0	13
European Union	16	14	0	0	16	0	46
Switzerland	3	2	0	0	3	0	8
United Kingdom	15	0	0	0	0	0	15
United States	558	58	19	539	22	32	1,228
Total	715	141	63	539	51	32	1,541

Table 2b | **Number of Records of Fuel Efficiency Data by Fuel and Bus Length**

Bus length	Diesel	Electric	Hybrid	Gasoline	NG	LPG
6 m	0	0	2	0	0	0
8 m	6	13	0	0	0	0
9 m	0	3	0	0	0	0
10 m	3	25	0	0	1	0
12 m	688	94	53	539	50	32
14 m	0	3	0	0	0	0
15 m	3	0	0	0	0	0
18 m	4	3	8	0	0	0
23 m	2	0	0	0	0	0
25 m	7	0	0	0	0	0
27 m	2	0	0	0	0	0
Total	715	141	63	539	51	32

Notes: Abbreviations: NG: natural gas; LPG: liquified petroleum gas; m: meters.

Sources: Roychowdhury 2010; APTA 2018; Borén 2019; Chen et al. 2017; Guo et al. 2015; Boulter et al. 2009; Giraldo and Huertas 2019; Gota et al. 2014; He et al. 2018; MJB&A 2013; Barnitt and Chandler 2006; Barnitt et al. 2008; GGGI and CSTEP 2016; Lammert 2008; S. Zhang et al. 2014b; Göhlich et al. 2014; Dreier et al. 2018; Barnitt 2008; Huo et al. 2012; ISSRC 2013; X. Wu et al. 2013; Q. Song et al. 2018; HBEFA 2019; EEA 2019b; Zhou et al. 2016; Prohaska et al. 2016; AC Transit 2018; Dallmann 2019; Goswami and Chandra Tripathi 2019.

locations in the default dataset. This does not necessarily mean that data are less available in these regions, or that the results are less accurate for these regions. The Tool is not intended to include a comprehensive dataset. The data collection process and the size of the dataset were affected by time and resources available.

The default fuel efficiency of buses by fuel and by country (see Table 3) is calculated as a sample average. When local data are not available, users can refer to geographic regions with similar characteristics.

There are some discrepancies in the Tool's default dataset worth mentioning. First is the discrepancy between lab test results and real-world operational fuel efficiency, the latter of which is usually higher due to diverse operational conditions (Tietge et al. 2017). Variances are large and depend on various impacting factors (see Sections 3.3.1 and 5.1 for more information). In addition, different driving cycles applied during the tests represent different operational conditions, which may lead to discrepant test results. For example, in Table 3, the fuel efficiency for diesel buses listed for India is quite high because the average speed from Indian data sources was 40–67 kilometers per hour (km/h) (Gota et al. 2014), while the average speed in many other places was less than 30 km/h. Therefore, the Tool does not try to compare countries but rather provides country-specific data for reference.

Also, although emission standards are not directly correlated with fuel efficiency, as it is a standard used to control emissions, in reality it may affect fuel efficiency. To be compliant with the standard, emissions reduction technologies may be applied to the bus, which increase the weight or impact the combustion process of the vehicle. Therefore, buses with different emission standards may have different fuel efficiencies. In the Tool, default data were collected by emission standard when available. But the Tool does not provide an analysis on how emissions reduction technology affects the actual operational efficiency of buses.

Table 3 | **Fuel Consumption Data by Country and Fuel for 12-Meter Buses (mean and range)**

Region	Diesel (L/100km)	Electric (kWh/100km)	Hybrid (L/100km)	Gasoline (L/100km)	NG (MJ/100km)	LPG (MJ/100km)
Brazil	46.7		17.6			
	(33.5-55.0)		(4.9-58.8)			
Chile	37.5		25.2			
	(36.0-38.9)		(25.2-25.2)			
Colombia	37.7		31.8			
	(37.7-37.7)		(29.9-33.6)			
Mexico	34.4					
	(21.4-57.2)					
China	45	150.3	37.7		1,433.9	
	(27.9-88.4)	(90.7-260.6)	(22.9-81.9)		(1,333.3-1,610.0)	
India	26.6	158.3	30.7		2,079	
	(17.9-50.0)	(150.0-166.7)	(30.7-30.7)		(1,848.0-2,310.0)	
European Union	37.3	173.1			1,827.7	
	(30.9-46.8)	(118.0-360.0)			(1,471.9-2,664)	
Switzerland	44.5	188.7			2,039.1	
	(43.4-45.7)	(188.2-189.3)			(1,978.4-2,099.1)	
United Kingdom	45.4					
	(22.9-101.1)					
United States	46.1	154.1	46.7	32.1	2,171.8	1,812.8
	(11.3-101)	(15.9-311.1)	(29.3-75)	(10.2-95.6)	(1,142.9-4,955)	(105.3-2,897.5)

Notes: Abbreviations: NG: natural gas; LPG: liquified petroleum gas; L/100 km: liters per 100 kilometers; kWh/100 km: kilowatt-hours per 100 kilometers; MJ/100 km: Megajoules per 100 kilometers.

Sources: Chen et al. 2017; Roychowdhury 2010; Guo et al. 2015; Boulter et al. 2009; Giraldo and Huertas 2019; Gota et al. 2014; He et al. 2018; MJB&A 2013; Barnitt and Chandler 2006; Dreier et al. 2018; X. Wu et al. 2013; Q. Song et al. 2018; EEA 2019b; Zhou et al. 2016; Borén 2019; APTA 2018; Dallmann 2019; Goswami and Chandra Tripathi 2019; Barnitt et al. 2008; GGGI and CSTEP 2016; Lammert 2008; Göhlich et al. 2014; Barnitt 2008; Huo et al. 2012; ISSRC 2013; HBEFA 2019; Prohaska et al. 2016; AC Transit 2018; S. Zhang et al. 2014b.

3.2.3 Emission Factors

In this tool, a tank-to-wheel (TTW) approach is used to calculate local air pollutants and a well-to-wheel (WTW) approach (including well-to-tank and tank-to-wheel components) is used to calculate carbon emissions. We used two approaches because the major impact from air pollutants—that on local public health—occurs on the tailpipe side (TTW approach), while local carbon emissions have a global impact (WTW approach). For the same reason, at the social cost appraisal stage, only local impacts from air pollutants are monetized, while the global impacts of carbon emissions are monetized.

Tailpipe emissions

As was the case for fuel efficiency, emission factors were collected mainly from studies conducting field or road tests. Results of lab tests that simulated real-world driving cycles in different cities were used when field test data were not available. It was assumed that battery electric buses have zero tailpipe emissions since they use only electricity. A sample sheet of EF data for China (Table 4) shows the wide variation in emission factors by fuel type and emission standard, and even for buses using the same standard.

It should be noted that the Tool uses only European emission standards due to data availability and to reduce the complexity of the Tool. China has been implementing European standards for heavy-duty vehicles since 2000. Although the China VI standard is more stringent than Euro VI, at the time of this tool's development, operational data for China VI were limited. Therefore, using European emission standards to represent China's standards is feasible. For US cases, since it has been over 10 years since the Environmental Protection Agency last released an exhaust emission standard for urban buses (2007), the Tool does not distinguish between standards for US cases, but shows an average of values found in the data sources. The Tool also uses averages rather than specific standards for India and South American countries, due to limited data and sources being unclear about emission standards.[6]

Upstream emission factors

Upstream emissions for buses of different technologies were calculated based on emission factors of fuel. Emission factors of electricity depend largely on the local grid mix. Countries like China and India rely heavily on coal, which contributes to higher carbon intensities, while Brazil has abundant hydropower and

Table 4 | **Air Pollutant Emission Factors in China by Emission Standard (mean and range)**

Pollutant (g/km)	Diesel						Hybrid		
	Pre Euro	Euro I	Euro II	Euro III	Euro IV	Euro V	Euro III	Euro IV	Euro V
THC	25.9	24.2	21.2	16.4	7.5	3.8	1.0	3.2	
	(9.2-64)	(8.6-60)	(7.6-52.8)	(0.8-41)	(2.1-17.8)	(1.4-8.9)	(0.8-1.2)	(3.0-3.5)	
HC	4.9	1.1	0.6	0.5	0.2	0.1	0.2	0.1	
	(2.7-8.2)	(0.6-1.8)	(0.4-1.8)	(0.2-1.3)	(0.1-0.7)	(0.1-0.3)	(0.2-0.2)	(0-0.2)	
NO_x	16.8	15.1	13.3	13.3	13.8	12.1	10.3	5.7	
	(9.7-30.6)	(8.7-27.5)	(7.7-24.3)	(4-24.3)	(2-27)	(6.7-22.6)	(7.6-13)	(2.2-12.3)	
PM2.5	1.7	1.3	1.2	0.5	0.4	0.2		0.2	
	(0.9-3.4)	(0.7-2.6)	(0.5-2.3)	(0.3-1.0)	(0.1-0.7)	(0.1-0.4)		(0.1-0.3)	
CO_2			807.6	844.2	1,161.9	787.3		754.4	646.0
			(807.6-807.6)	(844.2-844.2)	(737.3-2,150.8)	(787.3-787.3)		(389.1-1,440.5)	(646-646)

Notes: Pre Euro was the emission standard implemented before Euro I. In China, the Euro I standard was implemented for heavy-duty vehicles in 2000 (Y. Wu et al. 2012). EEV stands for "enhanced environmentally friendly vehicles," which is somewhere between Euro 5 and Euro 6. Abbreviations: NG: natural gas; g/km: grams per kilometer; CO: carbon monoxide; NO_x: nitrogen oxides; PM2.5: particulate matter of 2.5 micrometers or less in diameter; CO_2: carbon dioxide; THC: total hydrocarbons.

Sources: He et al. 2018; S. Zhang et al. 2014; X. Wu et al. 2015; Yue et al. 2016; MEE 2014; Hu et al. 2009; Chen et al. 2017; Q. Song et al. 2018; Y. Wu et al. 2012; Yang et al. 2016.

Table 5 | **Carbon Dioxide Emission Factors by Country and Fuel**

Country	Diesel (g/L)	Electricity (g/kWh)	NG (g/MJ)
China	490.60	610.21	
India		731.20	
Mexico		449.00	
Brazil	428.18	110.21	
Austria		108.98	
France		48.48	
Germany		402.14	
Norway		11.18	
Sweden		12.60	
Switzerland		11.82	
European Union		326.90	
United Kingdom		244.71	
United States	567.92	427.03	10.32

Notes: Abbreviations: NG: natural gas; g/L: grams per liter; g/kWh: grams per kilowatt-hour; g/MJ: grams per Megajoule.

Sources: Dreier et al. 2018b; He et al. 2018; Zhou et al. 2016a; MJB&A 2013; Tao et al. 2016; Climate Transparency 2019; IMP 2017; EEA 2017; Rangaraju et al. 2015; Li and Yang 2020; EPA 2020.

the local grid emission factor is relatively low. Country-specific grid emission factors are shown in Table 5.

Grid emission factors also vary by electricity market and time of use, even within the same country (Holland et al. 2016). For example, in markets run by different independent system operators (ISOs) in the United States, the electricity mixes and emission factors vary. Also, when the generation capacity of renewables is higher (e.g., solar generation is high on sunny days), the electricity is cleaner than when the grid draws more on fossil fuel generation. Users are encouraged to use the most applicable emission factors from their target regions. However, as such detailed and local specific data are available only for a few places, and hard to collect in detail from all regions and countries, the default inputs of this tool are country averages.

3.2.4 Social Cost Factors

Social cost factors (SCFs), expressed in US$ per tonne of each pollutant, are the least available data type. Most countries do not have localized SCF data at either the national or city level. Results of existing studies still have high uncertainty. In this tool, we primarily used data on the social cost of carbon (SCC) from Ricke et al. (2018) as well as transport-specific SCFs of other air pollutants from Europe (van Essen et al. 2019), which covers all major impacts including health effects, crop loss, biodiversity loss, and material

Table 6 | **Social Cost Factors for Transport Emissions (US$/tonne)**

Country	CO_2	CH_4	N_2O	PM10	PM2.5	NO_x	CO	HC
Brazil	24.20			7,528.59	41,525.41	7,190.99		405.13
China	24.10	812.00	7,461.00	8,745.73	48,238.80	8,353.55	1,146.00	470.62
European Union	0.00			24,753.00	136,530.00	23,643.00		1,332.00
India	85.40			3,138.25	17,309.64	2,997.52		168.87
Mexico	11.90			9,679.07	53,386.78	9,245.03		520.85
United States	42.00	1,200.00	15,000.00	33,264.74	183,478.15	31,773.05		1,790.03
Global	417.00			10,236.80	56,463.06	9,777.75		550.86

Notes: European social cost factors (SCFs), and therefore the localized SCFs for other countries' air pollutants, cover all impacts including health effects, crop loss, biodiversity loss, and material damage. Abbreviations: CO_2: carbon dioxide; CH_4: methane; N_2O: nitrous oxide; PM10/PM2.5: particulate matter of 10 or 2.5 or less micrometers in diameter, respectively; NO_x: nitrogen oxides; CO: carbon monoxide; THC: total hydrocarbons.

Sources: SCFs for greenhouse gasses (CO_2, CH_4, N_2O): EPA n.d.; World Bank 2017; Ricke et al. 2018; World Bank and IHME 2016. SCFs for air pollutants were calculated through a value transfer approach based on data from the European Union (van Essen et al. 2019). We used a unit value transfer approach with income adjustments based on the recommendation of (van Essen et al. 2019; World Bank and IHME 2016).

damage. Then we localized the SCFs to other countries by using the income data of GDP (PPP) per capita from each country; we assumed income elasticity, e, to be 1.2 for low- and middle-income countries and 0.8 for high-income countries (World Bank and IHME 2016). See Table 6 for the SCFs used in the Tool and Section 4.4 for more information about the localization method.

3.3 Other Factors Affecting Efficiency and Emissions

Bus operational efficiency and emissions are affected by multiple other factors. In the default dataset under "Advanced Features," the Tool captures three key variables: operational speed, load factor, and air conditioning (AC). These factors are commonly discussed in papers and analyzed during road tests. Temperature and slope are environmental factors that affect the operational efficiency and emission factors of buses and are often of concern to operators during the initial phases of electric bus adoption. However, due to data availability, it is difficult to estimate the exact impact of these factors, which is discussed later as a limitation of this tool.

Ideally, correction factors for these variables can help adjust the variances. However, the data in the default dataset cannot generate a valid or robust correction factor. In addition, the information varies a great deal under different conditions, geographies, and even operational behaviors, so it would not be possible to use just one number to represent bus operational efficiency and emissions. Therefore, in this tool, default fuel efficiencies and emission factors are collected by different speeds and load factors and whether AC is running, when such information is available. Users may choose different combinations of these variables to get the specific fuel efficiency and emission factor information they are looking for.

Some additional explanations and analyses are provided in the next section, which try to capture the general impact these factors have on fuel efficiency and emissions with some ballpark numbers. Users can refer to the information when using the Tool.

3.3.1 Speed, Load Factor, and Air Conditioning

Studies generally agree that emission factors (in grams per liter or grams per kilowatt-hour) decrease as the vehicle speeds up and increase as the load increases (Huang et al. 2013; Yao et al. 2015; S. Zhang et al. 2014; He et al. 2018; X. Wu et al. 2015). However, the variations depend on specific operational conditions and local circumstances, which make it hard to modify EFs by a single correction factor. For instance, in a study in China (He et al. 2018), fuel consumption at the speed of 5–10 km/h is 2.00–2.65 times that at a speed over 30 km/h for a 10-meter electric bus; for a 12-meter electric bus, a 12-meter hybrid bus, and a 12-meter diesel bus, the numbers are 2.01–2.16, 2.77, and 2.61, respectively. In a study done in Brazil (Dreier et al. 2018b), when the speed decreases from 25–30 km/h to 15–20 km/h, the fuel consumption increases by 36 percent to 142 percent. Things are more complicated for air pollutants. He et al. (2018) show that for diesel buses, the correction factors in terms of speed (5–10 km/h versus over 30 km/h) of THC, NO_x, and PM2.5 are 3.16, 3.10, and 3.02, respectively. Calculated using the European Environmental Agency's (EEA's) 2019 air pollutant emission inventory guidebook, the emission factors at the speeds of 30 km/h versus 50 km/h of CO, THC, NO_x, and PM2.5 are 1.52, 1.54, 1.24, and 1.33, respectively (EEA 2019b).

In terms of passenger load, the EEA (2019a) indicates that emission factors for CO, THC, NO_x, and PM2.5 at full load compared with an empty load are 1.33, 0.99, 1.32, and 1.30, respectively. From empty load to half load, He et al. (2018) find an increase in the emission factors of pollutants varying from 1.13 to 1.33.

The fuel efficiency of ICE buses generally decreases on extreme hot and cold days due to the use of AC or a heating system (Kwon et al. 2017; S. Zhang et al. 2014a; S. Zhang et al. 2014c; He et al. 2018). Studies in China show that operating with air conditioning increases the fuel consumption of hybrid buses by 32–55 percent but only by 3–26 percent for diesel buses (S. Zhang et al. 2014b). Though most pollutant emissions increase as AC operates, emissions sometimes decrease; for example, by 40 percent for NO_x and 21 percent for THC emitted by hybrid buses (S. Zhang et al. 2014b) and by 9 percent for THC emitted by LPG buses (Hu et al. 2009).

3.3.2 Temperature

The impact of extreme temperature may be still larger for battery-powered electric buses. On cold days, there is no excess engine heat to be used for cabin heating (Rastani et al. 2019). And both excessively hot and cold temperatures lead to battery degradation or a reduction in battery range (Neubauer and Wood 2014; Yuksel and Michalek 2015).

3.3.3 Slope

Studies of light-duty and heavy-duty vehicles consistently show that on-road tailpipe emission factors increase with road grade or slope, due to larger driving resistance and more frequent high engine load points (Gallus et al. 2017; L. Zhang et al. 2019; Prakash and Bodisco 2019). The emissions characteristics for mountainous and lowland areas are therefore different. The effect is similar for ICE vehicles and electric vehicles. However, research focused on electric buses is still limited and it is hard to provide an accurate factor.

In addition, although not included in this tool due to a lack of data and variances, vehicle age, driving behavior, and fuel quality also impact efficiency and emissions. In general, older vehicles and aggressive driving behavior increase energy consumption. Higher octane fuels with less complete combustion may reduce fuel efficiency and increase emissions. Other factors are not included in the Tool because of inconsistent findings or difficulty quantifying the impacts. These include after-treatment devices like selective catalytic reduction (SCR) systems and particulate filters, which can significantly reduce NO_x and PM emissions, respectively (Weiss et al. 2012; Mccaffery et al. 2020). However, SCR may not function well when exhaust temperature is low (Liu et al. 2011; S. Zhang et al. 2014a). Evidence also shows that aggressive driving could contribute to high NO_x emissions (Huang et al. 2013; Prakash and Bodisco 2019), but driving styles are hard to define and quantify.

4. CALCULATIONS

The general output calculation methodology is the same as that in the first version of this tool, the Bus Costs and Emissions Appraisal Tool (Cooper et al. 2019). **Financing cost, annualized cost, unit cost, and emissions calculation methodologies are the same as those used in the previous version.** For local air pollutants, the categories have been narrowed down to PM2.5, PM10, NO_x, THC, and CO, given applicability. Simplification and adjustments were made in a few categories below, based on data availability, user friendliness, and electric bus–related features. The Tool also applies two general methods for cost-related calculations:

- A **present value (PV)** calculation is used to address lifespan differences between buses. All direct and indirect costs of buses over their lifetimes are discounted to present values so that costs are comparable. Avoided social costs, or social benefits, are also translated into present values. However, a net present value approach is not used here since the costs and social benefits are not calculated in a comparable way—all bus costs are private costs to the internal account of bus operators, while social benefits represent the external benefits that are in the category of the public account—and they cannot simply be added together.
- **Total cost of ownership (TCO)** is used for the bus cost calculation because of the different cost profiles of different bus technologies over different bus lifespans. Electric buses can have higher upfront procurement costs, but can save costs during operation and have longer operational lives. Although the higher upfront costs may not be ideal for bus operators, the total costs may be lower over the lifetime of a bus. TCO methodology can thus be a more accurate way to make cost comparisons between diesel and electric buses. In this tool, TCO is translated into present value for final comparison.

4.1 Capital Costs

The capital cost, or upfront procurement cost, calculation has been adjusted slightly from the previous version of the Tool (Equation 1). A subsidy is included in the function to capture the public grant option. A subsidy need not be considered if the procurement cost or down payment is not the original price and already includes a subsidy (e.g., in China's case, the procurement cost reflects the original procurement price minus the government procurement subsidy). Infrastructure cost includes procurement and construction costs. Users have the flexibility not to include subsidy- and infrastructure-related costs, and to adjust the number of chargers and the electricity price based on their business models.

Equation 1.

$$\begin{aligned}&\textit{PV of Lifetime Capital Cost}\\ &= DP - RV - Subsidy + n \times (IFP+IFC) + \sum_{i=1}^{L} \frac{P_i}{(1+r)^i}\end{aligned}$$

where DP = down payment; RV = PV of bus's residual value; n = number of infrastructures; IFP = infrastructure procurement cost and IFC = infrastructure construction cost, both of which happen in year 0; P_i = principal in year i; r = discount rate; L = bus useful life; i = year i.

4.2 Operation and Maintenance Costs

The operation and maintenance costs are simplified in this tool and incorporate cost categories listed and defined as follows: Labor cost is the operating labor cost; fuel cost includes the cost of electricity if the bus uses electricity; other operating costs include insurance and any additional operating costs; maintenance costs include a fixed annual maintenance cost and maintenance labor cost (depending on business model); the overhaul cost is a one-time engine overhaul or battery replacement cost occurring during the bus's lifespan (Equation 2).

Equation 2.

$$\begin{aligned}&\textit{Total O\&M Cost}\\ &= \textit{Labor Cost} + \textit{Fuel Cost} + \textit{Other Operating Costs}\\ &\quad + \textit{Maintenance Costs} + \textit{Onetime Overhaul}\\ &\quad\ \textit{Cost} + \textit{Infrastructure O\&M Costs}\end{aligned}$$

4.3 Infrastructure O&M Costs

In the previous version of the Tool, the variable "(additional) depot/infrastructure cost" was considered a one-time upfront cost for infrastructure in the initial year (year 0). It was calculated based on the infrastructure construction cost, the retrofit cost, and the cost of other special tools. In this version, infrastructure cost represents only procurement and construction costs. Other costs related to operating and maintaining the infrastructure in some business models are captured in this new category. To simplify the calculation and given data availability, the costs are calculated based on the annual operation and maintenance costs of the overall infrastructure (e.g., all chargers operated by the bus operator), rather than on the basis of a single infrastructure.

The PV of total infrastructure-related costs is also included in the outputs, combining the PV of infrastructure-related capital costs and the PV of infrastructure O&M costs (Equation 3). The costs are split into two categories in the Tool.

Equation 3.

$$\textit{PV of Lifetime Infrastructure O\&M Cost} = \sum_{i=1}^{L} \frac{(IFO+IFM)_i}{(1+r)^i}$$

where *IFO* = annual infrastructure operation cost shared by all infrastructures; *IFM* = annual infrastructure maintenance cost shared by all infrastructures; *r* = discount rate; *L* = bus useful life, *i* = year *i*.

Maintenance and Overhaul Costs

Maintenance costs (Equation 4) and overhaul costs (Equation 5) are simplified in the Tool, due to data availability, differences in maintenance models, and the reduced need for overhaul due to technology enhancement. However, a one-time overhaul cost is still included in the Tool to capture the potential need for engine overhaul and battery replacement.

Equation 4.

$$\textit{PV of Lifetime Maintenance Cost} = N \times \sum_{i=1}^{L} \frac{(FAM+AM+ML)_i}{(1+r)^i}$$

where *N* = number of buses within a bus type; *FAM* = fixed annual maintenance cost; *AM* = additional maintenance cost; *ML* = maintenance labor; *r* = discount rate; *L* = bus useful life, *i* = year *i*.

Equation 5.

$$\textit{PV of Lifetime Overhaul Cost} = N \times \frac{OO_n}{(1+r)^n}$$

where *N* = number of buses within a bus type; *OO* = One-time engine overhaul cost or battery replacement cost; *r* = discount rate; *L* = bus useful life, *n* = the year when the overhaul happens (*n* = L/2+1 if L is even and *n* = (L+1)/2 if L is odd).

4.4 Social Cost

We employed a commonly used, top-down approach to calculate social cost due to its simplicity and fewer data requirements. This practice entails reviewing the existing studies, obtaining initial social cost factors (usually in $/tonne) from different countries, and localizing the SCFs through a "value transfer" method (NEEDS 2009). SCFs measure the total social cost per unit mass pollutant within specified geographical boundaries. The social cost, therefore, can be estimated by multiplying SCF (in US$/tonne) by the amount of each air pollutant (in tonnes) within a specific region. Although it has a high level of uncertainty, it is the most appropriate way to evaluate social costs for a tool like this that covers multiple geographic regions. The total social costs (Equation 6) are represented separately as the sum of the costs of CO_2 (as the climate forcer) and the sum of all air pollutants (as the local public health threats; i.e., PM2.5, PM10, NO_x, THC, and CO).

Equation 6.

$$\textit{PV of Social Cost}_j = N \times \sum_{i=1}^{L} \frac{Emission_{ij} \times SCF_j}{(1+r)^i}$$

where *Emission* = annual emissions of a certain air pollutant; *SCF* = social cost factor of a certain air pollutant; *r* = discount rate; *j* = type of atmospheric emissions, *i* = year i.

The value transfer method is applied to localize SCFs in the Tool. The value transfer procedure converts the estimated values from the "study site" to "another site" by adjusting for income. It can fill in gaps where country or regional values are not available from primary sources (van Essen et al. 2019). PPP-adjusted GDP per capita is used for value transfer calculations to address income differences across countries. This is an intermediate step and not an outcome calculation. The function is shown in Equation 7:

Equation 7.

$$\mathrm{SCF_{os}} = \mathrm{SCF_{ss}} \times \left(\frac{\text{GDP (PPP) per capita}_{\mathrm{os}}}{\text{GDP (PPP) per capita}_{\mathrm{ss}}}\right)^{e}$$

where, *PPP-adjusted GDP per capita* is in US$/capita; SCF is in US$/tonne; *OS* is the "other site," or the other city or country for which we'd like to calculate SCFs; *SS* is the study site that already has the local SCF data; *e* is income elasticity of SCF, where income is the PPP-adjusted GDP per capita. We assume e = 1.2 for middle-income countries and 0.8 for high-income countries (World Bank and IHME 2016).

5. LIMITATIONS AND FUTURE DEVELOPMENT OF THE TOOL

5.1 Limitations

Given the universal nature of the Tool and its global target audience, the Tool includes only general data and simplified functions to increase its applicability.

The use of general data points from a literature review may not reflect real-world performance results. In addition, since the Tool has many variables and requires user input, the outputs also involve uncertainty. As briefly mentioned in Section 3.2, the data included in the Tool differ greatly across countries. Besides the factors that impact fuel efficiency and emissions discussed in Section 3.3, bus procurement, operation, and maintenance costs also depend on local context. Thus, if users use only the default cost information provided by the Tool, or default data combined with some local information, the results can provide only a general picture of the potential costs, rather than an estimate of the actual costs. Therefore, we recommended using the Tool as a first step in understanding the costs and social benefits of using different bus technologies. Other planning tools[7] can be applied together with this one to provide a comprehensive picture of the situation and help bus operators and city officials plan for a bus fleet upgrade.

The adoption of simplified functions—such as in the financing options section—is another limitation of the Tool. Table 7 shows some examples of procurement models and payment options observed in 22 cities operating electric buses (Moon-Miklaucic et al. 2019). It is hard to capture these nuances in one tool. However, the key differences in procurement costs and loan options have been included. In addition, cost categories, accounting rules, and other economic variables like discounting factors impact the results but are highly variable locally. Related information in this tool is only a reference point.

The social cost calculation methodology adopted in this tool also has limitations.

SCF values for certain air pollutants (e.g., PM2.5) can vary by more than three orders of magnitude (S. Song 2017). The reason could be that citizens assign very different willingness-to-pay values to pollution and health, or that the literature is very limited, with most existing studies still in their early stages and showing significantly different results (S. Song 2018; van Essen et al. 2019). The uncertainties in social cost evaluations will remain for a long time and sometimes be unavoidable, especially for developing countries (van Essen et al. 2019).

The current value transfer approach (using income adjustment) might underestimate SCFs in some countries or cities with high population densities. There is a positive correlation between SCFs and the density of the exposed population (S. Song 2017), so ignoring the influence of density might cause inaccurate SCF estimates. Future studies should further adjust the SCFs based on this and other factors, if necessary. For example, we will further develop the methodologies of SCF localization techniques to consider population density and many other characteristics in the countries for which we have data to better predict values in other places (e.g., benefit function transfer technique, meta-analysis if there are more available data). Decision-makers should also keep in mind that some uncertainties will always be there. And given current data limitations, the estimates could not include all negative externalities such as social inequity. Decision-makers should always pay attention to the range of uncertainty and provide a detailed interpretation about why it exists.

5.2 Potential Future Development of the Tool

The Tool in its current form may not address all the concerns and needs of the intended audience. Additional related functions may be added to the Tool following user feedback. The topics below are regularly raised in discussions about electric buses. They are worth discussing by policy-makers and bus operators but are not the current focus of the Tool.

Impact on the job market. The growth of electric vehicles is transforming the entire vehicle industry. New players, such as stakeholders along the battery supply chain and charging infrastructure manufacturers, are

Table 7 | **Examples of Different Payment and Acquisition Methods for Electric Buses**

Type of Acquisition	Source	Features
Cash purchases		Grants often cover upfront costs but are time-limited and irregular
		Preferential pricing sets prices at rates lower than otherwise available in the market
		In-kind incentives provide support in the form of goods, services, training, and transactions that do not involve money
	Operating budgets and budget transfer	Often used to cover operational or capital expenses
		Includes farebox revenue and revenue from other operations such as property leasing and advertising or taxes
Debt financing	Concessional loan	Provided by financier at flexible lending conditions
		Can encourage higher lending rates among local banks for environmentally beneficial investments
	Green bond	Created to fund projects that have positive environmental or climate benefits
		Backed by issuer's entire balance sheet
Leasing	Lease-to-buy	Between operator and bus manufacturer
		Operator pays rent over the course of the agreed-upon lease period and then purchases the bus at a designated price at the end of the contract
		Allows operators to purchase buses without tying up their cash
	Purchase-leaseback	Seller of asset leases the same asset from the buyer they sold it to
		Especially used in cities where third party leasing companies are not allowed to purchase vehicles directly
		Details of arrangement are made immediately after sale of the asset
	Battery lease	Manufacturers own battery during lease term, and replace batteries when needed
	Operating lease	No residual value risks
		Predictable cash flow and cash flow benefits due to fixed monthly cost
		Monthly payment paid out of operating income and offset against taxable profits
	Financial lease	Only pay interest on the outstanding value
		Potential tax and VAT benefits
		Trade-in value: potential to profit from careful maintenance and use
		Vehicle appears as an asset on the balance sheet

Sources: Moon-Miklaucic et al. 2019.

entering the market, whereas vehicle maintenance workers and those in the conventional vehicle manufacturing industry may experience job losses (Todd et al. 2013). The Tool has a labor input regarding bus operators and maintenance workers but does not address the dynamics of the labor market.

Operation decisions and implications. Ideally, electric buses can replace ICE buses at a 1:1 ratio. However, due to various factors impacting the actual bus fleet operation—such as bus route selection, operation schedule, technology maturity, and location of charging infrastructure—the number of electric buses needed may be more than the number of original ICE buses (Xue et al. 2019). The Tool allows users to assume a certain replacement ratio in the advanced features, but does not help users estimate what the ratio is.

Maintenance decisions and implications. Electric buses generate lower maintenance costs because they are less complicated mechanically than diesel buses (Borén 2019), though battery replacement can be a burden to operators. In China, manufacturers usually provide guarantees for battery maintenance and/or replacement, with details differing by contract. Maintenance schemes also differ, with some operators employing labor on-site, and others contracting out for a service package. Such variations are hard to capture in this tool and need to be analyzed on a case-by-case basis.

Charging infrastructure planning and business models. The Tool mainly focuses on the bus fleet. Charging infrastructure is considered in a general manner, but is not correlated with the features of buses. Charging infrastructure location planning itself is an important topic for electric vehicle adoption and requires detailed modeling work, which is not within the scope of this tool. Business models for charging infrastructure vary by location and company (Hove and Sandalow 2019) and bus operators are encouraged to work with local service providers to determine the models that are most applicable.

Financial planning and risk assessment. The Tool can compare the costs of different financial mechanisms used when purchasing buses, including financial products like subsidies and loans or other options such as preferential electricity rates and battery leasing to reduce cost factors. Users can apply the results to analyze the potential financial risks of different financing options to the bus operators, considering the operators' existing financial situations, such as revenue profiles and other expenses. However, due to the existing scope, the Tool cannot provide a comprehensive risk assessment for users, other than making cost comparisons among different scenarios. In addition, the Tool does not allow users to directly explore and develop potential financing options. Measures such as battery leasing and financial leasing are innovative financing options that help lower the risks and costs associated with electric bus procurement (Moon-Miklaucic et al. 2019). Whether operators should adopt any new mechanisms should be analyzed on a case-by-case basis. Users can compare the cost implications associated with different financing options by adjusting the inputs in the Tool, but the current version of the Tool does not make recommendations to users about which financial mechanism might be optimal for them.

This tool provides an entry point for users to compare cost, operational, and emission data for different types of buses and understand the cost, emission, and social benefit implications of converting from diesel to electric bus fleets. City governments and bus operating agencies should conduct detailed analyses based on local information and business models before making any decisions regarding their bus fleets.

APPENDIX 1. EXPLANATIONS OF INPUTS

Variable	Unit	Description
Country*	Investment incentive	Countries with default data. For the current version, users cannot customize country name, but can select the available country that best reflects the conditions in their location.
City		Cities with default data. For the current version, users cannot customize city name, but can select either the available city that best reflects the conditions in their location or "general" to see country averages for the remaining variables. Users can input their own data in both cases.
Discount rate*	%	A discount rate is the rate of return used to discount future cash flows back to their present value.
Social discount rate*	%	The social discount rate (SDR) is the discount rate used in computing the value of funds spent on social projects. It is an estimate of how society values consumption at different points in time. This gives a social time preference (STP) approach that is appropriate for discounting costs and benefits measured in consumption units. The SDR reflects a society's relative valuation of today's well-being versus well-being in the future. The appropriate selection of an SDR is crucial for cost-benefit analysis and has important implications for resource allocations. SDR is normally lower than corporate discount rates. There is wide diversity in SDRs, with developed nations typically applying a lower rate (3–7%) than developing nations (8–15%). The selection of the SDR is highly controversial and there is no consensus among economists. It is good practice to not use a single SDR, but to apply a stochastic approach whereby the SDR varies with the expected outcomes. It is also widely accepted that SDRs should decline over time, giving increasingly more weight to future generations. It is worth noting that the SDR used in the Tool incorporates social projects that address other issues in addition to climate change. Thus, it is larger than the near-zero SRD (0–3%) used for climate-related projects; e.g., the SDR for the United States is set at 7% in the Tool, and that for the UK at 3.5%.
Bus Fleet Information		
Bus size*	m	The Tool includes a variety of bus lengths. The most common is 12 meters (m), which is the major city bus length in many countries. The available bus sizes in the drop-down list within the Tool depend on the available default data in the city or country selected.
Fuel type*	L, kWh, MJ	The Tool includes common fuel types, including diesel, hybrid, electric, natural gas (compressed natural gas and liquified natural gas), gasoline, and liquified petroleum gas (LPG). The units vary based on the fuel type for emission factors and fuel efficiency. Normally, for diesel, hybrid, and gasoline buses, liters (L) are used; for electric buses, kilowatt-hours (kWh) are used; and for natural gas and LPG buses, Megajoules (MJ) are used.
Emission standard*		The Tool specifies only European emission standards based on data availability and to reduce the complexity of the Tool. Some countries may have their own emission standards but these are not reflected in the Tool. Users can refer to Section 3.2.3 for more information.
Number of buses*		The number of buses in a fleet.

Annual distance traveled (VKT)*	km	The (average) annual distance a bus of a certain type travels.
Operational years*	years	The typical useful life of a bus of a certain type. This should reflect the length of time after which buses must be retired or sold for reuse.
Fuel efficiency*	L/100 km kWh/100 km MJ/100 km	Fuel consumption by distance traveled.
Cost Factors		
Procurement		
Purchase price*	$/bus	The cost to buy one bus of a certain type, including all taxes and deductions that may be applied toward the base price.
Procurement subsidy	$/bus	The subsidies that can be applied to this bus, if not included in the purchase price.
Residual value*	%	The expected residual value of a single bus of a certain type.
Down payment*	%	The percentage required as a down payment for a loan to finance a bus of a certain type.
Loan interest rate*	%	The yearly interest rate that a certain bus type's loan will have.
Loan time*	years	The expected term of the loan.
Operation		
Annual labor cost (operation)	$/bus/year	The total cost to hire drivers for a certain bus type. Any factors taken into account for one bus type and fleet should also be included in subsequent bus types and fleets to remain consistent.
Fuel price*	$/L $/kWh $/MJ	The current fuel price for a certain bus type.
Fuel cost projection	%	The projected annual increase or decrease in fuel price for a certain bus type.
Additional fuel price*	$/bus/year	The cost for any fuel additive, charging service fee, or other fee.

Additional operational costs	$/bus/year	Any other operational costs that weren't covered in the previous categories. Any factors taken into account for one bus type and fleet should also be included in subsequent bus types and fleets to remain consistent. Battery leasing costs can be included in this category.
Insurance	$/bus/year	The cost of any insurance used.
Maintenance		
Annual general maintenance cost*	$/bus/year	The average maintenance cost for one bus of a certain type. If the maintenance is not done in-house, but contracted out, then the contract costs should be included here.
Annual labor cost (maintenance)	$/bus/year	The total cost to hire maintenance workers for a certain bus type. Any factors taken into account for one bus type or fleet should also be included in subsequent bus types and fleets to remain consistent.
Additional maintenance costs	$/bus/year	Any other maintenance costs that weren't covered in the previous categories. Any factors taken into account for one bus type or fleet should also be included in subsequent bus types and fleets to remain consistent.
One-time overhaul cost	$/bus	The Tool assumes only one overhaul during the total lifespan of a bus, if one is needed. It largely depends on the operator's contract with the manufacturer, and whether the operator decides to replace the entire vehicle at once or just key parts. The cost of a battery replacement or engine overhaul can be included here for electric buses and ICE buses.
Infrastructure		Infrastructure related to charging (for electric vehicles) or fuel filling (for ICE vehicles). Depots are not considered a default infrastructure-related cost. However, if users want to include depot-related costs, they should fill in related information as annual operational costs, maintenance costs, or other one-time costs, based on local business models for depots. Users can refer to Section 2.3 for more information.
Additional		
Administration	$/year	Any overarching indirect costs that weren't covered in the previous categories, but that are important to include for the correct cost calculation of a certain fleet.
Other taxes and fees	$/year	Any additional taxes and fees that weren't covered in the previous categories, but that are important to include for the correct cost calculation of a certain fleet.

Emission factors		Emission factors include tailpipe emissions (tank-to-wheel) and upstream emissions (well-to-tank).
Tailpipe	g/L, g/MJ	The default data are collected by bus length, fuel type, and emission standard, when such data are available for tailpipe emissions. Tailpipe emission factors cover air pollutant emissions and carbon emissions for all types of buses. Electric buses have zero tailpipe emissions in this tool.
Upstream	g/kWh	Upstream emission factors are collected for different fuels, including emission factors of fossil fuel production processes, and grid emission factors, which account for emissions generated by electricity used when operating electric buses. Upstream emission factors cover carbon emissions for all types of buses.
Social cost factors		The Tool defines social cost as the cost of externalities. Social cost factors measure the total social cost per unit mass of each pollutant (in US$/tonne) at the national level. Social cost represents the sum of the private (internal) and external costs (Korzhenevych et al. 2014; S. Song 2017).
Advanced features		Please refer to Sections 2.2 and 3.3 for more information.
Replacement ratio		The replacement ratio refers to the number of electric buses—or buses with more advanced technology—it takes to achieve the same level of service as one traditional ICE bus. Ideally, the ratio is 1:1. We recommend users use 1:1 and 2:1 to represent different scenarios and levels of technology readiness.

Notes: Variables with an asterisk represent mandatory variables. When data are either not available or not applicable, a 0 must be filled in for the Tool to function. Abbreviations: ICE: internal combustion engine; km: kilometer; L/100 km: liters per 100 kilometers; kWh/100 km: kilowatt-hours per 100 kilometers; MJ/100 km: Megajoules per 100 kilometers; g/L: grams per liter; g/MJ: grams per Megajoule; g/kWh: grams per kilowatt-hour.

Source: Authors.

APPENDIX 2. DEFAULT DATA

Table A2.1 a–g | **Tailpipe/Exhaust Emission Factors for 12-Meter Buses by Country/Region**

a.

China	Diesel						Hybrid			Gasoline						NG			
	Pre Euro	Euro I	Euro II	Euro III	Euro IV	Euro V	Euro III	Euro IV	Euro V	Pre Euro	Euro I	Euro II	Euro III	Euro IV	Euro V	Euro II	Euro IV	Euro V	EEV
CO	31.1	29.1	25.3	19.2	8.5	4.3	1.0	3.2		522.2	316.8	79.2	42.8	21.0	21.0	17.9	7.0	1.2	9.8
CO_2			807.6	844.2	996.7	787.3		736.0	646.0							667.7	1,056.1		836.5
HC	5.9	1.3	0.8	0.6	0.2	0.1	0.2	0.1		17.0	16.4	6.2	2.9	1.5	1.5	6.5		1.4	1.5
NO_x	19.5	17.5	15.3	15.2	16.1	14.3	10.3	5.9		7.5	3.9	3.9	2.3	1.2	0.9	19.8	6.9	4.4	5.8
PM2.5	1.9	1.5	1.3	0.6	0.4	0.2		0.2		0.5	0.2	0.1	0.1	0.1	0.1				

b.

India	Diesel	NG
	Euro II	Euro II
CO	1.2	3.2
CO_2	782.1	729.7
THC	0.2	1.5
NO_x	8.6	5.4

c.

	Austria		France		Germany		Norway		Sweden		Switzerland	
	Diesel	NG	Diesel	NG	Diesel	NG	Diesel	NG	Diesel	NG	Diesel	NG
CO	1.2	0.7	1.9	0.7	0.7	1.2	0.8	0.8	1.6	0.8	0.7	0.8
CO_2	831.5	827.0	952.1	1006.9	1223.9	1291.8	831.2	987.5	1032.5	1019.9	1143.6	1114.8
THC	0.1	0.2	0.1	0.2	0.1	0.4	0.0	0.3	0.0	0.3	0.0	0.3
NO_x	2.0	0.9	3.7	1.5	3.4	2.5	1.8	1.2	2.5	1.3	3.5	1.6
PM2.5	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0

d.

	Mexico	Chile		Colombia		Brazil			
	Diesel	Diesel	Hybrid	Diesel	Hybrid	Diesel		Hybrid	
						Average	Euro V	Average	Euro V
CO	26.7	7.6	0.4	6.4	3.3	7.1		2.6	
CO_2	750.0	993.8	667.4	1,011.0	843.7	1,257.8	1,341.2	1,232.1	595.4
THC		0.1	0.0	0.5	0.0	0.2		0.1	
NO_x	5.7	14.1	2.6	12.2	3.9	11.8		8.1	

e.

US	Diesel	Hybrid	NG
CO	5.1	0.1	3.4
THC	0.0	0.0	3.6
NO_x	7.4	0.5	4.1
PM2.5	0.3		0.0
CO_2	922.4	1,008.8	897.3

f.

UK	Diesel						
	Pre Euro	Euro I	Euro II	Euro III	Euro IV	Euro V	Euro VI
CO	5.7	3.1	2.6	2.5	0.3	0.26	0.3
THC	2.1	1.0	0.6	0.5	0.0	0.03	0.0
NO_x	16.9	10.9	11.5	10.4	6.0	3.76	0.8
CO_2	1,249.5	1,045.7	1,006.5	1,056.8	998.6	1,020.92	1,020.9

g.

EU	Diesel								NG			
	Pre Euro	Euro I	Euro II	Euro III	Euro IV	Euro V	EEV	Euro VI	Euro I	Euro II	Euro III	EEV
CO	5.6	2.5	2.2	2.3	1.1	1.5	0.15	0.2	8.4	2.7	1.0	0.6
THC	1.7	0.6	0.4	0.4	0.1	0.1	0.01	0.0	7	4.7	1.3	1.2
NO_x	17.1	11.1	11.4	9.6	6.4	4.3	6.35	0.6	16.5	15.0	10.0	3.8
PM2.5	0.8	0.4	0.2	0.2	0.0	0.0		0.0	0.02	0.0	0.0	0.0

Notes: Units are in grams per kilometer. Emission standards are provided if they were given in the source. Abbreviations: NG: natural gas; CO: carbon monoxide; CO_2: carbon dioxide; THC: total hydrocarbons; NO_x: nitrogen oxides; PM2.5: particulate matter of 2.5 micrometers or less in diameter.

Source: CARB 2019; Chen et al. 2017; Dreier et al. 2018; Ntziachristos and Galassi 2014; EEA 2019a; Guo et al. 2015; Goswami and Chandra Tripathi 2019; Giraldo and Huertas 2019; Matzer et al. 2019; He et al. 2018; Hu et al. 2009; MEE 2015; Merkisz et al. 2016; MJB&A 2013; ISSRC 2013; Roychowdhury 2010; Q. Song et al. 2018; X. Wu et al. 2015; Y. Wu et al. 2012; S. Zhang et al. 2014b; S. Zhang et al. 2014c; Zhou et al. 2016.

Table A2.2 | **Fuel Efficiency of 12-Meter Buses by Country/Region**

Country	Emission Standard	Diesel (L/100km)	Electric (kWh/100km)	Hybrid (L/100km)	NG (MJ/100km)
China	Average	40.9	149.9	33.1	1,437.3
	EEV				1,410.0
	Euro II				
	Euro III	30.7			
	Euro IV	31.8			
	Euro V	37.1		28.2	
India	Average	29.0		24.3	
	Euro I	24.5			
	Euro II	26.0			
	Euro III	23.4			
	Euro IV	22.6			
Austria	Average	30.9	136.7		1,471.9
	France	36.0	133.3		1,627.1
Germany	Average	46.6	262.0		1,967.4
	Norway	31.4			1,595.7
Sweden	Average	39.3	157.6		1,648.0
	Switzerland	43.4	188.2		1,978.4
United Kingdom	Pre Euro	55.2			
	Euro I	44.4			
	Euro II	42.3			
	Euro III	45.8			
	Euro IV	42.4			
	Euro V	44.0			
	Euro VI	44.0			
Mexico	Average	34.4			
Chile	Average	37.5		25.2	
Colombia	Average	37.7		31.8	
Brazil	Average	49.1		43.7	
	Euro V	44.6		10.1	
European Union	Pre-Euro	43.6			
	Euro I	35.8			2,664.0
	Euro II	35.8			2,472.0
	Euro III	35.8			2,184.0
	Euro IV	35.8			
	Euro V	35.8			
	EEV				2,184.0
	Euro VI	35.8			

United States	Diesel (L/100km)	Electric (kWh/100km)	Hybrid (L/100km)	NG (MJ/100km)	Gasoline (L/100km)	LPG (MJ/100km)	Biodiesel (L/100km)
Average	46.1	154.1	46.7	2,171.8	32.1	1,812.8	66.8

Notes: Abbreviations: NG: natural gas; LPG: liquified petroleum gas; L/100 km: liters per 100 kilometers; kWh/100 km: kilowatt-hours per 100 kilometers; MJ/100 km: Megajoules per 100 kilometers.

Sources: Chen et al. 2017; Roychowdhury 2010; Guo et al. 2015; Boulter et al. 2009; Giraldo and Huertas 2019; Gota et al. 2014; He et al. 2018; MJB&A 2013; Barnitt and Chandler 2006; Dreier et al. 2018; X. Wu et al. 2013; Q. Song et al. 2018; EEA 2019a; Zhou et al. 2016; Borén 2019; APTA 2018; Dallmann 2019; Goswami and Chandra Tripathi 2019; Barnitt et al. 2008; GGGI and CSTEP 2016; Lammert 2008; Göhlich et al. 2014; Barnitt 2008; Huo et al. 2012; ISSRC 2013; HBEFA 2019; Prohaska et al. 2016; AC Transit 2018; S. Zhang et al. 2014b.

Table A2.3 | **General Profiles of Countries in the Tool**

Country	Discount Rate	Discount Rate Year	Social Discount Rate	Social Discount Rate Year	Inflation Rate	Bank Lending Rate	Bank Lending Rate Year
United States	0.25%	2020	3.50%	2018	0.60%	3.25%	2020
United Kingdom	0.10%	2020	3.50%	2018	1.20%	0.35%	2020
European Union	0.25%	2017	3.00%	2018	1.20%	0.25%	2018
Austria	0.00%	2020	3.00%	2018	0.40%	1.33%	2020
Poland	0.10%	2020	3.00%	2018	3.20%	2.41%	2020
France	0.25%	2017	3.00%	2018	0.30%	1.20%	2020
Germany	0.25%	2017	3.00%	2018	0.30%	1.93%	2020
Sweden	0.00%	2020	3.00%	2018	0.50%	0.10%	2020
Switzerland	-0.75%	2020	3.00%	2018	-0.40%	2.63%	2020
Brazil	8.73%	2020	5.10%	2008	3.60%	40.73%	2020
China	2.90%	2020	8.70%	2019	3.00%	4.35%	2020
India	4.25%	2020	9.90%	2019	3.30%	13.50%	2020
Chile	3.35%	2015	4.60%	2008	3.40%	4.82%	2020
Colombia	6.25%	2019	4.20%	2008	3.50%	9.96%	2020
Mexico	7.25%	2017	3.30%	2008	2.70%	6.30%	2020

Sources: CEIC 2020a; CEIC 2020b; Trading Economics 2020a; Trading Economics 2020b; Moore and Vining 2018; Freeman et al. 2018; Lopez 2008; Global Petrol Prices 2020.

Table A2.4 | **Fleet Assumptions**

Country	VKT (km/year /bus)	Operational Years	Average Speed (km/h)	Bus Length (m)	Residual Value (%)	Charger Construction Costs ($)	Charger Procurement Cost ($)	Charger Operation Costs ($/year)	Charger Maintenance Costs ($/year)
United States	40,250	12	>30	12	0	28,312	75,000		
United Kingdom	60,000	12	20-25	12	0	28,312	75,000		
European Union	60,000	12	20-25	12	0	28,312	75,000		
Austria	60,000	12	20-25	12	0	28,312	75,000		
Poland	60,000	12	20-25	12	0	28,312	75,000		
France	60,000	12	15-20	12	0	28,312	75,000		
Germany	60,000	12	20-25	12	0	28,312	75,000		
Sweden	60,000	12	20-25	12	0	28,312	75,000		
Switzerland	60,000	12	15-20	12	0	28,312	75,000		
Brazil	88,000	10	20-25	12	0	5,784	20,128.32	867.60	86.76
China	57,962	13	15-20	12	0	5,784	20,128.32	867.60	86.76
India	39,600	15	15-20	12	0	5,784	20,128.32	867.60	86.76
Chile	111,120	12	20-25	12	0	5,784	20,128.32	867.60	86.76
Colombia	60,000	12	20-25	12	0	5,784	20,128.32	867.60	86.76
Mexico	60,000	12	20-25	12	0	5,784	20,128.32	867.60	86.76

Notes: Abbreviations: VKT: vehicle kilometers traveled; km: kilometers; m: meters.

Sources: Nicholas 2019; Shengang Securities 2020; Urban Bus Toolkit 2006; Q. Song et al. 2018; ACEA 2020; MEE 2012; Dimensions.com n.d.

ENDNOTES

1. It is worth noting that emissions at power plants will increase as the plants generate electricity to power the vehicles, redistributing the pollution that previously came from vehicle tailpipes in densely populated areas to power plant locations, which tend to be less populated.

2. PM10 and PM2.5 refer to particulate matter with diameters of 10 and 2.5 micrometers or less, respectively.

3. In the Tool's database, most studies include carbon dioxide, methane, and nitrous oxide using the 100-year global warming potentials suggested by the Fifth Assessment Report of the United Nations Intergovernmental Panel on Climate Change: 1,34, and 298, respectively; one US study included black carbon (with a global warming potential of 900) instead of nitrous oxide.

4. Work in progress.

5. This does not necessarily mean that data are more available in these regions, or that the results are more accurate for these regions. The dataset is not intended to be comprehensive. The collection process and the size of the dataset were limited by time and resources available.

6. Emission standards other than European standards exist; for example, the U.S. Environmental Protection Agency standards are used in Central American countries and those that have signed on to the North American Free Trade Agreement. However, these standards are not included in this version of the tool. Future development may cover more emission standards.

7. Work in progress.

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We use our research to influence government policies, business strategies, and civil society action. We test projects with communities, companies, and government agencies to build a strong evidence base. Then, we work with partners to deliver change on the ground that alleviates poverty and strengthens society. We hold ourselves accountable to ensure our outcomes will be bold and enduring.

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We don't think small. Once tested, we work with partners to adopt and expand our efforts regionally and globally. We engage with decision-makers to carry out our ideas and elevate our impact. We measure success through government and business actions that improve people's lives and sustain a healthy environment.

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