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Strategy for Low Carbon Commercial Vehicles in Bhutan

TA-8572 Action on Climate Change in South Asia

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ACRONYMS

ADB	Asian Development Bank
AC	Air Conditioning
BAU	Business as Usual
BC	Black Carbon
BEB	Battery Electric Bus
BRT	Bus Rapid Transit
CAGR	Compound Annual Growth Rate
CAPEX	Capital Expenditure
CARB	California Air Resources Board
CNG	Compressed Natural Gas
COPERT	Computer Programme to calculate Emissions from Road Transport
Corinair	CORe Inventory AIR emissions of EEA
EIRR	Economic Internal Rate of Return
FCC	Freight Consolidation Centres
FIRR	Financial Internal Rate of Return
GBF	Green Bus Fund
GHG	Greenhouse Gas
GWP	Global Warming Potential
HDV	Heavy Duty Vehicle
ICCT	International Council on Clean Transportation
ICE	Internal Combustion Engine
IMF	International Monetary Fund
IPCC	Inter-Governmental Panel on Climate Change
LCB	Low Carbon Bus
LCEB	Low Carbon Emission Bus
LEB	Low Emission Bus
LVC	Light Commercial Vehicle
LNG	Liquefied Natural Gas
MOIC	Ministry of Information and Communications
NEC	National Environment Commission
NDC	Nationally Determined Contribution
NPV	Net Present Value
OECD	Organisation for Economic Co-Operation and Development
OLEV	Office of Low Emission Vehicles
OPEX	Operational Expenditure
PM	Particulate Matter
RSTA	Road Safety and Transport Authority
TCO	Total Cost of Ownership
TfL	Transport for London
TTW	Tank-to-Wheel
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework on Climate Change Convention
WHO	World Health Organization
WTT	Well-to-Tank
WTW	Well-to-Wheel

SUMMARY

1. Transport related GHG emissions in Bhutan are estimated at around 240,000 tCO_2 for 2015. A Business as Usual (BAU) scenario based on the vehicle growth rate projects a tripling of emissions by 2030.

2. The low carbon vehicle strategy focuses on commercial vehicles due to the large impact per vehicle and the financial viability of implementing hybrid or electrified transport in this sector. The baseline vehicle against which low carbon units are compared are new Euro 4 vehicles of the same category and size.

3. Overall Bhutan is very well posed for a low carbon vehicle strategy. It is one of few countries with a 0-emission grid based on renewables, has a very pro-active government with a focus on sustainable development, protection of environmental resources and low carbon emissions and has small urban centres with short distances and relatively small units favouring electric mobility. The contextual situation for electro-mobility is therefore ideal. At the same time electric mobility in taxis, buses as well as small trucks has taken large strides forward recently improving considerably vehicle reliability, performance, range, and vehicle usability.

4. The following graph shows the core proposed strategy for the next 5 years for commercial low carbon vehicles.

5. The number of taxis shall be reduced whilst increasing the number of public transport buses. This results in increased passenger transport efficiency, less congestion and air pollution and reduced energy usage. The current number of taxis in Bhutan per inhabitant is very high due to having a limited public transport supply. Remaining taxis shall be electrified. Total cost of ownership is higher for electric compared to gasoline taxis so incentives are required. The strategy proposes that by 2030 100% of the fleet or around 2,000 units are electric. The GHG reduction per electric taxi is 7 tCO_2per annum or 62 tCO_2 during the commercial lifespan of the vehicle.

6. Public urban bus transport shall be fostered through the expansion of a convenient, modern, safe public transport system based on medium and standard sized buses. This will significantly increase the number of urban buses as well as the mode share of public transport. The urban driving conditions of Bhutan with relatively small daily distances driven, small buses and limited passenger demand all favour the usage of Battery Electric Buses (BEBs). BEBs have comparable total costs of ownerships to diesel units but higher risks and a much higher initial investment therefore requiring financial incentives. The strategy proposes that by 2030 more than 90% of all urban buses (around 250 units) are electric. On average each BEB reduces 35-40 tCO_{2e} per annum or 650-850 tCO_{2e} during its commercial lifespan.

7. For inter-urban buses BEBs are currently not considered as the most appropriate technology due to longer distances driven, partially difficult road conditions and lack of charging stations. Hybrid buses can be used for inter-urban services thereby reducing fuel consumption by 25%. For operators to invest in this technology incentives will be required which reduce or eliminate the differential incremental investment compared to adiesel bus. The strategy proposes that by 2030 more than 90% of the 700 units are hybrids. On average each hybrid bus reduces 11-15 tCO_{2e} per annum or 160-210 tCO_{2e} during its commercial lifespan.

8. To reduce urban congestion and improve freight efficiency small pilot freight consolidation centres are proposed which operate with electric trucks. Latter could be leased or rented to private operators. This would allow for a more efficient handling of urban cargo, an improved load factor of trucks, and reduced congestion whilst improving the air quality. Recently important developments in urban trucks towards electrification have been made and the technology is now wider available as well as financially more viable. The GHG impact per e-truck is 11-15 tCO_2per annum or 170-220 tCO_2 over the commercial lifespan of the truck. A pilot fleet of 50 light commercial vehicles and small trucks with a freight consolidation centre is proposed.

9. For inter-urban trucks currently no technically and financially viable low-carbon option exists. It is foreseen that with further battery development also long-range electric trucks will be available and commercially viable, but this is not expected to happen in the next few years.

10. Emission reductions equivalent to 13% of current CO_2 transport emissions or 5% of projected 2030 Business-As-Usual transport emissions of Bhutan are possible by implementing this strategy. This includes only emission reductions due to usage of low carbon vehicles and not the mode shift from reducing taxi numbers and increasing urban bus numbers. The impact would be primarily in urban settings which would also profit from reduced air and noise pollution.

11. Low-carbon vehicles are close to being commercially viable. However, this depends critically on various uncertain factors such as the development of fossil fuel prices. As finance strategy an approach is proposed which initially finances 100% of incremental capital expenditure. The financial incentive is then gradually reduced. This approach has been followed successfully in China as well as in the UK with funds promoting low carbon vehicles. Total subsidies of around 40 MUSD are required. The following table shows the number of vehicles which would be subsidized during a 9-yearperiod and the expected GHG impact.

Number of Low Carbon Vehicles and CO_2-Reduction (over entire commercial lifespan of vehicles)

Vehicle	Number of vehicles	CO_2 reduction in tons
Electric taxis	1,750	109,000
Battery Electric Urban Buses	175	118,000
Hybrid Inter-Urban Buses	440	71,000
Electric Urban Light Commercial vehicles and Small Trucks	50	8,000
Total	**2,415**	**306,000**

Around 2,500 low carbon vehicles could be co-financed with such a fund of which over 80% electric and around 20% hybrid vehicles with a life-time impact of more than 300,000 tCO_2 avoided. The marginal abatement cost relative to the fund investment would be 130 USD/tCO_2 avoided. This includes only the direct impact, not however the indirect impact of further electric and hybrid vehicles bought after fund closure.

1. INTRODUCTION

This report is realized within an ADB financed program of supporting Bhutan in pursuing low-carbon and climate resilient development. Within this framework a vehicle emission control strategy and a vehicle emissions roadmap were realized. The vehicle emissions roadmap includes thereby as one of the focal areas low carbon vehicles. The low carbon commercial vehicle strategy provides the base for putting this focus into practice.

The structure of this report is:

- Chapter 2 realizes a short summary on the existing climate and policy framework including policies and strategies for the promotion of electric vehicles;
- Chapter 3 gives a short background on transport emissions in Bhutan;
- Chapter 4 justifies the focus on commercial vehicles;
- Chapter 5 describes the methodology used to assess the environmental and financial parameters;
- Chapter 6 focuses on taxis;
- Chapter 7 focuses on buses;
- Chapter 8 focuses on light commercial vehicles and trucks used in the urban context;
- Chapter 9 outlines the low carbon vehicle strategy;

2. POLICY FRAMEWORK

The Kingdom of Bhutan is a highly vulnerable landlocked mountainous country which will be greatly affected by climate change. The country has made a commitment to remain carbon neutral with the vision of being carbon negative (with the sink capacity of the forests exceeding Greenhouse Gas emissions). The Nationally Determined Contribution (NDC) reiterates the commitment of Bhutan realized originally in the year 2009 to remain carbon neutral.

Hydropower run-of-the-river schemes account for almost 100% of the electricity generation in Bhutan with the country exporting significant amounts of hydroelectricity. Bhutan has policies in place to contribute to Greenhouse Gas (GHG) mitigation including prominently the promotion of zero emission vehicles. The NDC explicitly states as sector policies and plans the promotion of a low carbon transport system including promotion of non-fossil powered transport such as electric and fuel cell vehicles as well as improving efficiency and emissions from existing vehicles[1].

The Transport Vision 2040 has as vision “environment-friendly” transport and as one of the goals environmental sustainability[2].The Program is embedded within the country’s long-term strategic vision of the development of the transport sector to the year 2040. This includes an approach that involves moving people, goods, and information in ways that reduce the impact on the environment, develop the economy, and strengthen society. It includes using more energy-efficient transport modes, improving

[1] NEC, 2015
[2] ADB, 2013

transport choices, using cleaner fuels and technologies, applying information technology, and adopting progressive urban and regional planning approaches to reduce or replace physical travel. It includes as regulation strategy introducing incentives for fuel-efficient and green vehicles.

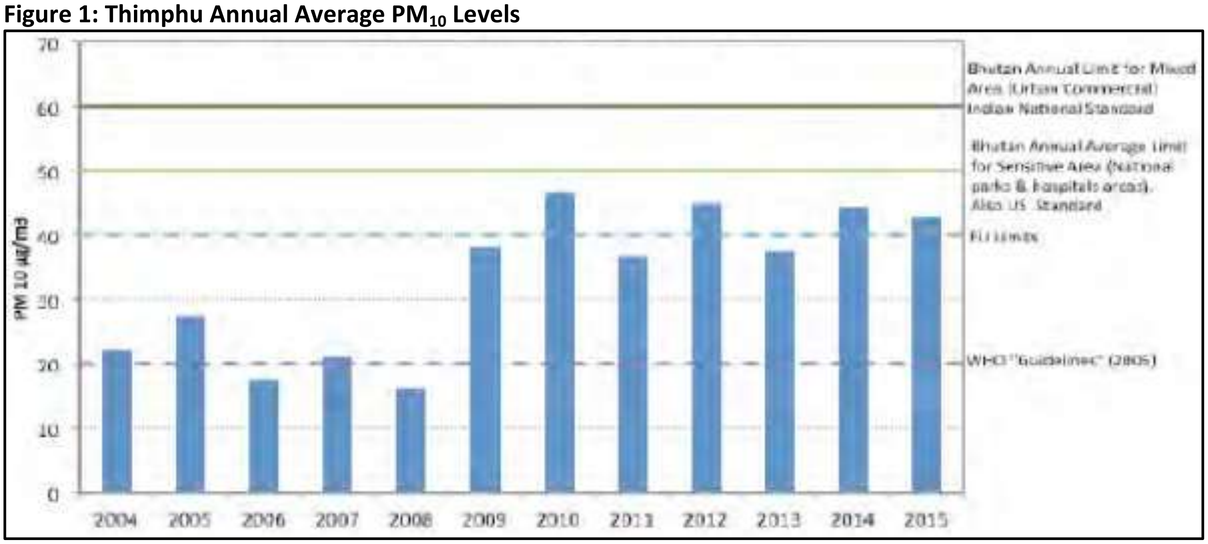
Bhutan has launched an ambitious initiative to promote the use of electric vehicles to address both environmental pollution and fossil fuel dependency. A technical study for electric vehicles was realized in 2016 which however focused on taxis and passenger cars[3].

3. TRANSPORT EMISSIONS IN BHUTAN

The population of Bhutan is around 800,000 persons. The number of vehicles operating in Bhutan is estimated at around 84,000 units as of end 2016 of which more than 50% are registered in Thimphu[4]. The Compound Annual Growth Rate (CAGR) in the last 10 years has been 10%.

The air quality of urban areas in Bhutan is still good. However, Thimphu's annual average PM_{10} measurements show increasing levels. Monitored levels are below the national standard but above the WHO guideline (see figure below).

Figure 1: Thimphu Annual Average PM_{10} Levels



Source: NECS station, NEC, 2016, figure 34

Data from other stations (Rinchending, Bajothang, Kanglung) also show that PM_{10} levels are increasingly critical.

The following figure indicates the distribution of vehicle types. It shows that passenger cars are predominant followed by motorcycles. Latter are 4-stroke units due to a ban of 2-stroke motorcycles

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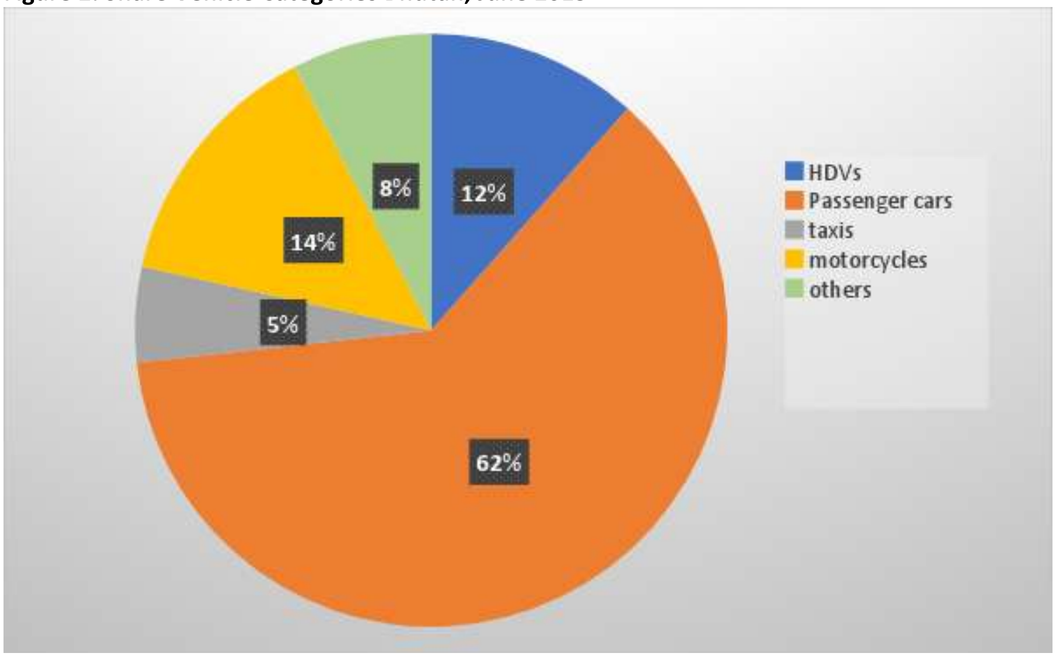
[3] World Bank, 2016

[4] http://www.rsta.gov.bt/rstaweb/load.html?id=82&field_cons=MENU; data from RSTA of vehicles with annual registration indicate that these figures might overstate actually operating vehicles due to not considering sufficiently vehicles which have been scrapped.

established in 1996[5].Around 50 urban public transport buses operated as of 2015 in Bhutan – however, it is planned to increase this figure significantly with the establishment of a modern bus-based public transport system[6].

Figure 2: Share Vehicle Categories Bhutan, June 2015[7]



Source: RSTA Annual Report 2014/15

Heavy Duty Vehicles (HDVs) include diesel powered large and medium sized trucks and buses[8]. Bhutan purchases all its fuel from India. India produces since April 2017 only diesel with a sulphur contents of 50ppm. Since 03/2008 all vehicles imported to Bhutan must meet the Euro 2 standard with an upgrading to Euro 4 expected in 2018 (India has established since 04/2017 the BS-IV standard equivalent to Euro 4).

A bottom-up based vehicle emissions inventory including local pollutants as well as GHGs (CO_2 and Black Carbon) was realized in the year 2017 for Bhutan (see following tables)[9].

Table 1: Vehicle Pollutant Emissions Bhutan 2015 (in tons and as share)

Vehicle category	PM		NO_2		SO_2	
	tons	Share	tons	Share	tons	share
Passenger cars	9.5	24%	174	10%	12	28%
Taxis	0.9	2%	29	2%	2	5%

[5] NEC, 2010
[6] MOIC
[7] Based on a total of 73,815 vehicles
[8] Medium sized HDVs have been classified as trucks and buses between 3.5 and 7.5t whilst the remaining HDVs are classified as being primarily trucks and buses between 7.5 and 16t
[9]Grütter Consulting, 2017

Motorcycles	0.1	0%	13	1%	0	1%
Heavy Duty Vehicles (HDVs)	28.3	73%	1,509	88%	30	67%
Total	**38.9**		**1,724**		**45**	

Source: Grütter Consulting, 2017

HDVs are responsible for 70-90% of all local pollutants.

Based on the fuel import data of 2015 GHG emissions of Bhutan for the transport sector excluding kerosene for domestic air transport are 288,000 tCO_2 of which 74% are caused by diesel usage[10]. This represents a 70% increase from 2005 i.e. a CAGR of 5.5%. The following table shows GHG emissions from the domestic transport sector excluding Indian vehicles (called re-export). This represents the GHG emissions of the registered Bhutanese vehicle fleet. Total vehicle GHG emissions estimated bottom-up are 238,000 tCO_2 excl. Black Carbon.

Table 2: Vehicle GHG Emissions Bhutan 2015 (in tCO_{2e} and as share)

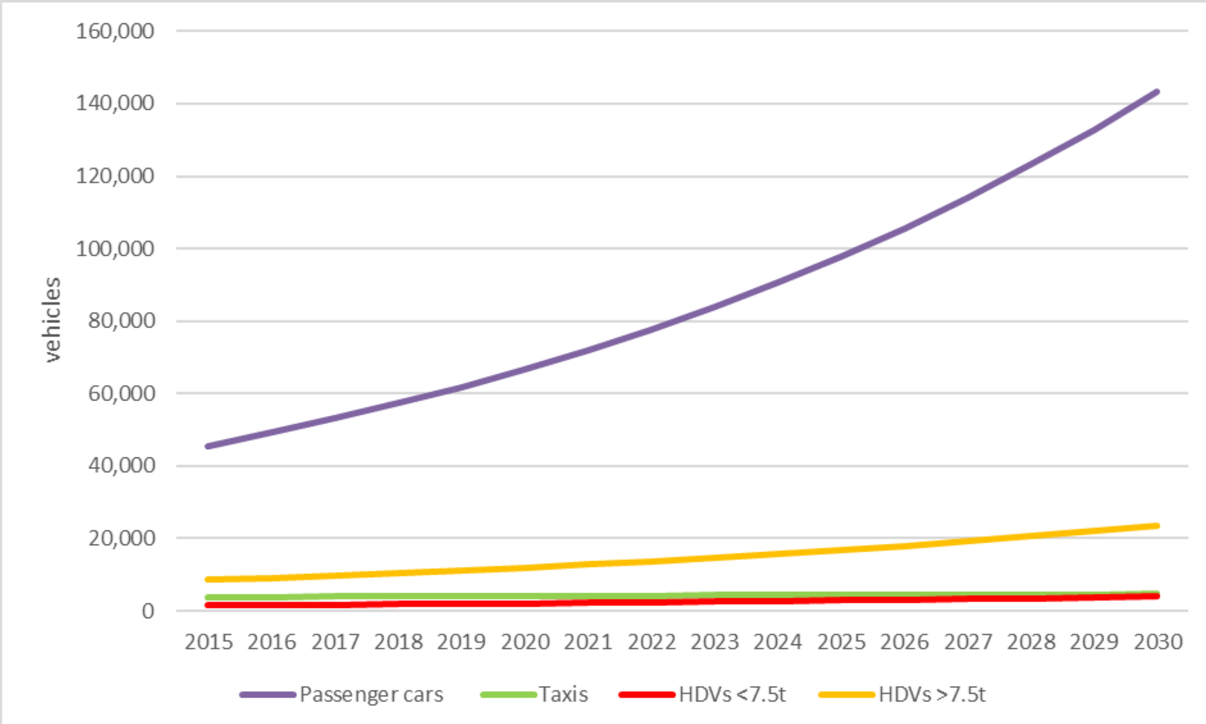
Vehicle category	CO_2		CO_2 plus Black Carbon	
	Tons	share	Tons	share
Passenger cars	80,399	34%	86,988	33%
Taxis	17,315	7%	17,886	7%
Motorcycles	4,542	2%	4,575	2%
HDVs	135,868	57%	152,438	58%
Total	**238,125**		**261,887**	

Source: Grütter Consulting, 2017

A Business as Usual (BAU) projection based on a continuation of current vehicle and fuel standards and based on the growth rate per vehicle sector was made. It is expected that Bhutan will increase the number of vehicles to 180,000 units by 2030 (see following figure).

[10] This includes Indian vehicles

Figure 3: Vehicle Projections (Vehicle Stocks) Bhutan 2015-2030



Source: Grütter Consulting, 2017

BAU vehicle emissions will reach 660,000 tCO_2 by 2030 for the transport sector excluding Indian vehicles.

4. FOCUS ON COMMERCIAL VEHICLES

Commercial vehicles include taxis, buses and trucks. The term commercial vehicle is related to its business activity (vehicles transporting goods or paying passengers). The reasons for selecting commercial vehicles for a low carbon vehicle strategy are due to the potential emission impact and the implementation potential which is related to the financial profitability, the involved complexity and risk and potential finance sources to cover incremental costs.

Emissions Impact Potential

Commercial vehicles account for 20% of all registered vehicles but for 64% of GHG emissions. The GHG emission reduction potential in commercial vehicles is thus much higher than for private passenger cars and motorcycles. Also, emissions and reduction potentials per vehicle unit are much higher for commercial vehicles due to having a higher fuel consumption rate and a much higher annual average mileage.

Financial Potential

The potential profitability of low carbon vehicles is much higher for commercial vehicles than for passenger cars. The incremental cost as percentage of the capital investment (CAPEX) is comparable for all vehicle groups. The annual savings due to reduced fossil fuel usage are however much higher for commercial vehicles due to higher annual mileage. This reduces the payback time and increases the financial profitability. Also, commercial vehicles are bought more in accordance with a cost calculation i.e. business criteria including fuel efficiency and annual energy cost are a more important factor for decision taking than with private vehicles.

Implementation Potential

The strategy to focus on commercial vehicles has a much higher implementation potential due to:

- Fewer stakeholders need to be convinced due also to many companies having multiple vehicles;
- A focus can be made on vehicles used primarily for urban trips thus having less issues with remote servicing and with vehicle driving range for electric units;
- The installation of chargers can be made in a more centralized manner e.g. at central taxi stops, bus or truck depots.
- A financial package can be easier structured due to lower marginal abatement costs and a higher impact also on other pollutants. Also subsidizing public transport vehicles or trucks can be socially easier justified than subsidizing private cars which are primarily owned by the wealthier segments of society.

5. METHODOLOGICAL APPROACH

Initially GHG emissions are considered based on a Tank-to-Wheel (TTW) approach. Well-to-Tank (WTT) emissions related to fuel extraction, refinery and transport are included for information purposes only. Electricity based indirect emissions related to the production, transmission and distribution of electricity are included but are in the case of Bhutan 0 due to producing all electricity through renewables. The GHGs included under the United Nations Framework Convention on Climate Change (UNFCCC) are carbon dioxide (CO_2), methane (CH_4), nitrous oxides (N_2O), perfluorocarbons (PFCs), hydrofluorocarbons (HFCs), sulfur hexafluoride (SF_6) and trifluoride nitrogen (NF_3). Relevant for the transport sector are only CO_2, CH_4 and N_2O. However, according to methodologies for determining emissions from the transport sector of the UNFCCC, N_2O as well as CH_4emissions are marginal for vehicles using liquid fuels. CO_2 emissions are determined based on the energy consumption according to the IPCC methodology (2006):

$$E_{CO2,C} = FC_x \times NCV_x \times EF_{CO2,x}$$

where:

$E_{CO2,C}$	CO_2 emissions due to combustion
FC_x	Consumption of fuel type x
NCV_x	Net Calorific Value of fuel type x
$EF_{CO2,x}$	CO_2 emission factor of fuel type x

A scientific assessment of Black Carbon(BC) emissions and impacts found that these are second to CO_2 in terms of climate forcing. BC is on average 2,700 times more effective on a mass-equivalent basis than CO_2 in causing climate impacts within 20 years, and 900 times more effective within 100 years[11]. Due to its relevance BC emissions in terms of CO_2 equivalent are therefore also included. BC is part of particulate matter (PM) from diesel engines. The GHG impact of BC is determined based on the mass of $PM_{2.5}$emissions (using the European emission model COPERT), the fraction of BC in $PM_{2.5}$and the GWP_{100} of BC.

Local pollutants included in the calculations are particle matter ($PM_{2.5}$), NO_x and SO_2. These are the most important air pollutants related to vehicle emissions. Reduced emissions of these pollutants are also valued in economic calculations by including the pollution cost values. The average unit cost per pollutant is based on median values of countries from Asia and Oceania excluding industrialized economies as no values are reported for Bhutan and also data on health costs, air pollution levels and air pollution related health problems is not available. The pollutant values for other countries calculated by the IMF are based on ground level local pollution levels and the health impact and costs caused by this pollution[12]. This is based on determining the pollution exposure of the population and how the additional pollution exposure increases mortality risks using concentration response functions relying primarily on work realized by the World Health Organization's Global Burden of Disease project. Mortality risks or more precisely the value per premature death avoided are thereafter valuated economically based on stated preference studies realized by the OECD[13].

Table 3: Economic Cost per Pollutant

Pollutant	Cost per ton emitted in USD 2015
Particle Matter $PM_{2.5}$	45,700
NO_2	330
SO_2	1,560
CO_2	40

Source: Grütter Consulting, 2017 based on the median of non-industrialized Asia/Oceania countries as listed in IMF, 2014, Table A.4.2.1. updated to USD 2015 using GDP deflator; methodology developed by IMF, 2014

The comparison baseline vehicles to low carbon vehicles are new Euro 4 units using 50ppm sulphur fuels and not the vehicles currently operating in Bhutan. This is justified as Bhutan imports all fuel from India with 50ppm sulphur contents and India, from which the large majority of vehicles are sourced, produces Euro 4 vehicles since April 2017. Bhutan has also indicated that it will implement the Euro 4 standard very soon. As the decision for a low-carbon vehicle is taken when procuring a new unit, the comparison base must be a new vehicle of conventional technology against a new low carbon vehicle.

[11] see Bond, 2013 or World Bank, 2014

[12] IMF, 2014 table A4.2.1 for pollutants

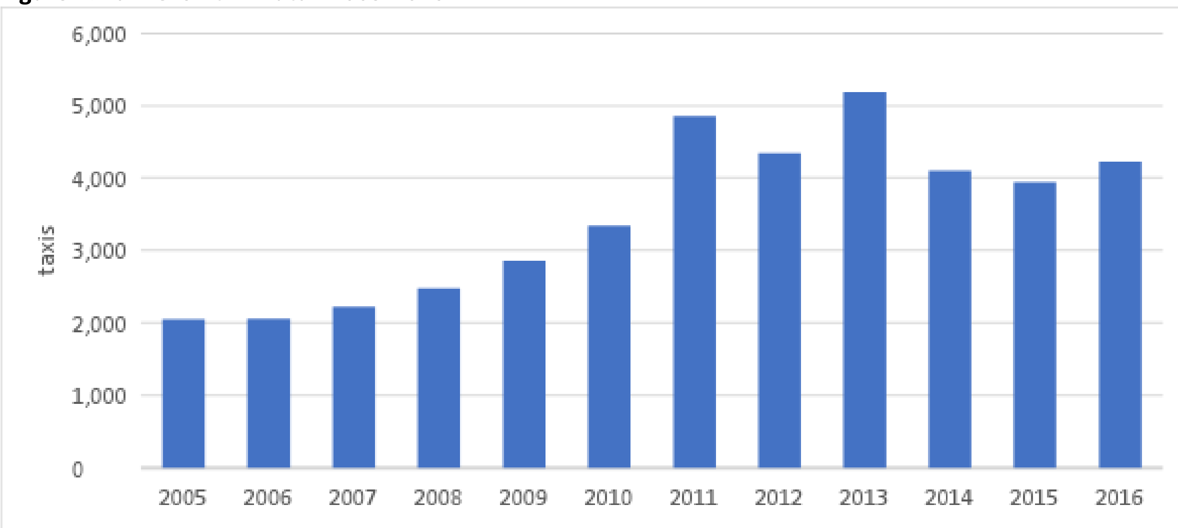
[13] Stated preference studies in general reveal lower values than revealed preference studies; therefore, pollution damage estimates might be understated by the IMF

6. TAXIS

6.1. Introduction

As of January 2017, Bhutan had around 4,200 taxis of which 91% are registered in Thimphu and Phuntsholing[14]. The maximum taxi age is currently limited to 9 years. Taxi numbers have more than doubled since 2005 growing with a CAGR of 7% - however, not in a linear manner as can be seen from the following figure.

Figure 4: Taxi Growth Bhutan 2005-2016



Source: RSTA, based on taxi numbers as of 31st of December of each year

In Thimphu nearly 300 taxis are available per 10,000 inhabitants which is considered a very high number[15]. This is due to the lack of a convenient and reliable public transport system. Around 86% of taxis are gasoline powered and basically small engine size units between 0.8 and 1.4l[16]. Only 6 units are electric. Realizing transportation with taxis results in high emissions, congestion, high fuel usage and a high accidentality rate. The following chart shows the CO_2 emissions per passenger-kilometre (pkm) comparing taxis with cars and buses in Thimphu.

Figure 5: CO_2 Emissions per pkm per Mode in Thimphu

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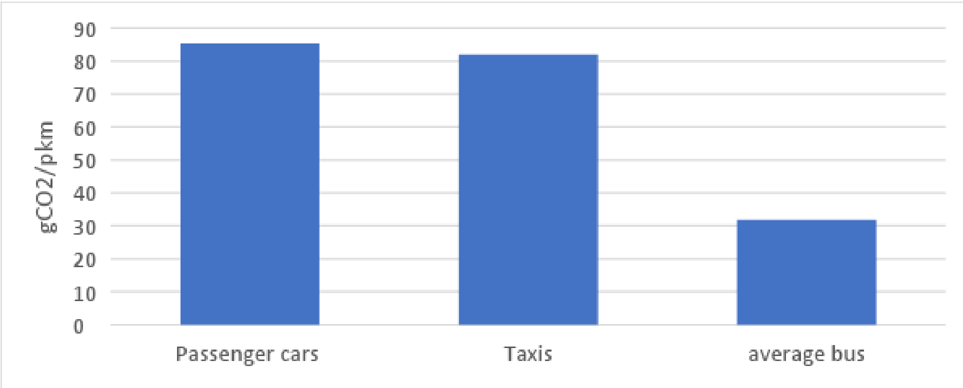
[14] RSTA Motor Vehicle Statistics as of 31/01/2017

[15] See KPMG, 2017

[16] RSTA data



Source: Grütter Consulting, 2017a for emission factors per km (based on bottom-up transport emission model for Bhutan); occupation rates per mode from IFC, 2011 based on traffic surveys

Buses as used currently in Thimphu have factor 3 lower emissions for transporting passengers than taxis. Taxis account for 31,000 tCO_2 emissions in the year 2016 equivalent to around 12% of total transport based CO_2 emissions of Bhutan[17].

To reduce emissions, increase safety and reduce congestion Bhutan wants to promote sustainable, attractive urban transport. This implies restricting the numbers of taxis to ensure mode switch towards buses. Low carbon taxis are a strategy which needs to be in line with the promotion of bus-based public transport as even low carbon units will have a larger environmental and congestion impact bus-based passenger transport. Restricting the permits for new taxis is also a good entry point for fostering new technologies, especially electric taxis due to following points:

- Taxi replacement numbers will be very low for various years thus allowing for a slow transition period during which prices of electric vehicles will further drop.
- Required subsidies will be low in absolute terms due to a limited number of replacement taxis.
- Regulations requiring all new taxis to be registered in urban areas to be electric could easily be enforced thereby limiting in a natural manner the number of new taxis whilst still offering an alternative for new entrants or people which need to replace their taxi.

Electric taxis have been included in various analysis such as the World Bank “Bhutan Electric Vehicle Initiative”[18] or the GEF project “Bhutan Sustainable Low-Emission Urban Transport Systems” which has a focus on taxis.

6.2. Technology Options

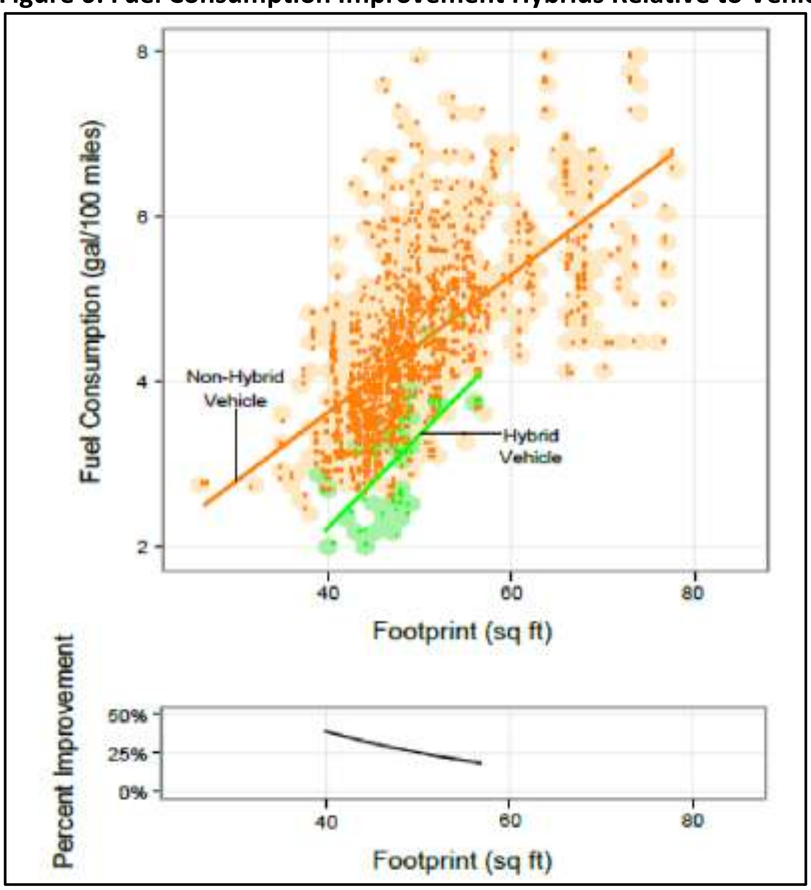
Main low-carbon options for taxis are hybrid, plug-in hybrid and full electric vehicles.

Hybrid and Plug-in Hybrid Taxis

[17] Grütter Consulting, 2017a based on 2016 taxi number RSTA, average mileage of 40,000km/a (based on survey realized 2017) and the emission factor per km of taxis
[18] World Bank, 2016

Hybrid vehicles are getting increasingly popular. Japan has already a market share of 20% of hybrid passenger cars and 30% excluding the unique Kei-class (very small lightweight vehicles capped at 660cc) whilst other countries have shares between 2 and 10%. Hybrid taxis are especially popular as they have a high annual mileage allowing to recover the incremental investment with subsequent fuel savings. Based on the US EPA hybrid passenger cars reduce fuel consumption by 25-30%. The figure below shows the fuel efficiency gains in relation to the vehicle size. This shows that smaller hybrid vehicles like used as taxis, have a larger fuel efficiency gain percentage wise than larger vehicles such as SUVs.

Figure 6: Fuel Consumption Improvement Hybrids Relative to Vehicle Size, USA, 2015



Source: EPA, 2016, Figure 5.12

The well-known Vincentric study compared directly hybrid with non-hybrid vehicles of the same make/model and shows an average range of around 25% improvement[19].

Plug-in hybrid vehicles can be re-charged and have an electric drive range of 40-60km. For a taxi this is clearly insufficient to cover daily operations with typical daily mileage rates being around 200km. They would thus need to have access to fast-chargers to increase their electric driving range. This could be a critical constraint not making plug-in hybrids very attractive for taxis.

One of the limitations of hybrid taxis is their limited availability for the small-sized taxi units typically used in Bhutan with the Maruti Alto with 800cc being the most popular model[20]. The Vincentric study shows that the total cost of ownership (TCO) for most hybrid models is lower than that of gasoline vehicles whilst the upfront price premium is 3,000-6,000 USD per vehicle[21]. Hybrid vehicles are therefore for normal mileage customers not yet attractive based on a 5-year payback but might well be for taxi operators which have a significantly higher mileage and can thus recover their incremental investment much sooner. However, as mentioned, this is only true for mid-sized vehicles such as the Toyota Prius, where competitive hybrid models are available.

Electric Taxis

Multiple cities, including Thimphu are making trial tests or already have large fleets of electric taxis running. In London by law from 1 January 2018, all new black cabs will have to be battery-powered electric models as part of TfL's effort to reduce toxic pollution from diesel engines. 200 fast-chargers are being installed until 2020 in the city. Cabbies with an existing taxi older than 10 years will be able to claim a payment from TfL of up to £5,000 towards the cost of the new zero-emission taxis.

Electric vehicle models are available now from multiple manufacturers and with all types of drive ranges. However, due to a potentially high daily mileage of taxis, fast re-chargers can be an essential component for the promotion of e-taxis.

Potentially the most interesting e-taxi models for Bhutan will be the Nissan Leaf, of which already 6 units are operating as taxis in Bhutan, and Indian e-vehicles such as the new Mahindra e20plus. Latter

[19] The most popular hybrid car (Toyota Prius) was however excluded in the study due to lack of a comparable non-hybrid vehicle; http://vincentric.com/Home/Industry-Reports/Hybrid-Analysis-October-2014

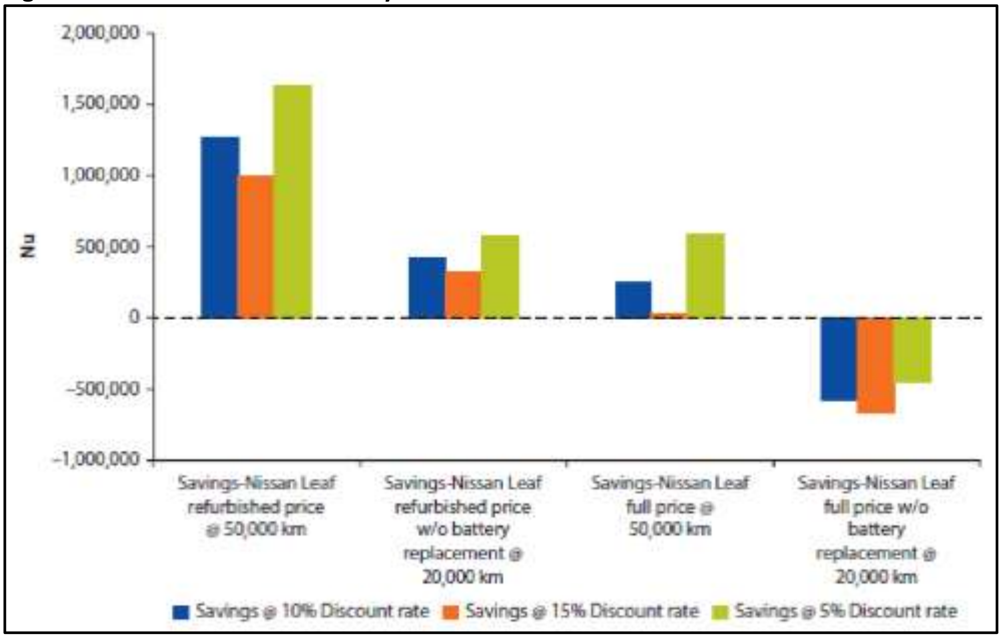
[20] Maruti plans to offer the Swift model as hybrid version in India – most other hybrid models are however larger vehicle versions with bigger engines.

[21] ICCT, 2015

however has a limited drive range (in practice less than 100km) and requires for fast charging 1½ hours, which reduces its practicability a lot[22]. The new Nissan Leaf on the other hand has an electric drive range of up to 350km which is sufficient without re-charge during the day i.e. this can be down at night using slow-chargers[23].

A TCO analysis made by the World Bank[24] shows that e-taxis are cheaper or comparable to conventional taxis (see figure below). However, this calculation is dependent on a continuation of current tax policies favouring e-vehicles, the chosen discount rate, fuel prices and expected fuel price increases and annual mileage[25].

Figure 7: TCO as Calculated 2014 by World Bank for e-Taxi



Source: World Bank, 2016, Figure 5.8

Re-doing the calculations with current figures (see annex 1) the TCO of an electric taxi is around 15% higher than for a gasoline unit. However, results are dependent on multiple factors.Private operators are clearly aware of significantly higher upfront costs for the vehicle and lack information of actual maintenance costs and energy savings. These factors result as a barrier towards procurement of electric taxis.

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[22] https://www.mahindrae2oplus.com/pages/buyers-guide/specifications

[23] https://www.nissan.co.uk/vehicles/new-vehicles/leaf-2018.html&cid=psmQNAUbfwD_dc%7cD.html

[24] World Bank, 2016

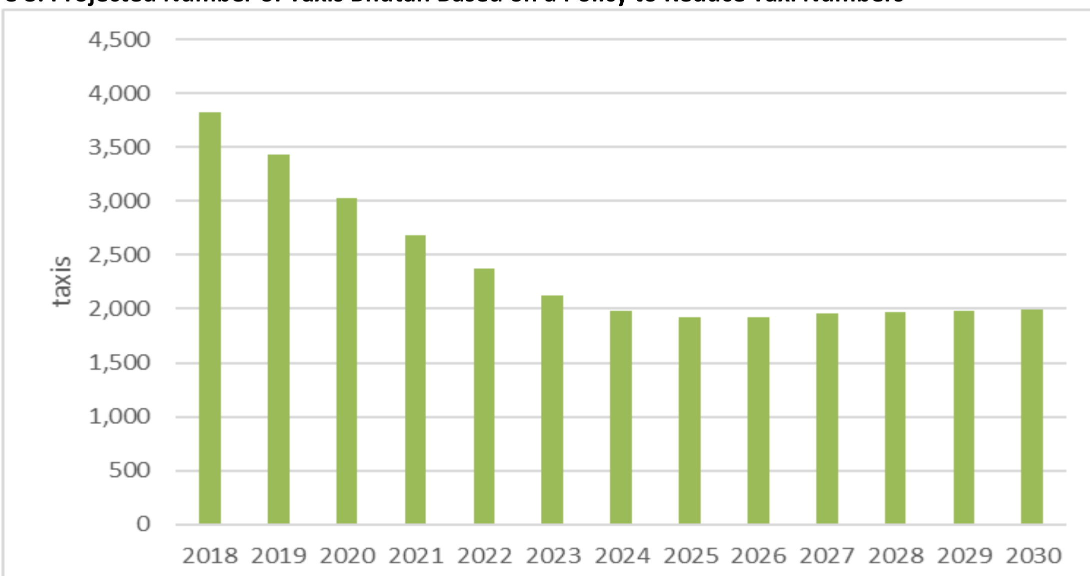
[25] The World Bank study assumed annual distances of 50,000km (a survey realized in 2017 showed a distance of 40,000 km or 20% less), a fuel price of Nu 63 (valid July 2014) with a fuel price escalation of annually 7% plus a fuel tax of 5% (as of October 2017 the fuel price is Nu 59 i.e. lower and not higher than in 2014 i.e. no fuel price escalation occurred). The TCO also included a social cost of carbon which means that it is in fact a social or economic TCO and not a financial TCO.

6.3. Strategy Proposed

Basically, the strategy focuses on two core elements:

1. The number of taxis shall be reduced to favour public transport. Taxis are an inefficient means of mass transport in terms of energy usage, emissions, economic cost, usage of road space and accidentality. Commensurate with an increased supply of bus-based public transport services it is suggested to reduce the number of taxis by issuing initially maximum 50 new permits per year (these could be auctioned off) without renewing permits for taxis which are retired due to reaching of their maximum age[26]. This policy shall be continued until reaching a stock of around 2,000 units or a level in accordance with the increased bus supply. Based on the maximum age of taxis the following figure shows the number of taxis in Bhutan if this policy is implemented.

   Figure 8: Projected Number of Taxis Bhutan Based on a Policy to Reduce Taxi Numbers

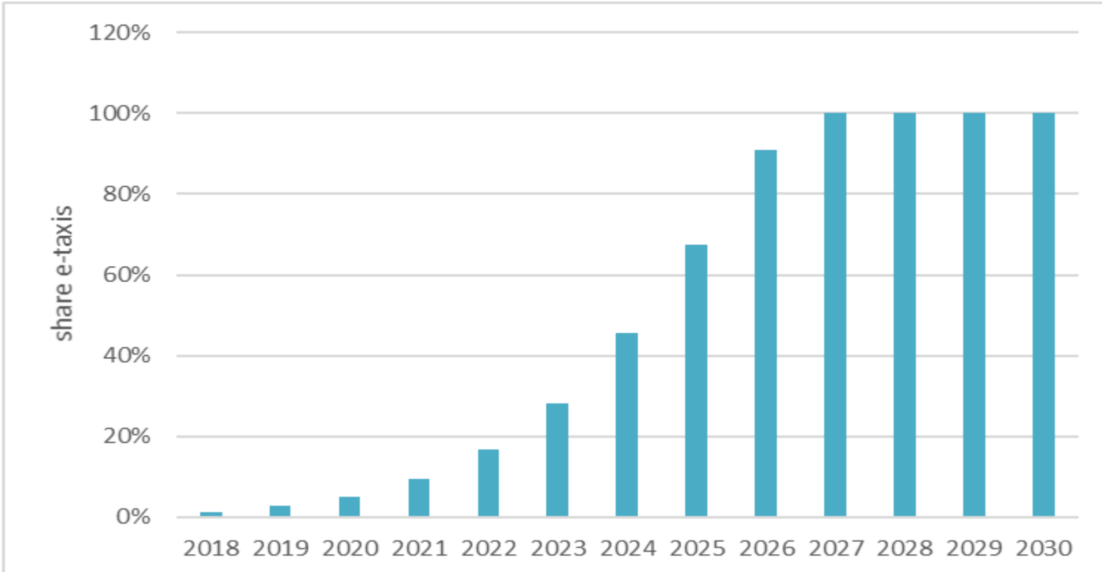
   

   Source: Grütter Consulting, see Annex 1

2. All new registered taxis from 2018 onward need to be fully electric. Based on the average annual replacement rate and the policy of reducing taxi numbers the share of e-taxis would increase gradually and reach 100% by 2027. The growth in initial years is very moderate due to the overlaying policy of reducing taxi numbers. Until 2020 annually 50 e-taxis would be introduced. However, this is not considered as a problem but rather as an advantage as e-taxis will improve their commercial viability over time and having a strategy with low absolute numbers at the start will come at a lower economic cost. The focus would need to be on e-taxis with a sufficient battery size and corresponding driving range without re-charging during the day as the numbers of fast re-chargers would be limited due to the relatively low absolute number of units. The following figure shows the projected increase in the share of e-taxis when implementing this policy.

[26] This amount could then be gradually increased e.g. year 1-3 50 units per year and then increase to 100 units etc.; see Annex 1 for a proposal

Figure 9: Projected Share of e-Taxis in Bhutan



Source: Grütter Consulting, see Annex 1

The GHG impact of promoting e-taxis is a cumulative reduction of nearly 100,000 tCO_2 until 2030 increasing proportional to the number of e-taxis[27]. Annual GHG reductions by 2030 are 14,000 tCO_2. Calculations are based only on the replacement of conventional taxis with e-taxis and not on the reduced amount of taxis overall (this GHG impact is far larger but is attributed to a mode shift toward buses and not the result of a strategy to promote low carbon taxis).

7. BUSES

7.1. Technology Options

Low carbon bus (LCB) technologies which match the fuels available in Bhutan are hybrid, opportunity charge and battery electric buses (BEBs). Gaseous buses are not analysed as neither Compressed Natural Gas nor Liquefied Natural Gas is available in the country. Electric trolleybuses are also not included in the analysis as the passenger demand on bus routes in Bhutan is relatively low and often smaller buses are used not making it viable to invest in infrastructure for trolleybuses.

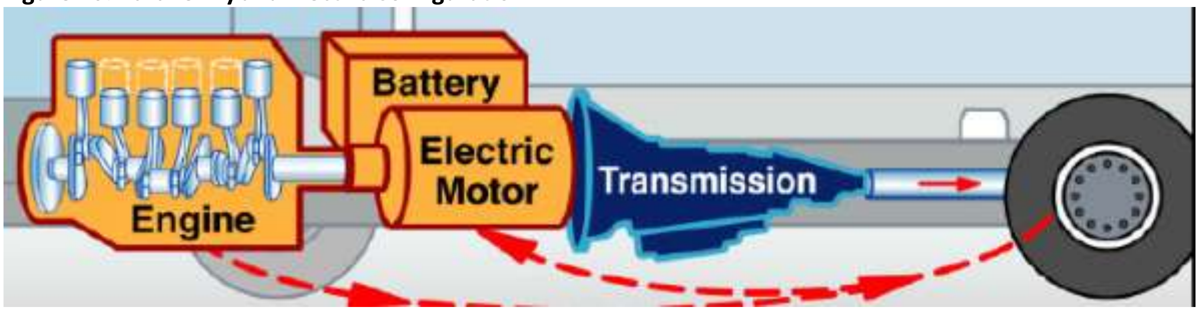
7.1.1 Hybrid Buses

Types of hybrids include basically series and parallel hybrids as well as “mild” hybrids using e.g. flywheels to recover braking energy. A differentiation is made between “conventional” and “plug-in” hybrids. Latter allow for electric charging by an external power source. Fuel efficiency gains in hybrids are basically due to being able to use a smaller than normal conventional internal combustion engine

[27] Core data factors are a mileage of 40,000km per unit (based on a survey realized for the ADB in 2017); the number of conventional taxis as per Annex 1; average CO_2 factor per km of conventional taxis 180 gCO_2/km (Grütter Consulting, 2017a); 0 emissions of e-taxis due to having 0 grid emissions in Bhutan

(ICE) operating at constant periods of maximum efficiency, and usage of regenerative braking (energy lost due to braking is recovered and utilized to charge the battery).

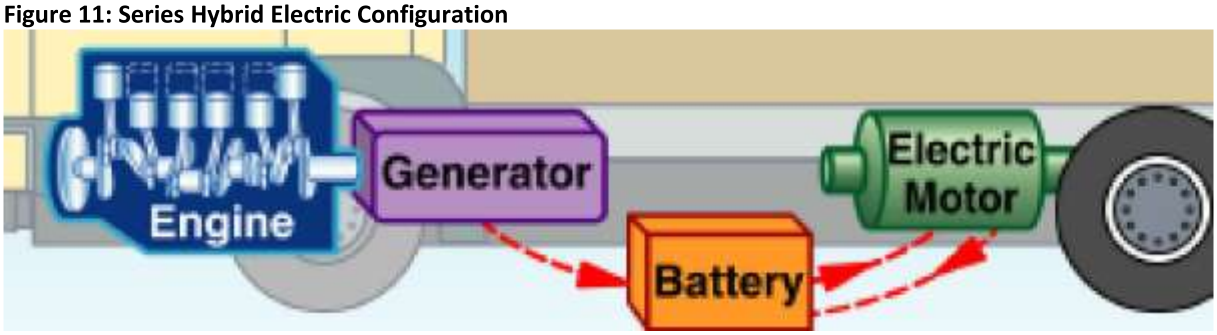
Figure 10: Parallel Hybrid Electric Configuration



Source: Southwest Research Institute

In a parallel hybrid, the engine powers the drive axle and a generator that can either charge the battery pack or directly drive the axle. The ICE and the electric motor are connected to the transmission independently. The electric motor is designed to provide power during stop-and-go traffic while at highway speeds the vehicle is powered solely by the ICE. In addition, through a process called regenerative breaking, energy lost due to braking is recovered and utilized to charge the battery. Parallel hybrids in general have a greater fuel efficiency than series hybrids at constant high speeds.

Figure 11: Series Hybrid Electric Configuration



Source: Southwest Research Institute

In a series hybrid, there is no mechanical link between the ICE and the drive axle. The engine powers a generator that charges the battery pack. The electricity powers a motor which turns the wheels of the vehicle. Since the ICE is not connected to the wheels it can operate at an optimum rate and can even be switched off for short periods of time for a temporary all-electric operation of the bus. Series hybrids in general fare better in stop-and-go urban driving.

Plug-in hybrid buses are powered by a battery that is rechargeable from an external power supply. They also have an on-board engine that also recharges the same battery. The bus running time in electric mode will depend on the characteristics of the route, the frequency of charging and the configuration of the vehicle and its energy systems. Plug-in hybrids are available in many configurations with different electric mode ranges, depending on battery size and charging system. They are often used in opportunity charging systems where they can potentially operate up to 100% in electrical mode (see next chapter). Unlike hybrid vehicles, plug-in hybrids are also generally included in the list of electric vehicles. It is considered a relatively new technology, but many Chinese cities have large fleets of plug-in

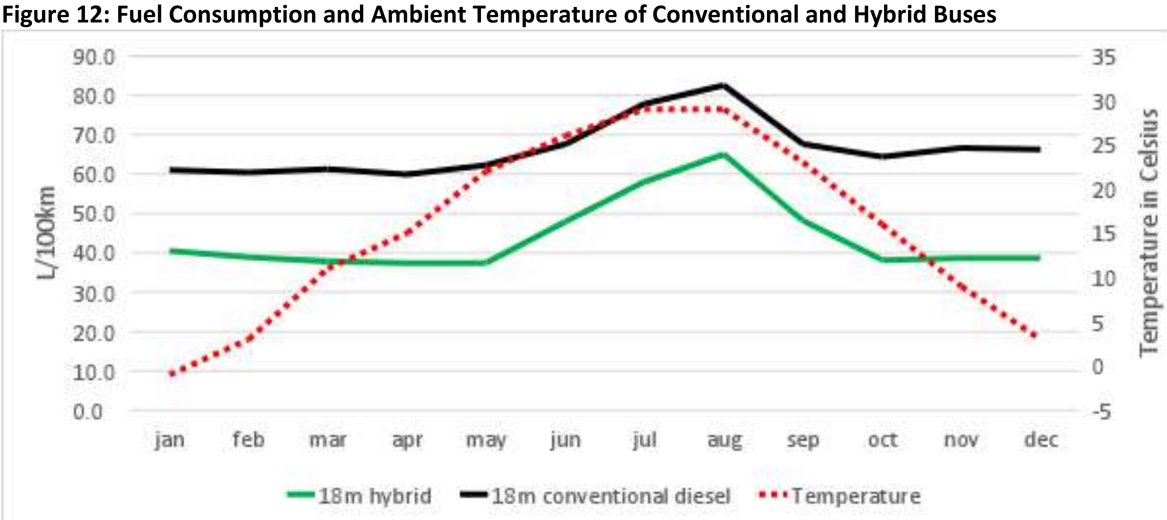
hybrid buses operating since various years – albeit due to various reasons Chinese bus operators do not charge the plug-in hybrids with the grid thus not using the technology according to its potential.

Photo 1: Hybrid Buses

Source: Hybrid bus in Bogota, Colombia; plug-in hybrid bus in Zhengzhou, China

It has been observed that hybrid buses are affected more than conventional buses from very hot or very cold climates and when the AC is heavily used. Conventional buses also use more fuel when using AC but it affects them less than hybrids. The following figures contrast the monthly average temperatures in Zhengzhou with specific fuel consumption of diesel buses and 18m Euro IV hybrids operating on the same BRT routes.

Figure 12: Fuel Consumption and Ambient Temperature of Conventional and Hybrid Buses



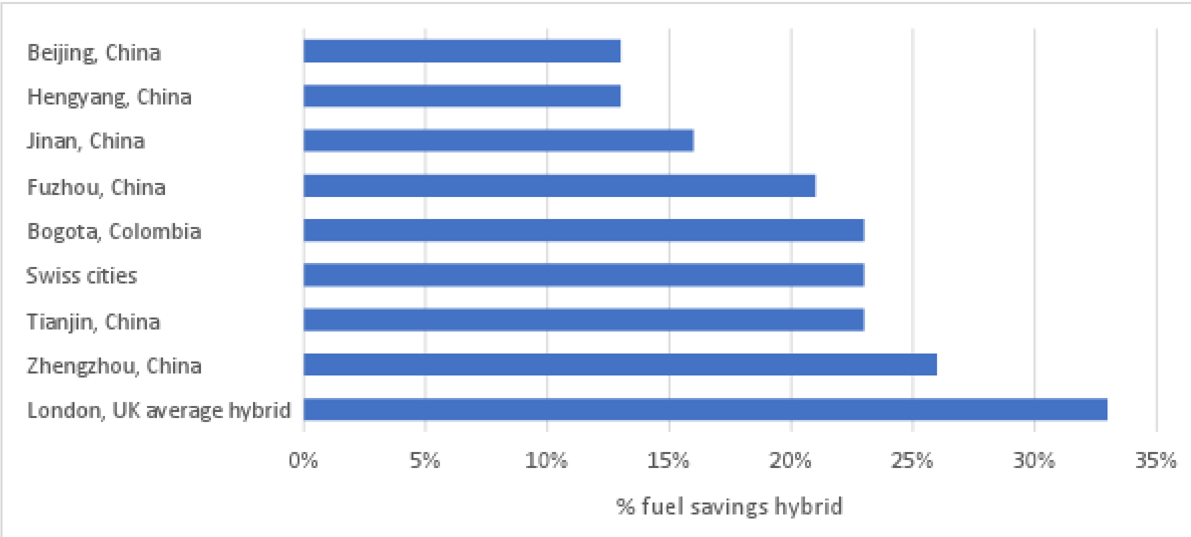
Source: Grütter Consulting based on data of bus operator

The environmental impact of LCBs is due to reduced fossil fuel consumption. This translates directly in CO_2 reductions. BC, CH_4 and local pollutant reductions are also relative to fuel savings[28]. Additional reductions of local pollutants are possible due to the fact that the hybrid bus can employ a smaller engine running at constant revolutions thus having lower emissions per km and per energy usage compared to a conventional fossil fuel bus. This has however not been taken into account in the calculations.

[28]See e.g. VBZ, Hallquist, 2013 or Pütz, 2014

The following graph shows average fuel savings of hybrids in different cities. All data is based on comparing same size and types of conventional and hybrid units operating on comparable routes. The average improvement rate of hybrids is thereby 20-25% compared to conventional buses i.e. hybrids will result in 20-25% lower energy consumption, GHG as well as local pollutants emissions. Differences between cities are basically due to bus types and brands used and their different hybrid systems.

Figure 13: Comparison Energy Savings Hybrids various Cities



Source: Grütter Consulting based on data of bus operators[29]

Plug-in hybrids can have a considerable higher impact depending on the battery size with which the bus is equipped, the average daily distance, operational conditions influencing the energy consumption and – most important – the number of charges of the hybrid per day. Plug-in hybrids can potentially reduce emissions by 40-60% and if used within opportunity charge systems even more (see following chapter).

In terms of noise emissions, hybrid buses have approximately 3 decibels less noise compared to a diesel bus[30].

The differences between hybrid and conventional diesel buses in life-cycle emissions at the production stage are minimal. According to an analysis carried out by PE International on behalf of the German Ministry of Transport, Construction and Urban Development, a hybrid bus has an environmental impact 10% larger than a diesel bus in its production phase. The higher GHG emissions in this phase are offset by fuel savings after around 14,000 km of operation, i. e. in relation to the total mileage of the vehicle during its useful life, these emissions are irrelevant[31]. A life cycle analysis based on the EIO-LCA model

[29] with exception of Swiss cities each bus operator has minimum 300 hybrids operating on the same routes as conventional buses with data collection of minimum 12 months per bus; London includes 12m and 14m double decker buses; Zhengzhou includes 12m, 14m and 18m hybrids; All other cities 10.5, 12m and 14m hybrids; Buses include Euro III, IV, V and VI units; Fuels used include diesel, CNG and LNG (comparison always between hybrid and conventional same fuel type) – no significant difference between fuel types found concerning fuel savings; bus passenger capacity same for hybrids and conventional units; Data on distance driven based on GPS or turn-arounds; data on fuel consumption based on RFID or fuel invoices; brands included are Wright Buses, Volvo, MAN, Yutong, CSR, Foton, Golden Dragon, Kinglong, and Zhongtong.

[30] Faltenbacher, 2011

[31] Faltenbacher, 2011

(Carnegie Mellon University, USA) also reveals marginal differences in environmental impact between production and maintenance of a conventional diesel and a hybrid bus in terms of GHG, PM_{10}, NO_x, SO_2 emissions and water use. The environmental impacts of the construction and maintenance phase are in all cases much lower than, for example, WTT emissions caused by fuel production[32].

The following table shows for different cities and operators the additional investment for the purchase of a hybrid bus. More informative than the absolute CAPEX of the bus is the incremental investment between a conventional diesel and a hybrid bus as costs vary widely according to the region of purchase, bus-operator specifications and volumes of purchase.

Table 4: Additional Investment for a Hybrid Bus

City/country	12m bus	18m bus	Make
Europe	35%		Average value of various operators; Euro VI
Washington, USA	40%	35%	New Flyer, Gillig, Schetky, Nova; Euro VI equivalent; Washington State Department of Enterprise Services
Zhengzhou, China	30%	25%	Euro V, Yutong
Tianjin, China	25%		Euro V, Yutong
Jinan, China	35%		Euro IV, Zhongtong
Beijing, China	32%		Euro IV, Foton
Median additional cost	**34%**		

Source: operators

Plug-in hybrid buses have incremental costs relative to their battery size. Typically, an incremental cost relative to a diesel unit is around 60%. Slow re-chargers will require an investment of around 3,000 USD per bus[33].

Potentially the batteries or capacitors need to be exchanged once during the lifespan. There are also manufacturers (e. g. Volvo) that offer battery rental, charging a mileage fee. The total maintenance costs are considered equal to diesel buses. Hybrids have higher maintenance costs concerning the propulsion system, but lower costs in maintaining the braking system and in tyres. The total cost of the hybrid is slightly lower or equal to that of conventional diesel units. This calculation is based on global estimates of operators with large hybrid fleets such as TfL London, Jinan, Hengyang, Fuzhou and Zhengzhou as well as comparisons of bus maintenance costs made by the California Air Resource Board analysing available King County Metro Transit (KCMT) and New York City Transit (NYCT) data[34].

According to large operators of hybrids the bus availability rate is equal to that of diesel buses. The same is reported by the California Air Resources Board[35]. In pilot fleets the availability is sometimes lower due

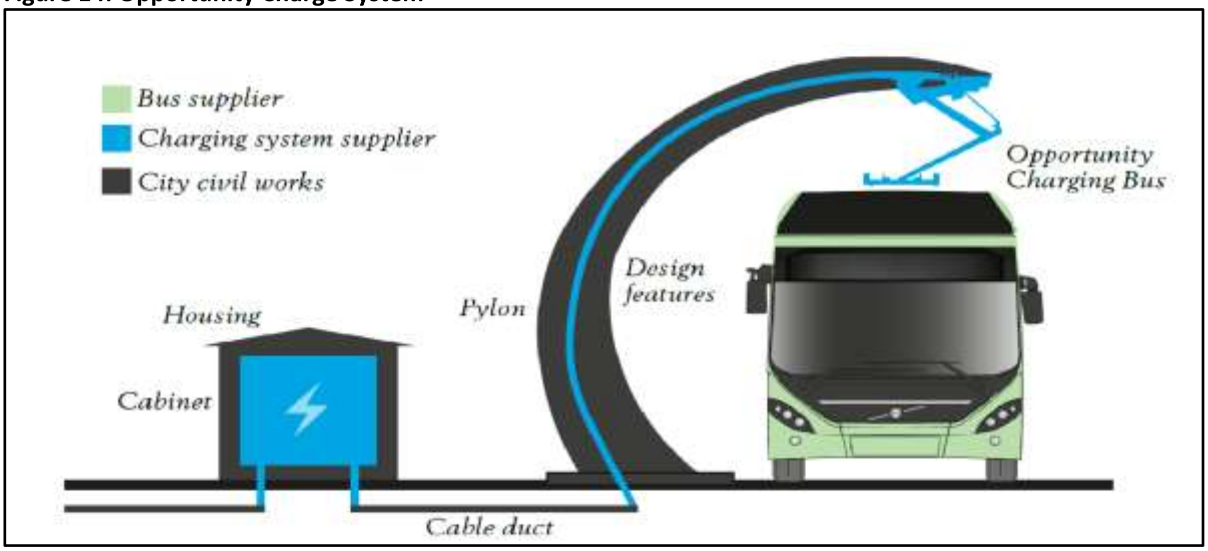
[32] Ercan, 2015
[33] Based on information from Chinese operators; 50-60 kW charging station with 2 nozzles
[34] CARB, 2016
[35] CARB, 2015

to the lack of spare parts or long lead times for spare parts delivery. However, the main reason is more due to the use of a small number of buses and not due to the hybrid technology itself.

7.1.2. Opportunity Charge Systems

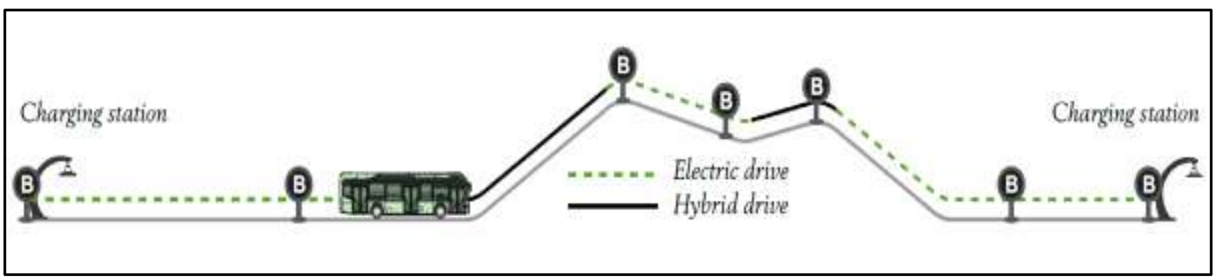
Opportunity charge systems are characterized by operating with plug-in hybrid buses or electric buses that are loaded on the route, either at charging points throughout the entire bus circuit or at the first and/or last stop. The following figure shows an example of such a system.

Figure 14: Opportunity Charge System



Source: Volvo

Figure 15: Example of Opportunity Charge System with Hybrid Bus



Source: Volvo

There are multiple types of opportunity charge systems undergoing trials basically in Europe, the US, Korea and China with variations in recharge time, amount of electricity recharged, as well as types of buses. A description of different systems that are currently in operation is given[36].

Barcelona

Barcelona's opportunity charge system operates with articulated electric buses that are recharged at the final stations of the route. The following table shows the characteristics of the pilot system being tested with 2 buses.

[36] See ZeEUS

Table 5: Opportunity Charge System of Barcelona

Parameter	Case Barcelona
Route characteristics	7.5km long route (one-way) with 1% gradient and 5 minutes of headway between buses
Bus characteristics	Electric articulated 18m buses with AC, no heating; 125 kWh batteries; electricity consumption of 2.5-3.9 kWh/km
Opportunity charge system characteristics	2 fast charging points throughout the entire route (1 at each end station) with 400kW power and charging through a pantograph; recharging time 5 minutes sufficient to run 100% electric with more than 20% battery capacity; overnight slow recharging at the bus depot with 50kW charger with an approximate duration of 3.5 hours.

London

London's opportunity charge system operates with hybrid buses that are reloaded at the final stations of the route. The following table shows the characteristics of the pilot system being tested with four buses.

Table 6: Opportunity Charge System of London

Parameter	Case London
Route characteristics	11km long route (one-way) with 7-12 minutes of headway between buses; 15-18 buses during the peak time on the route
Bus characteristics	Plug-in hybrid double decker buses; electricity consumption in electric mode of 2kWh/km
Opportunity charge system characteristics	2 fast charging points throughout the entire route (1 at each end station) with inductive floor charging of 60 kW and a recharge time of 7-14 minutes sufficient to run 40% electric; overnight slow recharging at the bus depot.

Figure 16: Inductive Re-Charging

Source: ZeEUS, 2014

Stockholm

Stockholm's opportunity charge system operates hybrid buses that are reloaded at the final stations on the route. The following table shows the characteristics of the pilot system being tested with 9 buses. Similar systems are in operation in Gothenburg, Luxembourg as well as Charleroi and Namur in Belgium. The latter has since October 2017 the largest system in Europe with about 90 hybrid buses and 12 fast charging stations[37].

Table 7: Opportunity Charge System of Stockholm

Parameter	Case Stockholm
Route characteristics	8.5km long route (one-way) with 9 buses during the peak hours
Bus characteristics	Plug-in hybrid 12m buses with 9kW batteries (in Luxembourg 76 kW); electricity consumption in electric mode of 1.1kWh/km without AC or heating
Opportunity charge system characteristics	2 fast charging points throughout the entire route (1 at each end station) with 150kW and a recharge time of 3-6 minutes. Each minute of re-charge is sufficient to run the bus around 1km on electric mode; overnight slow recharging with 11kW and a duration of 3-4 hours at the bus depot.

Photo 2: Opportunity Charge Systems in Goteborg and Luxembourg

Geneva

In Geneva, an ultra-fast charging system called "flash charging" has been implemented with bi-articulated and articulated electric buses (TOSA: Trolleybus Optimization Power Supply System)[38].

Table 8: Opportunity Charge System of Geneva[39]

Parameter	Case Geneva
Route	12km long route (one-way) with 30 stations, 10 minutes of headway and 10,000

[37] https://www.smmt.co.uk/2017/02/europes-largest-single-operator-electric-bus-fleet-to-arrive-this-autumn/
[38] http://new.abb.com/grid/technology/tosa
[39] http://new.abb.com/grid/technology/tosa y http://ge.ch/transports/actualites/tosa-ligne-23-cest-parti-lunion-partenariale-publique-privee-au-service-du-bus-du-futur

characteristics	passengers per day
Bus characteristics	12 articulated 18m electric buses
Opportunity charge system characteristics	The system has an ultra-rapid charging at 13 stations with 600 kW and 15-20 seconds of “flash charging”. At the end of the route the bus is charged for 4-5 minutes. The flash stations are connected to the 50kVA electricity network and have a 3kWh storage unit for smoothing peaks in consumption.

In the case of Bhutan flash-charging is not considered as an option as this system requires high passenger demand on the routes to be financially feasible. Inductive charging might also not be a good option as systems have experienced difficulties if pavements are not clear. Viable options are however standard opportunity charge systems such as operated e.g. in Luxembourg with end-of -route charging with a Pantograph using 10-12m hybrid or electric buses.

The environmental impact is either idem to BEBs (see next section) if used with electric buses or idem to plug-in hybrid buses if used with hybrid units. Incremental bus costs for the Pantograph are around 5,000 USD whilst opportunity charge systems cost per re-charge point around USD 150,000 i.e. around USD 300,000 per route[40]. The financial viability of the system depends very much on the number of buses operating the route which again determines the number of re-charging points required at the route ends[41].

7.1.3. Battery Electric Buses (BEBs)

It is estimated that 98% of electric buses run in PR China. In PR China there are fleets of hundreds of BEBs operating for several years in several cities, while in Europe or the U. S., there are mainly pilot fleets with some units that are recently expanding to commercial fleets with more than 20 or 30 buses.

Photo 3: BEBs

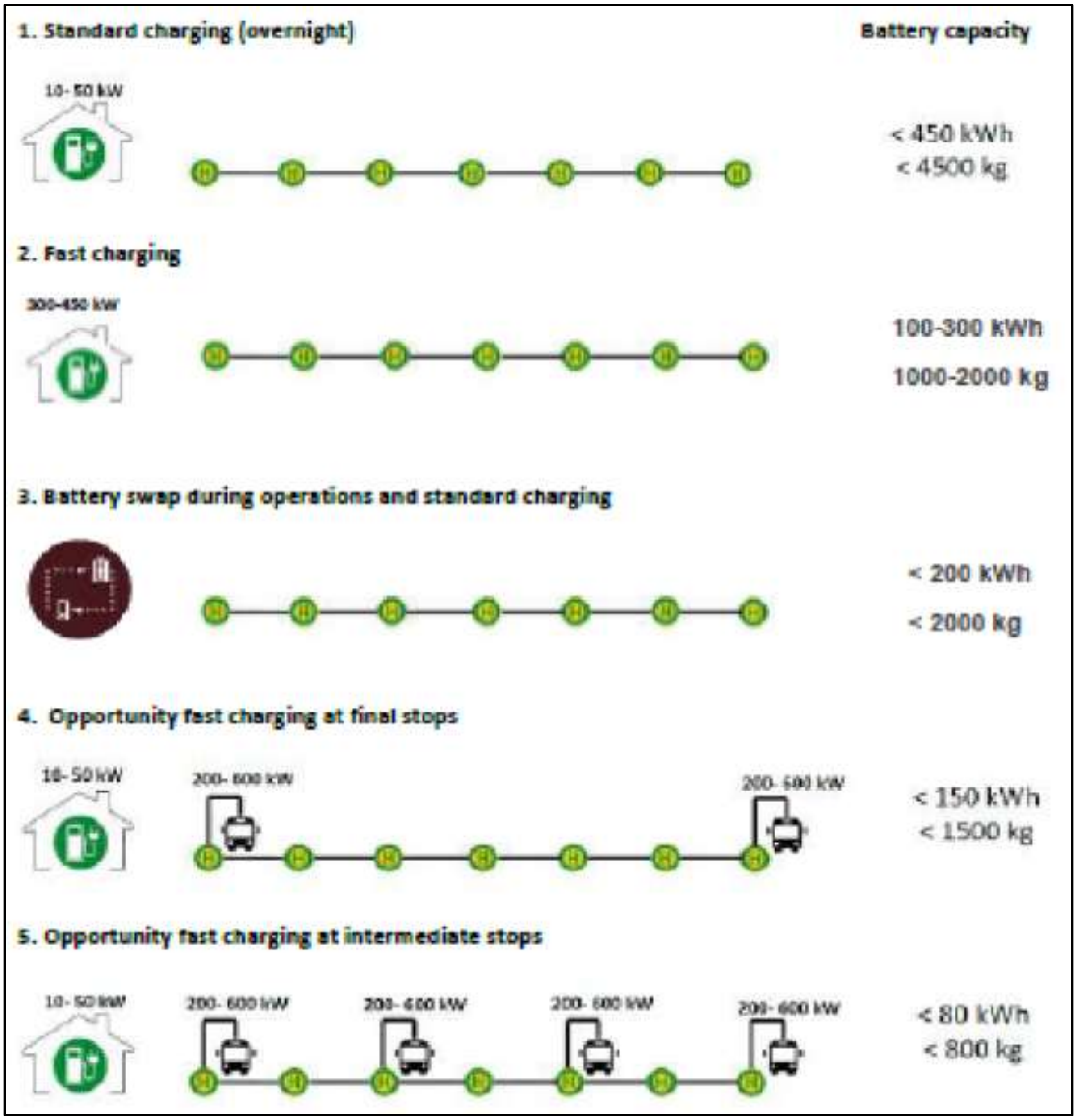
[40] See https://www.arb.ca.gov/msprog/bus/4thactwgmtng_costs.pdf; Landerl, 2017; Chinese system

[41] The re-charge time cannot be higher than the headway between buses to not create queues for re-charging or more than 1 re-charger must be available.

Source: Shenzhen, Tianjin, Fuzhou, Beijing

Battery Electric buses (BEBs) are vehicles with electric motors and batteries that are charged along the route, exchanged during the day or are loaded at specific sites during the day and / or at night. The main differences between types of BEBs refer to their charging system which again influences the driving range, operational flexibility, vehicle weight and passenger capacity and costs. The following figure shows main charging possibilities.

Figure 17: Charging Options for BEBs



Source: Grütter Consulting adapted from Landerl, 2017

Standard Charging

The core features of buses with standard overnight slow charging is that the bus needs to carry a large amount of batteries to allow for a sufficient daily range to cover all activities. This implies a large space requirement and a high weight due to batteries as well as a complex battery management system as batteries are spread out in the vehicle with different temperatures. In a 12m bus typical battery capacities are in the order of 350-450 kWh to allow for a driving range of 200-300km. This results in an additional bus weight of 3-4 tons. The volume and weight of batteries result in a reduction of passenger capacity in the order of 10-20% (either due to limited space or axle weight limitations). The additional weight also results in a higher electricity usage of such buses. Typical overnight charging requires 4-6

hours of charging with 15-50 kW chargers. The main investment is in buses, with slow chargers being very low cost or even part of the bus package. Operation-wise the BEBs can be used flexibly on different routes and charging is also simple at the depot. Also, the operator can potentially take advantage of lower electricity tariffs during off-peak periods thus reducing energy costs.

Photo 4: Charging Systems BEBs

Source: Beijing, Tianjin

Fast Charging

Fast charging has grown rapidly in popularity due to the availability and lower prices of fast-chargers with a power rating of 300-500kW. Buses can be charged in 15-30 minutes from 20-100% depending on the battery capacity of the bus, the charging unit and the number of power sockets of the bus (in general 2 and on some models 4). The battery capacity of such buses is 100-200 kWh and in general they are charged once during the day with either fast or slow charging during the night. The battery capacity and therefore weight and space requirements are halved compared to the 1st option, thus reducing also costs. However, investments need to be made in infrastructure. Electricity costs for fast-charging during the day might also be significantly higher than during the night. Operation-wise fast charging can be more complex as buses need to be recharged either at the depot or near to the route using mobile chargers (used e.g. in Jinan, China). Buses potentially still have a slightly reduced passenger capacity compared to conventional units but the reduction is marginal.

Battery Swap Systems

Various Chinese cities have established battery swap stations and systems including Beijing, Jinan and Zhengzhou. Buses have a similar battery capacity and configuration as for fast charging. However, instead of charging the batteries in the bus, latter are removed by robots and replaced with new units. This takes around 10-20 minutes i.e. a comparable time as fast-charging. Battery swap stations are very expensive, buses must return to these stations and battery swap systems are not standardized thus being locked-in with certain producers. Due to large availability and relatively low cost today of fast chargers this approach is not followed anymore by cities.

Opportunity Charging

See former chapter.

Environmental Impact

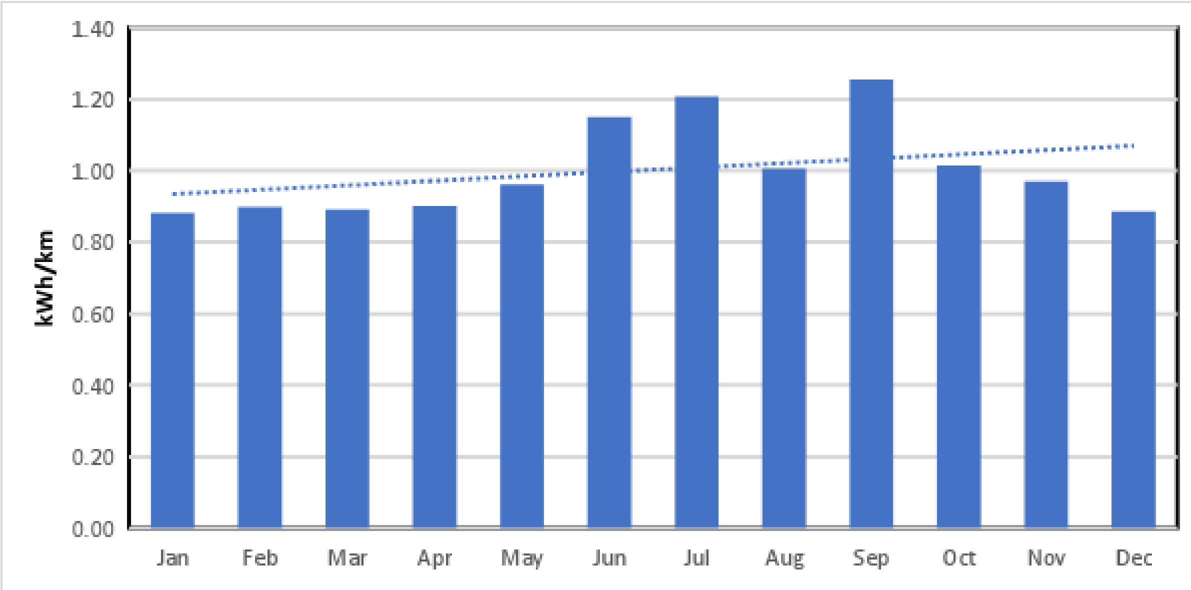
The following table reflects results of energy consumption of BEBs of 12m. There is a great fluctuation in consumption, according to buses, route and weather conditions with values reported between 1 and 2.6 kWh per km.

Table 9: Energy Consumption 12m BEBs

City/Country	Energy consumption in kWh/km	Comment	Source
Zhengzhou, China	1.1 kWh/km	Not used fully in hot summer months; 110 BEBs	BRT Zhengzhou, 2016
Fuzhou, China	1.0 kWh/km min/max: 0.88 / 1.26	Not usedon steep routes; 210 BEBs; average 220 kWh battery	Fuzhou Public Transport Group, 2017
Beijing, China	1.2 kWh/km	Used only on short routes	Beijing Bus Group, 2017
Tianjin, China	1.5 kWh/km	Over 1,300 12m BEBs operating on all routes	Tianjin Bus Group, 2017
Europe, pilots	1.6 kWh/km	Muenster, Germany 1.8 kWh/km; Rotterdam, Netherlands 1.4 kWh/km; Mannheim, Germany 1.2-2.0 kWh/km; Dresden, Germany 1.3-2.1 kWh/km	Landerl, 2017; ZeEUS; Rieck, 2014
California, USA	1.3 kWh/km	Foothill Transit	NREL, 2017

The performance of BEB's is very sensitive to climatic conditions. Consumption can be 50% higher in very hot seasons and with high use of AC or in times of severe cold and a high usage of heating. The following graph shows the consumption of BEBs of 12m in Fuzhou, PR China for one year.

Figure 18: BEB Energy Usage During the Year 2016



Source: Fuzhou Public Transport Group, 2017

The environmental impact of electric buses is 0 local emissions as well as around 50% lower noise emissions (around 10 decibel less than diesel units)[42]. A comparative measurement in Germany of a Euro VI diesel bus with a BEB revealed a difference of 16 dB when the bus starts from a station and 8 dB when passing by[43].

BEBs have zero local emissions in terms of GHGs due to the 100% renewable electricity grid of Bhutan. BEBs also have zero combustion-related emissions. BEBs however still provoke local non-combustion related emissions of Particle Matter[44].

Upstream and downstream emissions of BEBs are related to bus and battery manufacturing and disposal. When considering life-cycle emissions of BEBs, the type of battery used and the assumptions, e. g. source and type of raw material extraction used, have a strong influence. The subsequent use of batteries also influences their use. In the case of PR China, for example, the batteries used in buses are re-utilized for electricity storage for stationary applications. Batteries can be used in such cases without problem for another 20 years as they still retain more than 50% of their capacity while for vehicles the batteries are removed if their retention capacity drops below 70-80%.

The difference in life-cycle emissions in the production phase from BEBs to conventional diesel buses is minimal. A life cycle analysis based on the EIO-LCA model (Carnegie Mellon University, USA) reveals marginal differences between a conventional diesel bus and a BEB in terms of environmental impact on GHG, PM_{10}, NO_x, SO_2 emissions and water use in the production phase of the bus and its maintenance.

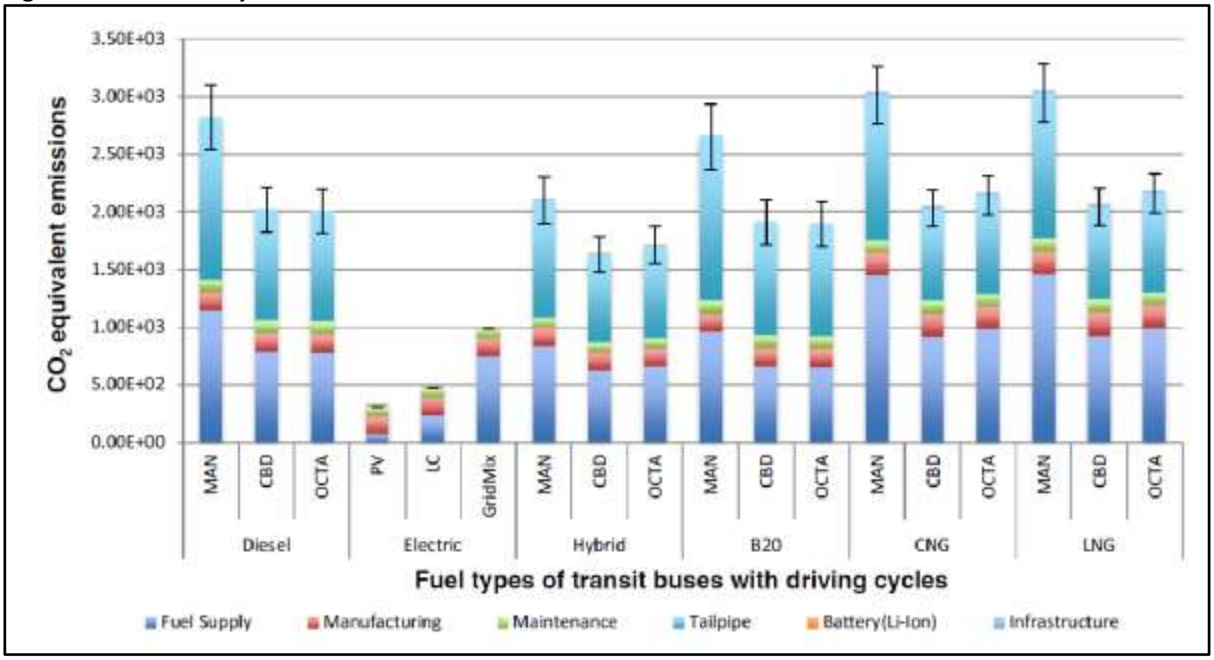
[42] http://new.abb.com/future/de/tosa

[43] http://news.emove360.com/public-comparison-e-bus-much-quieter/?lang=e

[44] particulate matter emissions from brake, tire and road re-suspension; in terms of $PM_{2.5}$ these non-combustion emission sources represent around the same amount of emissions as combustion related $PM_{2.5}$ emissions of a Euro IV bus (TRL, 2014)

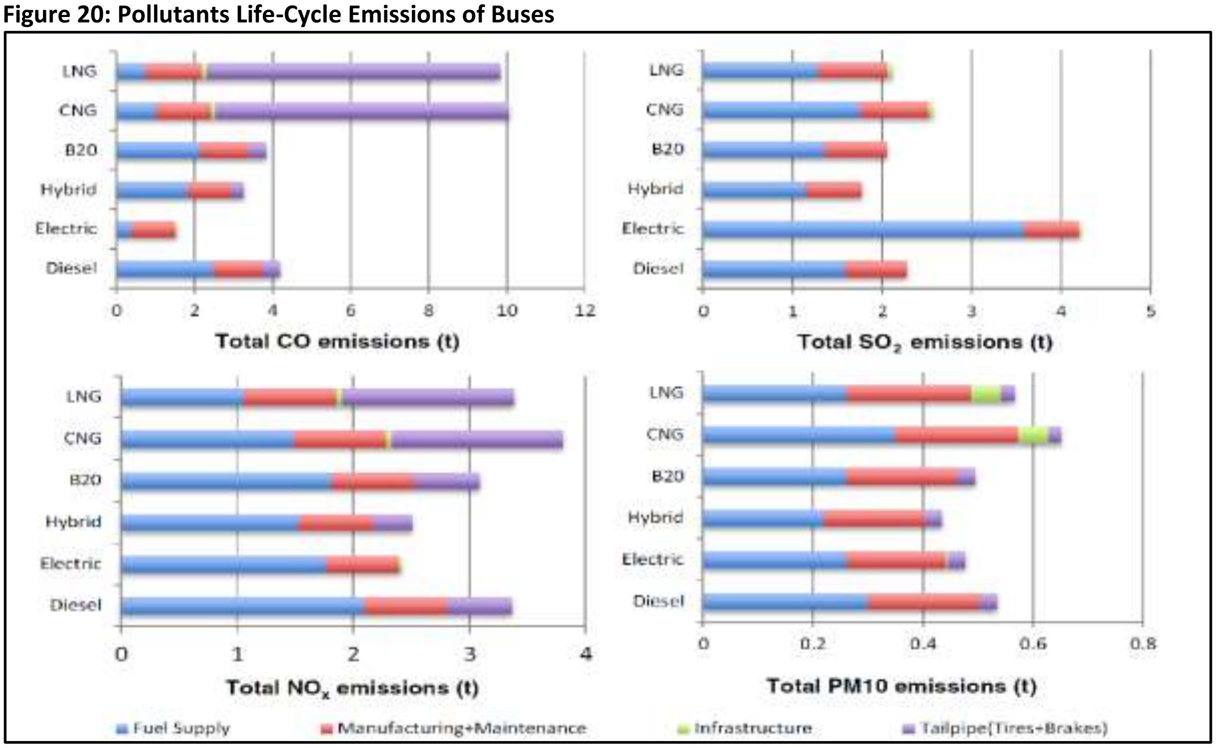
The environmental impacts of the construction and maintenance phase in all cases are much lower than, for example, the WTTemissions caused by energy production[45].

Figure 19: GHG Life-Cycle Emissions of Buses



Source: Ercan, 2015, figure 4

Figure 20: Pollutants Life-Cycle Emissions of Buses



Source: Ercan, 2015, figure 5

[45] Ercan, 2015

Cooney's study (2013) also confirms that the main emissions of the BEBs, as far as GHG is concerned, are produced by electricity generation and not by the manufacture of the bus and its batteries, where diesel buses and BEBs are comparable.

Finance

The following table shows the incremental Capital Expenditure (CAPEX) of BEBs.

Table 10: Incremental CAPEX BEBs

City/Country	Diesel Bus USD	BEB USD	Incremental Investment	Comment
Fuzhou, PR China	85,000	250,000	294%	High floor with AC; automatic gearbox; capacity of 70 passengers; battery of 230 kWh with a range of 120-180km; 8-year battery warranty; diesel comparison bus Euro IV valid for 2015; source: Fuzhou Public Transport Group
Tianjin, PR China	91,000	303,000	233%	12m bus with capacity of 70 passengers; 329 kWh battery; data year 2016; source: Tianjin Bus Group
Beijing, PR China	133,000	303,000	128%	12m bus with capacity of 70 passengers; 102 kWh battery; data year 2017; source: Beijing Bus Group
Piedmont, Italy	250,000	470,000	88%	Range 170km; price of 2016; Source: SPP Regions
Washington, USA	440,000	880,000	100%	Low-floor; average of Green Power, Proterra and BYD; 5 year battery warranty; year 2014; Source: Washington State Department of Enterprise Services

Manufacturers in general guarantee a service life of 5-8 years for batteries. Also, investment must be made in charging systems for batteries. One slow charger is in general used per bus whilst for fast chargers 4 or more buses share the same charging unit.

In terms of maintenance, there is a very large variation in estimates, ranging from half the maintenance costs of a diesel bus to higher costs than those of diesel units. In theory, the maintenance costs of BEBs should be well below diesel buses because they have fewer moving parts. The trend of large fleets also clearly goes in this direction. However, spare parts are still more expensive for BEBs, staff needs to be higher qualified than for diesel buses and some components still lack a high reliability. Also tyre usage tends to be slightly higher for BEBs due to the increased bus weight.

The availability of BEBs is not yet at the level of diesel buses. Although the propulsion system is technically simpler, there are still frequentproblems with the battery management system as well as problems with bus elements that are not directly related to the electrical parts. The bus availability of BEBs is estimated 5% lower compared to conventional units by CARB (2016) which is a value also reported by various Chinese cities.

7.2. Proposed Technology Option

Two types of buses and services with distinct features operate in Bhutan:

- Urban public bus transport which is still incipient, with around 50 units operating currently;
- Inter-urban buses operating on longer distances.

7.2.1. Technology Option for Urban Buses

Urban public bus operations in Bhutan have following distinct characteristics:

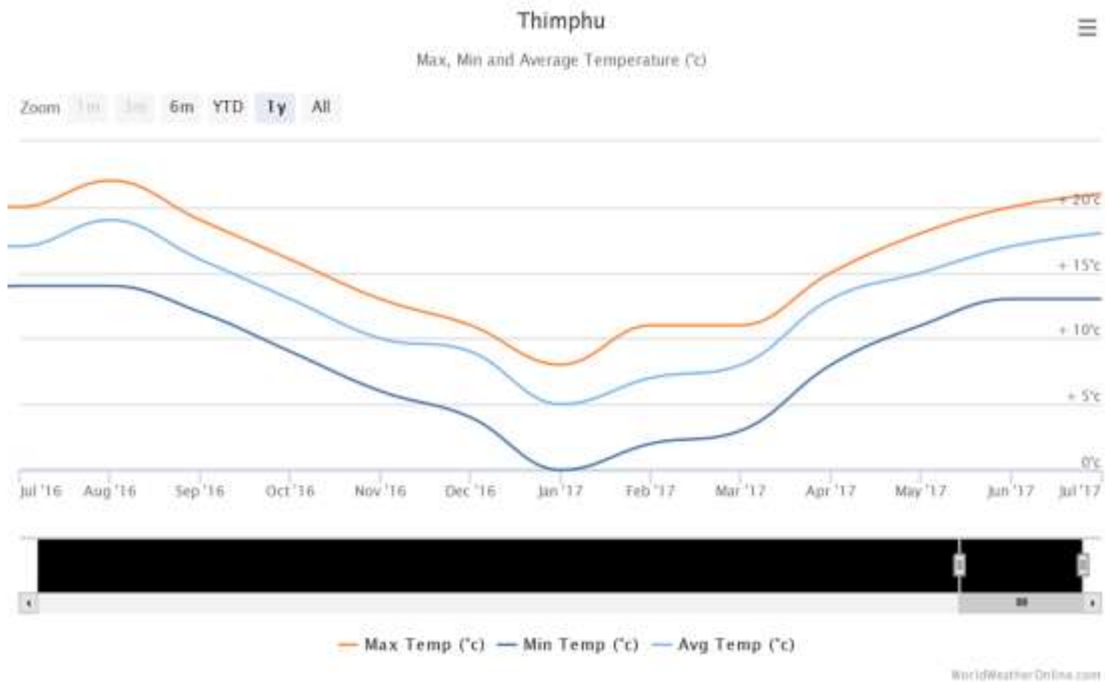
- Average annual mileage of buses is with 30,000km per year very low. Routes operated are relatively short with a low bus frequency and limited bus operating hours. Short routes, short operating hours and low annual mileage all favour electric buses, which are typically used under such circumstances as this allows to operate with a limited battery pack and allows for sufficient time for re-charging. Typically, Chinese cities with large BEB fleets have annual distances driven between 10,000 and 40,000km in line with bus usage in Bhutan. Hybrid buses on the other hand will not result commercially viable with such low annual mileage.
- Buses used in Bhutan are small and medium sized units with a passenger capacity of between 20 and 50 passengers. This is due to the limited passenger demand. Even with higher passenger demand the bus frequency will rather be increased as this makes public transport more attractive. Also, roads in Bhutan tend to be narrow favouring smaller units. It is therefore expected that also in the future the majority of buses will be 6-10 meter units. This again favours BEBs which are basically produced as smaller units up to 12meters. In many Chinese cities large fleets of 6, 8 and 10m BEBs are used (see photo below). Such buses are much lighter and require far less batteries. Hybrid buses on the other hand are basically produced as 10m or larger units and savings tend to be higher for larger and heavier units (due to brake energy recovery).

Photo 5: Electric Coaster and 10m Bus in China

- Driving speeds are low due to road conditions (narrow and curvy roads). This favours electric as well as hybrid units due to braking energy recovery.
- Roads can be steep in Bhutan which would require higher powered electric or hybrid vehicles. Latter will consume more electricity. Technically seen this does not constitute a problem for LCBs but it is a condition which needs to be considered when formulating the vehicle tender specifications.

- Temperatures in Thimphu are moderate. Summer months have average temperatures below 20^0C and winter months are moderate with average temperatures above 0^0C (see graph below). This allows to operate buses without AC and with limited heating during few winter months. This favours strongly BEBs as well as hybrids where high usage of AC or heating drains batteries and results in high energy usage.

Figure 21: Average Annual Temperatures in Thimphu



The operational conditions of urban bus services in Bhutan clearly favour BEBs as alternative to diesel vehicles. Also, the 100% renewable electricity production of the country, the necessity to import all diesel and the Bhutanese climate change strategy all clearly favour electric vehicle solutions. Hybrid buses on the other hand can work well in the Bhutanese operational conditions but will be a very costly solution due to usage primarily of smaller buses (hybrid coasters are e.g. not widely available) on short routes with limited annual mileage.

In the following sections the environmental impact of the usage of BEBs and the economic and financial viability as well as potential technical risks will be assessed. To assess the impact of a BEB fleet the following core parameters are used.

Table 11: Main Parameters Urban Buses Bhutan

Parameter	Value	Comment/Source
Diesel sulphur contents	50ppm	In accordance with diesel imported from India since 04/2017 (Indian fuel standard)
Baseline bus standard	Euro IV diesel	Euro IV is the standard in India since 04/2017 and shall also be introduced in Bhutan in 2018

Types of buses	6-8m coaster buses 10-12m standard buses	Currently 50 units operate of this size in Bhutan(around 50% coaster and 50% standard size units)
Annual average distance driven	30,000km	Distance driven by urban buses based on a survey of buses Thimphu, 2017 and information provided by MOIC
Diesel fuel consumption	Coaster: 31 l/100km Standard Bus: 5 1 l/100km	Coaster: MOIC average units procured since 2012 Standard bus: COPERT, 2017 based on Euro IV 12m bus with 15km/h average speed, 2% gradient, 50% load
Electricity consumption	Coaster: 0.7 kWh/km Standard Bus: 1.2 kWh/km	Coaster: average of 6-8m BEBs in Beijing and Jinan, 2016; Standard bus: 12m bus; average value of multiple fleets in China and data of European and US pilots

7.2.2. Technology Option for Inter-Urban Buses

Around 300 inter-urban buses operate in Bhutan[46]. These are basically small and medium sized units for 20-30 passengers operating on longer distances. This makes operations with BEBs difficult and would require fast-charging stations in different areas. Also, curvy and sometimes steep roads do not favour BEBs. The most appropriate low-carbon bus solution is therefore hybrid buses. The following table shows core parameters of baseline and hybrid buses used for the impact assessment.

Table 12: Main Parameters Inter-Urban Buses Bhutan

Parameter	Value	Comment/Source
Diesel sulphur contents	50ppm	In accordance with diesel imported from India since 04/2017 (Indian fuel standard)
Baseline bus standard	Euro IV diesel	Euro IV is the standard in India since 04/2017 and shall also be introduced in Bhutan in 2018
Types of buses	6-8m coaster buses	
Annual average distance driven	55,000km	Distance driven by inter-urban buses based on survey of buses Thimphu, 2017
Diesel fuel consumption	Coaster: 31 l/100km	MOIC average units procured since 2012
Hybrid fuel savings	25%	Average range is taken

[46] RSTA cited in KPMG, 2017. p.36

7.3. Environmental Impact

7.3.1. Environmental Impact Usage BEBs for Urban Buses

The environmental impact of BEBs is based on baseline Euro IV diesel buses and 0-exhaust emissions as well as 0 electricity production and transmission emissions of BEBs. All parameters for calculations can be found in Annex 2.

The following table shows annual emission reductions per electric Coaster and per electric 12m bus.

Table 13: Environmental Impact per BEB per Annum

Parameter	Coaster Bus	12m Bus
CO_2 reductions	25 t	41 t
GHG reductions WTW incl. BC	32 t	52 t
$PM_{2.5}$ reductions	0.002 t	0.002 t
NO_x reductions	0.24 t	0.28 t
SO_2 reductions	0.001 t	0.001 t

Electric buses have been taken with a lifetime of 20 years based on significantly reduced vibrations and components with a longer lifespan compared to diesel units for which the lifespan was assumed at 14 years[47].

Based on introducing 50 new urban electric buses (50% Coasters and 50% 12m buses) annual GHG reductions of around 2,000tCO_2 are possible.

7.3.2. Environmental Impact Hybrid Inter-Urban Buses

The environmental impact of hybrids is based on baseline Euro IV diesel buses. All parameters for calculations can be found in Annex 2.

The following table shows annual emission reductions per hybrid bus.

Table 14: Environmental Impact per Hybrid Bus per Annum

Parameter	Reduction Hybrid Bus
CO_2 reductions	11 t
GHG reductions WTW incl. BC	15 t
$PM_{2.5}$ reductions	0.001 t
NO_x reductions	0.11 t
SO_2 reductions	0.001 t

[47] Clean Fleets, 2014; VBZ, Switzerland

Hybrid buses have been taken with the same lifetime as diesel buses i.e. 14 years. Based on running 300 hybrid buses (the current fleet) annual GHG reductions of around 4,000tCO_2 are possible

7.4. Financial and Economic Impact

7.4.1. Urban BEBs

The incremental investment for BEBs is between 90,000 (Coaster) and 160,000 USD (12m standard bus) per unit including 3,000 USD for the slow charger. Batteries need to be replaced every 8 years, albeit with strongly dropping battery prices (see following table). Diesel buses have a shorter lifespan and thus need to be replaced after 14 years whilst BEBs have a lifespan of 20 years. Annual savings due to lower energy costs and lower maintenance costs start in year 1 with 7-12,000 USD (Coaster/12m bus) of which less than 10% are due to maintenance savings. Savings are expected to increase over time due to increasing diesel prices. The following table shows main parameters used for calculations.

Table 15: Parameters BEB Economic Calculations

Parameter	Value	Unit	Source
discount factor	7%		average for investment projects based on Zhu, 2016, Table C1
diesel fuel cost	0.81	USD/l	Price at gas stations mid 2017
electricity cost	0.041	USD/kWh	Block III tariff
CAGR price increase diesel	2%		World Bank 04/2017, real USD prices for 2030 66 USD/bbl; price June 2017 48 USD/bbl[48]
Social cost of carbon SCC (CO_2)	40	USD/t	IMF, 2014, p.67 has a SCC of USD 35 with USD 2007 which corresponds to 40 USD of 2016
Cost of SO_2	1,600	USD/t	Median levels of ground level local pollution Asia and Oceania excl.industrialized economies; IMF, 2014, Table A.4.2.1. (USD 2010 converted to USD 2016[49])
Cost of NO_2	350	USD/t	
Cost of PM	46,000	USD/t	
Incremental cost BEBs	120%		Average value of sur-cost of BEBs in China, USA, Europe; Grutter Consulting, 2017b
CAPEX coaster diesel	70,000	USD	2016 price of 60,000 USD but Euro II; Adapted for 2018 price Euro IV
CAPEX 12m bus	150,000	USD	World Bank estimate for Euro VI unit 205,000 USD; adapted for Euro IV version and semi-low floor
lifespan batteries	8	years	warranty of manufacturers
lifespan diesel bus	14	years	RSTA
lifespan BEB	20	years	

[48] based on https://ycharts.com/indicators/average_crude_oil_spot_price
[49] using http://stats.areppim.com/calc/calc_usdlrxdeflator.php

cost batteries per kWh 2017	500	USD/kWh	Cost of replacement batteries in China 2017; Grütter Consulting, 2017b
CAGR change of battery cost	-12%		US DOE projections, 2017 (assumed for next 10 years then stable)[50]
Investment cost chargers	3,000	USD	Average cost Zhengzhou, Jinan, Tianjin; Europe 5-25kUSD; Source: Beijing, Tianjin, Jinan; Landerl, 2017
Number of chargers	50		1 charger per bus; overnight charging
Lifespan chargers	20	years	CARB, 2016
Maintenance costs BEBs relative to diesel units	90%		Landerl, 2017 50% to 100% of diesel; CARB, 2016 70% of diesel; Tianjin higher cost due to more expensive components and 20% higher tyre usage; Fuzhou 20% lower cost
Residual battery value	20%		relative to value of new battery set at time of replacement: usage for stationary applications; source: BYD
Batteries Coaster	100	kWh	Based on average daily mileage, electricity consumption, 20% reserve and 20% minimum in battery with 1x charging
Batteries 12m bus	170	kWh	
Maintenance cost diesel unit	0.2	USD/km	Estimate Grütter Consulting

On average BEBs would have a Financial Internal Rate of Return of 8% (slightly lower for 12m buses and slightly higher for Coasters) which is marginally above the benchmark rate of 7%. Including the economic value of reduced pollution the Economic Internal Rate of Return (EIRR) reaches 10%. This shows that total cost of ownership of BEBs for Bhutan would be comparable to using modern diesel units and that BEBs are financially viable for Bhutan. BEBs have higher risks concerning bus availability, bus maintenance cost, electricity usage, battery replacement time and calculations are also dependent on future expected price increases of diesel and electricity as well as differential CAPEX investment cost. However, it is clear from above that BEBs make economic sense whilst having significantly higher upfront costs resulting in an additional upfront investment for a fleet of 50 units of around 7 MUSD plus having a higher operational risk making financial incentives crucial for their implementation.

7.4.2. Inter-Urban Hybrids

The incremental cost of hybrids is 35% compared to conventional diesel units (see chapter 7.1.1.). For other cost components see the former chapter. Over the commercial lifespan of 14 years hybrids are profitable and have a FIRR of 17% and an EIRR of 21%. The same caveats apply for hybrids as for BEBs concerning assumptions and risks of a new technology. The incremental investment for a fleet of 300 units would be around 7.5 million USD.

[50] https://energy.gov/sites/prod/files/2017/02/f34/67089%20EERE%20LIB%20cost%20vs%20price%20metrics%20r9.pdf

7.5. Technology Risks

BEBs and to a minor degree hybrid buses have comparable risks compared to conventional units. Risks include:

- The profitability of LCBs depends to a considerable extent on the future diesel price. While it is expected that this price will increase the exact magnitude and timepoint of increases is unknown.
- The lifespan of batteries is not well known. Bus producers today guarantee 8 or even more years for battery lifespan or realize battery leasing contracts. Experience of more than a decade with hybrids in China has shown that over 50% of the fleet did not require battery replacement in the first 8-10 years of operations. However, this component is still considered a risk by many operators. For BEBs batteries are a considerable albeit strongly diminishing cost factor and therefore battery lifespan is critical.
- Actual energy consumption and energy savings under Bhutanese road conditions including high gradients and curvy roads is unknown. This risk element can be reduced with pilot fleets or with vehicle testing. This is a factor which must also be reflected clearly in any bidding documents for buses.
- Maintenance costs of large hybrid fleets are comparable to diesel units. However, if the fleet is small then spare parts will not be available, mechanics will have limited experience and know-how with electric components and bus standstill times will increase considerably. This has also been experienced by the bus operator in Thimphu with conventional diesel buses from a different brand i.e. the phenomena is basically linked to usage of “exotic” buses i.e. small fleets.
- Maintenance cost of BEBs should be lower than for diesel units due to less movable parts and no ICE. Also braking pads are used less due to regenerative braking through the engine. On the other hand, tyre usage will be slightly higher due to a higher bus weight. The experience of BEB operators has been that at least initially BEB maintenance costs are higher than of diesel units due to more expensive spare parts, due to requiring more skilled maintenance staff and, at least with some bus producers, due to lack of experience with bus production resulting in faulty non-electric components such as AC, suspension etc.
- Bus availability rates of BEBs tend to be around 5% lower than of diesel units due to more breakdowns in operations.
- The passenger capacity of BEBs is around 5-10% lower than of a conventional diesel bus (in most cases) due to space being taken up for batteries and bus weight (this can result in a higher axle weight restricting the number of passengers). However, the battery size conceived for BEBs in urban areas of Bhutan is relatively small and this factor is therefore marginal.

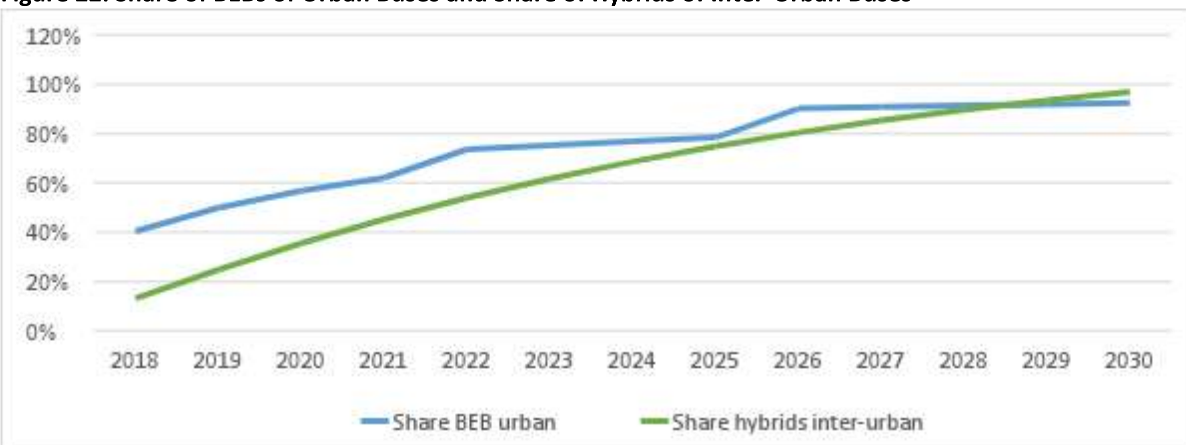
Some of the risks are perceived risks (by the bus operators) which in practice have shown to be of minor nature in large fleets. However, they are still present and prevent operators from investing in such units. The core business and purpose of bus operators is to transport passengers and they want to do this in the least risky manner from a financial perspective. This lack of appetite for risk taking in bus technologies explains why many operators do not invest in LCBs except if risk taking is honoured with substantial financial incentives. Whilst some of the risks can be mitigated through pilot fleets this is in general not considered an appropriate strategy as very small fleets have a limited validity in statistical terms and result in high operational and maintenance cost due to lacking spare parts and experienced mechanics. It therefore makes more sense to invest in larger fleets and to realize one-off subsidies to

bus operators thereby compensating their risk. This strategy has been followed by all countries which have introduced on a massive base low carbon buses including prominently the UK with the Green Bus Fund (more recently the Low Carbon Bus Fund) or the subsidies at National, Provincial and City level in China for New Energy Buses. In both countries initial incremental investment of LCBs have been fully covered through subsidies.

7.6. Implementation Path

The implementation path is based on all new buses procured (replacement buses plus additional buses) from 2018 onwards being BEBs for urban transport and hybrid units for inter-urban transport. Eventually in the future with an improved battery technology and sufficient fast-charging points also inter-urban buses could be replaced with electric units. The following graph shows the projected development of the share of BEBs and hybrid units as share of urban and inter-urban buses when implementing this strategy. By 2031 no more conventional buses would ply the streets of Bhutan.

Figure 22: Share of BEBs of Urban Buses and Share of Hybrids of Inter-Urban Buses



Source: Grütter Consulting; see Annex 2 for details

The LCB strategy would reduce annually by 2030 16-20,000 tCO_2 (CO_2 only or WTW incl. BC) equivalent to around 2-3% of projected 2030 BAU transport GHG emissions. It would also reduce annually 1.1 ton of $PM_{2.5}$ emissions, 1.3 t of SO_2 emissions and 136 t of NO_x emissions.

8. URBAN TRUCKS

8.1. Technology Options

No commercially viable low carbon long-haul trucks are currently on the market. For urban settings however electric versions are available, especially in the range of trucks up to 8 tons (see following pictures). These can be used for urban deliveries, waste collection and other purposes.

Photo 6: Urban Electric Trucks

Source: left to right Iveco Daily Electric; Fuso eCanter; StreetScooter; EForce

The following table shows some core features of the listed vehicles.

Table 16: Main Characteristics of Selected Urban E-Trucks

Parameter	StreetScooter[51]	Iveco Daily Electric	Fuso eCanter	EForce[52]
Load capacity	1 t	1.5-5.6 t[53]	4.6 t	9 t
Range	80 km	80-280 km[54]	100 km	200-300 km[55]
Price	USD 50,000[56]	USD 80-130,000[57]	Only leased currently at USD 1,000 per month	USD 500,000

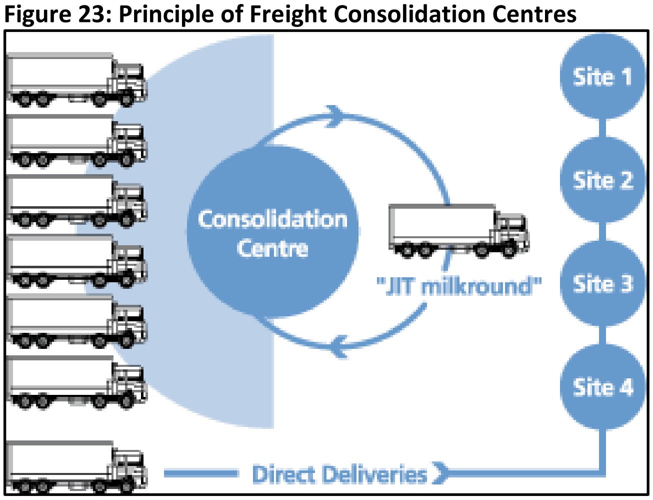
A combination of trucks with a payload of 1t (Light Commercial Vehicles or LCVs) and up to 5t (small truck) is considered as sufficient for urban distribution services including waste collection. An interesting

[51] Company of Deutsche Post
[52] Based on Iveco 18t truck
[53] Depending on model and configuration
[54] The vehicle can be bought with 1, 2 or 3 battery sets
[55] Urban setting 300km; highway 200km
[56] Depending on versions; see https://www.streetscooter.eu/produkte/work
[57] Depending on configuration and number of batteries

combination could be to establish one or two small Freight Consolidation Centres(FCC) at the city borders of Thimphu. All deliveries within the city would need to be done with trucks of the FCC. All trucks of the FCC again would be electric and could be managed on a vehicle rent base per hour and distance with the consolidation centre being the owner of the trucks and fast or slow-charging them. They could also perform own services consolidating different deliveries and thereby increasing average load factor of trucks. Only trucks en-route would be allowed to pass through Thimphu without delivery of goods within the city. This would greatly improve the air quality and reduce congestion due to using e-trucks whilst also having less traffic movement of trucks due to freight consolidation.

FCCs are distribution centres, situated generally close to a town centre, shopping mall or construction sites, at which part loads are consolidated and from which a lower number of consolidated loads are delivered to the target area. A consolidation centre often tends to have multiple objectives, but the most common aims are associated with reducing congestion, traffic disruption and vehicle emissions within the primary urban area that the consolidation centre serves. FCCs can minimise warehousing costs and CO_2 emissions while encouraging higher vehicle load factors or modal shifts through modifications in the timing and routing of the vehicles, vehicle size optimization, consolidation of trips and usage of low-emission vehicles. This can ensure that distances driven, fuel consumption and the number of operating vehicles are lowered while the remaining vehicles are being driven at higher capacities.

Figure 23: Principle of Freight Consolidation Centres



To have a significant size and impact from the start a pilot project structured around a FCC could be done with 50 electric trucks of which 30 small units of 1 ton and 20 medium sized units of up to 5 tons. The range of 100km daily is considered as sufficient for urban services. However, some fast chargers could also be installed at different points in the city allowing for rapid re-charging of trucks if required. Based on the experience with a such a pilot e-truck project this could then be further expanded.

8.2. Environmental Impact

The following table shows the environmental impact estimated per vehicle and for a fleet of 50 e-trucks.

Table 17: Environmental Impact e-Trucks (tons emission reductions)

Parameter	Annual			Lifespan truck		
	per LCV	per small truck	Fleet	per LCV	per small truck	Fleet
CO_2 emission reductions	8	14	530	125	210	7,944
GHG emission reductions WTW incl. BC	11	18	685	166	265	10,277
$PM_{2.5}$ emission reductions	0.001	0.001	0.04	0.016	0.010	0.67
NO_x emission reductions	0.03	0.08	2.41	0.39	1.22	36
SO_2 reductions	0.0003	0.0004	0.017	0.004	0.007	0.25

Annual emission reductions of a small fleet of urban e-trucks in Thimphu are in the order of 8-10,000tCO_2. In practice emission reductions would certainly be higher however, due to the impact of the FCC which results in higher average load factors as well as in less movement of larger trucks.

8.3. Economic Impact

E-trucks are novel and only recently has the market started to develop in a vigorous manner, not least due to the German Postal Service having started production of their own small delivery vehicle (now expanding also to delivery trucks) at a much lower cost than models offered by traditional vehicle manufacturers. Tesla has announced to build a long-haul e-truck and other large truck producers have significantly increased their efforts and are now offering attractive options for urban trucks. Prices are significantly higher than for conventional vehicles, especially taking into consideration that in Bhutan primarily Indian vehicles are being used. The following table shows core financial data used. The comparison base is thereby an electric truck with a diesel powered Euro IV engine of comparable characteristics.

Table 18: Parameters e-Trucks Economic Calculations[58]

Parameter	Value	Unit	Source
LCV diesel CAPEX	7,000	USD	ICCT, 2016
CAPEX diesel small truck	20,000	USD	Based on Iveco Daily Electric, For Transit or comparable of Indian manufacturer
CAPEX LCV electric	50,000	USD	Streetscooter, 2017
CAPEX small truck electric	80,000	USD	Streetscooter large version, 2017 or Iveco Daily Electric 1 battery set
Lifespan LCV/small truck	16	years	Standard lifespan with limited annual mileage

[58] See also former chapter on BEBs for other data parameters not specific for e-Trucks e.g. discount factor

Annual mileage	25,000	km	Daily 80km @ 330 operational days
Investment cost chargers	2,000	USD	Streetscooter, 2017; slow chargers
Number of chargers	50	units	1 per vehicle
BatteriesLCV	30	kWh	Streetscooter; Iveco Daily Electric
Batteriessmall truck	60	kWh	

The Net Present Value of both trucks is negative with a FIRR of 0% and an EIRR of 1-3%. This shows that e-trucks are not financially profitable and require incremental concessional finance. The total incremental upfront finance for a fleet of 50 trucks is around 2.5 MUSD.

9. LOW-CARBON STRATEGY

9.1. Technology Strategy

Overall Bhutan is very well posed for a low carbon vehicle strategy based on electric vehicles. It is one of few countries with a 0-emission grid based on renewables, has a very pro-active government with a focus on sustainable development, protection of environmental resources and low carbon emissions and has small urban centres with short distances and relatively small units favouring electric mobility. The contextual situation for electro-mobility is therefore ideal. At the same time electric mobility in taxis, buses as well as small trucks has taken large strides forward recently improving considerably vehicle reliability, performance,range,and vehicle usability. A growing operating experience of large fleets especially in China is available. Prices have dropped significantly (of vehicles, batteries and of charging stations) making commercial electric vehicles viable under a viewpoint of total cost of ownership.

The following graph shows the core proposed strategy for the next 5 years for commercial low carbon vehicles. In the long-term the development will surely go towards further electrification. However, development in technological and financial terms in the field of electro-mobility is very fast and it therefore makes limited sense to design detailed long-term strategies.

Figure 24: Strategic Direction Commercial Low Carbon Vehicles

Taxis

The number of taxis shall be reduced whilst increasing the number of public transport buses. This allows for a more efficient mean of transport, less congestion, less air pollution and reduced energy usage. The current number of taxis in Bhutan per inhabitant is very high due to having a limited public transport supply.

Remaining taxis shall be electrified. Electric taxis with the current incentive policies have a slightly higher TCO than gasoline units. Also, high upfront costs make it difficult for taxi operators to gear towards

electric units. Therefore, a financial strategy is required to massify electric taxis and a GEF project under auspice of the UNDP is taking up this task.

Buses

Public urban transport with buses shall be promoted in Bhutan through the expansion in urban areas of a convenient, modern, safe public transport system based on medium and standard sized buses. This will significantly increase the number of urban buses operating in Bhutan as well as the mode share of public transport.

The urban driving conditions of Bhutan with relatively small daily distances driven, small buses and limited passenger demand all favour the usage of electric buses. Also, climatic conditions (neither extremely cold nor very hot thus only requiring limited heating and no AC) favour the usage of BEBs. Battery electric buses in this segment have proven their operational performance in many cities in China and could be used without problems in Bhutanese cities. The TCO of BEBs is positive i.e. BEBs are commercially viable. As with taxis, this depends however on uncertain future parameters whilst initial upfront incremental investments and risks faced by the operator are visible from the start. Financial incentives to move towards such units are therefore required.

For inter-urban buses BEBs are currently not considered as the most appropriate technology due to longer distances driven, partially difficult road conditions and lack of charging stations. Hybrid buses could well be used for inter-urban services thereby reducing fuel consumption whilst being commercially viable over the entire life-cycle of the bus. Again, for operators to invest in this new technology incentives will be required which reduce or eliminate the differential incremental investment compared to a conventional unit.

Trucks

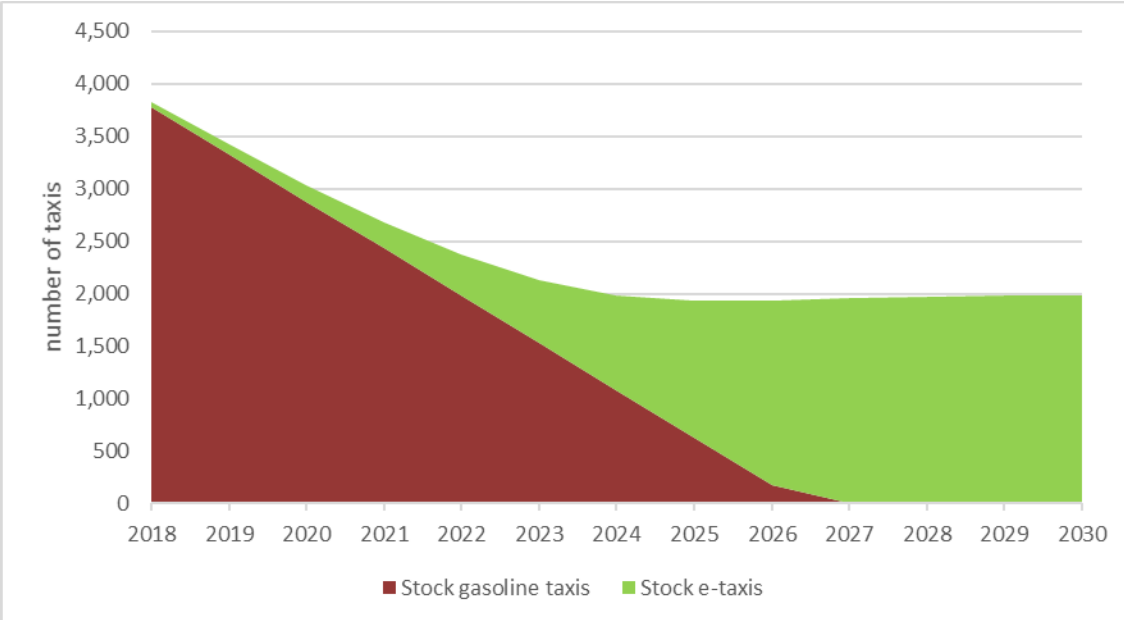
To reduce urban congestion and improve freight efficiency small pilot freight consolidation centres are proposed which operate with electric trucks. Latter could be leased or rented to private operators. This would allow for a more efficient handling of urban cargo, an improved load factor of trucks, and reduced congestion whilst improving the air quality. Recently important developments in urban trucks towards electrification have been made and the technology is now wider available as well as financially much more viable.

For inter-urban trucks currently no technically and financially viable low-carbon option exists. It is foreseen that with further battery development also long-range electric trucks will be available, but this will not happen in a commercial manner in the next few years.

9.2. Implementation Strategy

In taxis the total number of units is projected to decrease by around 50%. The stock of e-taxis is built up slowly reaching by 2027 100% of the taxi fleet (see following graph).

Figure 25: Taxi Stock and Electric Taxi Share

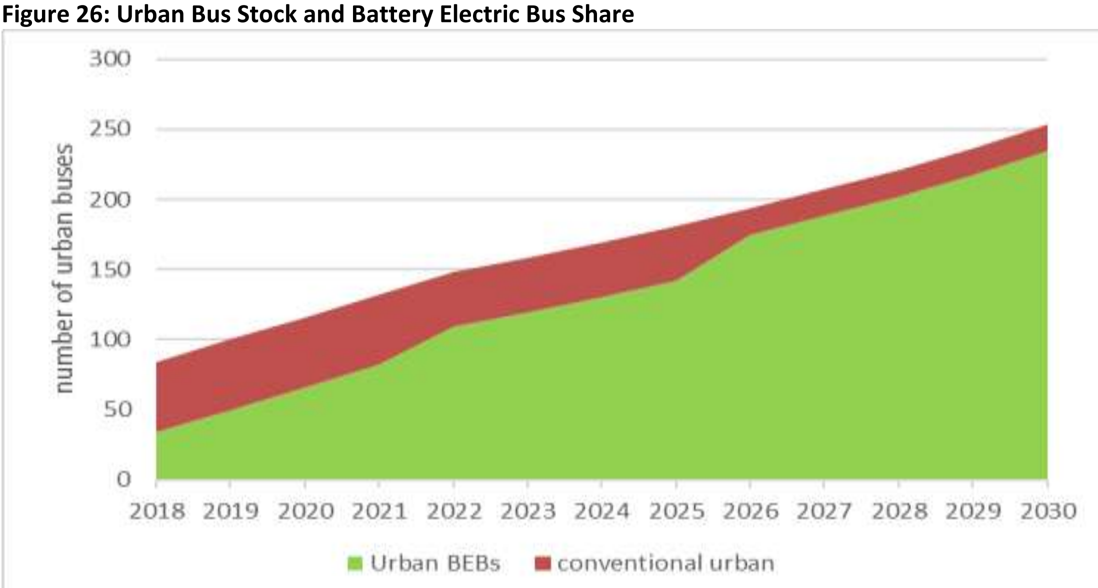


Source: Grütter Consulting

The GHG reduction per electric taxi per annum is 7tCO_2 or 62 tCO_2 during the commercial lifespan of the vehicle. Annual GHG reductions for the entire taxi fleet reach by 2030 14,000 tCO_2. The air quality impact is of minor nature as conventional taxis are basically gasoline powered.

In urban buses there is an expansion of the number of units with around 250 medium and standard sized urban buses plying the streets by 2030 instead of 50 units today. It is proposed that all new units be BEBs. However, due to the average lifespan of buses of 14 years not all urban buses would be BEBs by 2030 as many conventional buses have only been procured recently. The share of BEBs would however reach very quickly 50% and more than 90% from 2026 onwards (see figure below).

Figure 26: Urban Bus Stock and Battery Electric Bus Share

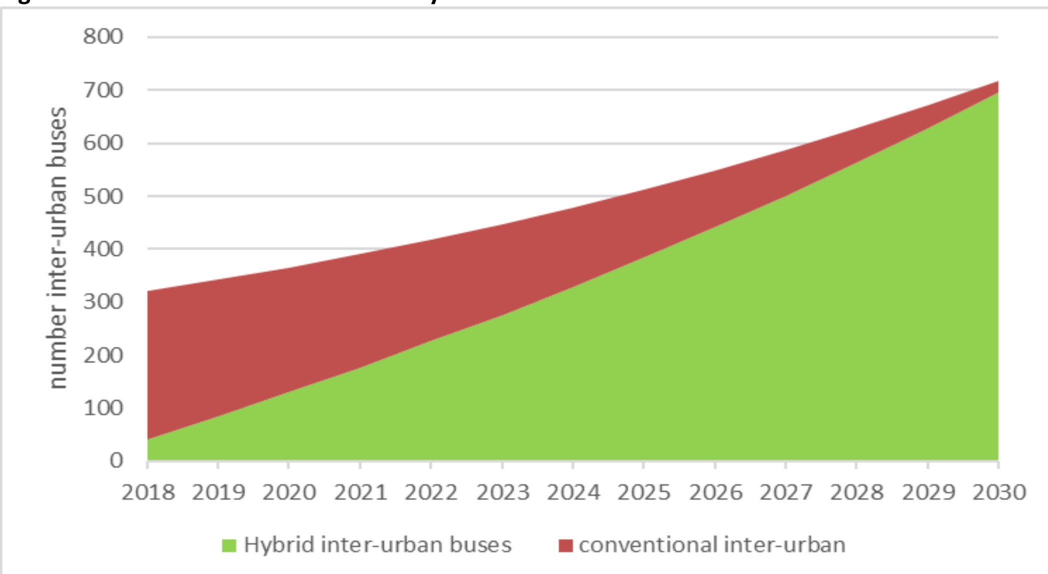


Source: Grütter Consulting

On average each BEB would reduce 35-40 tCO_{2e} per annum or 650-850 tCO_{2e} for its commercial lifespan (range is for CO_2 only and for CO_{2e} WTW incl. Black Carbon). By 2030 some 8-10,000 tCO_{2e} could be reduced on an annual base with the urban bus fleet.

Relative to economic growth also the number of inter-urban buses is expected to grow. The share of hybrid buses would reach around 50% by 2022 and more than 90% by 2028 (see figure below).

Figure 27: Inter-Urban Bus Stock and Hybrid Bus Share



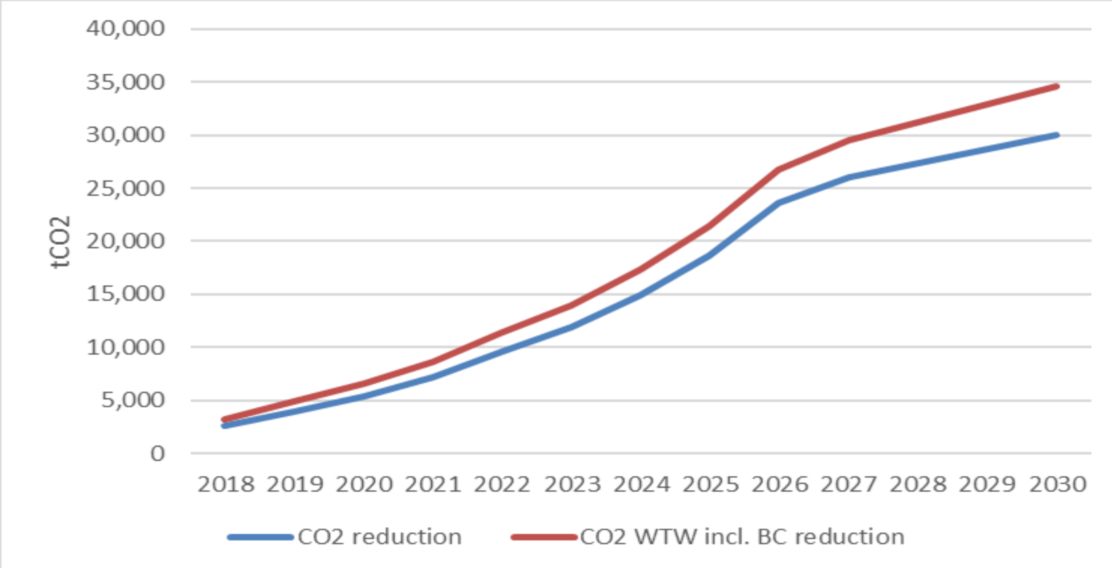
Source: Grütter Consulting

On average each hybrid bus reduces 11-15 tCO_{2e} per annum or 160-210 tCO_{2e} for its commercial lifespan (range is for CO_2 only and for CO_{2e} WTW incl. Black Carbon). By 2030 some 8-10,000 tCO_{2e} could be reduced on an annual base in inter-urban buses.

For trucks a pilot program with 50-trucks is proposed. The expansion of this program would depend on results achieved and the demand for urban trucks in the different areas of Bhutan. The GHG impact per e-truck is 11-15tCO_2 or 170-220tCO_2 over the commercial lifespan of the truck. This would amount to annual CO_2 reductions of around 500-700tCO_2 for the fleet of e-trucks.

Total GHG emission reductions are shown in the following graph.

Figure 28: GHG Reductions Low Carbon Vehicle Strategy



Source: Grütter Consulting

Emission reductions are by 2030 around 30-35,000tCO_2 equivalent to 13% of current CO_2 transport emissions or 5% of projected 2030 Business-As-Usual transport emissions of Bhutan. This includes only emission reductions due to usage of low carbon vehicles and not the mode shift from a reduced taxi number towards buses. The impact would be primarily in urban settings which would also profit from lower air as well as reduced noise pollution.

More than 80% of transport related GHG emissions by 2030 are due to passenger cars and inter-urban trucks. For these different strategies need to be designed. For passenger cars incremental costs and usage restrictions are still significant whilst for long-haul trucks no viable low-carbon technology has yet gone beyond pilot tests. Therefore, currently the options for electrification of transport in Bhutan are primarily for commercial urban vehicles.

9.3. Finance Strategy

9.3.1. Profitability of Low Carbon Vehicles

The following table shows the profitability of the different Low Carbon Vehicles compared to conventional units. The IRR reflects thereby the rate of return on the incremental investment which needs to be realized to purchase a low-carbon unit.

Table 19: Financial Performance of Low Carbon Vehicles

Parameter	e-taxis	Urban BEBs[59]	Inter-urban hybrid bus	e-trucks
Average initialincremental CAPEX per unit	USD 15,000	USD 135,000	USD 25,000	USD 50,000
Average annual OPEX savings per unit[60]	USD 3,600	USD 12,400	USD 4,200	USD 2,800
FIRR	19%	8%	17%	0%
EIRR	22%	10%	21%	2%

Low-carbon vehicles are close to being commercially viable. However, this depends critically on various factors which are uncertain including:

- Development of energy prices in the future including diesel fuel price (projected price increase of 2% annually for fossil fuels and no price increase assumed for electricity);
- Actual maintenance costs and standstill time of electric vehicles which depend to a significant extent on the availability of spare parts, trained mechanics and a sufficiently large fleet size;
- Actual energy consumption of electric vehicles and assumed baseline energy consumption of conventional units;
- Incremental investment of electric units;
- Life-span and replacement costs of batteries. Based on trend projections by US-DOE a further sharp decline over the next years of battery costs has been factored into calculations.

Above factors make the procurement of low carbon vehicles a financially risky venture in Bhutan. Average payback times for the incremental investment are also very long with 6 years for taxis, 12-15 years for buses and no full recovery of the incremental investment for trucks. It is therefore obvious that financial incentives to compensate for the additional risk and increase the attractiveness of low carbon vehicles are essential. The two countries with the largest fleets of low carbon buses (China and UK) have thereby also used the same instrument to promote such units.

9.3.2. Successful Schemes to Promote Low Carbon Buses

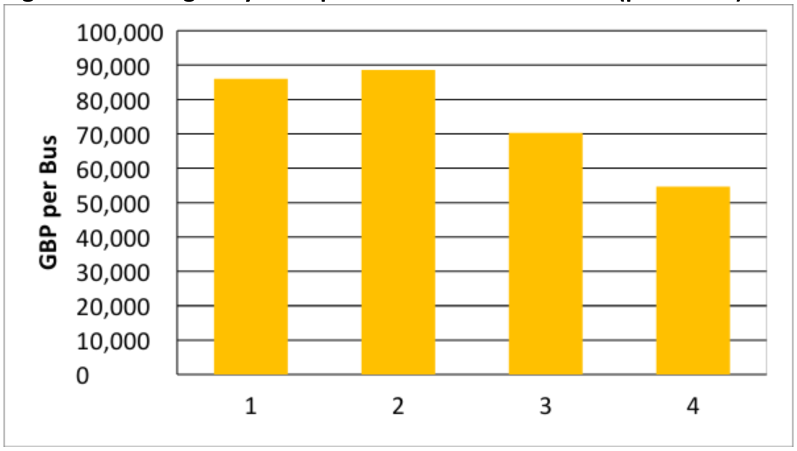
UK Low Carbon Bus Promotion

The £30m[61] UK Low Emission Bus (LEB) Scheme was launched 2015 by the Office of Low Emission Vehicles (OLEV) under its £500m budget 2015-2020 tosupport the purchase of low emission vehicles across England and Wales. This scheme replaces an earlier low carbon emission bus (LCEB) or Green Bus Fund (GBF) established 2009 which in its 4 rounds 2009 to 2013 financed more than 1,200 low-carbon buses (basically hybrids)[62] . Of the 1,200 buses financed by this scheme around 60% were double-deckers and 40% single-deckers. 89% of buses were hybrids, 7% biogas and 4% pure electric buses. Total

[59] Average medium and standard sized unit
[60] Average non-discounted over commercial life-span
[61] around 40 million USD
[62] http://webarchive.nationalarchives.gov.uk/20120606212701/http://www.dft.gov.uk/publications/green-bus-fund-round-1/

funding used for the 4 rounds was £89 million or around £72,000 per bus[63] - however this figure declined over time (see figure below, reaching 2012 £55,000[64] as average for double and single-deckers).

Figure 29: Average Payment per LCB in Green Bus Fund (per round)



Round 1: 2009; Round 2: 2010; Round 3: 2011; Round 4: 2012
Source: calculation by Grütter based on http://webarchive.nationalarchives.gov.uk/20120606212701/http://www.dft.gov.uk/publications/green-bus-fund-round-1/

The fund operates as a Challenge Fund which is a competitive financing facility to disburse in this case public sector funds for incentive driven solutions providing the smallest possible financial contribution to a given goal[65] making it less risky for private operators. Each round was based on competitive bidding ensuring that the lowest amount was paid per LCB using the budget available with fixed criteria for award giving: In GBF the criteria was expressed as minimum 30% lower WTW GHG emissions compared to an Euro III diesel bus with equivalent passenger capacity and in LEB the threshold was minimum 15% plus points given relative to the GHG reduction with the comparison base Euro V. The maximum size of grant claimed is the difference between the cost of the low carbon bus and the cost of its standard diesel equivalent. In the LEB a maximum 75% of the cost-difference and 90% including top-up funding for zero-emission capabilities and lower GHG emissions than 15% below the threshold value, favoring however bids with lower funding requests, is paid. In practice due to competitive bidding the funding paid by LEB is significantly less than the maximum threshold value established. Interesting is the fact that the amount of finance required per bus decreased over the 4 years from near to £90,000 to £55,000 i.e. a reduction of around 40% in 4 years which would amount for 2012 to a funding of around 60% of differential costs (see figure above)[66]. Reductions in the funding amount are due basically to more operators wanting to access the fund and seek finance thus increasing competition for funds.

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[63]around 100,000 USD per bus at the exchange rates prevalent at that time

[64] equivalent to USD 80,000

[65] stated objectives are an increase in the uptake of low and ultra-low emission buses speeding up the full transition to and ultra-low emission bus fleet in England & Wales and reducing the need for subsidy support; improve air quality; attract investment to the UK

[66] Estimates of DfT put differential costs of hybrids at £90,000 (12m single decker); £180,000 for a plug-in hybrid and £170,000 for a full electric bus.

Obviously, the risk premium has reduced over time, due also to experience of the operators with hybrids which require less support to invest in hybrids[67].

Additionally, the Bus Service Operators Grant was reformed in April 2009 to encourage improvements in fleet fuel efficiency and provide a level playing field for low carbon emission buses introducing an incentive of an additional payment of six pence for each km which operators realize with LCBs.

Transport Scotland has a similar fund (Scottish Green Bus Fund) which entered 2015 already in its 6th round and which offers as maximum 80% of price differentials between a LCB and a diesel equivalent.

Technology Funds for Chinese LCBs

The Ministry of Science and Technology started implementing with the 10th5-year plan (2001-2005) a project to foster new energy vehicles (defined as electric, fuel-cell, hydrogen and hybrid vehicles) which includes support in technological R&D as well as in the commercialization of such vehicles. Since 2007 a shift has been made to focus finance from R&D towards industrialization and in 2009 subsidies for the purchase of new energy vehicles were introduced. This national policy was supported by local governments e.g. in the cities of Beijing, Shanghai, Chongqing, Shenzhen, Zhengzhou, Guangzhou, Wuhan etc. with additional local subsidies, often tied to local producers. Due to this policy by 2012 China had already more than 20,000 LCBs running in around 25 cities and by end 2016 China had 165,000 LCBs representing around 27% of the urban bus fleet[68]. The majority of subsidized vehicles until 2012 were hybrids - since 2012 however, no more subsidies are given for the purchase of hybrid buses but only for plug-in hybrids and for full electric units. On average around 1/3 of the subsidy given is from the National Government, 1/3 from the Provincial Government and 1/3 from City Authorities. Subsidies typically cover 100% or more of the investment cost difference between a conventional bus and a plug-in hybrid or BEB thus making it cheaper for bus companies to procure BEBs than diesel or CNG units.

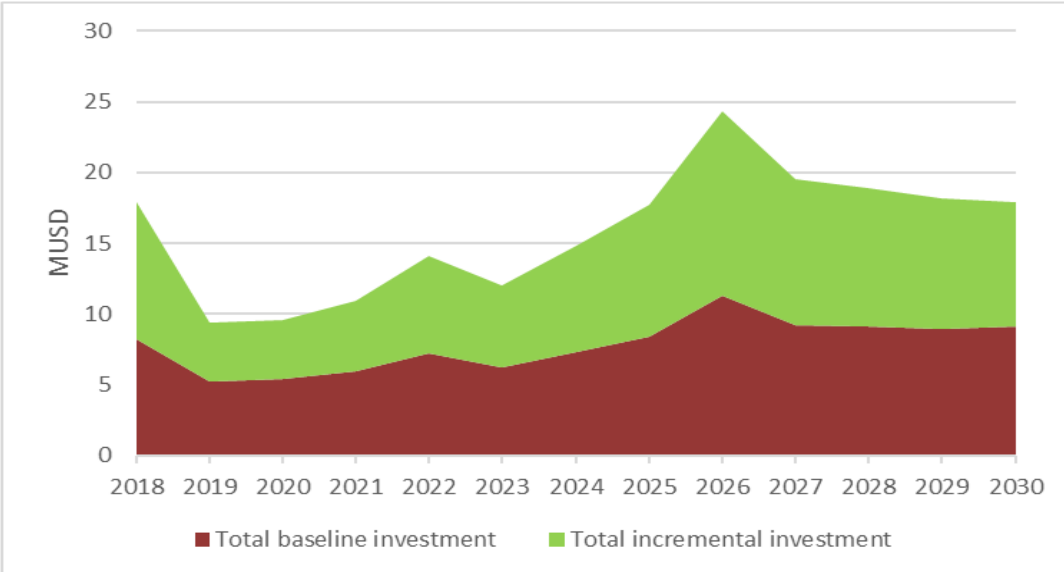
9.3.3. Finance Requirement and Finance Sources

The following figure shows total and incremental initial investment (this excludes investment for battery replacement) for low carbon vehicles over time and cumulative. The baseline investment corresponds to the value of conventional new vehicles i.e. this investment would also be realized under a BAU scenario.

Figure 30: Baseline and Incremental Investment for Low Carbon Vehicle Implementation

[67] Most operators are private sector and have to run profitable.

[68] Grutter Consulting, 2017b



Source: Grütter Consulting

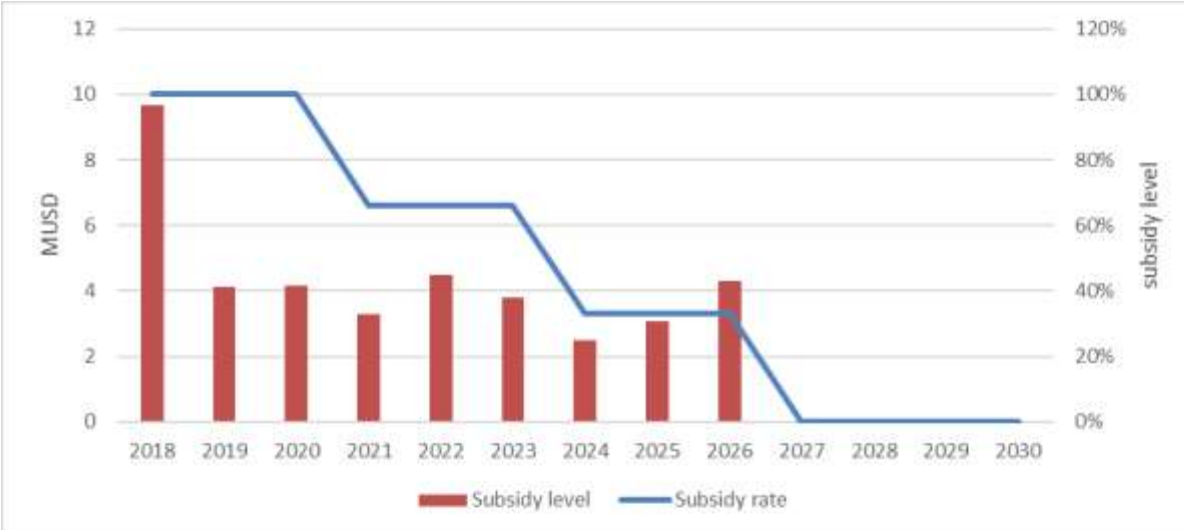
The following table shows total, baseline and incremental investment for the initial 5 years and cumulative 2018-2030.

Table 20: Investment Requirements Low Carbon Vehicle Strategy (MUSD)

Area	Cumulative initial 5 years			Cumulative 2018-2030		
	Baseline CAPEX	Incremental CAPEX	Total CAPEX	Baseline CAPEX	Incremental CAPEX	Total CAPEX
Taxis	3	6	10	26	52	78
Urban buses	12	15	28	26	32	58
Inter-urban buses	16	6	21	49	17	66
Urban trucks	1	3	3	1	3	3
Total	32	30	62	101	104	205

In total a cumulative investment of 205 MUSD is required until 2030. 50% of this investment would also be required under BAU to purchase conventional vehicles. Around 100 MUSD are incremental monies. However, this incremental investment has positive returns. With increased electric and hybrid vehicle penetration risks are reduced and the necessity of upfront subsidies gets minor. As finance strategy, an approach is therefore proposed which initially finances 100% of incremental CAPEX reducing this upfront investment by 1/3 every 3 years. From year 10 onwards no more subsidies are given. Also,subsidy levels are adjusted every 3 years based on the incremental CAPEX (it is expected that electric vehicles will get cheaper) and relative energy price development (fossil fuel versus electricity price). This approach has been followed successfully in China as well as in the UK with funds promoting low carbon vehicles. The following graph shows the expected finance volume and subsidy rate.

Figure 31: Proposed Subsidy Rates and Subsidy Volume for Low Carbon Vehicles



Source: Grütter Consulting

The finance could be structured through a Low Carbon Vehicle Fund. Total subsidies over the 9-year period would be around 40 MUSD. The following table shows the number of vehicles which would receive partial finance in the 9 years of operation of the fund and the expected CO_2 reduction over the commercial lifespan of these vehicles.

Table 21: Number of Vehicles and Commercial Lifespan CO_2-Reduction Co-Financed 2018-2026

Vehicle	Number of vehicles	CO_2 reduction in tons
Taxis	1,750	108,920
Urban Buses	175	117,547
Inter-Urban Buses	441	70,772
Urban Trucks	50	7,944
Total	**2,416**	**305,183**

Around 2,500 low carbon vehicles could be co-financed of which over 80% electric and around 20% hybrid vehicles with a life-time impact of more than 300,000 tCO_2 avoided. The marginal abatement cost relative to the fund investment would be 130 USD/tCO_2 avoided. This includes only the direct impact, not however the indirect impact of further electric and hybrid vehicles bought after 2026.

ANNEX 1: TAXI CALCULATIONS

Calculations are based using the data of the World Bank study[69] but updating them for critical figures.

Parameter	Value	Comment
Vehicle Price based on Nissan Leaf	USD 24,000	Based on local car dealer[70]
Gasoline taxi based on Maruti Suzuki Alto	USD 8,000	Based on local car dealer[71]
Battery cost	USD 2,500	World Bank, 2016, Table C.2 but lower value assumed due to battery costs dropping at 12% per annum[72]
Battery replacement	150,000km	World Bank, 2016, Table C.2
Gasoline price	USD 0.96/liter	Price at petrol station October 2017[73]
Gasoline price annual increase	2%	World Bank 04/2017, real USD prices for 2030 66 USD/bbl; price June 2017 48 USD/bbl[74]
Electricity price	0.041 USD/kWh	Block Tariff III
Electricity price increase	2.5%	Same assumed as for gasoline
Average annual distance travelled	40,000 km	Survey realized by ADB, 2017
Fuel economy gasoline	7.6 l/100km	Corinair, 2016, Table 3-27, based on Euro 1 to 3, 0.8-1.4l
Fuel economy electric	21 kWh/100km	US EPA rating for Nissan Leaf
Maintenance cost gasoline	0.05 USD/km	World Bank, 2016, Table C.2
Maintenance cost electric	0.035 USD/km	World Bank, 2016, Table C.2
Commercial lifespan	9 years	Based on maximum allowed for taxi
Discount rate	10%	World Bank, 2016, Table C.2

[69] Zhu, 2016, Table C2

[70] http://cars.bt/newcars/carproducer/nissan/

[71] http://cars.bt/newcars/car/maruti-suzuki-alto-800-2016/

[72] S DOE projections, 2017; https://energy.gov/sites/prod/files/2017/02/f34/67089%20EERE%20LIB%20cost%20vs%20price%20metrics%20r9.pdf

[73] http://www.globalpetrolprices.com/Bhutan/gasoline_prices/

[74] https://ycharts.com/indicators/average_crude_oil_spot_price

The TCO of the gasoline vehicle is USD 37,000 or 0.10 USD/km whilst the TCO of the electric taxi is USD 42,000 or 0.12 USD/km i.e. higher.

Finance Calculations		
Parameter	**Unit**	
Incremental vehicle CAPEX year 1	USD	16,000
OPEX saving year 1	USD	3,174
NPV	USD	4,118
FIRR	%	19%
EIRR	%	22%
MAC based on NPV finance (CO2 only)	USD/tCO2	-66
MAC based on non-discounted CF (CO2 only)	USD/tCO2	-218

Fleet	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
retired units	450	450	450	450	450	450	450	450	450	425	381	336	298
new e-taxis	50	50	50	100	150	200	300	400	450	450	400	350	300
taxi stock	3,828	3,428	3,028	2,678	2,378	2,128	1,978	1,928	1,928	1,953	1,972	1,985	1,988
Stock gasoline taxis	3,778	3,328	2,878	2,428	1,978	1,528	1,078	628	178	0	0	0	0
Stock e-taxis	50	100	150	250	400	600	900	1,300	1,750	1,953	1,972	1,985	1,988

Fleet Impact	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
CO2 reduction	346	692	1,037	1,729	2,766	4,149	6,224	8,990	12,102	13,504	13,636	13,730	13,747

ANNEX 2: BUS PROJECTIONS

1. Technical Parameters

Parameter	Value	Unit	Source
NCV of diesel	43	MJ/kg	IPCC, 2006, table 1.2
CO_2 emission factor of diesel	74.1	gCO_2/MJ	IPCC, 2006, table 1.4
Density of diesel	0.844	kg/l	IEA, 2005
Well-to-tank mark-up factor diesel	23%		UNFCCC, 2014, Table 3
GWP_{100} of BC	900		Bond, 2013; see also IPCC, 2013, Table 8.A.6
BC fraction of $PM_{2.5}$	75%		HDV Euro IV based on Copert, 2016, table 3-117
Conversion factor Sulfur ppm	0.084	gSO_2/l	based on molecular equivalency
Sulfur level in diesel	50	ppm	Fuel imported in Bhutan since 04/2017
Specific fuel consumption diesel Coaster	31	l/100km	MOIC average units procured since 2012
Specific fuel consumption diesel 12m bus	51	l/100km	COPERT, 2017 based on Euro IV 12m bus with 15km/h average speed, 2% gradient, 50% load (Tier 3 approach)
$PM_{2.5}$ emissions coaster Euro IV	0.063	g/km	COPERT, 2017 based on Euro IV midi bus with 15km/h average speed, 2% gradient, 50% load (Tier 3 approach)
$PM_{2.5}$ emissions 12m bus Euro IV	0.0745	g/km	COPERT, 2017 based on Euro IV midi bus with 15km/h average speed, 2% gradient, 50% load (Tier 3 approach)
NO_x emissions coaster Euro IV	7.936	g/km	COPERT, 2017 based on Euro IV midi bus with 15km/h average speed, 2% gradient, 50% load (Tier 3 approach)
NO_x emissions 12m bus Euro IV	9.185	g/km	COPERT, 2017 based on Euro IV midi bus with 15km/h average speed, 2% gradient, 50% load (Tier 3 approach)
Specific electricity consumption Coaster	0.7	kWh/km	average of 6-8m BEBs in Beijing and Jinan, 2016; Gruttre Consulting, 2017
Specific electricity consumption 12m bus	1.2	kWh/km	average value of multiple fleets in China and data of European and US pilots; Grutter Consulting, 2017
Grid electricity factor Bhutan	0	$kgCO_2/kWh$	National Communications Bhutan; NEC
Number of urban coasters buses	25		MOIC; number of current units and expected number of units to be purchased in the next 5 years
Number of urban 12m buses	25		
Annual average distance driven urban bus	30,000	km	Survey realized 06/2017 and data of MOIC of buses in Thimphu, 2016
Lifespan BEB	20	years	BEB lifespan idem to electric trolleybus significantly larger to diesel bus
Operational days	310	days	estimate
Fuel saving hybrid bus	25%		Grutter Consulting, 2017; average
Number of inter-urban coasters	300	buses	KPMG, 2017
Annual average distance driven inter- urban bus	55,000	km	Survey realized 06/2017
Lifespan diesel or hybrid bus	14	years	RSTA

Environmental Calculations Impact per BEB per Annum (tons)

Parameter	Coaster	12m
CO_2 emission reduction	25	41
GHG emission reductions WTW incl. BC	32	52
$PM_{2.5}$ emission reduction	0.002	0.002
NO_x emission reduction	0.24	0.28
SO_2 reduction	0.001	0.001

Environmental Calculations Impact per Hybrid per Annum (tons)

Parameter	Hybrid Coaster
CO_2 emission reduction	11
GHG emission reductions WTW incl. BC	15
$PM_{2.5}$ emission reduction	0.001
NO_x emission reduction	0.109
SO_2 reduction	0.001

Environmental Calculations Fleet and Lifespan BEBs (tons)

Parameter	Coaster lifespan	12m bus lifespan	Fleet per annum	Fleet lifespan
CO_2 emissions	500	823	1,654	33,078
GHG emissions WTW incl. BC	641	1,042	2,104	42,078
$PM_{2.5}$ emissions	0.04	0.04	0.10	2.1
NO_x emissions	4.8	5.5	13	257
SO_2 emissions	0.02	0.03	0.05	1.0

Environmental Calculations Fleet and Lifespan Hybrids (tons)

Parameter	Lifespan	Fleet per annum	Fleet lifespan
CO_2 emissions	160	3,439	48,144
GHG emissions WTW incl. BC	206	4,405	61,673
$PM_{2.5}$ emissions	0.01	0.26	3.6
NO_x emissions	1.5	32.7	458
SO_2 emissions	0.02	0.43	6.0

2. Economic Parameters

Parameter	Value	Unit	Source
discount factor	7%		average for investment projects based on World Bank, 2016, Table C1
diesel fuel cost	0.81	USD/l	Price at gas stations mid 2017
electricity cost	0.041	USD/kWh	Block III tariff
CAGR projected price increase diesel	2%		World Bank 04/2017, real USD prices for 2030 66 USD/bbl; price June 2017 48 USD/bbl based on https://ycharts.com/indicators/average_crude_oil_spot_price
Social cost of carbon SCC (CO_2)	40	USD/t	IMF, 2014, p.67 has a SCC of USD 35 with USD 2007 which corresponds to 40 USD of 2016
Cost of SO_3	1,600	USD/t	Median levels of ground level local pollution Asia and Oceania; includes countries reported with values excluding Australia, Brunei, Japan, Korea, Singapore and Taiwan; IMF, 2014, Table A.4.2.1. (USD 2010 converted to USD 2016 using http://stats.areppim.com/calc/calc_usdlrxdeflator.php)
Cost of NO_3	350	USD/t	
Cost of PM	46,000	USD/t	
Incremental cost BEBs	120%		Average value of sur-cost of BEBs in China, USA, Europe; see Grutter, 2017 (battery size is not very large - see below)
CAPEX coaster diesel	70,000	USD	2016 price of 60,000 USD but Euro II; Adapted for 2018 price Euro IV
CAPEX 12m bus	150,000	USD	WB estimate for Euro VI unit 205,000 USD; adapted for Euro IV version and semi-low floor
lifespan batteries	8	years	warranty of manufacturers
lifespan diesel bus	14	years	RSTA
lifespan BEB	20	years	BEB lifespan idem to electric trolleybus significantly larger to diesel bus
Cost batteries per kWh 2017	500	USD/kWh	Cost of replacement batteries in China 2017; Grutter Consulting, 2017
CAGR change of battery cost	-12%		US DOE projections, 2017 (assumed for next 10 years then stable); https://energy.gov/sites/prod/files/2017/02/f34/67089%20EERE%20LIB%20cost%20vs%20price%20metrics%20r9.pdf
Cost chargers	3,000	USD	Average cost Zhengzhou, Jinan, Tianjin (charger with 2 nozzles; thus 50% of investment of 1 charger); Europe 5-25kUSD; USA part of bus cost; Source: Beijing, Tianjin, Jinan; Landerl, 2017; CARB, 2016
Number of chargers	50		1 charger per bus; overnight charging
Lifespan chargers	20	years	CARB, 2017
Maintenance costs relative to diesel units	90%		Landerl, 2017 50% to 100% of diesel; CARB, 2016 30% lower; Tianjin higher cost due to more expensive components and spare parts and 20% higher tyre usage due to higher vehicle weight; Fuzhou 20% lower cost
Residual battery value	20%		relative to value of new battery set at time of replacement: usage for stationary applications; source: BYD
Battery size Coaster	100	kWh	Calculated based on average daily mileage, electricity consumption, 20% reserve and 20% minimum in battery with 1x charging
Battery size 12m bus	170	kWh	
Maintenance cost diesel unit	0.2	USD/km	estimate Grutter Consulting
Incremental cost Hybrids	35%		Grutter Consulting, 2017

Finance Calculations BEBs

Parameter	Unit	Coaster	12m bus	Fleet
Incremental bus CAPEX year 1	USD	84,000	180,000	6,600,000
Incremental infrastructure year 1	USD	3,000	3,000	150,000
Maintenance savings year 1	USD	600	600	30,000
Energy saving year 1	USD	6,672	10,917	439,725
NPV	USD	19,800	-2,480	433,000
FIRR	%	10%	7%	8%
EIRR	%	12%	9%	10%
MAC based on NPV finance (CO2 only)	USD/tCO2	-40	3	-13
MAC based on non-discounted CF (CO2 only)	USD/tCO2	-229	-187	-203

Finance Calculations Hybrids

Parameter	Unit	Hybrid bus
Incremental bus CAPEX year 1	USD	24,500
Energy saving year 1	USD	3,453
NPV	USD	12,604
FIRR	%	17%
EIRR	%	21%
MAC based on NPV finance (CO2 only)	USD/tCO2	-79
MAC based on non-discounted CF (CO2 only)	USD/tCO2	-211

Bus fleet requirement

	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Urban buses public transport	*34*	*16*	*16*	*16*	*27*	*10*	*11*	*12*	*33*	*13*	*14*	*15*	*17*
Coaster buses replacement	0	0	0	0	11	0	0	0	10	0	0	0	0
Coaster buses additional	10	7	7	7	7	5	6	6	6	7	7	8	8
12m buses replacement	0	0	0	0	0	0	0	0	10	0	0	0	0
12m buses additional	24	9	9	9	9	5	5	6	7	6	7	7	9
Other buses (all Coaster units)	*42*	*43*	*45*	*47*	*49*	*50*	*53*	*55*	*57*	*60*	*62*	*65*	*68*
average replacement	21	21	21	21	21	21	21	21	21	21	21	21	21
new units	21	22	24	26	28	29	32	34	36	39	41	44	47

Environmental impact

	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
CO_2 reduction	1,719	2,757	3,819	4,903	6,285	7,189	8,152	9,179	10,932	12,042	13,216	14,449	15,799
CO_2 WTW incl. BC reduction	2,188	3,513	4,867	6,250	8,015	9,170	10,402	11,714	13,950	15,368	16,867	18,443	20,167
$PM_{2.5}$ reduction	0.11	0.18	0.25	0.33	0.42	0.49	0.55	0.63	0.74	0.82	0.91	0.99	1.09
NO_x reduction	14	22	31	41	53	61	69	79	93	103	113	124	136
SO_2 reduction	0.10	0.18	0.26	0.34	0.44	0.52	0.61	0.70	0.82	0.92	1.02	1.13	1.25

Share LCBs

	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Urban BEBs	34	50	66	82	109	119	130	142	175	188	202	217	234
Hybrid inter-urban buses	42	85	130	177	226	276	329	384	441	501	563	628	696
conventional urban	50	50	50	50	39	39	39	39	19	19	19	19	19
conventional inter-urban	279	257	236	214	193	171	150	129	107	86	64	43	21
Share BEB urban	40%	50%	57%	62%	74%	75%	77%	78%	90%	91%	91%	92%	92%
Share hybrids inter-urban	13%	25%	36%	45%	54%	62%	69%	75%	80%	85%	90%	94%	97%

ANNEX 3: E-TRUCKS

1. Technical Parameters

Parameter	Value	Unit	Source
Number of LCV (1t payload)	30		assumption
Number of small trucks (5t payload)	20		assumption
Annual average distance driven	25,000	km	Based on 80km/d and 330days per year
SFC diesel LCV	12	l/100km	Euro IV diesel, Copert Tier 3 with 15km/h; speed function table 3-64
SFC diesel small truck	21	l/100km	Euro IV; based on Copert Tier 3 with 50% load, 2% slope and 15km/h average speed
Electricity consumption LCV	0.3	kWh/km	Based on Work L of streetscooter
Electricity consumption small truck	0.7	kWh/km	Estimate based on small buses
$PM_{2.5}$ emissions LCV	0.042	g/km	Euro IV diesel, Copert Tier 3 with 15km/h; table 3-64 and 3-65
NO_2 emissions LCV	1.05	g/km	Euro IV diesel, Copert Tier 3 with 15km/h; table 3-64 and 3-65
$PM_{2.5}$ emissions small truck	0.027	g/km	Euro IV; based on Copert Tier 3 with 50% load, 2% slope and 15km/h average speed
NO_2 emissions small truck	3.25	g/km	Euro IV; based on Copert Tier 3 with 50% load, 2% slope and 15km/h average speed
BC fraction LCVs	87%		Copert, table 3-117
BC fraction small trucks	75%		Copert, table 3-117
Lifespan	15	years	assumption

Environmental Calculations (tons)

Parameter	Annual			Lifespan		
	per LCV	per small truck	Fleet	per LCV	per small truck	Fleet
CO_2 emission reduction	8	14	530	125	210	7,944
GHG emission reductions WTW incl. BC	11	18	685	166	265	10,277
$PM_{2.5}$ emission reduction	0.001	0.001	0.04	0.016	0.010	0.67
NO_x emission reduction	0.03	0.08	2.41	0.39	1.22	36
SO_2 reduction	0.0003	0.0004	0.017	0.004	0.007	0.25

2. Economic Parameters

Parameter	Value	Unit	Source
Cost diesel small truck	20,000	USD	Based on cost India
Cost diesel LCV	7,000	USD	ICCT, 2016 based on Indian LCVs
Cost electric LCV	50,000	USD	based on streetscooter
Cost electric small truck	80,000	USD	Expected cost of large streetscotter version and lower end Iveco daily
Cost chargers	2,000	USD	Streetscooter
Number of chargers	50		1 per vehicle
Lifespan chargers	20	years	CARB 2017
Residual battery value	20%		based on BYD
Battery size LCV	30	kWh	Based on streetscooter
Battery size small truck	60	kWh	Based on Iveco daily 2 battery sets
Battery lifespan	8	years	average warranty

Finance Calculations

Parameter	Unit	LCV	small truck	Fleet
Incremental vehicle CAPEX year 1	USD	43,000	60,000	2,490,000
Incremental infrastructure year 1	USD	2,000	2,000	100,000
Energy saving year 1	USD	2,195	3,505	135,943
NPV	USD	-19,017	-19,076	
FIRR	%	-1%	1%	
EIRR	%	1%	3%	
MAC based on NPV finance (CO2 only)	USD/tCO2	153	91	
MAC based on non-discounted CF (CO2 only)	USD/tCO2	37	-27	

BIBLIOGRAPHY

ADB (2013), Bhutan Transport 2040 Integrated Strategic Vision

Bond et.al. (2013), Bounding the Role of Black Carbon in the Climate System: A Scientific Assessment. *Journal of Geophysical Research*. doi:10.1002/jgrd.50171

CARB (2016), Advanced Clean Transit Program; Literature Review on Transit Bus Maintenance Cost

CARB (2015), Draft Technology Assessment: Heavy-Duty Hybrid Vehicles

Clean Fleets (2014), Clean Buses – Experiences with Fuel and Technology Options

Cooney G. et.al. (2013), Life Cycle Assessment of Diesel and Electric Public Transportation Buses. *Journal of Industrial Ecology, 17(5):689-699*

EEA (2016), Air pollutant emission inventory guidebook 2016 (update 12-2016)

EPA (2016), Trends Report 2016: Light-Duty Automotive Technology, carbon Dioxide Emissions, and Fuel Economy Trends: 1975 Through 2016

Ercan T., Tatari O. (2015), A hybrid life cycle assessment of public transportation buses with alternative fuel options. *International Journal of Life Cycle Assessment 20: 1213-1231*

Faltenbacher M. et. al. (2011), Abschlussbericht Plattform Innovative Antriebe Bus (Auftraggeber Bundesministerium fur Verkehr, Bau und Stadtentwicklung

Grütter Consulting (2017a), Vehicle Emission Control Strategy Bhutan

Grütter Consulting (2017b), New Energy Buses in Cities of the PR China: Impact and Scope for Improvement

Hallquist A.M. et.al. (2013), Particle and gaseous emissions from individual diesel and CNG buses*. Atmos. Chem. Phys., 13, 5337-5350*

ICCT (2015), Hybrid Vehicles: Technology Development and Cost Reduction

IFC (2011), Bhutan Urban Transport System: System Selection and Eco-Friendly Feasibility Report

IMF (2014), Getting Energy Prices Right

IPCC (2006), Guidelines for National Greenhouse Gas Inventories

KPMG (2017), National Transport Policy of Bhutan 2017 – Policy Protocol Report

Landerl P. (2017), Stats and Future Perspectives of Electric Buses in Urban Public Transport

NEC (2016), Bhutan State of the Environment Report 2016

NEC (2015), Kingdom of Bhutan Intended Nationally Determined Contribution

NEC (2010), Environmental Standards

NREL (2017), Foothill Transit Battery Electric Bus Demonstration Results: Second Report

Pütz R. (2014), Quo Vadis Linienbusbetrieb?, *VDV Jahrestagung 2014, 05/2014*

Rieck F.G. (2014), NEMS: Electric Buses at Rotterdam

TRL (2014), Briefing paper on non-exhaust particulate emissions from road transport

VBZ, Elektrobusse bei den Verkehrsbetrieben Zürich

World Bank (2016), The Bhutan Electric Vehicle Initiative: Scenarios, Implications and Economic Impact

World Bank (2014), Reducing Black Carbon Emissions from Diesel Vehicles: Impacts, Control Strategies, and Cost-Benefit Analysis

ZeEUS (2014), London: Demo Description and Implementation Plan