FINANCING THE TRANSITION TO SOOT-FREE URBAN BUS FLEETS IN 20 MEGACITIES

JOSHUA MILLER, RAY MINJARES, TIM DALLMANN, LINGZHI JIN



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International Council on Clean Transportation
1225 I Street NW Suite 900
Washington, DC 20005 USA

communications@theicct.org | www.theicct.org | @TheICCT

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EXECUTIVE SUMMARY

Urban buses produce one-quarter of black carbon emissions from road transport, despite constituting only 1% of the global on-road vehicle fleet. Black carbon is a potent short-lived climate pollutant with a warming impact 900 to 3200 times that of carbon dioxide. As a harmful ultrafine component of particulate matter, black carbon operates as a universal carrier of toxins into the lungs and bloodstream, thereby contributing to premature deaths from outdoor air pollution globally. These black carbon emissions come from older-generation diesel engine technology, found in more than 80% of new buses sold today. Investments in "soot-free" engine technology in urban bus fleets will accelerate progress toward addressing urban air pollution and near-term climate change.

This report addresses the opportunities for facilitating, and the barriers to financing, the transition to soot-free urban bus fleets in 20 megacities. A soot-free engine is any diesel or alternative fuel engine that meets Euro VI or U.S. 2010 emission standards, such as any diesel engine with a diesel particulate filter, gas engine, or dedicated electric drive engine. These engines, in combination with ultralow-sulfur diesel (10 ppm S or less) or alternative fuels, are capable of a 99% reduction in diesel black carbon emissions. The Climate & Clean Air Coalition (CCAC) launched the Soot-Free Urban Bus Fleets Project in 2015 to accelerate the deployment of soot-free engine technologies in 20 large cities around the world. This report provides the technical basis for city officials, local fleet operators, and financial institutions to jointly increase the finance of soot-free urban bus fleets in these cities.

Despite higher upfront cost, a transition to soot-free technology in these 20 cities over the next 10 years is associated with cumulative cost savings in the tens of billions of dollars. In these cities, soot-free urban bus fleets will on average deliver lower total cost of ownership, relative to the higher-polluting buses purchased today, within 5 to 9 years of purchase. These buses would require lower financial outlays over the life of the vehicle in most cities (17 of 20) and under most cases (including a wide range of diesel prices, capital costs, and bus operating efficiencies), despite a higher upfront cost. For example, a 10-year shift to soot-free technologies in all 20 cities assuming median diesel fuel prices would result in 3% to 40% lower total cost of ownership (see Figure ES-1). These cost savings are attributable to the lower operating costs of soot-free buses, which arise from using less (or less expensive) energy coupled with lower maintenance costs for certain technologies (i.e., diesel hybrids and dedicated electric drive). The monetized value of climate and health benefits adds to the savings and can justify investments in soot-free buses in all 20 cities, even under conservative assumptions. In light of the potential social and economic return on investment, this study provides a basis for city officials, fleet operators, and financial institutions to finance the transition to soot-free urban bus fleets.

City	a) Private total cost of ownership							b) Total cost of ownership including social damages						
	Low Diesel Price	Moderate Diesel Price	High Diesel Price	Low BEB Price	High BEB Price	Low Efficiency Routes	High Efficiency Routes	Low Diesel Price	Moderate Diesel Price	High Diesel Price	Low BEB Price	High BEB Price	Low Efficiency Routes	High Efficiency Routes
Abidjan	-11%	-13%	-23%	-14%	-11%	-13%	-2%	-21%	-26%	-35%	-27%	-21%	-23%	-11%
Accra	-10%	-12%	-23%	-13%	-10%	-13%	-1%	-21%	-26%	-32%	-28%	-21%	-22%	-12%
Addis Ababa	-14%	-23%	-34%	-27%	-8%	-18%	-3%	-43%	-47%	-53%	-51%	-39%	-47%	-34%
Bangkok	-13%	-23%	-35%	-29%	-13%	-15%	-8%	-16%	-23%	-32%	-33%	-15%	-14%	-11%
Bogota	-5%	-8%	-19%	-10%	-5%	-8%	-1%	-12%	-18%	-32%	-28%	-12%	-14%	-4%
Buenos Aires	-17%	-25%	-34%	-27%	-16%	-18%	-13%	-20%	-25%	-33%	-35%	-17%	-27%	-15%
Casablanca	-11%	-12%	-20%	-13%	-11%	-13%	-2%	-15%	-16%	-22%	-17%	-15%	-18%	-4%
Dar es Salaam	3%	-8%	-21%	-9%	6%	3%	9%	-15%	-22%	-30%	-30%	-11%	-22%	-9%
Dhaka	-20%	-29%	-40%	-31%	-15%	-24%	-8%	-32%	-38%	-45%	-40%	-29%	-34%	-20%
Istanbul	-34%	-40%	-47%	-43%	-31%	-38%	-25%	-36%	-40%	-46%	-43%	-32%	-38%	-24%
Jakarta	-12%	-22%	-33%	-21%	-9%	-14%	-5%	-16%	-23%	-31%	-25%	-13%	-15%	-10%
Johannesburg	-9%	-17%	-27%	-22%	-6%	-9%	-9%	-13%	-19%	-27%	-23%	-10%	-13%	-13%
Lagos	-6%	-10%	-21%	-12%	-6%	-9%	0%	-19%	-25%	-35%	-27%	-19%	-21%	-11%
Lima	-1%	-12%	-24%	-10%	0%	1%	2%	-10%	-17%	-26%	-29%	-5%	-7%	-5%
Manila	-7%	-9%	-16%	-8%	-7%	-9%	-1%	-14%	-15%	-24%	-17%	-14%	-16%	-4%
Mexico City	-1%	-3%	-8%	-2%	-1%	-1%	-1%	-5%	-10%	-14%	-10%	-5%	-5%	-5%
Nairobi	2%	-8%	-20%	-10%	8%	2%	17%	-21%	-27%	-34%	-30%	-17%	-22%	-7%
Santiago	-4%	-6%	-14%	-4%	-4%	-7%	0%	-10%	-11%	-17%	-12%	-10%	-13%	-2%
Sao Paulo	-11%	-17%	-28%	-12%	-11%	-13%	-6%	-15%	-17%	-26%	-26%	-15%	-18%	-10%
Sydney	-5%	-11%	-20%	-6%	-5%	-6%	-2%	-8%	-13%	-20%	-10%	-8%	-8%	-6%

Total cost of ownership of least-cost soot free technology relative to baseline

-50% … 20%

Figure ES–1. Total cost of ownership and social damages of soot-free buses relative to baseline technologies in 20 megacities. The technology and fuel selected reflects a least-cost option for each city. Panel (a) gives total cost of ownership in the form of direct financial outlays including costs of bus and infrastructure acquisition, operation, and maintenance. Panel (b) gives total cost of ownership but combines estimates in Panel (a) with the monetized social value of climate and health benefits from carbon dioxide and black carbon emission reductions from soot-free buses.

The principal financial barrier to deploying soot-free urban bus fleets is the acquisition and payment model used by cities, operators, and financial institutions, not higher upfront cost. The potential net savings to cities and operators shows that the financial capital already exists to support an investment in cleaner technology. The challenge is to change from a capital acquisition model to a services acquisition model, which would make operational savings available to pay for higher upfront cost of the vehicle itself. To achieve this, fleets will require new vehicle acquisition and payment models designed from a total cost of ownership perspective. A shift toward a "least cost of ownership" model and away from a "least cost of vehicle procurement" model is one example of how cities and financial institutions can begin to eliminate financial barriers to soot-free bus deployment.

Finance institutions are in a position to facilitate a shift toward soot-free urban bus fleets. This effort begins with a change in perspective in favor of a services acquisition and total cost of ownership approach to assistance programs. Financing institutions should consider the development of acquisition models where lifecycle cost savings allow the transition to soot-free buses to pay for itself. This approach is needed not just from public finance agencies, but also from bus manufacturers that offer lending assistance in combination with goods and services. Finance institutions, including those that provide climate finance, can provide direct assistance to cities and fleet operators, such as loan guarantees or concessional financing where climate and health benefits are greatest. Cities that seek finance for feasibility studies of soot-free bus projects (based on successful cases) can benefit from guidelines published by finance institutions able to support them. And finance institutions that directly support investments in sustainable public transport, including bus rapid transit, can commit to finance exclusively the procurement of soot-free vehicles and fuels. These actions can facilitate a wholesale shift of financial resources and financing models.

City officials and their public agencies can take several steps to increase access to and better finance a transition in the urban bus fleet. Cities that require purchase based on least-cost bids for new vehicles can modify procurement standards and grant new weight to least cost of ownership. In lieu of paying the upfront purchase price of vehicles, leasing and service contracts covering the vehicle in full or its high-cost components (such as batteries) over the full or partial vehicle lifetime can lower risks to credit agencies and thereby increase access to credit. Takeover clauses offered by public agencies can also lower risks to creditors. Such guarantees may also lower risk premiums and reduce the cost of borrowing. Cities can further lower their credit risk by making bus operations more efficient via improved bus dispatch systems, route optimization, centralized fare collection, fare evasion penalties, and partnerships with private collectives to gain economies of scale through formalized fleet management. These combined actions not only can reduce risks to lenders but also would free up available capital and improve overall delivery of public transit service.

Finance is an important tool, particularly in regions where policy action is difficult. But finance can be linked to or support policy action, which is arguably more rapid and effective at delivering a future transition in the urban bus fleet. Japan, the United States, the European Union, Canada, South Korea, Turkey, and many local jurisdictions including Beijing, Delhi, Los Angeles, London, Santiago, and others have shifted to soot-free urban bus fleets through policy action. Local and national officials can mimic the efforts in these countries—for example, by setting minimum Euro VI emission standards and investing in clean liquid, gas, and electric fuel infrastructure. National officials can target early delivery of clean fuel to urban areas to support bus fleets. And city officials can insert minimum Euro VI emission requirements in procurement contracts. Adjustments to taxation of fuel and vehicle sales can ensure that subsidies are supporting the cleanest Euro VI diesel, gas, and dedicated electric drive vehicles rather than older-technology diesel engines. And concessions with private operators can set requirements on uptake of zero-emission dedicated electric drive vehicles, fleet retrofit, and fleet replacement.

Further research opportunities exist to guide and support finance toward soot-free technology deployment in city fleets. These opportunities include collection of more specific fleet data in cities, refinements to total cost of ownership analysis based on case studies, and improvements to financial modeling to align technology options with route characteristics in cities. The ongoing monitoring and reporting of the transition to soot-free technologies in cities should continue.

1. INTRODUCTION

One-fifth of global anthropogenic emissions of carbon dioxide (CO_2) and black carbon (BC) originate in the transport sector (Minjares, 2015). BC is a potent short-lived climate pollutant with a warming impact 900 to 3200 times that of CO_2. As an ultrafine component of particulate matter, BC is a major contributor to air pollution and premature deaths globally (Climate & Clean Air Coalition, 2017). Although urban buses typically have lower CO_2 emissions per passenger carried than private cars, they account for about one-quarter of BC emissions from road transport despite constituting only about 1% of the vehicle fleet. More than 80% of all new buses purchased in 2014 were diesel, but only about 20% of all new buses (diesel or otherwise) are equipped with available emission control technologies that guarantee "soot-free" performance.

We define soot-free engine technologies as those that achieve a 99% reduction in tailpipe BC emissions relative to uncontrolled diesel exhaust (Chambliss *et al*., 2013). These technologies include any diesel or alternative fuel engines certified to Euro VI or U.S. 2010 emission levels. Soot-free buses can be powered by a wide range of fuels including fossil diesel, compressed natural gas (CNG), biogas, or other liquid biofuels, as well as electric drive engines including hybrid drive, fuel cell, and battery electric drivetrains.

As many of the world's largest cities expand their bus fleets to decarbonize their transport sectors and address growing demands for urban mobility, a concurrent need exists to address urban air pollution and climate change by ensuring that all new buses are equipped with the best available emission controls for diesel BC. In response to this need, the Climate & Clean Air Coalition (CCAC) developed the Soot-Free Urban Bus Fleets Project to accelerate the adoption of soot-free engine technologies that are capable of effectively eliminating BC emissions from urban bus fleets in cities worldwide.

The CCAC is an intergovernmental partnership with a mission to reduce the climate and health impacts of short-lived climate pollutants worldwide. The Soot-Free Urban Bus Fleets Project is jointly implemented by four international organizations: the International Council on Clean Transportation (ICCT), United Nations (UN) Environment, C40 Cities, and Centro Mario Molina–Chile (CMMCh). Over the past 2 years, this project has encouraged cities to buy soot-free buses, and manufacturers to sell them, through regional workshops and research. It aims to secure commitments that will accelerate the transition to soot-free buses starting in 20 megacities around the world. The project focuses on the following cities: Abidjan, Accra, Addis Ababa, Bangkok, Bogotá, Buenos Aires, Casablanca, Dar es Salaam, Dhaka, Istanbul, Jakarta, Johannesburg, Lagos, Lima, Manila, Mexico City, Nairobi, Santiago, São Paulo, and Sydney.

As shown in Figure 1, several of these cities have committed (or are required by national emissions standards) to purchase buses that meet Euro VI emission standards. For example, all new buses purchased by the Transantiago system in Santiago, Chile, are required to meet Euro VI standards starting in September 2017 (UNEP, 2017).

Figure 1. Target cities supported by the soot-free urban bus initiative. Not Committed indicates cities that have not yet committed to procure only soot-free buses.

Many factors will need to come together to enable the transition of urban bus fleets to soot-free technologies, not only in these 20 target cities but also worldwide. These factors include technical considerations such as technology readiness and suitability,[1] the availability of appropriate fuels, and economic factors such as the cost of achieving soot-free performance. Cost is among the most commonly cited barriers among cities considering a commitment to transition to soot-free buses. Existing procurement and contracting practices often favor or require the bus technology option with the lowest purchase price. These practices will need to be updated to allow for bus technologies such as hybrids and electric buses that cost more upfront but reduce operating and maintenance costs. In some cases, soot-free bus technologies lead to lower net financial costs over the lifetime of the bus. Accelerating the global transition to soot-free buses will also reduce the social costs of bus transport, which include climate and health damages of tailpipe BC emissions and fuel lifecycle CO_2 emissions.

Because the social costs of bus emissions are not uniformly reflected in price signals for vehicles and fuels, new financing models are needed to accommodate higher

1 Operational challenges are discussed for battery electric buses (page 31), alternative fuels (page 30), and ultralow-sulfur diesel fuels (page 37).

upfront financial costs with operational savings and mitigate the risks of adopting new technology; likewise, new national and local policies are needed to remove the barriers to soot-free technology adoption.

This report aims to address these challenges with several audiences in mind. The first target audience includes city officials and local fleet operators in a position to transition to cleaner fuels and engines in their next bus procurement. The second audience includes financial institutions, both domestic and international, that will evaluate their role in accelerating the global transition to soot-free bus fleets. The third audience includes national government policymakers who can support cities through policies to increase the uptake of cleaner fuels and technologies in their bus fleets.

The information presented in this report begins in Section 2 with a discussion of the total cost of ownership approach to fleet procurement, which may better reflect the financial investment needed to support clean technology than the standard procurement approach. This report estimates total fleet ownership costs in each of 20 cities and a schedule of bus purchases consistent with largely replacing each city's bus fleet over the next 10 years. The analysis looks closely at five bus types ranging from small to bi-articulated buses. Following this discussion, Section 3 presents options for bus acquisition and availability of financing sources to enable the purchase of soot-free buses. Section 4 addresses barriers to soot-free bus procurement, recommending actions to improve procurement, contracting, and operating practices and to expand access to financing sources. Finally, Section 5 discusses the findings of the preceding sections with recommendations for cities and financial institutions.

2. ASSESSMENT OF FINANCING DEMAND IN 20 MEGACITIES

This section presents the difference in total cost of ownership (TCO) of soot-free technology in each of 20 megacities versus the technology in the existing fleet. It begins with an overview of the determinants of TCO and illustrates how these components change over the ownership term of the vehicle. Next, it describes the framework for comparing the TCO of various bus technology options in a given city. Finally, it provides an overview of the total and incremental costs of shifting new bus purchases to soot-free technologies in the 20 megacities. A detailed description of data inputs and calculation methods is provided in Section 6.

2.1. TOTAL COST OF OWNERSHIP VERSUS ONE-TIME PURCHASE PRICE

Existing procurement and contracting practices often favor or require the bus technology option with the lowest purchase price. Purchase price, however, is a poor measure of the total cost of owning and operating a vehicle: over a 10- to 15-year service life, operating and maintenance costs will amount to several times the purchase price of a conventional diesel bus. Using purchase price as the metric for cost also biases such comparisons against hybrid, electric drive, and other bus technologies that have a higher purchase price but lead to substantially reduced operating and maintenance costs, and in some cases, lower net costs over the lifetime of the bus.

A better metric for comparing the costs of different bus technologies is TCO (also known as lifecycle cost). TCO is defined as the sum of the costs to acquire, operate, and maintain the vehicle and its associated fueling infrastructure over a specified ownership period. Table 1 summarizes the components of TCO that are considered for the financing analysis. Because the objective is to evaluate those costs that depend on the selection of bus technology, some cost components—such as the costs of administration, staffing, license and registration, and insurance—are not evaluated. Including those costs would not be expected to change the outcome of this analysis. For this analysis, costs in future years are discounted at a rate of 7% per year. This rate generally reflects the social opportunity costs of capital and is at the upper end of the range of discount rates applied by the World Bank (Akbar *et al*., 2014).

Table 1. Components of total cost of ownership.

Category	Component	Definition
Bus and infrastructure purchase	Down payment	Initial cash outlay for bus or infrastructure purchase. The remainder is assumed to be covered by a loan.
	Loan payments	Principal and interest payments over a specified loan period.
	Resale value	If the duration of planned operation is shorter than the bus service life, this positive cash flow considers the resale value of the depreciated vehicle.
Operation and maintenance	Fueling	Annual cost to fuel the vehicle, determined by vehicle efficiency, distance traveled, and fuel price.
	Other operational	Includes the cost of diesel exhaust fluid for diesel buses with selective catalytic reduction systems (typically Euro IV+).
	Bus maintenance	Cost of regular bus maintenance; includes tires, parts, lubricants, etc.
	Infrastructure maintenance	Where not already included in the retail fuel price, includes the cost of infrastructure maintenance and operations.
	Bus overhaul	For bus purchases that do not include a warranty for the service life of the vehicle, a major mid-life overhaul would include the cost of battery replacement for electric buses and engine overhaul for other buses. For this analysis, battery warranties are assumed to cover the bus operating life.

Figure 2 shows how these cost components can change over the service life of the vehicle. The first year of ownership (denoted year zero) includes the down payment, whereas loan payments on the bus are spread out over the first 5 years of ownership. In this example, the sixth year of ownership includes an overhaul of the engine. Fueling and maintenance costs account for most of the costs of ownership (and operation) once the bus loan is paid off. After its ownership term (10 years in this case), the depreciated bus is assumed to be sold (e.g., to an independent local operator); in this case, the resale of the depreciated vehicle is shown as a negative cost.

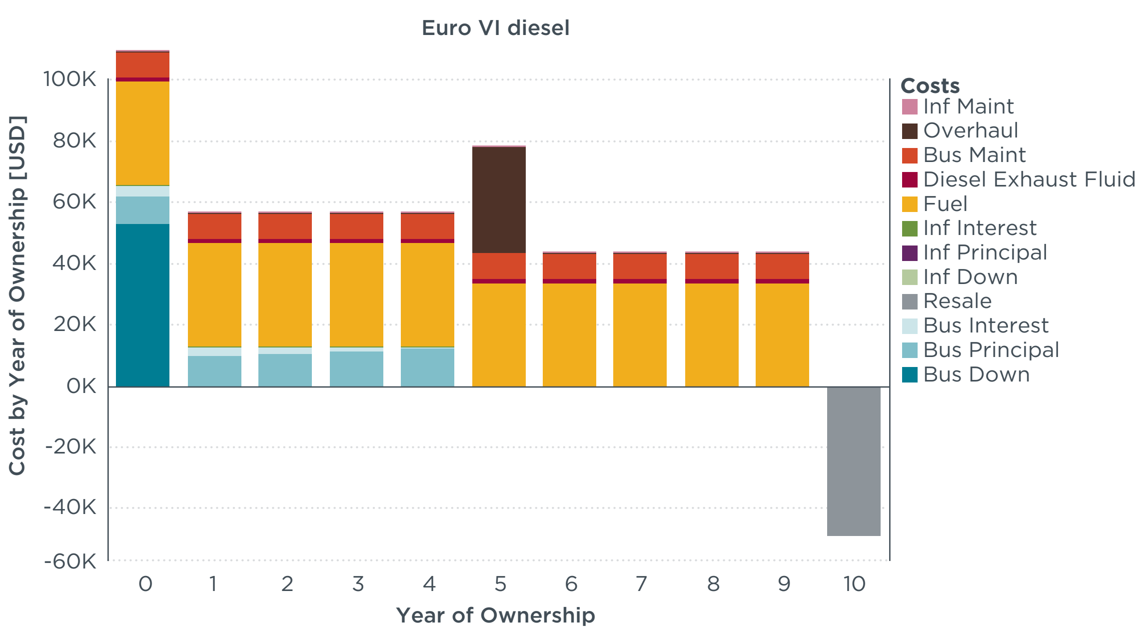


Figure 2. Costs of bus ownership by year of operation for a medium Euro VI diesel bus in São Paulo. Costs abbreviated 'Inf' apply to the fueling infrastructure, whereas others apply to the vehicle.

Figure 3 compares the cost of various bus technologies in Bangkok using two metrics: purchase price[2] and TCO. As shown in panel (a), Euro IV diesel buses have the lowest purchase price, whereas hybrid, gas, and battery electric buses (BEBs) have substantially higher purchase prices. Yet as shown in panel (b), the results for TCO are precisely the opposite: Over a 15-year[3] ownership period, hybrid, gas, and BEBs would cost 12% to 17% less than a Euro IV diesel bus. This example illustrates the advantage of using TCO in procurement decisions, as opposed to only the purchase price of the vehicle. If only purchase price were considered in the selection of bus technology, the total cost to own and operate the vehicle would be substantially higher than a technology with a somewhat higher purchase price but lower combined operating and maintenance costs.

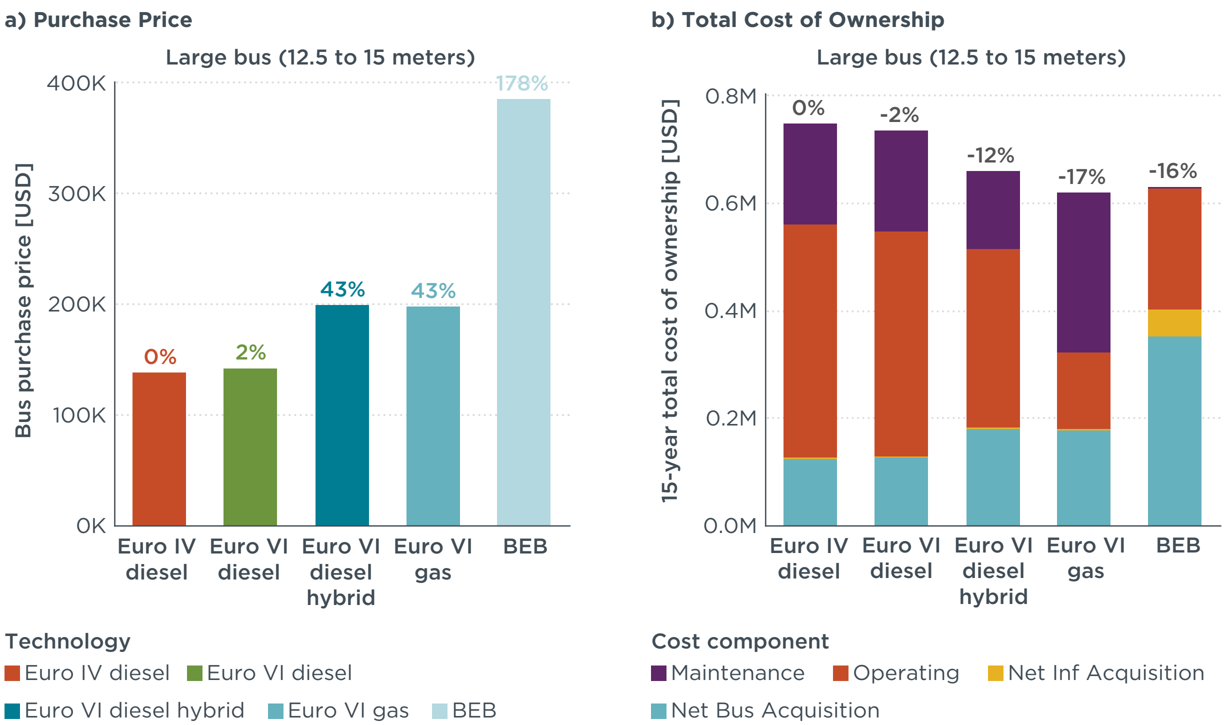


Figure 3. Comparison of technology costs for a large bus in Bangkok. a) Bus purchase price. b) Total cost of ownership over 15 years. Notes: Data labels indicate percent change from baseline technology, Euro IV diesel. Maintenance costs include infrastructure (inf) and buses. Operating costs include fuel and diesel exhaust fluid. Acquisition costs include down payment and loan payments minus any bus resale value at the end of its ownership term. Acquisition cost data for BEB includes service and maintenance. Bus efficiency data are for a medium-speed urban route. M, million; BEB, battery electric bus.

In the following section, we draw upon local data inputs from each of the 20 target cities to compare the TCO of soot-free engine technologies in those cities. Comparisons of the TCO of individual bus technology options in a city are sensitive to many factors, including actual bus purchase prices, financing terms, annual mileage, fuel prices, operating efficiency, local labor costs to maintain vehicles and infrastructure, and design of the bus purchase and/or service contract. Where these

2 See page 37 for a discussion of purchase price data by city.

3 See page 10 for a discussion of bus ownership periods.

data inputs are incomplete or unavailable, we apply a set of default data derived from other cities and international data sources. These data sources and assumptions are explored in further detail in Section 6.

2.2. METHODS AND DATA

Technology and fuel availability in 20 megacities

The soot-free technology options available to each city depend on the local availability and quality of fuels and infrastructure. For each city, the baseline technology is defined as the diesel bus technology that meets the minimum emissions standards in that country and uses locally available diesel fuel. Table 2 indicates the present quality of locally available diesel fuel and status of access to natural gas in each city. As shown, ultralow-sulfur diesel with fewer than 10 to 15 parts per million (ppm) sulfur is available in 10 of the 20 cities evaluated, whereas natural gas is available for transportation in 16 cities. Three cities—Abidjan, Addis Ababa, and Nairobi—have no existing access to gas or diesel fuels that would enable soot-free technology. In cities that lack access to ultralow-sulfur diesel or (natural or bio-) gas, there may be a need to either import these fuels or coordinate with the national energy (or oil) ministry to secure their availability. Whereas buses powered by diesel and gas are sold separately from their fueling infrastructure, manufacturers of BEBs more commonly bundle charging infrastructure with their vehicle(s).[4] BEBs are therefore assumed to be available as a technology option in all cities (page 31). In cities considering the deployment of BEBs, the public sector should work with utilities to ensure that the grid accommodates new charging capacity at a reasonable electricity rate. In some cities, grid upgrades may incur costs that are additional to those considered in this analysis; however, the costs of charging infrastructure may also be lower than considered here (e.g., in cases where chargers are included in the purchase price of the vehicle). Both for their high contribution to local air pollution and their emissions of BC, diesel generators in these megacities (where applicable) are not considered a viable source of electricity for zero-emission electric buses.

4 Includes depot charging and opportunity charging; see page 31.

Table 2. Diesel fuel quality and availability of natural gas in 20 megacities. Data were obtained by the ICCT and UN Environment from government and consultant sources. Estimates of average electricity grid carbon intensity are provided on page 38.

Region	Country	City	National diesel sulfur limits	Access to natural gas	Sources
Africa	**Cote d'Ivoire**	Abidjan	>2000 ppm; 50 ppm imports from 1 July 2017	no	(1, 2, 20)
	Ethiopia	Addis Ababa	>2000 ppm	no	(2, 20)
	Ghana	Accra	>2000 ppm; 50 ppm imports from 1 July 2017	yes; CNG bus pilots	(1, 2, 20)
	Kenya	Nairobi	50	no	(3, 20)
	Morocco	Casablanca	10	data unavailable	(12)
	Nigeria	Lagos	>2000 ppm; 50 ppm imports from 1 July 2017	yes	(1, 2, 20)
	South Africa	Johannesburg	allows 500 and 50 ppm diesel	yes; operating DDF buses	(5, 6)
	Tanzania	Dar es Salaam	50	yes	(3, 20)
Asia	**Bangladesh**	Dhaka	2500 (500 max for imported diesel)	yes	(15, 20)
	Indonesia	Jakarta	allows 3500 and 500 ppm diesel; 50 ppm expected by 2020	yes; operating CNG buses	(16, 20)
	Philippines	Manila	50; limited availability of 10 ppm	yes	(14, 20)
	Thailand	Bangkok	50 (HSD Grade); limited availability of 10 ppm	yes; operating CNG buses	(7, 20)
Latin America	**Argentina**	Buenos Aires	1500 (Grade 2, rural), 500 (Grade 2, city), and 10 (Grade 3)	yes	(4)
	Brazil	São Paulo	500 and 10 (select metropolitan areas)	yes	(8)
	Chile	Santiago	15	yes	(9)
	Colombia	Bogotá	50; TransMilenio exploring 10 ppm procurement	yes	(2)
	Mexico	Mexico City	500 and 15 (Mexico City, Guadalajara, Monterrey, and along US-Mexico border)	yes, operating CNG buses	(13)
	Peru	Lima	50	yes, operating CNG buses	(11, 19, 20)
Other	**Australia**	Sydney	10	yes, operating CNG buses	(10, 18)
	Turkey	Istanbul	10	yes, operating CNG buses	(2, 17)
Number of cities where current fuel availability enables soot-free buses			**10**	**16**	

Sources
(1) CCAC Nigeria Communique (http://staging.unep.org/Transport/new/PCFV/pdf/2016Nigeria_WorkshopReport.pdf)
(2) UNEP diesel fuel sulfur levels Dec. 2016
(3) www.ccacoalition.org/en/news/east-african-clean-diesel-now-reality
(4) Stratas advisors (https://stratasadvisors.com/Insights/071516-Argentina-Fuel); Resolución N° 1283/2006, 478/2009 and 5/2016, Ministerio de Energia y Mineria
(5) Personal communication, JDT and SAPIA. "DDF" refers to Diesel Dual-Fuel, an engine that operates from both diesel and gas.
(6) www.sasol.com/media-centre/media-releases/sasol-launch-south-african-first-10-ppm-diesel
(7) Supat Wangwongwatana, CCAC Soot-Free Urban Bus Fleets in Asian Cities workshop presentation
(8) ICCT, http://theicct.org/state-of-clean-transport-policy-2014; ANP 50/2013
(9) http://transportpolicy.net/index.php?title=Chile:_Fuels:_Diesel_and_Gasoline
(10) www.legislation.gov.au/Details/F2009C00145
(11) www.theicct.org/case-study-adoption-low-sulfur-fuel-standards-peru
(12) Stratas Advisors Global Fuel Quality Developments presentation: http://staging.unep.org/transport/New/PCFV/pdf/11gpm/11gpm_PCFV_HuimingLi.pdf
(13) NOM-016-CRE 2016
(14) PNS/DOE QS 004:2012 = specifications; DC No. DC2015-06-004 = implementation
(15) http://archive.dhakatribune.com/environment/2015/jan/15/govt-introduce-low-sulphur-diesel
(16) http://transportpolicy.net/index.php?title=Indonesia:_Fuels:_Diesel_and_Gasoline
(17) www.otobus.istanbul/toplu-ta%C5%9Fima/otobues-filosu.aspx
(18) http://fleetlists.busaustralia.com/sta.php?flsummary=STA
(19) www.ecgnet.org/sites/default/files/Comparative_Case_Studies_Three_IDB_supported_Urban_Transport_Projects.pdf
(20) UN Environment

Figure 4 shows the baseline and soot-free technology options evaluated in this study in each city. Baseline diesel bus technology is determined by the quality of locally available fuels and the most recently implemented national emissions standards. In cities where new bus purchases are certified to different standards (e.g., Euro VI for public fleets and Euro V for all buses), the baseline technology is defined as the least stringent level of emission control among new buses. This assumption would result in a conservatively high estimate of the incremental costs to transition to soot-free buses in the case that they have higher costs of ownership than baseline technologies.

	Pre-Euro VI diesel				Soot-free options			
City	Euro II diesel	Euro III diesel	Euro IV diesel	Euro V diesel	Euro VI diesel	Euro VI diesel hybrid	Euro VI gas	BEB
Abidjan	■				■	■		■
Accra	■				■	■	■	■
Addis Ababa	■							■
Bangkok			■		■	■	■	■
Bogota			■		■	■	■	■
Buenos Aires				■	■	■	■	■
Casablanca			■		■	■		■
Dar es Salaam		■					■	■
Dhaka	■						■	■
Istanbul					■	■	■	■
Jakarta			■				■	■
Johannesburg			■		■	■	■	■
Lagos	■				■	■	■	■
Lima			■				■	■
Manila			■		■	■	■	■
Mexico City			■		■	■	■	■
Nairobi			■					■
Santiago				■	■	■	■	■
Sao Paulo				■	■	■	■	■
Sydney				■	■	■	■	■

Technology
- Euro II diesel
- Euro III diesel
- Euro IV diesel
- Euro V diesel
- Euro VI diesel
- Euro VI diesel hybrid
- Euro VI gas
- BEB

Figure 4. List of technology options evaluated for each city. With the exception of Istanbul (where new buses are subject to national Euro VI standards), baseline technologies are assumed to be pre-Euro VI diesels. Baseline buses in Bangkok are assumed to meet Euro IV based on available 50 ppm sulfur fuel. Some cities with gas (natural gas and biogas) buses in operation may have a cleaner starting point than the baseline technology, which would result in a conservatively high estimate of the costs of switching to soot-free buses. Gas buses have naturally low tailpipe particulate matter (PM) emissions; however, because Euro VI gas buses also achieve substantially lower NO_x emissions (a precursor to secondary PM) at minimal cost, we recommend these be required to meet Euro VI rather than some earlier Euro standard.

Bus purchase schedules

The number of new buses purchased in the starting year of the analysis (i.e., 2018) is estimated using data on the size and age distribution of the bus fleet in each city (Jin *et al*., 2017). As shown in Figure 5, some cities such as São Paulo and Buenos Aires generally limit the ownership period of buses to 10 years, whereas other cities such as Mexico City and Lima have a substantial number of buses older than 15 years. Because the actual number of buses purchased in a given city tends to vary unpredictably, this study estimates that the number of new buses purchased annually over the next 10 years will at least equal the rate of assumed fleet turnover; for example, a city with an average bus ownership period of 10 years would need to replace approximately 10% of its fleet each year to maintain its fleet size. Based on the age profiles of their existing bus fleets, Casablanca, Johannesburg, Dhaka, Buenos Aires, São Paulo, Santiago, and Istanbul are assumed to have an average bus ownership period of 10 years; the remaining cities are assumed to have an average bus ownership period of 15 years to account for a substantial share of buses that are still in operation after 15 years (e.g., in Mexico City and Lima). This study does not attempt to estimate fleet growth, as this has no effect on the relative identification of least-cost soot-free technologies in each of the cities or the relative incremental costs of a transition to soot-free emissions. Financing need and emission impacts are positively associated with the number of buses in a fleet, so any change to this assumption of fleet growth should scale linearly with financing need and these emission impacts within each city. Note that this analysis focuses strictly on new bus purchases; cities or operators purchasing secondhand buses are outside the scope of this analysis.[5]

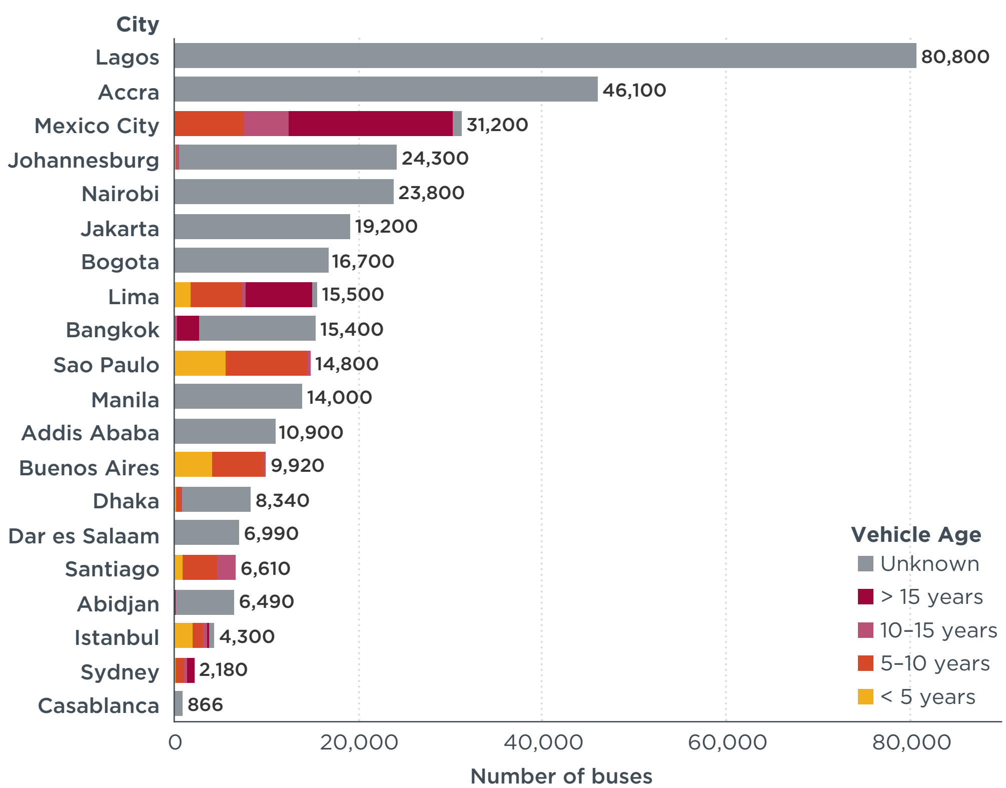


Figure 5. Age distribution of bus fleets by city. Data labels indicate the total number of buses in operation and are rounded to three significant digits.

This analysis looks closely at five bus types ranging from small to bi-articulated buses (Table 3). Data inputs such as purchase price, efficiency, mileage, and pollutant

5 This analysis does not attempt to determine whether all 20 cities currently purchase new or second-hand buses. To ensure a like-like comparison, lifecycle costs are compared only for new bus purchases. Yet as cities in the United States, European Union, and Japan begin to retire soot-free buses (possibly as soon as 2019), it is likely that soot-free options will also become available on the second-hand market.

emissions are defined for each bus type to ensure comparability. Figure 6 shows the estimated number of new buses purchased in 2018 by city and bus type. As shown, most of the cities in Africa have a high share of small buses, which include minibuses, whereas cities in Latin America tend to have a higher share of large buses.

Table 3. Classification of bus types used in total cost of ownership analysis.

Bus type	Typical vehicle length	Minimum seats	Examples
Small	10 m	20	Minibus, Midibus
Medium	12 m	25 to 33	Basico, Standard
Large	12.5 to 15 m	33 to 38	Padron
Articulated	18 to 23 m	37 to 54	Articulated
Biarticulated	27 m	47+	Biarticulated

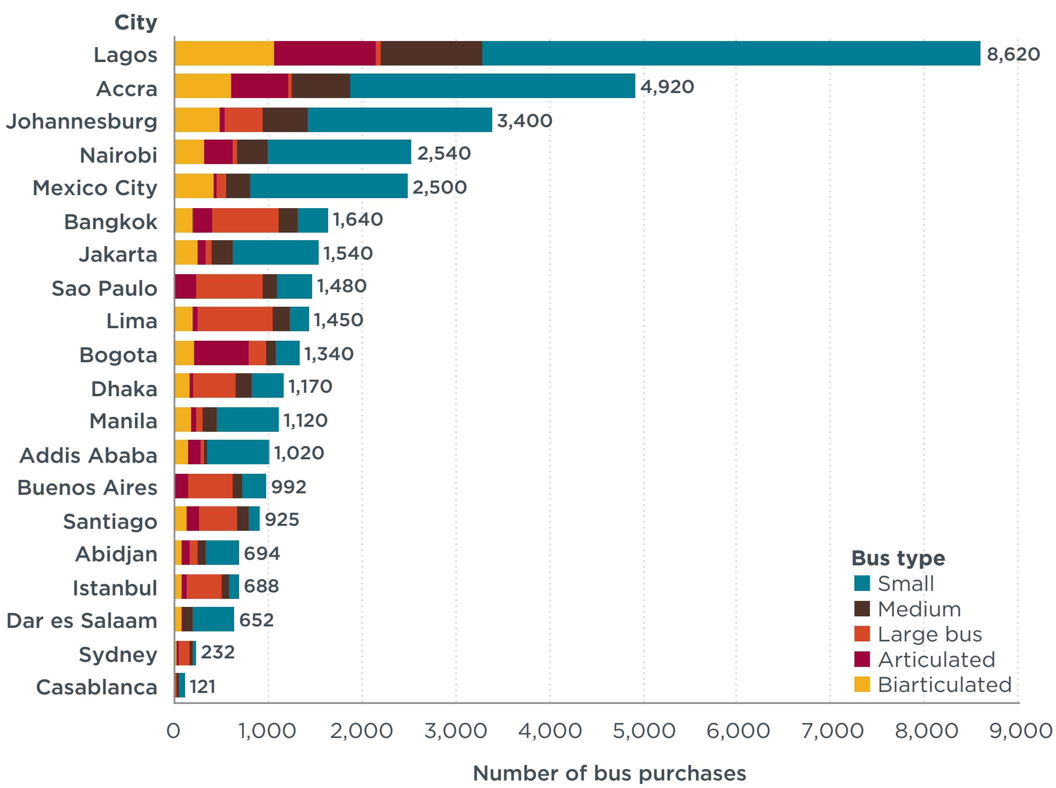


Figure 6. Assumed number of new buses purchased in 2018 by city and bus type. Data labels are rounded to three significant digits.

Technology purchase scenarios and sensitivity cases

The total costs of ownership for new bus purchases are evaluated for three technology purchase scenarios, including a baseline and two soot-free technology pathways. The Baseline scenario assumes that cities purchase diesel buses that at a minimum conform to nationwide standards, are limited by available fuel quality, and are not soot-free technologies unless currently required for all new buses. This technology scenario serves as a reference point for the costs of a "business-as-usual" progression of bus purchases. Next, the Least Cost Soot-Free scenario assumes that cities purchase whichever soot-free technology has the lowest TCO for a given bus type. Finally, the Least BC Emissions scenario assumes that cities purchase the soot-free technology with the lowest tailpipe emissions (i.e., zero-emission BEBs). By evaluating two soot-free bus purchase scenarios—one with the least financial cost and the other with the lowest emissions—the analysis yields not only a comparison of TCO with baseline technologies, but also the incremental TCO to minimize emissions from urban bus fleets.

To account for uncertainty in this analysis contributed by limits in the available data, each of these three technology purchase scenarios is evaluated for each of seven sensitivity cases shown in Table 4. These cases reflect a range of assumptions for three key data inputs—diesel fuel prices, BEB purchase price, and bus operating efficiency—over the duration of the TCO analysis. The Low Diesel Price case assumes a continuation of low diesel fuel prices, current BEB prices, and bus operations consistent with medium-speed urban routes. The Moderate and High Diesel Price cases assume that the retail price of diesel fuel recovers from currently low levels (additional details in Section 6.3). The Low BEB Price case assumes that declining battery costs decrease the purchase price of BEBs to 1.2 times the price of diesel buses (page 35), whereas the High BEB Price case reflects a higher-than-expected estimate of the purchase price of BEBs (page 35). Finally, the Low Efficiency Routes and High Efficiency Routes cases show the variation in results if buses operate under more congested or less congested route conditions, which influence the efficiency of various technology options (page 35). Other factors such as changes in gas prices or electricity rates could affect TCO but are not evaluated here.

Table 4. Definition of sensitivity cases.

<table>
<tr><th>Sensitivity case</th><th>Diesel fuel prices</th><th>BEB prices</th><th>Operating efficiency</th></tr>
<tr><td>Low Diesel Price</td><td>Current fuel prices</td><td rowspan="3">Current BEB prices</td><td rowspan="5">Medium-speed urban</td></tr>
<tr><td>Moderate Diesel Price</td><td>Current + 0.2 USD/liter</td></tr>
<tr><td>High Diesel Price</td><td>Current + 0.5 USD/liter</td></tr>
<tr><td>Low BEB Price</td><td rowspan="4">Current fuel prices</td><td>1.2 x price of diesel buses</td></tr>
<tr><td>High BEB Price</td><td>2 x price of diesel buses</td></tr>
<tr><td>Low Efficiency Routes</td><td rowspan="2">Current BEB prices</td><td>Low-speed urban</td></tr>
<tr><td>High Efficiency Routes</td><td>Suburban</td></tr>
</table>

2.3. TOTAL COST OF OWNERSHIP OF BASELINE AND SOOT-FREE BUSES IN 20 MEGACITIES

The optimal soot-free technology in each of 20 megacities will depend on the underlying policy path to achieve a soot-free emissions target, and whether this is based on achieving the least cost-emissions reductions or the greatest absolute emissions reductions. Figure 7 shows a Least Cost Soot-Free technology pathway that corresponds to the Low Diesel Price case. Under these assumptions, diesel hybrids are estimated to be the least-cost soot-free technology for at least several bus types in 10 of the 20 cities evaluated. BEBs and CNG buses are estimated to have the lowest TCO for some or all bus sizes in 10 and 7 cities, respectively. Dedicated Euro VI diesel buses are estimated to be the least-cost soot-free option only in three cities, and then only for one or two bus sizes.

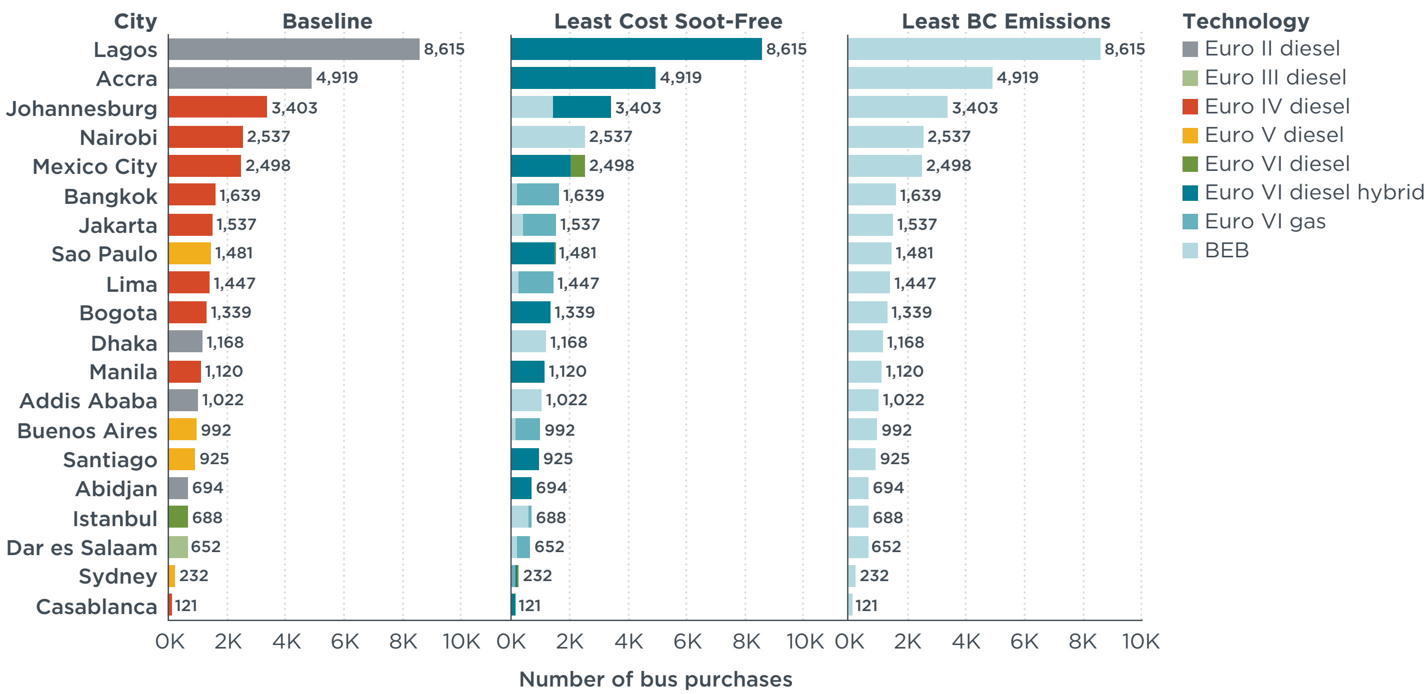


Figure 7. Estimate of new buses purchased in 2018 by city and technology purchase scenario. Least Cost results are shown for a case with Low Diesel Prices. In cities with multiple technologies indicated for a Least Cost scenario, these apply to different bus sizes. Price discounts for higher bus volumes are not included in this analysis.

The Least Cost Soot-Free purchase scenario results in lower costs of ownership than the Baseline in all cases. Figure 8 shows the cumulative costs of ownership of new buses purchased from 2018 to 2027; results are summed across all 20 target cities. The purchase of soot-free buses in these cities over the next 10 years is associated with cumulative cost savings in the tens of billions of dollars (e.g., $13 billion USD in cost savings in a case with low diesel prices). On average, soot-free buses achieve lower net costs of ownership than baseline technologies within 5 to 9 years of operation. This is partly enabled by the dynamic technology choice built into the Least Cost scenario. In contrast, the Least BC Emissions purchase scenario could result in equivalent, higher, or lower costs of ownership than the Baseline, depending on the input assumptions. These results show that a technology decision framework emphasizing the most cost-effective strategies for emissions control can reveal investments in soot-free technologies that not only pay for themselves but also lower the total cost of public transit service.

The most attractive emissions control strategy in each city will vary with underlying fleet operational variables. Under cases with low diesel prices, High BEB prices, or low-efficiency routes (the latter two also assuming low diesel prices), Euro VI diesel hybrids are the most prevalent least-cost soot-free technology, followed by BEBs and Euro VI CNG buses (in other cities or for other bus types). In contrast, if diesel prices increase or BEB prices decline, BEBs would become the most prevalent least-cost soot-free technology. Lastly, the only case in which dedicated Euro VI diesel buses are the most prevalent least-cost soot-free technology is one with continued low diesel fuel prices coupled with suburban operating conditions (characterized by higher speeds and fewer stops). A transition to purchases of new buses with soot-free technologies would make even more sense from a cost perspective when the social benefits of emissions reductions are accounted for.

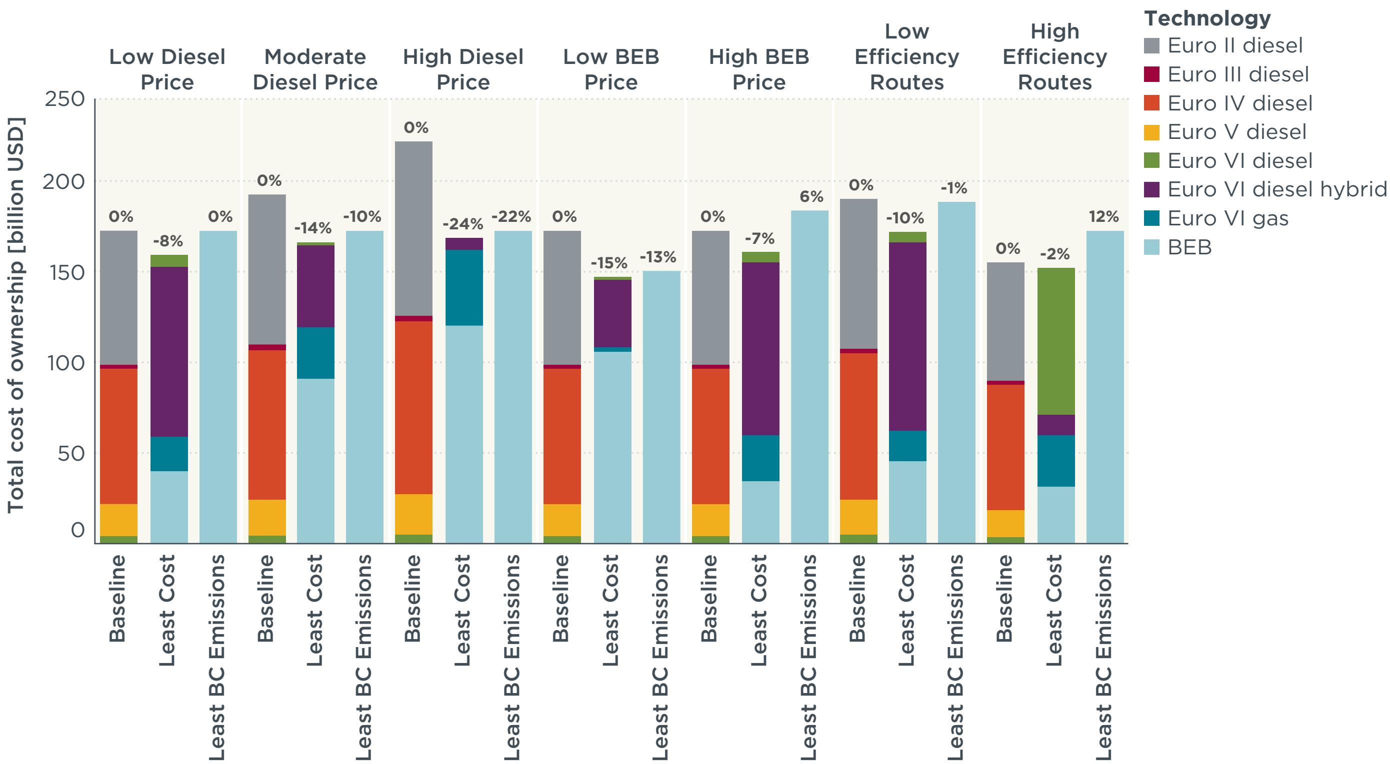


Figure 8. Total cost of ownership of new buses purchased from 2018 to 2027 by technology.

2.4. VALUING THE CLIMATE AND HEALTH BENEFITS OF SOOT-FREE BUSES

The cost components described in Section 2.1 describe only the financial outlays associated with bus procurement and operation. The emissions of CO_2 and BC from these buses incur costs borne by society that are not directly paid by the operator. Because investments in clean fuels and technologies can generate broader social benefit, this study undertook an estimate of the additional climate and health damages of tailpipe BC emissions and fuel lifecycle CO_2 emissions from bus procurement. CO_2 emissions include the emissions from bus tailpipes; the production, refining, and distribution of fuels; and the generation of electricity used in BEBs. The climate and health damages of BC and CO_2 are monetized using global average estimates for the social cost of atmospheric release (Shindell, 2013). The median values from that study, which are based on 2010 emissions levels and a 3% discount rate, are used here.[6] These estimates—converted from 2007 USD to 2016 USD—are equivalent to approximately $300,000 per metric ton of BC and $93 per ton of CO_2. Although the precise value of climate and health damages varies according to time period and regional characteristics (e.g., geographic location, population size and density, and meteorological conditions),

6 A discount rate of 3% is the median value applied by the U.S. Government for the evaluation of climate damages (U.S. Government, 2016). Choosing a lower discount rate would increase the present valuation of climate and health damages or benefits, whereas choosing a higher discount rate would decrease this valuation.

these values are useful as general indicators of the relative magnitude of climate and health benefits derived from investments in soot-free bus technologies.

Figure 9 shows the same cumulative costs of ownership in Figure 8, but with the additional valuation of the climate and health impacts of tailpipe BC and fuel lifecycle CO_2 emissions. In the Low Diesel Price case, the social costs of pollutant emissions can be equal to more than 40% of the TCO of baseline diesel buses. With the social benefits of soot-free technology valued in this way, the Least BC Emissions scenario requiring zero-emission BEBs in all cities would in most cases (all but a High BEB Price or High Efficiency Routes case) result in the lowest combined private and social costs.

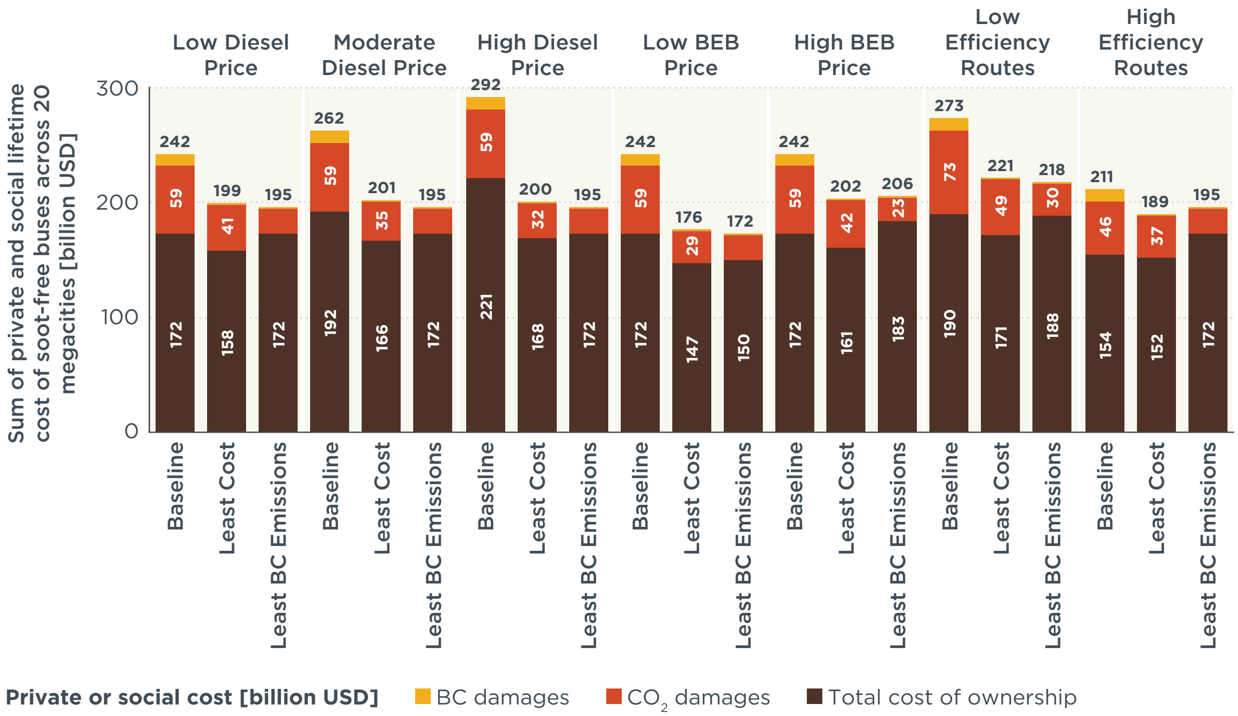


Figure 9. Total cost of ownership and social damages of new buses purchased from 2018 to 2027 in 20 megacities.

Figure 10 provides a summary of total costs in each city. These costs represent the least-cost soot-free technology in each city, relative to the baseline technology. To account for uncertainties in underlying data, the table presents a range of estimates across seven sensitivity cases for key data inputs. The percentages in panel (a) consider only the total costs of ownership paid by public or private bus operators. Considering only these financial outlays, soot-free buses generally have lower costs of ownership in most cities and under most cases. For example, under a case with Moderate Diesel Prices, shifting to soot-free technologies would reduce total costs of ownership in all 20 cities, with the reduction in costs ranging from 3% to 40%. These financial cost savings are attributable to the lower operating costs of soot-free buses, which arise from using less (or less expensive) energy coupled with lower maintenance costs for certain technologies (e.g., hybrids and BEBs). The percentages shown in panel (b) include the social damages of BC and CO_2 emissions. Panel (b) illustrates how the inclusion of climate and health benefits in any assessment of soot-free technologies will justify an investment in technology transition in all cities and under all sensitivity cases evaluated. In those cities that could have somewhat higher financial costs with soot-free buses in some cases (e.g., if Nairobi and Dar es Salaam were to have continued low diesel prices or high BEB prices), there is likely a greater need for government actions that strengthen the incentive for private operators to transition to soot-free technologies. Although Euro VI diesel hybrids are estimated to be the least-cost soot-free technology for several bus types in 10 of the 20 cities evaluated (Low Diesel Price case), diesel hybrids were not evaluated for certain cities (e.g., Nairobi and Dar es Salaam) with higher-sulfur fuel. To the extent that Euro VI diesel hybrids have lower lifecycle costs than BEBs for certain applications, actions to make ultralow-sulfur diesel available in these cities have the potential to reduce the costs of a transition to soot-free buses.

a) Private total cost of ownership

City	Low Diesel Price	Moderate Diesel Price	High Diesel Price	Low BEB Price	High BEB Price	Low Efficiency Routes	High Efficiency Routes
Abidjan	-11%	-13%	-23%	-14%	-11%	-13%	-2%
Accra	-10%	-12%	-23%	-13%	-10%	-13%	-1%
Addis Ababa	-14%	-23%	-34%	-27%	-8%	-18%	-3%
Bangkok	-13%	-23%	-35%	-29%	-13%	-15%	-8%
Bogota	-5%	-8%	-19%	-10%	-5%	-8%	-1%
Buenos Aires	-17%	-25%	-34%	-27%	-16%	-18%	-13%
Casablanca	-11%	-12%	-20%	-13%	-11%	-13%	-2%
Dar es Salaam	3%	-8%	-21%	-9%	6%	3%	9%
Dhaka	-20%	-29%	-40%	-31%	-15%	-24%	-8%
Istanbul	-34%	-40%	-47%	-43%	-31%	-38%	-25%
Jakarta	-12%	-22%	-33%	-21%	-9%	-14%	-5%
Johannesburg	-9%	-17%	-27%	-22%	-6%	-9%	-9%
Lagos	-6%	-10%	-21%	-12%	-6%	-9%	0%
Lima	-1%	-12%	-24%	-10%	0%	1%	2%
Manila	-7%	-9%	-16%	-8%	-7%	-9%	-1%
Mexico City	-1%	-3%	-8%	-2%	-1%	-1%	-1%
Nairobi	2%	-8%	-20%	-10%	8%	2%	17%
Santiago	-4%	-6%	-14%	-4%	-4%	-7%	0%
Sao Paulo	-11%	-17%	-28%	-12%	-11%	-13%	-6%
Sydney	-5%	-11%	-20%	-6%	-5%	-6%	-2%

b) Total cost of ownership including social damages

City	Low Diesel Price	Moderate Diesel Price	High Diesel Price	Low BEB Price	High BEB Price	Low Efficiency Routes	High Efficiency Routes
Abidjan	-21%	-26%	-35%	-27%	-21%	-23%	-11%
Accra	-21%	-26%	-32%	-28%	-21%	-22%	-12%
Addis Ababa	-43%	-47%	-53%	-51%	-39%	-47%	-34%
Bangkok	-16%	-23%	-32%	-33%	-15%	-14%	-11%
Bogota	-12%	-18%	-32%	-28%	-12%	-14%	-4%
Buenos Aires	-20%	-25%	-33%	-35%	-17%	-27%	-15%
Casablanca	-15%	-16%	-22%	-17%	-15%	-18%	-4%
Dar es Salaam	-15%	-22%	-30%	-30%	-11%	-22%	-9%
Dhaka	-32%	-38%	-45%	-40%	-29%	-34%	-20%
Istanbul	-36%	-40%	-46%	-43%	-32%	-38%	-24%
Jakarta	-16%	-23%	-31%	-25%	-13%	-15%	-10%
Johannesburg	-13%	-19%	-27%	-23%	-10%	-13%	-13%
Lagos	-19%	-25%	-35%	-27%	-19%	-21%	-11%
Lima	-10%	-17%	-26%	-29%	-5%	-7%	-5%
Manila	-14%	-15%	-24%	-17%	-14%	-16%	-4%
Mexico City	-5%	-10%	-14%	-10%	-5%	-5%	-5%
Nairobi	-21%	-27%	-34%	-30%	-17%	-22%	-7%
Santiago	-10%	-11%	-17%	-12%	-10%	-13%	-2%
Sao Paulo	-15%	-17%	-26%	-26%	-15%	-18%	-10%
Sydney	-8%	-13%	-20%	-10%	-8%	-8%	-6%

Total cost of ownership of least-cost soot free technology relative to baseline

-50% … 20%

Figure 10. Total cost of ownership and social damages of soot-free buses relative to baseline technologies in 20 megacities. The technology and fuel selected reflects a least-cost option for each city. Panel (a) gives total cost of ownership in the form of direct financial outlays including costs of bus and infrastructure acquisition, operation, and maintenance. Panel (b) gives total cost of ownership but combines estimates in panel (a) with the monetized social value of climate and health benefits from CO_2 and BC emission reductions from soot-free buses.

3. FINANCING OPTIONS FOR A TRANSITION TO SOOT-FREE BUSES

The previous section presented evidence in support of investments in soot-free urban bus fleets. This section provides a qualitative discussion of potential financing sources and acquisition models to enable the purchase of soot-free buses. As demonstrated in Section 2.3, soot-free buses may cost more upfront but pay back over the ownership period of the bus. Studies have analyzed funding sources and financing practices for public transit investments (EY, 2013; Lefevre & Leipziger, 2015). This discussion will focus on the elements of finance that are most relevant to support a transition to soot-free urban bus fleets.

3.1. MODELS FOR BUS ACQUISITION

Several options exist for acquiring new buses, each of which affects the need for and availability of various financing options. Bus acquisition options for public and private operators include cash or loan purchase as well as several kinds of leasing agreements: capital leases, operator leases, and battery leases. As shown in Table 5, the choice of these options can shift the credit, operational, and technology risks to the lender, operator, or manufacturer.

Table 5. Overview of bus acquisition options.

Acquisition method	Description	Ownership model	Notes on risk
Cash purchase	Full purchase price paid upfront	Operator	Operator bears technology risk
Loan purchase	Part of the cost is paid upfront; remainder is borrowed	Operator	Lender bears credit risk, which can increase the cost of borrowing
Capital lease (e.g., Scania, Proterra)	Lease payments are paid for the vehicle and/or fixed infrastructure for specified term	Operator may purchase at a specified residual value at end of lease	May be limited to local governments with investment-grade credit
Operator lease (e.g., Proterra)	Operator pays for use of the bus over a specified term	Operator may purchase at a specified residual value at end of lease	Manufacturer assumes operational risk
Component lease (e.g., Proterra)	Operating savings pay for specific sub-components (e.g., battery) over time	Manufacturer typically owns the battery during the lease term	Manufacturer assumes technology risk

For a cash or loan purchase, the bus is legally owned by the operator and listed on that operator's balance sheet as an asset. The operator may then write off part of the asset's value from the balance sheet as the bus depreciates. Under a leasing agreement, either the bus or some of its components (e.g., the battery) are legally owned by the lessor, not the operator. This may reduce the credit risk, because the lessor retains legal ownership of the asset in the case of default (EY, 2013). Operating leases or battery leases are potentially effective private financing strategies, as they reduce the financial commitments of operators and limit the performance risks of new technology. An operating lease typically gives operators the option to purchase the bus at the end of the lease term. A battery lease can be an attractive option for operators who seek protection from the risk of novel technology and lack information on durability, but who otherwise prefer to purchase the bus and handle operating expenses using conventional means. Battery leases also allow operators to spread out a high upfront payment and use some or all operational cost savings to cover these payments.

The tendency of private operators to have limited cash flow and low profit margins can be a barrier to securing operating leases. In such cases, public transit agencies may reduce the credit risk to the lessor by offering lease guarantees or takeover clauses; such provisions allow the public agency to take over the lease payments and operate or outsource the operation of the bus in the case of operator insolvency.

Leasing agreements are becoming more common and can be offered either directly by manufacturers or through specialized financing companies; in Sweden, for example, approximately 40% of buses are leased (EY, 2013). Such agreements commonly include a residual value and repurchase agreement that applies at the end of the lease term. Major manufacturers will often offer a finance option as part of a product offering, and they may refer to a partner that offers financing. Alternatively, manufacturers may draw up the lease agreement themselves before transferring it to the financing partner. Such niche financing companies may have connections to global second-hand market organizations that allow them to take on residual risks that banks cannot (EY, 2013). Leasing agreements may also include a service and maintenance contract, which can further reduce the risk of operating a new technology in a region with limited experience with that technology. Servicing is especially important in regions where local technical capacity is limited, not only to guarantee performance but also to reduce depreciation of the asset. Operators and manufacturers can reduce performance risk by agreeing to a “service” package, whereby the operator pays for vehicle service and maintenance provided by the vehicle manufacturer.

3.2. FINANCING OPTIONS FOR SOOT-FREE BUSES

As of yet, there is no direct and universal financing mechanism for soot-free bus deployment. There are, however, numerous existing financing strategies that could enable the purchase of soot-free buses; these include existing mechanisms supporting public transport modernization, expansion, and CO_2 reduction. As illustrated in Table 6, the procurement of buses and infrastructure could be supported by multiple institutions, with each playing a specialized role. Although the availability of some financing options (such as specific sources of climate finance) may depend on the public or private affiliation of the operator, most financing sources can be made available to private operators through participation in a project or facility developed by a government agency.

Table 6. Overview of governmental and commercial sources of bus finance.

Source	Examples	Financial products	Roles
Government incentives	UK Clean Bus Technology Fund, California HVIP	Retrofit incentives; point-of-sale price reductions	Partial coverage of incremental costs
Multilateral development banks	World Bank; Inter-American, African, and Asian Development Banks	Concessional loans, grants, guarantees, results-based financing	Bus and infrastructure acquisition and operations
Climate finance (including for NDCs)	Clean Technology Fund, Green Climate Fund, Global Environment Facility	Concessional loans, grants, guarantees, equity	Incremental cost of low carbon investments
National development banks	China Development Bank, Bancóldex (Colombia), Development Bank of the Philippines	Loans to buyers; credit lines to manufacturers	Intermediary for co-financing, blending of governmental and commercial sources
Export-import banks	OECD list of official export credits agencies; Berne Union association	Loans, guarantees, and insurance to exporters	Supports exporters
Commercial banks	List of 10 largest banks	Loans, lease financing, insurance	Largest volume of financing
Manufacturer leasing	Scania, Proterra	Lease financing for bus, infrastructure, or battery	Partial or full coverage of purchase cost
Specialized leasing companies	Connect through manufacturers		

Some financing sources, such as climate finance facilities and certain kinds of support from multilateral development banks, could especially support the introduction of soot-free buses on the basis of their benefits for air quality and climate. Examples of these sources include the Clean Technology Fund, the Green Climate Fund, and the Global Environment Facility (Table 7). As demonstrated in Section 2.4, soot-free bus technologies can nearly eliminate tailpipe BC and substantially reduce fuel lifecycle CO_2 emissions relative to conventional diesel buses; these benefits are important to quantify when cities or their respective national governments consider their policies and plans for bus procurement. Several of the climate finance sources listed in Table 7 offer readiness grants that could enable the development of clean bus policies and projects, with larger funds following to facilitate the deployment of soot-free buses and infrastructure. Although the amount of financing offered by these institutions is modest relative to the total likely financing demand, climate finance institutions can attract much larger volumes of co-financing from private and commercial sources (Table 7). For example, climate finance institutions that guarantee lease payments on soot-free buses could reduce the credit risk of manufacturer financing. The financing mechanisms offered by climate finance institutions can include grants, concessional loans, guarantees, and equity (ownership stakes). Concessional loans typically have very low fixed interest rates (e.g., 0.25%) and an extended grace period (Inter-American Development Bank, n.d.). For example, the Government of Chile is searching for financing (including with the Green Climate Fund) to shift 25% of new bus purchases in the Santiago Metropolitan Region to zero-emission electric drive technology by 2025.

Table 7. Overview of sources for low-carbon bus finance.

Source	Amount	Type	Eligibility	Sectors	Uses
Clean Technology Fund (CTF)	$5.6 billion; attracts up to 7x that amount in co-financing	Concessional loans	Middle-income countries	Public and private sectors	Demonstration and deployment
Green Climate Fund (GCF)	$10.3 billion; attracts co-financing	Grants, concessional loans, guarantees, equity	National and subnational organizations in developing countries. Applications are prepared in collaboration with GCF Accredited Entities, which include private, public, nongovernmental, subnational, national, regional, and international organizations including World Bank, UNDP, UNEP, ADB, AFC, AfDB, and others.	Public and private sectors	Readiness development, implementation, and monitoring
Global Environment Facility (GEF)	$4.4 billion; attracts up to 5.2x that amount in co-financing	Grants, loans, guarantees, equity	GEF recipient countries (developing and economies in transition). Applications are prepared in collaboration with GEF Agencies, which include World Bank, UNDP, UNEP, UNIDO, ADB, AfDB, and others.	Nationally driven; private sector may implement	Incremental costs of climate mitigation; enabling and projects

In a study of Bogotá's bus rapid transit system, the Inter-American Development Bank (IDB) identified higher upfront costs, perceived battery technology risks, and limited availability of local service suppliers as the primary barriers to switching from diesel buses to BEBs. Bogotá's procurement and operational strategy was able to reduce the technology risk by securing a battery lease from suppliers (with the cost based on distance traveled); it also enhanced the value proposition to private bus operators by allowing them to generate revenue from bus advertising space (Inter-American Development Bank, 2017). The financing strategy used a concessional loan to "crowd-in" a combination of co-financing from the national development bank and commercial banks. That case demonstrates the capacity to leverage concessional financing (e.g., from climate finance institutions or development banks) to attract much larger volumes from co-financing institutions.

Apart from direct financing sources, there is also a growing number of enabling facilities that can help cities and national governments transition to soot-free buses. The C40 Cities Finance Facility (CFF), for example, aims to provide up to $1 million in technical assistance and capacity development to its member cities for projects that can include procurement of soot-free (in this case, battery electric) buses. Additionally, C40 and the WRI Ross Center for Sustainable Cities have developed a Financing Sustainable Cities Initiative to help cities explore innovative procurement and financing models for BEBs. To date, several of the megacities evaluated in Section 2.3 have participated in the Financing Sustainable Cities Initiative, including Buenos Aires, Mexico City, and Santiago. In addition to receiving technical assistance through city-focused initiatives, cities may also receive support under the auspice of national governments for soot-free buses through the implementation of nationally determined contributions (NDCs). Established at Conference of the Parties (COP 22), the NDC partnership provides in-country support to formulate and implement NDCs, as well as to connect governments to bilateral and international financing sources. Because the UNFCCC currently focuses on GHG reductions (as opposed to BC), it is important for cities to quantify the GHG benefits of soot-free bus projects in addition to BC benefits. Cities or countries may also seek financial support for BC reduction projects to meet their sustainable development goals (SDGs), which include targets for sustainable transport and improved air quality.

4. ACTIONS TO INCREASE INVESTMENTS IN SOOT-FREE TECHNOLOGY

In principle, there is no financing gap standing in the way of a transition to soot-free urban bus fleets. Soot-free buses can result in lower lifecycle costs than conventional buses. A variety of purchase models and financing sources are available. Nevertheless, there are technical, operational, and economic barriers to the deployment of these technologies. Actions to expand access to financing for soot-free bus technologies can include the development of national and local policies; changes to procurement, contracts, and operating practices; and additional efforts by financing institutions. This section examines and recommends actions that governments and financing institutions can take to address these barriers and enable the accelerated deployment of soot-free bus technologies.

4.1. NATIONAL AND LOCAL POLICIES

Multiple national and local policies should be aligned to support the adoption of soot-free buses. These policies and their main effects are summarized in Table 8. For example, national governments can incorporate soot-free bus deployment targets into NDCs. This action can unlock access to international support for NDC implementation, including technical analysis, capacity building, and financing. Two other national-level actions—Euro VI new vehicle emissions standards and fuel quality regulations requiring investments in cleaner fuels—can ensure that all new vehicles and their fuels meet Euro VI emissions levels.

Given these national actions to protect public health, local governments can then determine the best technology options for their specific needs. The local corollary to national Euro VI emission standards is a city commitment to only procure or contract buses meeting Euro VI emissions. Cities can tender for the purchase of new buses, requiring minimum Euro VI emissions, while ensuring that the enabling fuels and servicing infrastructure are established. They may also specify, in franchising or concession guidelines, the procurement of new buses that must meet a minimum Euro VI emissions level. And they may require the operation of a minimum share of zero–tailpipe emission buses that increases over time. These are examples of local actions that complement or move ahead of national actions.

Various supporting economic incentives can be put in place at either the national or local levels. Direct investments in fueling and charging infrastructure can enable the uptake of buses using alternative fuels in both public and private fleets. Taxes for fuels and vehicles (or the removal of diesel fuel subsidies, where applicable) can also be optimized to enhance the market incentive for soot-free buses. As shown in Figure 8, for example, policies (or other factors) that increase the relative price of diesel fuels or lower the relative price of BEBs can substantially enhance the business case for zero-emission buses.

In addition to policies targeting new vehicles and their fuels, national or local governments can set policies that target emissions reductions from existing vehicles. These can include requirements to retrofit or replace in-use vehicles several years after the introduction of new emission standards (as with California's PM filter requirements). Alternatively, low-emission zones can set transparent access requirements for in-use vehicles entering or operating within a specified geographic area; also termed "environment zones," these have been implemented in many cities throughout Europe. National governments can encourage the local adoption of low-emission zones by developing frameworks for vehicle emissions labeling. For example, Germany's national labeling program establishes technology requirements for color-coded vehicle stickers (e.g., red, yellow, and green) that allow local governments to implement low-emission zones in several progressively stringent phases (Umweltbundesamt, 2016).

Table 8. Overview of national and local policies to support adoption of soot-free buses.

Jurisdiction	Policy	Effect
National	Nationally determined contributions	Receive international technical and financial support (UNFCCC, 2016)
	Sustainable development goal implementation	International technical and financial support
	New vehicle emissions standards	Technology-neutral; ensure all new bus sales meet Euro VI emissions levels
	Fuel quality regulations	Ensure availability or exclusive sale of ultralow-sulfur fuels; enable Euro VI emission controls; reduce PM emissions of in-use diesel vehicles
National or local	Investments in fueling/ charging infrastructure	Enable uptake of buses using alternative fuels (e.g., CNG, biogas, or electricity)
	Fuel tax reform	Enhance market incentive for hybrids, BEBs, and biogas buses
	Utility policies	Reform utility pricing schedules to guarantee time-of-use rate options for BEBs
	Vehicle tax reform	Remove tax penalty for buses with higher purchase price (e.g., hybrid, battery electric)
	Incentive funds for clean bus purchase	Retrofit incentives or point-of-sale price reductions to encourage soot-free bus purchase
	Retrofit/replacement requirements	Implement concurrently with new vehicle emissions standards/clean bus procurement to accelerate fleetwide emission reductions
	Financial and operational integration of public transport operators	Credit risk reduction resulting in lower financial costs. Centralized and card-based fare collection can lower the risk of misreporting revenues; centralized dispatch can lower demand risk.
Local	Commitments to procure soot-free buses	Procurement tenders and contracts require soot-free buses for public and private operation
	Low-emission zones (plus national enabling frameworks)	Increasingly stringent access requirements for in-use buses in cities with poor air quality

4.2. ENABLING CHANGES TO PROCUREMENT, CONTRACTS, AND OPERATING PRACTICES

The procedures in place for procuring, contracting, and operating buses can either help or hinder the adoption of soot-free bus technologies. As shown in Table 9, the barriers to soot-free bus deployment can be financial, technical, operational, or organizational. Financial barriers can include higher upfront costs and/or limited access to credit. Technical barriers can include the absence of cleaner fuels or new infrastructure for fueling or charging, as well as higher perceived technology risks such as the lifetime of batteries. Operational barriers can include inefficient route design, demand risks, transactional fraud, and fare dodging. Organizational barriers can include a limited supply of vehicle models that meet the desired technology requirements (e.g., local availability of Euro V CNG buses but not Euro VI CNG buses), as well as noncentralized ownership models in cities with a large number of small private operators.

Table 9. Barriers and opportunities of soot-free buses.

Barrier	Opportunity
Procurement guidelines and contract tenders prioritize options with lowest upfront cost	Use total cost of ownership (i.e., lifecycle cost analysis) to consider operational savings and net costs
Environmental impacts not factored into ownership cost	Demonstrate and monetize climate and health impacts; set minimum standards that consider these impacts
Requirements for new fueling/ charging infrastructure or imported fuels (e.g., ultralow-sulfur diesel)	Consider energy independence/security benefits of locally available electricity/gas; importing ultralow-sulfur diesel can enable fleetwide emission reductions
New technologies pose risks to operators and lenders	Battery leases can reduce technology risk of BEBs; operational leases can reduce vehicle operations risk; service contracts reduce maintenance risk; BEBs reduce risk of fuel price volatility
Risk of misfueling for diesel Euro VI buses where multiple grades are sold; charging infrastructure risks	Conduct regular fueling quality testing; public investments in charging facilities with utility coordination
Bus orders are infrequent and often too small to negotiate deals with manufacturers	Develop long-term (e.g., 10-year) refleeting strategy to attract more competitive bids from manufacturers; appoint national or regional coordinators to aggregate/ negotiate bus purchase orders
Special-ordered variants (heterogeneous specifications) limit the size of bus orders, increase purchase costs, reduce resale value, and increase investment risk	Prioritize functional requirements (environment, CO_2) over specification requirements (colors, fabrics, etc.); adhere to national, regional, or industry agreements
Short contracts with bus operators increase perceived risk to lenders	Extend contract periods or offer automatic renewal to soot-free bus operators meeting minimum standards
Age limits reduce the expected operational savings	Extend age limits of soot-free buses to useful life; apply confirmatory emission testing and safety screening
Route characteristics have variable effects on technology efficiency and operating cost	A mixed fleet of different technologies can address issues such as range limitations on longer routes; this can be optimized through ex ante route analysis and confirmatory pilots. Allowing operators to optimize buses among service routes could further reduce costs.

Procurement

The higher upfront costs of soot-free buses may be a challenge, especially for those private operators that have a small capitalization and low credit rating. New technologies such as BEBs can be seen as particularly risky by operators and lenders with little experience with new technology. Loan guarantees or concessional financing from climate finance institutions or takeover clauses offered by public agencies can lower the credit risks to lenders and lessors of soot-free technologies. Similarly, leasing strategies and service contracts can be structured to effectively manage operational and technology risks.

The higher purchase price of soot-free buses can be compounded by percentage-based sales taxes or value-added taxes. In cities where procurement procedures favor the option with the lowest purchase price, procurement decisions may fail to consider the operational savings and lower net cost of soot-free buses. Environmental externalities such as climate and health impacts may also be left out of the cost calculus, as these impacts can be difficult to monetize. Well-designed national and local policies as discussed in Section 4.1 can alleviate these affordability issues. For example, BEBs may be partially or fully exempted from certain sales taxes or value-added taxes. Shifting procurement and contracting priorities from lowest purchase price to lowest TCO can eliminate a barrier to soot-free bus deployment and likely reduce the costs of bus service.

Additional procurement strategies could potentially lower the purchase price of soot-free buses. One cited reason for high bus purchase prices is the limited number of buses purchased by a given city at any one time. Developing common national or regional bus specifications can reduce the number of special-ordered variants, lower the resale risk, and reduce purchase costs. In Sweden, for example, heterogeneous bus specifications are estimated to directly increase bus purchase costs by 10% (EY, 2013). The JIVE program in Europe also presents an approach to joint procurement of fuel cell zero-emission electric buses, with the explicit aim of scaling up procurement in order to reduce overall purchase cost (FCH, 2017). Standardized bus specifications can also lower the risks of new technologies, because greater standardization increases the resale value on the second-hand market in regions or countries with similar specifications. Alternatively, developing a long-term (e.g., 10-year) refleeting strategy that includes emissions certification requirements could attract more competitive bids from manufacturers with the possibility of more sales in subsequent years.

Contracting

As an alternative or addition to direct procurement by public transit authorities, some cities contract with private bus operators that provide bus service on behalf of the city. To win a contract, operators must meet the requirements of the tender, which include bus specifications, among others. For example, Metro Manila's public utility vehicle modernization program requires a minimum of Euro IV emissions for new franchises (Philippine News Agency, 2017). Public authorities in the future will be able to increase the stringency across the fleet by revising this in the future to require minimum Euro VI emissions performance.

Several factors can influence the investment risk and hence the cost of bus acquisition for private operators. For example, lenders may perceive a higher credit risk if contract periods are short, especially for those technologies that cost more upfront but pay back with operational savings. Extending the duration of contracts or offering automatic renewal to soot-free bus operators who meet minimum requirements could thus increase lender certainty and reduce the cost of bus acquisition. Similarly, extending maximum age limits for privately operated buses (e.g., 10 years in some cities) to match the useful vehicle life[7] can maximize operational savings and make full use of associated soot-free bus fueling or charging facilities. In cases where the TCO is higher for soot-free buses (but made up for by environmental benefits), contract renumeration formulas may be adjusted to compensate operators for the increased costs of soot-free buses.

Operations

In some cities, Euro VI diesel buses (including hybrids) may require cleaner fuels than the minimum fuel quality permitted by national regulations. In these cases, additional fuel quality testing may reduce the risk of misfueling (e.g., with higher-sulfur diesel).

7 Some manufacturers such as Proterra rate components such as the bus body with a useful life of up to 18 years.

The costs of conducting this sort of testing are likely to be very low relative to the overall cost of fueling. Periodic emissions testing can allow public agencies to screen for misfueling or poor maintenance and verify real-world emissions performance. A further strategy is for operators to purchase a service contract from the manufacturer, which places responsibility on the manufacturer to ensure fuel quality and make repairs when misfueling occurs.

The deployment of soot-free buses is compatible with the global trends of public transport formalization and growth of operator collectives. These trends could reduce the barriers to new technology uptake (e.g., higher upfront costs, low credit ratings, new maintenance practices, new fueling infrastructure) by facilitating risk pooling and greater economies of scale. Similarly, practices such as fleet management could reduce the costs of bus operation by allowing operators to optimize bus allocation based on real-time route characteristics and bus efficiency.

4.3. EXPANDING ACCESS TO FINANCING FOR SOOT-FREE BUS TECHNOLOGIES

Multiple institutions for climate finance and other international organizations have a valuable function in augmenting the technical capacity of cities to transition to soot-free buses (Section 3.2). Cities and countries may access this support by developing goals and policy reforms to encourage soot-free buses. Such actions could include the designation of soot-free buses in climate and development plans (e.g., NDCs and SDGs) and in local-level commitments to reduce the climate impacts of both CO_2 and BC. Financing institutions, in turn, could step up their engagement with cities to identify and communicate the financing options for transitioning to soot-free buses. This engagement could include the publication of guidelines specifically for soot-free bus projects along with the steps to apply for funding to support feasibility studies. Additional actions by multilateral and national development banks could include commitments to support the procurement of soot-free (Euro VI) buses as opposed to earlier bus technologies (i.e., Euro V) where appropriate fuels are available (see discussion on page 29).

5. CONCLUSIONS AND DISCUSSION

In this paper, we evaluate the costs of a 10-year transition to soot-free urban bus fleets in 20 megacities. We assess the sensitivity of TCO of soot-free technology in these cities to variation in diesel fuel prices, BEB purchase prices, and bus operating efficiency. Our results show that soot-free technology with the lowest potential lifecycle cost in each megacity will result in net savings relative to existing higher-polluting bus fleet technology, even under conservative assumptions. At an aggregate level, a transition to soot-free urban bus fleets can result in lower total costs to public and private operators than existing buses.

In all cases, soot-free buses have a higher upfront purchase price than existing bus technology in each city. Yet on average, soot-free technology will generate lower net TCO within 5 to 9 years of purchase. Our results show that the exclusive purchase of buses with soot-free technology in these cities over the next 10 years is associated with cumulative cost savings in the tens of billions of dollars. To capture these lower costs, cities wishing to transition to soot-free urban bus fleets will need to adopt strategies to cover the initial upfront investment. Financing institutions should consider the development of acquisition models where lifecycle cost savings allow the transition to soot-free buses to pay for itself. It is essential that cities and financial institutions take a TCO perspective in bus procurement decisions, unlike standard purchase models.

There are several technology options to achieve soot-free emissions. These technologies include dedicated Euro VI diesel buses, Euro VI diesel hybrid buses, buses powered by natural gas and biogas, and BEBs. The best soot-free technology option for a specific city, bus route, and point in time depends on many variables, including fuel quality and availability; local operational characteristics; and the prices of fuels, components, vehicles, and infrastructure. In this analysis, under a Low Diesel Price case, Euro VI diesel hybrids are estimated to be the least-cost soot-free technology for at least several bus types in 10 of the 20 cities evaluated. BEBs and CNG buses are estimated to have the lowest TCO for some or all bus sizes in 10 and 7 cities, respectively. Yet the underlying determinants of these costs are both uncertain (given the limited availability and quality of city-specific data) and subject to change (given declining battery costs, etc.).

The findings of this study suggest that cities can improve upon their understanding of the savings from soot-free bus deployment by undertaking the following actions:

» Collect data on actual bus operations and costs to understand lifecycle cost of buses in operation to inform route planning and bus procurement decisions.

» Identify, in partnership with local operators and manufacturers, potential least-cost soot-free (minimum Euro VI emissions) technology on a lifecycle basis that is most suitable to each category of bus size and bus route over the coming years.

A transition of new bus purchases to soot-free technologies would make even more sense from a cost perspective when the social benefits of emissions reductions are taken into account. In a Low Diesel Price case, the social costs of pollutant emissions can be equal to more than 40% to the TCO of conventional diesel buses. Although in principle any city can shift to soot-free technology and save money, there are certain soot-free technologies along certain bus routes for which this is not guaranteed. In those cities that could have somewhat higher financial costs with soot-free buses in some cases (i.e., if Nairobi and Dar es Salaam were to have continued low diesel prices or high BEB prices), there is a greater need for government actions that internalize the social costs of pollutant emissions and thus strengthen the incentive for private operators to transition to soot-free technologies.

National and local governments each have an important role to play in achieving soot-free bus performance. As demonstrated in the United States, the European Union, Canada, Japan, South Korea, and Turkey, national policies to improve fuel quality and implement Euro VI emissions standards can effectively ensure that all new vehicles demonstrate Euro VI performance. Yet local governments can also play a critical role in enabling or requiring a transition to soot-free performance. These actions can include adding minimum Euro VI emission requirements into procurement tenders and contracts; reforming local fuel and vehicle taxes that currently subsidize higher-polluting diesel fuels (containing more than 10 ppm sulfur) or vehicles; requiring public and private franchises to meet a minimum share of their in-use fleet with zero-emission buses; and adding retrofit or replacement requirements for new or existing franchises.

Governments also have an important function in addressing the technology challenges of deploying soot-free buses. Three cities—Abidjan, Addis Ababa, and Nairobi—have no existing access to gas or diesel fuels that would enable soot-free technology. Other cities assessed have access to gas for CNG or biogas buses but would need to import diesel to enable the introduction of Euro VI diesel buses or diesel hybrids. BEBs are assumed to be available in all cities, but as in nearly all cities, the rate and demand structure for vehicle charging will need to be arranged with local utilities. Fuel availability and quality limitations can be addressed by requirements to import cleaner fuels, investments in refinery upgrades, and regular fuel quality testing. Charging infrastructure is a good candidate for public investment as well as climate/development financing, because once deployed, it could enable large and small private operators to purchase BEBs through conventional financing channels.

Beyond government policies and technology/cost factors, one of the most important findings of this study is that new cleaner technologies with lower lifecycle costs require innovations in bus acquisition and financing in order to enable the transition to soot-free urban bus fleets. This begins with financing institutions, both domestic and international, taking a lifecycle cost of ownership perspective on their assistance programs. Direct assistance can include loan guarantees or concessional financing from climate finance institutions. Takeover clauses offered by public agencies can lower the credit risks to lenders and lessors of soot-free technologies, increasing access to public and private credit. Such guarantees can attract much larger volumes of co-financing from private banks and reduce the cost of borrowing by lowering risk premiums. Similarly, leasing strategies (notably battery leases) and service contracts over the full or partial lifetime of the vehicle can be structured to reduce the risks to operators and credit agencies of investing in new technology.

Cities may also be able to lower demand risks by making bus operations more efficient (e.g., improving bus dispatch systems, redesigning routes) and by working with private operators to explore opportunities for mutually beneficial formalization or collectivization. Likewise, cities may lower transactional operational risks by centralizing fare collection (i.e., smart cards) and equipping buses with technology or personnel to reduce the incidence of fraud and fare dodging. These actions to reduce credit risk could be included as part of a climate finance package that also addresses barriers to bus and infrastructure acquisition.

As soot-free and electric buses become more prevalent worldwide, financing institutions have an opportunity to step up their engagement with cities to communicate the options for transitioning to cleaner buses. This engagement could include the publication of guidelines specifically for soot-free bus projects (based on successful cases) along with the steps to apply for funding to support feasibility studies. Additional actions by multilateral and national development banks could include commitments to support the procurement of soot-free (Euro VI) buses and the cleaner diesel or alternative fuels necessary to support them, as opposed to earlier bus technologies operating with conventional higher-polluting fuels.

There are several opportunities to build upon this work as cities around the world continue the transition to soot-free and zero-emission buses. These opportunities include continued data collection, refined TCO analysis, and financial modeling to assess the best technology options for cities seeking to transition their fleets to cleaner buses. An additional recommendation for future study is to continue to implement, monitor, and report on the transition to soot-free and zero-emission buses in specific cities, and track this progress at the regional and global levels.

6. APPENDIX

6.1. SPECIAL CONSIDERATIONS FOR SOOT-FREE TECHNOLOGY

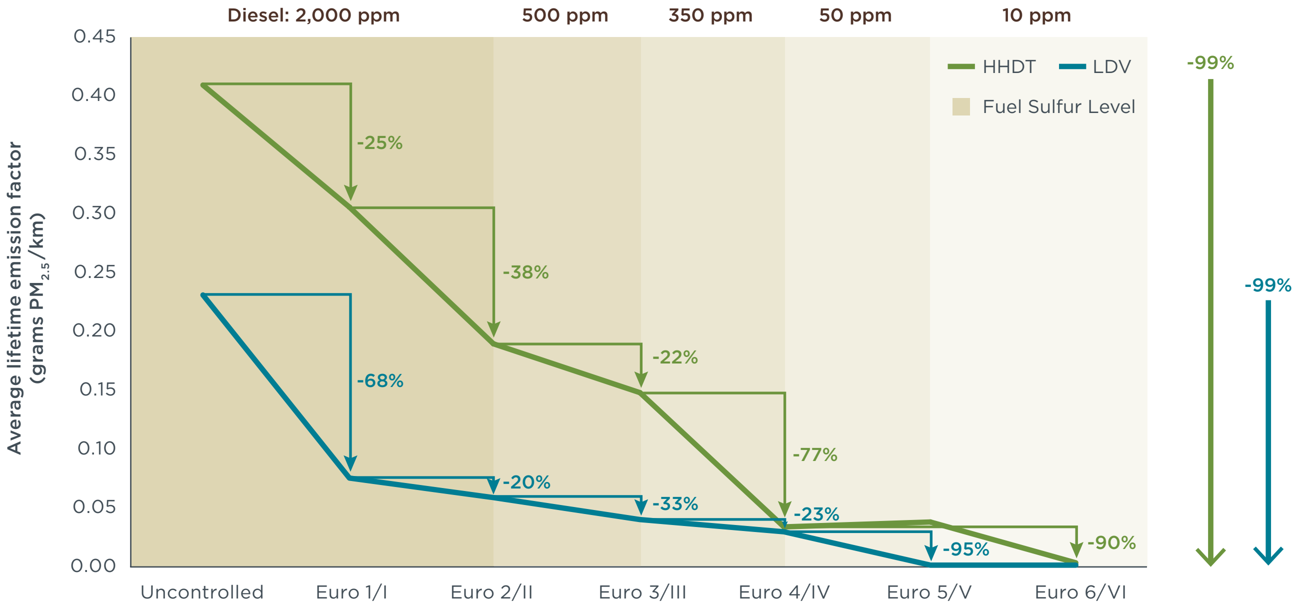
This section addresses three considerations for a transition to soot-free bus technology. Responses are provided to the following questions:

1. Do Euro V and Euro VI diesel buses use the same fuel? Are there any reasons why cities should continue to purchase Euro V buses?
2. What are the climate benefits of using alternative fuels? Can Euro VI buses run on biodiesel?
3. Is there a standard for electric bus charging technology? How can cities reduce the risk of charging infrastructure limiting bus purchases to one manufacturer?

Moving to Euro VI diesel buses

Half of the cities evaluated have access to locally produced or imported ultralow-sulfur diesel (ULSD), which contains a maximum of 10 to 15 ppm sulfur (TransportPolicy.net, 2017), yet these cities are standing still with their current Euro V emissions control technology. Although the fuel quality requirements of Euro V and Euro VI diesel vehicles are identical, it is not uncommon for cities with ULSD to continue to purchase Euro V diesel buses. This may in part relate to the terminology of ULSD as "Euro V" diesel (Shell, 2017), when it could also be appropriately termed "Euro VI" diesel. For cities currently at Euro IV standards, there is a good case to leapfrog directly from Euro IV to Euro VI following the example of India and skipping over Euro V (ICCT, 2015).

Not only do Euro V and Euro VI diesel buses use the same fuel, but Euro VI buses consistently outperform Euro V buses with lower total costs of ownership (Miller, 2017), lower real-world fuel consumption, and dramatically reduced emissions of local air pollutants, including $PM_{2.5}$, BC, and NO_X (Chambliss et al., 2013; Posada et al., 2016; VTT Technical Research Centre of Finland, 2016). As shown in Figure 11, the move from Euro V to Euro VI reduces bus average lifetime $PM_{2.5}$ emission factors by 90%, much greater than the 50% tightening of engine emission limits for PM mass. This disproportionate emission reduction from Euro V to Euro VI is achieved by the inclusion of a limit on particle number (PN) with Euro VI, which can only be met using a much more effective diesel particulate filter. The benefits to society of a shift from Euro V to Euro VI technologies outweigh the incremental emission control costs by a factor of 11 to 1 (Miller & Façanha, 2016). Hence, there is no technical or cost justification for the purchase of new Euro V diesel buses when Euro VI options are available.



Emission factors of $PM_{2.5}$ (g/km) are shown for heavy heavy-duty diesel trucks and light-duty diesel vehicles. Data labels indicate the percentage reduction in emissions from the previous standard, with the series on the right depicting the total percentage reduction from conventional (uncontrolled) to Euro 6/VI. SCR systems control NO_x (not shown) and allow engine tuning to reduce $PM_{2.5}$ emissions for heavy heavy-duty vehicles meeting Euro IV standards and light-duty diesel vehicles meeting Euro 6 standards. DPFs are employed to meet Euro 5 standards for light-duty diesels and Euro VI for heavy-duty vehicles.

Figure 11. Fine particulate ($PM_{2.5}$) average lifetime emission factors for diesel vehicles by emission standard and sulfur content. Reprinted from Chambliss et al. (2013).

Avoiding alternative fuel pitfalls

The most attractive soot-free technology options from a cost and emissions perspective tend to be Euro VI diesel hybrids, Euro VI CNG buses, and BEBs. In this section and the following, we elaborate on the potential climate benefits and technical considerations associated with buses powered by alternative fuels.

The climate benefits of alternative fuels depend on the raw material that go into them and the process of turning that material into fuel. The climate benefits of BEBs are greatest in cities with the least carbon-intensive electricity grids and smallest in cities with a high share of coal-fired power generation; likewise, these benefits can be expected to increase as cities increase the share of electricity generated from renewables. For CNG buses, using landfill or dairy biogas would result in climate benefits relative to fossil-derived CNG (CARB, 2017); however, biogas is also likely to be more expensive than fossil-derived CNG unless policies are put in place to reduce the price differential (Jaffe, 2016). In contrast to the potential for GHG benefits with low-carbon electricity or renewable biogas, buses using biodiesel or hydrotreated vegetable oil (HVO; also called "renewable diesel") derived from palm oil would increase GHG emissions relative to conventional diesel (CARB, 2016a; Valin et al., 2015).

There are only a few examples of Euro VI heavy-duty engines certified to run on 100% biodiesel or HVO, which may limit the international availability of these engines. Whereas CNG and electricity tend to be cheaper than conventional diesel, biodiesel and HVO tend to be more expensive (AFDC, 2017b). Euro VI engines must undergo additional emissions certification to operate with high-percentage HVO or biodiesel blends.

Without this certification, conventional Euro VI diesel engines are typically limited to 5 to 8% biodiesel blends (AFDC, 2017a; European Commission, 2017) whereas HVO blends can reach 30 to 50% without specialized equipment or engine modifications (Teter et al., 2016). Given the higher costs of biodiesel and HVO, we expect these fuels to have a more limited role (relative to CNG or electricity) in transitioning cities to soot-free buses. For these reasons, cities should carefully consider liquid biofuels and undertake a realistic assessment of their potential.

Reducing risk of lock-in for charging infrastructure

BEBs can either be charged on-route (while in operation) or at a bus depot (i.e., during breaks in service or overnight). Each charging technology has advantages and disadvantages with respect to operation and cost. On-route chargers can cost $250,000 to $350,000 per charger, but the costs per bus depend on the fleet size and number of chargers. Depot chargers can cost $50,000 per bus. The actual costs incurred by bus operators, however, depend on the purchase or leasing agreement. Some manufacturers such as BYD include the cost of depot chargers in their bus price. In this analysis, we do not make a determination of which technology should be used in various cities. We apply a one-time cost of $50,000 per bus for charging infrastructure; this cost is conservatively high because it does not account for economies of scale (i.e., the charging cost per bus declining with a larger number of buses). Additionally, we account for charging infrastructure maintenance costs, which BYD indicates are similar to the cost of maintaining diesel fueling stations (0.5 U.S. cents per liter of diesel-equivalent).

Although some charging technologies may carry a risk of "lock-in" to buying buses from a specific manufacturer, such risks are not uniform across charging technologies. The European Automobile Manufacturers Association (ACEA), which includes Daimler, Iveco, MAN, Scania, and Volvo, issued several recommendations in May 2017 to support the interoperability of charging technologies across manufacturers. For depot charging, ACEA recommends the use of CCS Combo 2 devices.[8] For opportunity charging (e.g., at end stops), ACEA recommends "contact rails on the roof the vehicle above the front axle; pantograph coming down from an overhead charging mast; and Wi-Fi protocol for communication between vehicle and charging mast" (ACEA, 2017). OppCharge is one example of a platform that supports interoperability for opportunity charging.

For private operators, a lack of charging infrastructure may be an important limitation to the introduction of BEBs (other than upfront cost), even in cities where BEBs have a lower TCO. In cities with both public and privately operated bus fleets, initial deployment of BEBs in public fleets could serve as a stepping stone to introduction to private fleets. Smaller private operators, which tend to have the lowest profit margins and limited cash reserves, may prefer conventional technologies unless a very strong financial incentive exists to change their purchase behavior. Hence, publicly operated charging infrastructure is a good candidate for climate/development financing, because once deployed, it could enable large and small private operators to purchase BEBs through conventional financing channels.

8 As of August 2017, ACEA's recommendation for depot charging differs from the specification of bus chargers sold by BYD.

6.2. EMISSIONS OF BLACK CARBON AND CARBON DIOXIDE

Table 10 summarizes the emissions mitigation potential of a transition to soot-free buses in all 20 cities. Results are totaled across the 20 cities for the years 2018 to 2041. Over the ownership period of new buses purchased from 2018 to 2027, soot-free technologies could prevent the release of approximately 35,000 tons of BC and hundreds of millions of tons of CO_2 across the cities evaluated. These emissions reductions are equivalent to 97 to 100% of baseline emissions for BC and 20 to 61% of baseline emissions for CO_2, depending on the mix of soot-free technologies deployed.

Table 10. Cumulative mitigation of black carbon and carbon dioxide emissions with soot-free buses in 20 megacities.

Scenario	Cumulative mitigation 2018–2041		Percent reduction compared to baseline technology	
	BC (kt)	CO_2 (Mt)	BC	CO_2
Least Cost	34.9–35.8	100–322	97–100%	20–50%
Least BC Emissions	35.9	255–463	100%	51–61%

Table 11 shows the total emissions of BC from bus tailpipes and fuel lifecycle CO_2 emissions for each scenario and sensitivity case evaluated. Results are totaled across the 20 cities evaluated and are shown by calendar year. BC emissions are shown in metric tons; CO_2 emissions are shown in millions of metric tons. The difference between the Baseline and Least Cost or Least BC Emissions scenarios indicates the BC and CO_2 mitigation associated with a transition to soot-free buses in all 20 cities.

Table 11. Emissions of black carbon and carbon dioxide from new bus fleets in 20 megacities, 2018–2041.

Scenario	Sensitivity	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041
BC [metric tons]																									
Baseline	Low diesel price	250	500	750	1000	1300	1500	1800	2000	2300	2500	2500	2400	2400	2400	2300	2100	1800	1600	1300	1100	860	650	430	220
	Moderate diesel price	250	500	750	1000	1300	1500	1800	2000	2300	2500	2500	2400	2400	2400	2300	2100	1800	1600	1300	1100	860	650	430	220
	High diesel price	250	500	750	1000	1300	1500	1800	2000	2300	2500	2500	2400	2400	2400	2300	2100	1800	1600	1300	1100	860	650	430	220
	Low BEB price	250	500	750	1000	1300	1500	1800	2000	2300	2500	2500	2400	2400	2400	2300	2100	1800	1600	1300	1100	860	650	430	220
	High BEB price	250	500	750	1000	1300	1500	1800	2000	2300	2500	2500	2400	2400	2400	2300	2100	1800	1600	1300	1100	860	650	430	220
	Low efficiency routes	250	500	750	1000	1300	1500	1800	2000	2300	2500	2500	2400	2400	2400	2300	2100	1800	1600	1300	1100	860	650	430	220
	High efficiency routes	250	500	750	1000	1300	1500	1800	2000	2300	2500	2500	2400	2400	2400	2300	2100	1800	1600	1300	1100	860	650	430	220
Least Cost	Low diesel price	7	14	21	27	34	41	48	55	62	69	67	66	65	63	62	55	48	41	35	28	22	17	11	6
	Moderate diesel price	4	8	11	15	19	23	27	30	34	38	38	37	37	37	36	32	29	25	21	17	14	10	7	3
	High diesel price	1	1	2	3	3	4	5	5	6	7	7	6	6	6	6	6	5	4	4	3	2	2	1	1
	Low BEB price	4	7	11	14	18	21	25	29	32	36	35	35	34	34	34	30	27	23	19	16	13	9	6	3
	High BEB price	7	14	21	28	35	42	49	56	63	69	68	67	66	64	63	56	49	42	35	28	23	17	11	6
	Low efficiency routes	7	14	21	28	35	42	49	56	63	70	68	67	66	64	63	56	49	42	35	28	22	17	11	6
	High efficiency routes	7	13	20	26	33	39	46	52	59	65	64	63	62	61	60	54	47	41	34	28	22	17	11	6
Least Emissions	Low diesel price	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Moderate diesel price	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	High diesel price	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Low BEB price	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	High BEB price	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Low efficiency routes	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	High efficiency routes	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CO_2 [million metric tons]																									
Baseline	Low diesel price	5	9	14	19	23	28	33	37	42	47	45	44	43	42	41	36	31	27	22	17	14	10	7	3
	Moderate diesel price	5	9	14	19	23	28	33	37	42	47	45	44	43	42	41	36	31	27	22	17	14	10	7	3
	High diesel price	5	9	14	19	23	28	33	37	42	47	45	44	43	42	41	36	31	27	22	17	14	10	7	3
	Low BEB price	5	9	14	19	23	28	33	37	42	47	45	44	43	42	41	36	31	27	22	17	14	10	7	3
	High BEB price	5	9	14	19	23	28	33	37	42	47	45	44	43	42	41	36	31	27	22	17	14	10	7	3
	Low efficiency routes	6	11	17	23	28	34	40	45	51	57	55	54	53	51	50	44	38	33	27	21	17	13	9	4
	High efficiency routes	4	7	11	15	18	22	26	29	33	37	36	35	34	33	32	28	24	21	17	13	11	8	5	3
Least Cost	Low diesel price	3	6	10	13	16	19	22	26	29	32	31	30	29	29	28	25	21	18	15	12	9	7	5	2
	Moderate diesel price	3	6	8	11	14	17	20	23	25	28	27	26	26	25	24	21	18	15	12	10	8	6	4	2
	High diesel price	3	5	8	10	13	15	18	21	23	26	25	24	23	22	21	19	16	14	11	8	7	5	3	2
	Low BEB price	2	5	7	9	12	14	16	19	21	23	23	22	21	21	20	18	15	13	11	8	7	5	3	2
	High BEB price	3	7	10	13	16	20	23	26	29	33	32	31	30	29	28	25	22	19	15	12	10	7	5	2
	Low efficiency routes	4	8	12	15	19	23	27	31	35	39	38	37	36	35	34	30	26	22	18	14	12	9	6	3
	High efficiency routes	3	6	9	12	15	18	21	24	26	29	29	28	27	26	25	22	19	17	14	11	9	6	4	2
Least Emissions	Low diesel price	2	4	6	7	9	11	13	15	17	19	18	17	17	16	15	13	12	10	8	6	5	4	2	1
	Moderate diesel price	2	4	6	7	9	11	13	15	17	19	18	17	17	16	15	13	12	10	8	6	5	4	2	1
	High diesel price	2	4	6	7	9	11	13	15	17	19	18	17	17	16	15	13	12	10	8	6	5	4	2	1
	Low BEB price	2	4	6	7	9	11	13	15	17	19	18	17	17	16	15	13	12	10	8	6	5	4	2	1
	High BEB price	2	4	6	7	9	11	13	15	17	19	18	17	17	16	15	13	12	10	8	6	5	4	2	1
	Low efficiency routes	2	5	7	10	12	14	17	19	21	24	23	22	21	21	20	18	15	13	10	8	6	5	3	2
	High efficiency routes	2	4	6	7	9	11	13	15	17	19	18	17	17	16	15	13	12	10	8	6	5	4	2	1

6.3. METHODS AND SENSITIVITY ANALYSIS

The following sections relate to the methods and data sources used for estimating the TCO of soot-free bus technologies relative to conventional technology. TCO was evaluated using a new model consisting of three components: an Excel input spreadsheet, a calculation script written in Python, and an Excel output spreadsheet. The input spreadsheet takes data specific to each city, bus type, and technology type. Section 6.5 specifies the default data sources used for each input. The full input spreadsheet is available upon request. The calculation script processes the input spreadsheet, applies user-specified defaults where city-specific information is not available, and performs the TCO calculations for each city, bus type, and technology type. The script also evaluates TCO according to a schedule of bus purchases: In this analysis, that schedule includes the projected number of new buses needed in the 20 target cities over the next 10 years.

Diesel fuel prices

As shown in Figure 12, the retail price of diesel varies substantially across the 20 target cities. These retail prices reflect differing levels of taxes or subsidies as well as historically low international diesel prices.

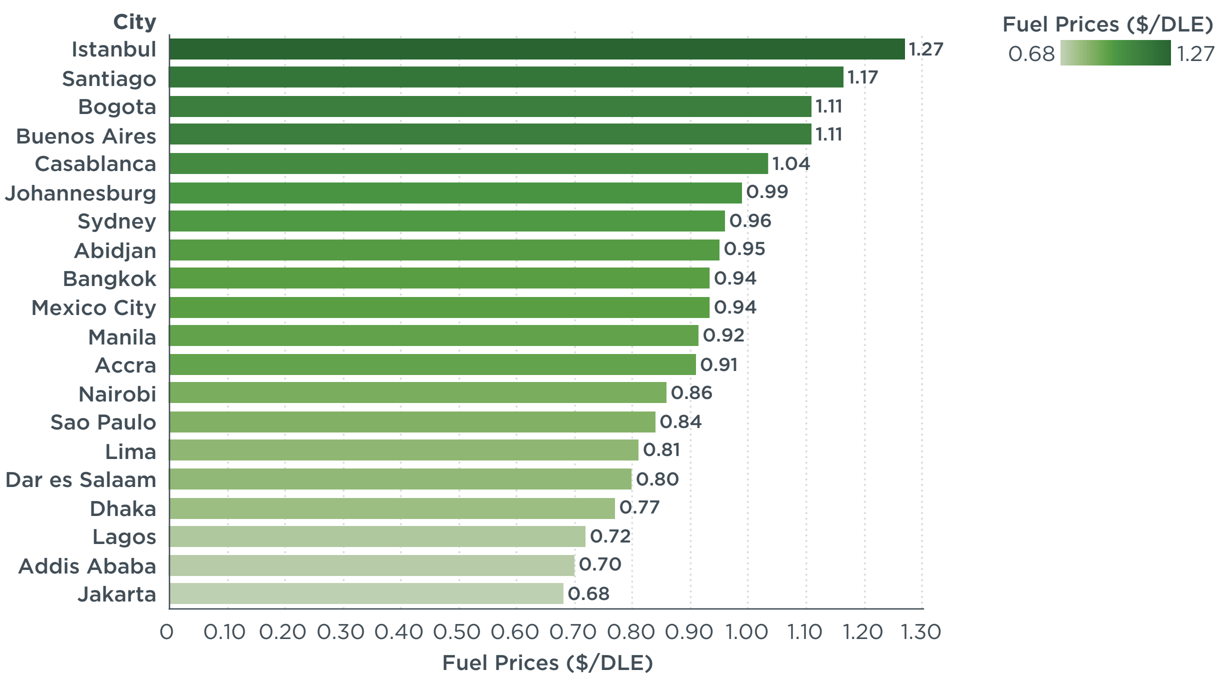


Figure 12. Retail diesel price by city as of June 2017 (USD per liter of diesel equivalent).

International oil and diesel fuel prices are still low relative to their average levels over the past 7 years (U.S. EIA, 2017). In 2015, diesel spot prices were 45% lower than their 2011–2014 average (excluding taxes). If diesel prices were to return to their 2011–2014 average levels, this would entail an 80% price increase from 2015 levels (excluding taxes). Because countries tax diesel fuel to varying degrees, such a change in diesel spot prices could increase the retail price of diesel by approximately 25% in countries with high diesel taxes and 60% in countries with low diesel taxes.

Diesel fuel prices are conservatively assumed to remain low for most of the sensitivity cases evaluated in this analysis. To assess the effect of a possible increase in diesel fuel prices on the relative TCO of different soot-free technologies, we consider two sensitivity cases in which diesel fuel prices increase from their current levels. The "Moderate Diesel Price" case assumes a 0.2 USD/liter increase in diesel fuel prices, equivalent to a 15% to 30% increase across cities. The "High Diesel Price" case assumes a 0.5 USD/liter increase in diesel fuel prices, equivalent to a 40% to 75% increase across cities.

Battery electric bus prices and electricity rates

California Air Resources Board (CARB) data indicate that BEBs sold in 2017 have a purchase price approximately 78% higher than equivalent diesel buses (multiplier of 1.78x). Proterra projections indicate that this price differential could decrease to ~1.2x by 2020 as a result of declining battery costs and increased economies of scale (CARB, 2016b). On the other hand, the current purchase price of BEBs relative to diesel buses could be greater than 1.78x in cities where conventional buses are less costly. The sensitivity cases for Low BEB Price and High BEB Price account for this variability by assuming that the purchase price of BEBs ranges from 1.2x to 2x the purchase price of diesel buses. The electricity rates for BEB charging are based on national average electricity rates. These rates range from 8 to 25 cents per kWh, with a mean of 18 cents per kWh.

Effects of route characteristics on bus efficiency

Route characteristics may have substantial impacts on the efficiency of different soot-free technologies. In the United States, the Altoona, Pennsylvania test program has evaluated the efficiency of EPA 2010 (Euro VI equivalent) buses over six different duty cycles. These duty cycles range from a commuter cycle (high speeds with infrequent stops) to urban (low speeds with frequent stops). The estimates of efficiency applied in most cases are for a duty cycle with medium kinetic intensity, similar to the Orange County Transit Authority (OCTA) cycle. To assess the potential effects of varying route characteristics on the relative TCO of different soot-free technologies, we consider two sensitivity cases for vehicle efficiency. One case applies efficiency estimates for a commuter cycle (less demanding, higher efficiency), whereas the other case assumes an urban cycle (more demanding, lower efficiency).

Relative to conventional diesel buses, the operational savings of hybrid buses in particular vary according to traffic conditions, with higher savings in stop-and-go/low-speed driving and lower savings in conditions with higher speeds and less frequent stops. BEBs consume 70% to 80% less energy per kilometer than conventional diesel buses, depending on the duty cycle (Dallmann et al., 2017). The High Efficiency Routes and Low Efficiency Routes sensitivity cases account for this potential variation. Section 2.3 illustrates the impact of traffic conditions on the choice of least-cost soot-free technologies in each city.

6.4. KEY DATA INPUTS AND SOURCES

Table 12 lists the key data sources used for the TCO analysis. The following sections elaborate on the sources and assumptions for each data input.

Table 12. Summary of key data sources for total cost of ownership analysis.

Input	Data sources	Comments
Baseline technology	ICCT Urban Bus Database	Based on minimum emissions standards and diesel fuel quality
Diesel fuel prices	WBDI, globalpetrolprices.com	Corresponds to low diesel price case
Other fuel prices	Default data from SP Trans	Electricity prices relative to diesel
Number of bus purchases	ICCT Urban Bus Database (for 20 cities)	Estimated from fleet size by bus type, assuming age limit of 10–15 years
Annual bus mileage	ICCT Urban Bus Database (for 7 cities)	Assume same mileage by technology
Bus purchase price	Default data from SP Trans, CARB	City-specific data for Bangkok, Dhaka, Jakarta, Johannesburg, Istanbul, Mexico City, Santiago, São Paulo, Sydney
Bus maintenance	Default data from SP Trans, CARB	Cost per vehicle-km traveled
Midlife overhaul	CARB – Advanced Clean Transit	Excludes BEB overhaul if battery warranty
Infrastructure	CARB – Advanced Clean Transit	Excludes CNG stations where already in use
Real interest rates	World Bank Development Indicators (WBDI)	Assume average rate for 2011–2015
Grid carbon intensity	IEA, IPCC	Assume national average emission rates

Data on real interest rates are based on national-level data obtained from the World Bank Development Indicators (World Bank, 2017). To reduce the influence of data gaps and fluctuation from year to year, average interest rates are derived from the period 2011 to 2015. The median and mean real interest rates among the 20 cities evaluated are 5.4% and 6.4% per year, respectively. These real interest rates are equivalent to nominal interest rates minus inflation.

Annual bus mileage

The annual distance traveled by buses in a given city can influence the choice of least-cost soot-free technology; higher mileages tend to favor technologies that cost more upfront but pay back over the operation of the vehicle (i.e., hybrids and electric buses). Data on average annual bus mileage were obtained for seven cities: Bangkok, Buenos Aires, Johannesburg, Lima, Santiago, São Paulo, and Sydney. These mileage estimates range from 45,000 to 84,000 km per year; where city-specific mileage data are unavailable, we assume the median value of 70,000 km per year.

Bus purchase prices

The potential for regional variation in bus acquisition costs is the largest source of uncertainty in our TCO calculations. Most cities do not report actual bus purchase prices separately from their operational budgets, and the operational budgets are seldom detailed enough to derive bus purchase or operating costs by technology. Manufacturers are even more reluctant to share this information.

Default data for bus purchase prices are based on a combination of empirical data from SP Trans in São Paulo and CARB databases. Where possible, the analysis considers city-specific purchase price data in place of defaults. City-specific purchase price data are used for CNG buses and BEBs in Bangkok; diesel and CNG buses in Dhaka and Jakarta; Euro VI diesel buses in Istanbul; Euro V and Euro VI diesel buses in Santiago; Euro V diesel buses in Sydney; Euro V diesel, Euro VI diesel, and CNG buses in Mexico City; and Euro IV and Euro V diesel buses in Johannesburg. Table 13 shows the default data for the purchase price of each bus technology relative to the purchase price of Euro V diesel buses.

Table 13. Default bus purchase price relative to Euro V diesel buses.

Euro II diesel	Euro III diesel	Euro IV diesel	Euro V diesel	Euro VI diesel	Euro VI biodiesel	Euro VI CNG	Euro VI hybrid	Euro VI ethanol	BEB
0.96	0.97	1.00	1.00	1.02	1.02	1.12	1.40	1.16	1.78

Maintenance costs

Maintenance cost estimates are based on empirical data from SP Trans in São Paulo, local surveys of operators in Mexico City, and CARB databases. We do not evaluate the opportunity costs of having buses off-duty during maintenance or overhaul; there are not enough data to indicate whether opportunity costs would favor BEB, hybrid, CNG, or diesel technologies. We do not evaluate the costs of inspection programs for vehicles or fuels apart from retail fuel prices and regular vehicle maintenance.

CNG infrastructure costs

As discussed in Section 2.2, natural gas is available for transportation in 16 of the 20 cities evaluated. We therefore assume that CNG infrastructure costs are reflected in retail CNG prices in cities where CNG buses are already in operation.

Risk of misfueling

There is a risk of misfueling in countries where multiple diesel fuel grades are sold. To reduce the risk of misfueling, government agencies could monitor the quality of diesel fuel being used in public bus fleets. Such fuel quality testing would likely have a very small incremental cost relative to the total cost of diesel fuel.

Grid carbon intensity

The lifecycle GHG emissions benefits of BEBs depend on the carbon intensity of the electricity used to power them. Estimates of climate benefits and social costs in this analysis rely on national average electricity emission rates shown in Figure 13. A thorough comparison of the climate impacts of bus technology options is provided by Dallmann et al. (2017).

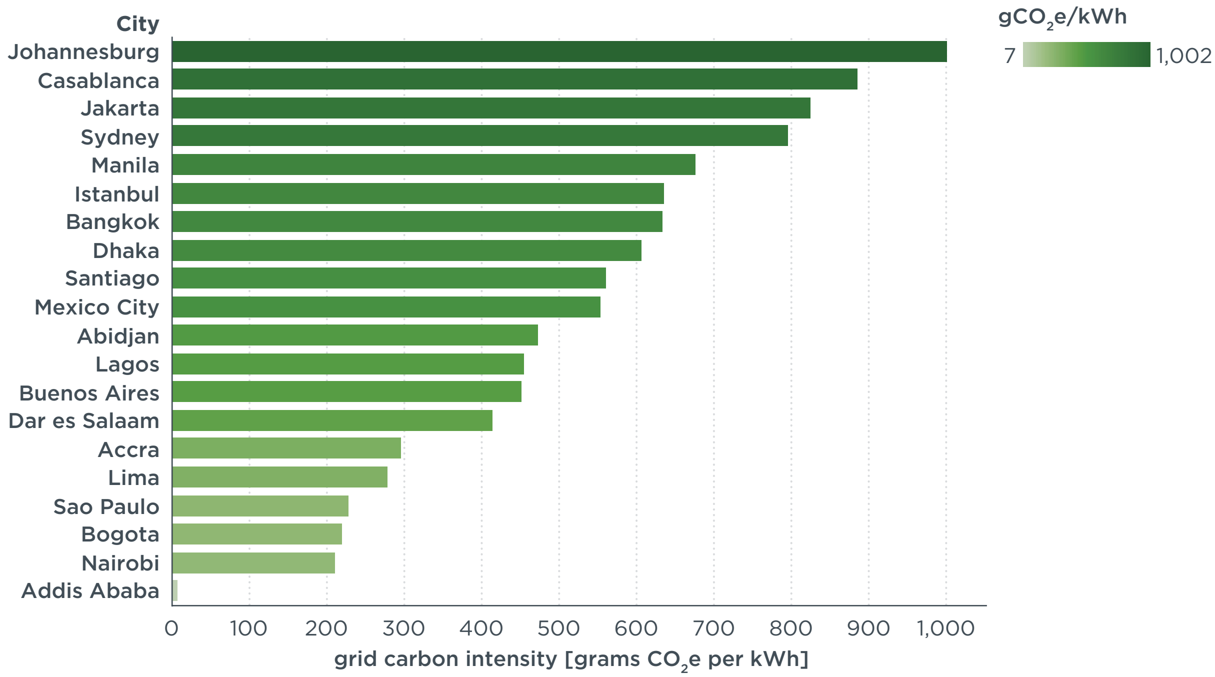


Figure 13. National average carbon intensity of electricity. Estimates are based on IEA and IPCC data.

6.5. LIST OF DATA SOURCES

The ICCT Bus Database sources its data from a combination of public sources and personal contacts, as summarized in Table 14.

Table 14. Survey results and sources from 20 target cities.

City	Category	Source	Description
Abidjan	Public sources	Phototrans website /Societe Des Transports Abidjanais (accessed Nov 2, 2016), TransAfrica (2010), Wikipedia (accessed Nov, 2016)	Fleet data
Accra	Public sources	TransAfrica (2010)	Fleet data
Addis Ababa	ICCT	Other project (Clean technology options for GEF Sustran projects in East Africa, sponsored by UNEP and UN-Habitat, 2012)	Fleet, activity, and cost data
	Public sources	TransAfrica (2010), journal article (2013)	Fleet data
Bangkok	Personal contact	Bangkok Mass Transit Authority (2016), Jakarta Soot-Free Buses Workshop (2016)	Fleet and cost data
	Public sources	Bangkok Mass Transit Authority (2015)	Fleet data
Bogota	Public sources	National Administrative Department of Statistic (2016), Brtdata.org (2014)	Fleet and activity data
Buenos Aires	Personal contact	Direccion Nacional de Cambio Climatico (2016)	Fleet data
Casablanca	N/A	N/A	N/A
Dar es Salaam	Public sources	African Development Bank Group (2015), The World Bank (accessed Jan, 2017), news articles, TransAfrica (2010), Wikipedia (accessed Jan, 2017)	Fleet data

City	Category	Source	Description
Dhaka	Personal contact	Roads & Highways Dept (2016), Jakarta Soot-Free Buses Workshop (2016)	Fleet and activity data
Istanbul	Public sources	Istanbul Electricity, Tramway and Tunnel General Management (2016), Otobus A.S. (accessed Dec, 2016), news articles (2011&2016)	Fleet, activity, and cost data
Jakarta	Personal contact	The Institute for Transportation and Development Policy, Jakarta Soot-Free Buses Workshop (2016)	Fleet data
	Public sources	Jakarta government website (2014), Policy Institute for the procurement of goods/service for Government (LKPP) (accessed Jan, 2017), Brtdata.org (2013)	Fleet and cost data
Johannesburg	Personal contact	Metrobus (2016), Rea Vaya (2016)	Fleet and activity data
	Public sources	TransAfrica (2010), Gautrain (accessed Nov, 2016), Rea Vaya (accessed Nov, 2016), The World Bank (accessed Nov, 2016), news articles (2014)	Fleet and activity data
Lagos	Public sources	The World Bank (accessed Nov, 2016), TransAfrica (2010)	Fleet data
Lima	Personal contact	Centro Mario Molina Chile (2016)	Fleet and activity data
Manila	Public sources	Land Transportation Franchising and Regulatory Board (2015), Land Transportation Office (2013)	Fleet data
Mexico City	Personal contact	Ministry of Environment (2016)	Fleet and activity data
	Public sources	Brtdata.org (2016)	Fleet and activity data
Nairobi	ICCT	Other project (Clean technology options for GEF Sustran projects in East Africa, sponsored by UNEP and UN-Habitat, 2012)	Fleet, activity, and cost data
	Public sources	TransAfrica (2010)	Fleet data
Santiago	Personal contact	Centro Mario Molina Chile (2016)	Fleet and activity data
	Public sources	Metropolitan public transportation directory (accessed Dec, 2016)	Cost data (tenders)
Sao Paulo	Public sources	Municipal Mobility and Transport, SPTrans (2016)	Fleet, activity, and cost data
Sydney	Public sources	State Transit Authority of NSW (accessed Dec, 2016), Australian Bus Fleet Lists (accessed Dec, 2016)	Fleet and cost data

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