Real World Performance of Hybrid and Electric Buses

Environmental and Financial Performance of Hybrid and Battery Electric Transit Buses Based on Real World Performance of Large Operational Fleets

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Contents

Abbreviations

AC	Air Conditioning
ADB	Asian Development Bank
AFD	French Agency for Development
BM	Build Margin
BRT	Bus Rapid Transit
CAF	Andean Development Corporation
CDM	Clean Development Mechanism
CM	Combined Margin
CNG	Compressed Natural Gas
CTF	Climate Technology Fund
EEV	Enhanced Environmentally Friendly Vehicles
FOEN	Swiss Federal Office of Energy
GEF	Global Environment Facility
GHG	Greenhouse Gases
GPS	Global Positioning Satellite
ICCT	International Council on Clean Transportation
ICE	Internal Combustion Engine
IDB	Inter-American Development Bank
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
IRR	Internal Rate of Return
LNG	Liquefied Natural Gas
NAMA	Nationally Appropriate Mitigation Actions
NCV	Net Calorific Value
NBFL	New Bus for London
OM	Operating Margin
PM	Particle Matter
RFID	Radio Frequency Identification
SDC	Swiss Agency for Development and Cooperation
SECO	Swiss State Secretariat for Economic Affair
SFOE	Swiss Federal Office of Energy
TDL	Transmission and Distribution Losses
TfL	Transport for London
TOD	Transit Oriented Development
TTW	Tank-to-Wheel
UITP	International Association of Public Transport
UNFCCC	United Nations Framework Convention for Climate Change
WTW	Well-to-Wheel

1. Introduction

1.1. Background

Transport is the 2nd source of global energy-related CO_2, and accounted 2012 for around 10 $GtCO_{2e}$ emissions, around half of global oil consumption and ¼ of global Greenhouse Gas (GHG) emissions from fossil fuels; moreover, transportation-driven CO_2 emissions have increased more rapidly than global emissions in the past two decades[1]. Annual GHG emissions from buses are expected to be 2015 in the order of 700 $MtCO_2$ with a 50% growth rate expected until 2030 due to an increasing vehicle stock[2]. GHG emissions in the order of 200 $MtCO_2$ could be avoided by using hybrid buses instead of conventional fossil fuel powered units. This represents roughly the annual total GHG emissions of the Netherlands. Using electric buses could increase the GHG reduction even more[3].

The number of buses, especially in Developing Countries, is growing rapidly. It is expected that latter will account for more than 80% of buses acquired by 2020[4] i.e. the major market and the major emission reductions potential with new technologies is clearly the Developing World. The focus of this report is therefore on the usage of hybrid and electric buses in Developing Countries.

1.2. Objective

The objective of the report and the "Hybrid and E-Bus Tool" is to compare hybrid and electric buses with that of conventional fossil fuel units. The report shows real-world fuel savings, emissions and economics of electric and hybrid buses especially in the context of Developing Countries.

Performance data of hybrid and electric buses has been reported in numerous documents. However information is either based on data provided by bus producers or on sample measurements made with pilot fleets or trials i.e. during a limited time with a small sample of vehicles. Conclusions based on small samples of buses tend to be unreliable and non-robust. This is due to the fact that fuel consumption, even of identical conventional buses, will vary significantly depending on the driving situation, the route characteristics, ambient conditions, the driver, bus maintenance, bus make and type, the usage of AC, type of tires used etc. Reliable and robust results can only be delivered if precise monitoring of fuel usage is made over a significant time span, with a large fleet of buses in the same city compromised of conventional as well as alternative traction units. In this manner units are compared in similar settings filtering out external effects. The same is true of financial data where small samples of alternative buses tend to lead to skewed results not least due to lack of experience of mechanics and drivers and lack of a stock of spare parts.

The innovative part of this report is that all data is based on large fleets of alternative buses operating in the same city parallel with conventional units. Data reported is of very high quality with

[1] ICCT, Global Transportation Energy and Climate Roadmap, 2012
[2] Calculation by Grütter Consulting based on vehicle-km reported by ICCT, Global Transportation Energy and Climate Roadmap, 2012
[3] Actual reductions depend on the electricity production mix in the country electric buses are deployed
[4] Frost & Sullivan, Strategic Analysis of Global Hybrid and Electric Heavy-Duty Transit Bus Market, 08/2013; unit shipment forecast

data of two of the involved cities also being externally verified by a 3rd Party due to being registered UNFCCC CDM (Clean Development Mechanism) projects. A core element of the report is also a focus on Developing Country cities as experiences might differ from those of Industrialized Countries. Cities used for this report are primarily Zhengzhou and Shenzhen in China and Bogota in Colombia. Also information from other cities e.g. London is included, based on literature review and interviews. The report thus includes data of major fleets of hybrid and electric buses worldwide. Comparison cities run also large bus fleets of conventional units allowing for a statistically robust and sound comparison.

The report is targeted to fleet managers as well as consultants working with fleet managers. The excel-tool provided together with the report allows for a simple environmental and financial comparison of hybrid and E-buses with conventional units thus showing savings or incremental costs of units including the marginal abatement cost per tCO_2 offset.

1.3. Contents

The report is structured around the following core parts:

- Chapter 2 presents the main cities discussed in this report being Bogota, Shenzhen and Zhengzhou;
- Chapter 3 relates core engine/fuel technologies and the market scenarios for transit buses;
- Chapter 4 focuses on environmental and economic aspects of hybrid buses;
- Chapter 5 focuses environmental and economic aspects of electric buses;
- Chapter 6 discusses climate finance opportunities available for hybrid and electric buses.

1.4. Repic and Grütter Consulting

This report is realized by Grütter Consulting with finance provided by Repic and Grütter Consulting.

Repic is a Swiss interdepartmental platform for the promotion of renewable energy and energy efficiency in international cooperation. It is a joint initiative of the Swiss State Secretariat for Economic Affairs (SECO), the Swiss Agency for Development and Cooperation (SDC), the Swiss Federal Office for the Environment (FOEN) as well as the Swiss Federal Office of Energy (SFOE). For more information see www.repic.ch

Grütter Consulting was founded 1996 and focuses on matching carbon finance with transport. The company has its headquarters in Switzerland and offices or partners in various Asian and Latin American countries. The company has realized more than 200 transport projects with carbon finance in all areas of freight and passenger transport and in this context is also responsible for the GHG aspects and monitoring of various Bus Rapid Transits (BRT) and of large bus fleets worldwide. For more information see www.transport-ghg.com

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2. Comparison Cities

2.1. Introduction

The dataset of the selected cities is unique and offers insights not available from other reports due to three core reasons:

- Hybrid and/or electric vehicles are deployed in the selected cities on a large scale. Hybrid and/or electric units have been operated, at least partially, since years. Therefore environmental as well as financial data are statistically reliable and robust. Pilot trials with a small amount of buses can lead to results which are strongly influenced by singular cases and can thus lead to questionable conclusions.
- The cities selected manage very large bus fleets. They have therefore next to a large hybrid or electric bus fleet also a large conventional diesel and/or Compressed Natural Gas (CNG) fleet operating under comparable conditions.
- The cities considered have an excellent data management system tracking environmental performance and costs, most notably fuel efficiency. In the case of Zhengzhou and Bogota the data is also being verified externally through a UN designated international entity as both manage CDM projects. Fuel efficiency data is reported per bus and per month. The high quality of data makes results reliable.

The uniqueness of the report therefore relies on comparing real world performance data of hybrid/electric and conventional vehicles based on large fleets operating under standard conditions.

Cities included in the report are basically Bogota, Shenzhen and Zhengzhou.

2.2. Overview Cities

Bogota is the capital and largest city of Colombia. It has an urban population of around 9 million inhabitants[5] in its metropolitan area and is situated at 2,625 meters.

Figure 1: Location Bogotá and BRT TransMilenio

Photo: Grütter

[5] Population numbers depend on source and definition. It can be based on administrative boundaries or on concepts like city, urban area, metropolitan or larger economic zone etc. The population numbers cited in this report are based on Demographia which defines an urban area as a continuously built up land mass of urban development that is within a labor market, without regard for administrative boundaries. Demographia uses maps and satellite photographs to estimate continuous urbanization. See Demographia, World Urban Areas 10th Edition, 2014

TransMilenio S.A. is a municipal company of Bogota and coordinates all bus operators of the BRT system. The Bogota BRT TransMilenio was the first registered CDM transport project worldwide and is monitoring and verifying GHG emissions of its bus system with assistance of Grütter Consulting since 2006.

Shenzhen is a major city in the south of Southern China's Guangdong Province, situated immediately north of Hong Kong. Its urban population is around 13 million inhabitants.

Figure 2: Location Shenzhen and Shenzhen Bus Group

Photo: Grütter

The public bus system in Shenzhen is currently operated by 3 large city bus companies: Shenzhen Bus Group Co., the City West Bus Company, and the City East Bus Company.

Zhengzhou is the capital and largest city of Henan province in North-Central China. The urban population is around 4 million inhabitants.

Figure 3: Zhengzhou Map and BRT

Photo: Grütter

The Zhengzhou Bus Communication Company which is part of the Municipal Government of Zhengzhou is the parent company of all bus companies. The Zhengzhou BRT is a registered CDM project and is monitoring and verifying GHG emissions of its bus system with assistance of Grütter Consulting since 2010.

The following table shows some core comparison figures of the bus fleets used in each involved city.

Table 1: Key Figures Bus Systems

	Bogota[6]	Shenzhen	Zhengzhou
Daily passengers	2.3 million	> 6 million	3.2 million
Number of buses	4,500	> 10,000	> 5,000
Major bus sizes	50% medium buses 20% standard 25% articulated 3% bi-articulated	Majority standard buses; some medium and some double-deckers	7% medium sized 67% standard 26% articulated
Fuel type used by conventional buses	100% diesel	CNG and diesel basically	Around 50% CNG and 50% diesel; some electric trolleybuses
Euro standards of buses	55% Euro II 20% Euro III 3% Euro IV 22% Euro V	Euro III, IV, V and 0-emission units (electric buses)	Euro III, IV, V and 0-emission units (electric buses)
Major bus manufacturers	Chevrolet, MB and Volvo[7]	BYD, Wuzhoulong	Yutong
Alternative traction buses as of mid 2014	200 diesel-hybrids (12m, no plug-in hybrids)	1,800 plug-in hybrids (12m) 1,300 electric buses (12m)	600 diesel-hybrids 2,000 CNG-hybrids 200 LNG-hybrids Around 1,300 of gas hybrids are plug-in 12m, 14m and 18m hybrids 110 electric buses (12m)

Medium sized bus: 8-11m; 30-60 passenger capacity
Standard bus: 12-14m; 60-100 passenger capacity
Articulated bus: 16-18m; 140-180 passenger capacity
Bi-articulated bus: 24m, 240-280 passenger capacity

3. Engine/Fuel Technologies for Transit Buses

3.1. Introduction

The focus of the study is on comparing the real-world performance of alternative powertrain of hybrids and E-buses (electric buses) with conventional diesel, CNG and LNG (Liquefied Natural Gas) buses[8]. Hybrids include serial, parallel and plug-in hybrids but not so-called “mild hybrids” with no independent electric powertrain. E-buses include battery charged buses. The report does not include electric trolleybuses as this technology is already used in many cities since decades. The report also does not include opportunity charged electric buses as this technology is still in the trial stage. The report also does not include hydrogen fuel cell buses this technology is also still in the trial stage with no experience with a large fleet of buses.

The report is about bus technologies and not fuels used. Therefore no discussion concerning the merits of gaseous or bio-fuels is made.

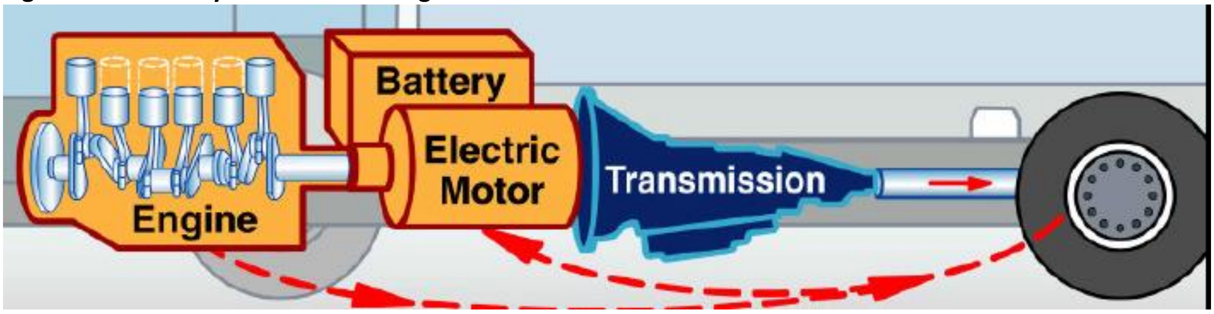
[6] Includes only BRT system and the integrated public transport operators
[7] Together around 80% of total fleet
[8] LPG buses are not includes as these only circulate in very small numbers.

The study focuses on the standard 12m transit[9] or city bus with an average passenger capacity of around 80 passengers (unseated). This is the major transit bus type circulating worldwide. The report however also includes information on larger buses (18m, articulated units).

3.2. Hybrid Buses

Types of hybrids include series, parallel, and blended hybrids. Blended hybrids use a combination of the two types of drive systems. Next to this a differentiation is made between "conventional" and plug-in hybrids. Latter allow for electric charging by an external power source.

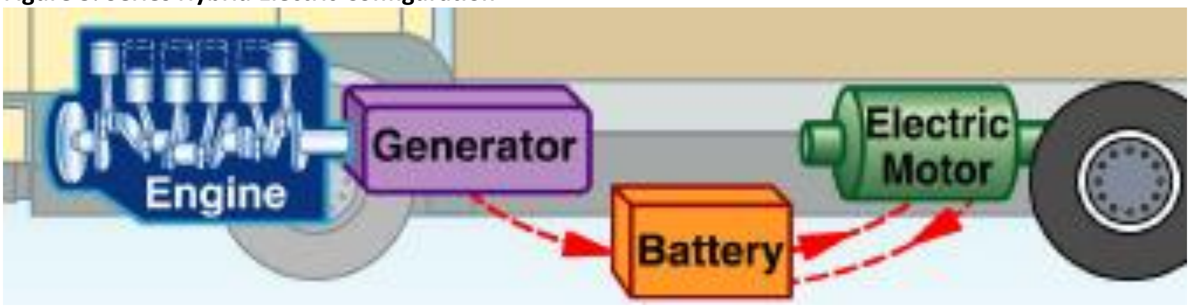
Figure 4: Parallel Hybrid Electric Configuration



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 combustion engine 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 internal combustion engine. In addition, through a process called regenerative breaking, energy lost due to braking is recovered and utilized to charge the battery.

Figure 5: Series Hybrid Electric Configuration



Source: Southwest Research Institute

In a series hybrid there is no mechanical link between the internal combustion engine (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.

[9] The term "transit" bus refers to buses that transport the public within intra city routes. Inter-city routes are operated by coach buses which not only have in general different technical features (e.g. higher power, no standing passengers) but also different fuel usage patterns.

Diesel-electric hybrids are commercially available since more than 15 years. New models are being developed by a range of manufacturers. CNG or LNG hybrid buses operate in a similar way to diesel-electric hybrids and are used basically in China.

Plug-in hybrids are powered by a battery which can be charged from an external power source. Plug-in hybrids have an on-board engine which can also recharge this battery. The key application of this is the ability to run in all electric mode part of the time. The amount the bus will run on electric mode will be highly dependent upon route characteristics, charging frequency and vehicle and energy systems configuration. Plug-in hybrids are a relatively new technology but cities like Zhengzhou or Shenzhen already operate large fleets of plug-in hybrids since around 2 years.

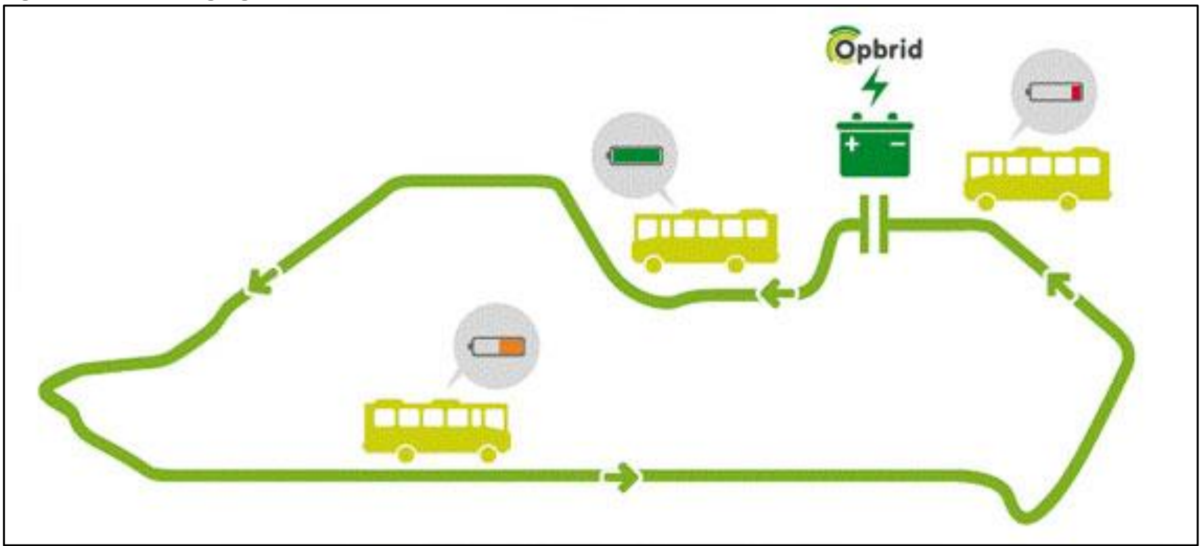
Standard hybrids run mostly with super-capacitors whilst plug-in hybrids run with batteries[10].

3.3. Electric Buses

Electric buses included in this report are battery electric vehicles powered solely by a rechargeable battery. Battery electric buses in general have a large amount of batteries on-board to achieve a sufficient driving range resulting in a considerable additional weight and space requirement. To resolve the trade-off between on-board battery requirement and driving range some electric battery manufacturers produce E-buses with rapid-change battery racks.

“Opportunity” electric buses are charged on route either at charging points throughout the bus circuit or at first and final stops (see Figure below for such a system). In Geneva an ultra-rapid charging system called flash charging is being tested with articulated buses (see Picture below). However such systems, albeit promising for the future, are still in their trail stage with no large fleets operating. They are therefore not included in the report.

Figure 6: Fast Charging of Electric Buses



Source: http://hybricon.se/word/projects/service-modules/; a 13km route requires 3 min. ultrafast charging at one site

[10] Capacitors act as an energy store, like batteries. Because classic capacitors are electrostatic, they can release charge very quickly. Batteries rely on a chemical processes, which evolve more slowly i.e. batteries have a higher energy density and capacitors can have a higher power density.

Photo 1: Flash Charging of Electric Buses (TOSA[11])

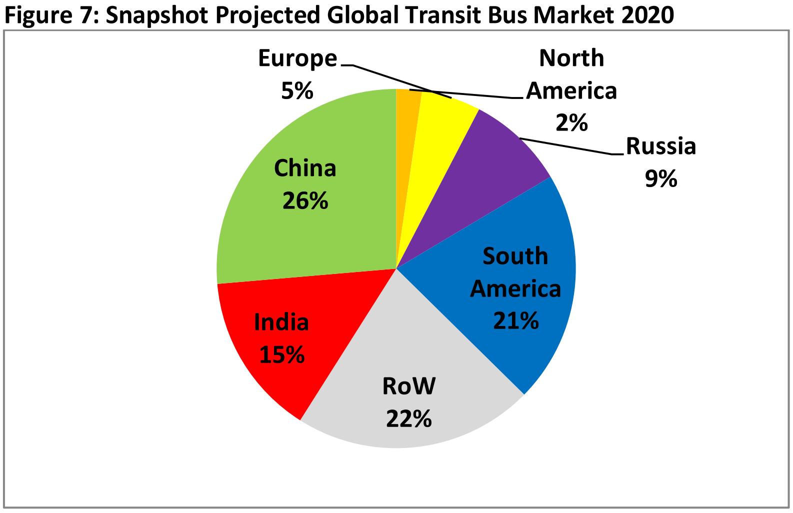

Source: http://www.tosa2013.com/

UITP (International Association of Public Transport) coordinates a consortium of 40 partners to work on the 4 year demonstration project ZeEUS (Zero Emission urban Bus System) aiming at extending the fully-electric solution to a wider part of the urban bus network. The project was launched January 2014 and covers innovative electric bus solutions with different electric powertrain systems to be demonstrated in 8 European cities with 35 electric 12m buses (including next to battery electric vehicles also plug-in hybrids and electric trolleys with batteries).

3.4. Market Penetration of Hybrid and Electric Transit Buses

The total bus stock 2010 is some 16 million units and is expected to rise to around 18 million units by 2020 and 20 million units by 2030. 2010 around 17% of all buses were operating in China, 12% in Korea, 6% in the US, 6% in Russia and 4% in India being the 5 largest bus operator countries. 2030 it is expected that China, India and Korea are the 3 countries with the largest bus stock[12]. The figures of ICCT (International Council on Clean Transportation) include not only transit buses but also inter-urban and other buses. In the following the focus is on transit buses. By 2020 it is expected that nearly 300,000 units of large transit buses are delivered. The following Figure shows which countries and regions will be the major buyers of buses.

Figure 7: Snapshot Projected Global Transit Bus Market 2020



Source: Frost & Sullivan, Strategic Analysis of Global Hybrid and Electric Heavy-Duty Transit Bus Market, 08/2013; unit shipment forecast

[11] Trolleybus Optimisation System Alimentation

[12] ICCT, Global Transportation Energy and Climate Roadmap, 2012, Appendix E

China alone will have a global market share of more than 25% of transit buses with more than 70,000 units being acquired. North America for example is only projected to buy in the same year around 6,000 units. India and Russia also have large market shares. Europe and North America will have together a market share of less than 8% and also far lower growth rates than other regions worldwide meaning that their relative importance in the bus market will further decline. The figure shows clearly that the virtues of electric and hybrid technology will have to be demonstrated in countries like China and India and regions like South America, ASEAN and African countries with the largest compound growth rate of all regions. Not surprisingly it is also expected that Chinese manufacturers such as Yutong, Wuzhoulong, Foton, Kinglong and BYD are expected to top the global hybrid and electric transit bus market with Volvo, ADL and Daimler featuring as non-Chinese members of leading manufacturers[13].

Globally more than 250 BRT systems are operational or under planning- This creates an enormous market potential for new vehicle purchase of electric and hybrid buses. Frost & Sullivan expect also for this reason that hybrid and electric buses will have a market share of new sold transit buses of around 15% by the year 2020 which means a compound annual growth rate of nearly 20% compared to 2012 – this growth rate is far higher than the overall transit bus growth rate of around 6%. It is expected that 2020 some 27,000 hybrid and electric units will be sold compared to some 8,000 units in the year 2012.

The following table gives a comparison of investment costs of standard 12m transit buses in different world regions comparing diesel, hybrids and electric units.

Table 2: Region Wise Price Comparison for Transit Buses (USD)

Market	Conventional diesel	Hybrid	Electric	Mark-up Hybrid	Mark-up Electric
China	$60,000-$90,000	$125,000-$200,000	$280,000-$350,000	115%	420%
India	$75,000-$110,000	$175,000-$255,000	$325,000-$410,000	130%	300%
Russia	$130,000-$180,000	$245,000-$325,000	$400,000-$500,000	85%	190%
Latin America	$200,000-$225,000	$280,000-$340,000	$410,000-$500,000	45%	115%
Rest of World	$100,000-$350,000	$195,000-$500,000	$300,000-$700,000	55%	120%
Europe	$250,000-$350,000	$420,000-$510,000	$575,000-$680,000	55%	110%
North America	$300,000-$400,000	$485,000-$540,000	$595,000-$690,000	45%	85%
Average	**$200,000**	**$330,000**	**$480,000**	**65%**	**140%**

Source: Frost & Sullivan, Strategic Analysis of Global Hybrid and Electric Heavy-Duty Transit Bus Market, 08/2013; based on regional market price in USD 2012

Following elements are thereby noteworthy:

- The investment cost per bus varies widely between regions;
- An electric bus acquired in China is in the price range of a conventional diesel unit in North America or Europe.

Mark-ups in percentage of hybrid and electric buses are far higher in low-price markets like China, India and Russia and far lower in high-priced markets such as Europe or North America. On average the absolute mark-up price tag for a hybrid bus is in the order of $100,000-$150,000 and for an electric unit $250,000 to $300,000. However price differences between conventional and hybrids as well as electric buses have reduced since 2012 as the results of the following chapters will show.

[13] Frost & Sullivan, Strategic Analysis of Global Hybrid and Electric Heavy-Duty Transit Bus Market, 08/2013

4. Hybrid Bus Performance

4.1. Introduction

The comparison of hybrid and convention units was made using the following criteria:

- Comparisons are made within the same city i.e. alternative energy buses of Bogota are compared with conventional buses of Bogota;
- Conventional and alternative buses operate the same routes or the same type of routes;
- Buses compared are of the same or comparable size and passenger capacity;
- Buses compared are of the same or comparable Euro standard and age;
- Bus performance is compared over the same time period.

Fuel consumption in Zhengzhou and Bogota is measured per bus either based on RFID (Radio Frequency Identification) or based on reports from filling stations. Distance driven is monitored by GPS records. Fuel consumption and distance driven is externally controlled and verified by auditing companies.

Bogota has recently acquired a fleet of 500 hybrid units of which some 200 units are operating as of October 2014. Bogota also operates a very large fleet of comparable modern diesel buses. The hybrid buses of Bogota are conventional (not plug-in) Volvo 12m hybrid buses for 80 passengers. Conventional as well hybrid buses have no AC.

Photo 2: Hybrid Buses in Bogota

Photos: Grütter

Zhengzhou operates since end 2010 a growing number of hybrids totalling around 2,800 units. The following table gives some information concerning hybrids used.

Table 3: Hybrid Bus Characteristics Zhengzhou

Parameter	Diesel-Hybrid Buses	CNG/LNG-Hybrid Buses
Number of hybrids in operation	2009: 20 units 2010: 20 units 2011: 460 units 2012: 590 units 2013/14: 600 units	2012: 960 units 2013/2014: 2,220 units of which around 200 LNG
Plug-in hybrids (included in the	0 units	1,300 units (all units acquired

number of hybrids listed above)		since 2013)
Size and passenger capacity	12m buses for 80 passengers 14m bus for 110 passengers 18m bus for 150 passengers	12m buses for 80 passengers 14m bus for 110 passengers 18m bus for 130 passengers
Manufacturer	Yutong	Yutong
Euro Standard	IV and V	V

Source: Zhengzhou Bus Communication Company, 2014

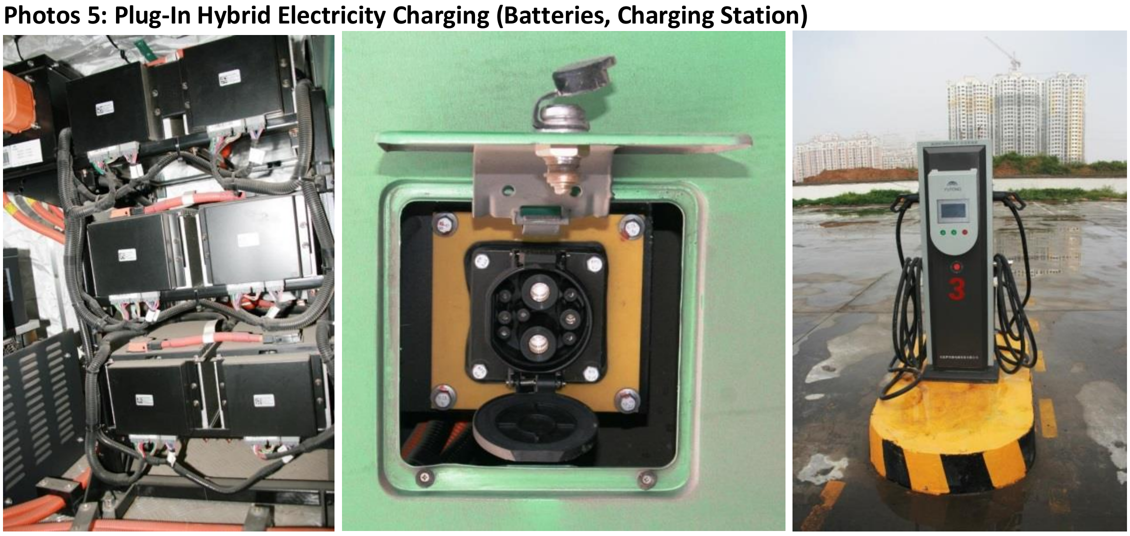
Photos 3: 12m and 14m Hybrids of Zhengzhou

Photos: Grütter

Photos 4: Plug-In 18m LNG and 12m CNG Hybrids of Zhengzhou

Photos: Grütter

Photos 5: Plug-In Hybrid Electricity Charging (Batteries, Charging Station)



Photos: Grütter

In total Zhengzhou operates some 2,800 hybrid units representing more than 50% of the total fleet. All hybrid buses have AC and all are parallel hybrids. Around 50% of units are plug-in hybrids. The plug-in hybrids allow for charging with an all-electric range of around 30 km and a charging time of 40 minutes. They are equipped with Lithium batteries whilst conventional hybrids have super-capacitors.

4.2. Environmental Performance of Hybrids

4.2.1. Literature Review

Many trials have been realized and continue to be realized with hybrid buses by numerous transit operators worldwide. Data on fuel savings and financial costs are often based on such trials – some just for a short period and the majority based on a very small fleet operating not necessarily comparable routes. The following table summarizes core findings of major studies with hybrid buses where, with exception of the C40Cities studies, fleets considered were significant (more than 50 units – albeit in Germany scattered over many cities) and operated over a longer time period.

Table 4: Fuel Savings Reported in Recent Hybrid Transit Bus Studies

Country	Fuel Savings	Comments	Study
Germany, various cities	10-20% fuel savings	Comparison with diesel units; based on around 60 hybrid buses of which the majority were articulated units[14]; results are only partially comparable as often only 1-5 hybrid buses were operated per city which not necessarily operated similar routes as diesel units.	PE International, Abschlussbericht Plattform Innovative Antriebe Bus, realized for BMVBS, 2011
London, UK	35-45% fuel savings[15]	TfL (Transport for London) has 650 hybrids in operations and plans to have 1,700 units in operation by 2016 (20% of the bus fleet); basically double-decker buses.	TfL, 2013 and 2014 and EU Clean Fleets Program (www.clean-fleets.eu)
Latin America (3 cities)	15-35% fuel savings	12m buses; based on trials during 2 days in Sao Paulo, Rio de Janeiro, Santiago de Chile and Bogota - results are thus to be taken with care	C40Cities, Low Carbon Technologies Can Transform Latin America's Bus Fleets, 2013
New York, USA	20-30% fuel savings;	New York has one of the world's largest hybrid fleet with around 1,700 units, which are however now being replaced partially with diesel units thus reducing the number of hybrids to around 1,300 units (30% of all buses); Relatively old hybrids (program started 15 years ago); best fuel economy of hybrids in low-speed stop-and-go traffic; AC usage in summer months has a much larger fuel economy impact on hybrids compared to diesel and thus reduces fuel savings of former.	NREL, Performance Comparison of Hybrid Electric, CNG, and Diesel Buses and New York City Transit, 2008

As mentioned the German study has some useful insights – however no solid conclusions concerning fuel savings or bus reliability can be drawn as the hybrid fleet was scattered over various cities with

[14] Articulated units tend to have lower fuel savings potentially due to hybrids being relatively new in this segment

[15] Lower rate conventional Hybrid and higher rate NBFL (New Bus for London); comparison based on Euro V hybrid and diesel.

different operational conditions. Comparisons between diesel and hybrid buses on comparable settings were thus limited to small samples with results not being statistically robust.

The study realized by C40Cities relied on a very small sample of new buses (less than 10 units spread over 4 cities) operating only for some days per city. Data can thus at best be called indicative but no valid conclusions concerning reliability or actual fuel savings of vehicles can be drawn from singular test drives. Variations are therefore also in a very wide range.

The most trustworthy data is from London and New York as both cities operate a large number of hybrids alongside comparable conventional diesel units operating on the same or similar routes over a significant time period.

Whilst New York has the longest experience with a large fleet of hybrid buses, the relevance of the data is as of today slightly diminished as hybrid bus technologies used in New York can be considered as outdated with no new hybrid bus entering the fleet the last 3 years.

London operates a fleet of more than 600 hybrid buses (the first ones entering operations in the year 2006) and plans to acquire more units having a fleet of around 1,700 or 20% of all units by 2016. London has also a large fleet of modern diesel buses operating in the same conditions which make comparisons meaningful. London operates as per end 2013 nearly 9,000 buses of which 40% are Euro 3 with DPF (Diesel Particulate Filter), 20% Euro 4, 30% Euro 5 and 10% EEV (Enhanced Environmentally Friendly Vehicles). Around 30% of buses are single deck and 70% double deck. Basically two types of hybrid buses are operated: “traditional” hybrids and a newly designed bus specifically for London, the New Bus for London or new Routemaster produced by Wrightbus.

Picture 6: New Bus for London

Photo: Grütter

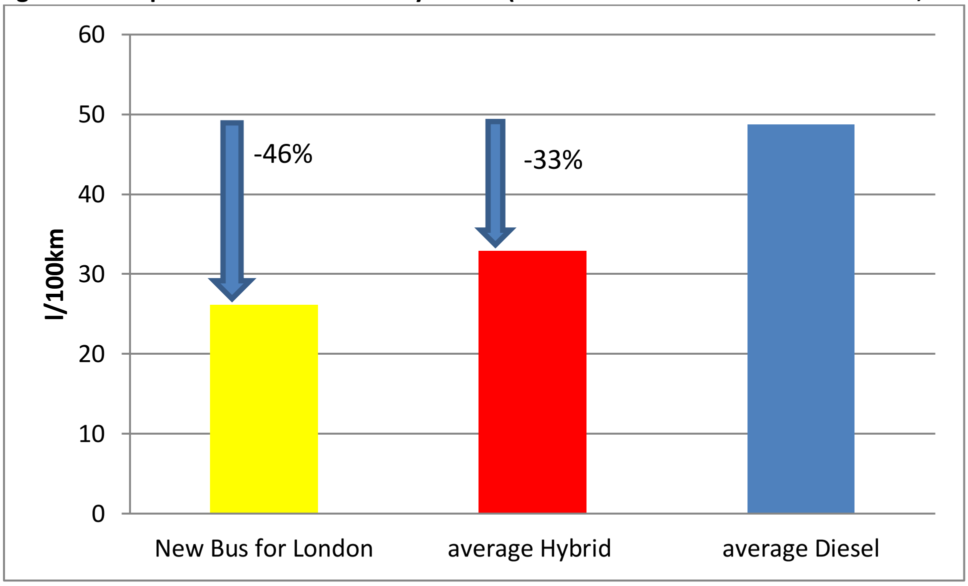
The following table and figure shows the fuel consumption of diesel buses, the common hybrid bus used in London and the New Bus for London.

Table 5: Fuel Efficiency Buses London 2013 (all Buses Double-Decker Euro V)

Bus Type	Specific diesel consumption (l/100km)	% savings versus conventional diesel
Conventional diesel	49	
"average" hybrid	33	33%
New Bus for London hybrid	26	46%

Source: TFL, 2014; "average" hybrid refers to hybrids which are not New Bus for London

Figure 8: Comparison of Fuel Efficiency Levels (Double-Decker Euro V Buses London, 2013)



Source: TFL, 2014; "average" hybrid refers to hybrids which are not New Bus for London

4.2.2. Environmental Performance of Hybrids in Bogota

Fuel Efficiency

The comparison of fuel consumption is made between 12m diesel hybrids Euro V and 12m diesel buses Euro V of the same characteristics, of the same operating enterprise and within the same time period. Buses in Bogota (conventional as well as hybrids) have no AC and fuel consumption values are fairly constant during the year. However significant differences between operating enterprises of TransMilenio concerning specific fuel consumption have been monitored although companies operate similar routes and buses. Therefore hybrids and conventional units have been compared within the same operator. The following table shows monitored diesel consumption for conventional Euro V and hybrid Euro V buses.

Table 6: Hybrid and Conventional Bus Fuel Efficiency Bogota for 12m Euro V Bus

Operator	Diesel Bus Fuel Efficiency	Hybrid Bus Fuel Efficiency	% Savings Hybrid
A	39 l/100km	30 l/100km	25%
B	44 l/100km	33 l/100km	25%

Source: Data from TransMilenio (daily records per bus); Data review, control and calculations by Grütter Consulting

Fuel consumption between the two operators varies by around 10% - however this is true for hybrids as well as for conventional diesel units. Fuel savings therefore are for both operators 25% for hybrid units.

GHG Emissions

To determine GHG emissions standard emission factors and calculation methods based on IPCC are used i.e. the amount of fuel used is multiplied with the Net Calorific Value (NCV) of the fuel and the corresponding CO_2 Emission Factor. The following table shows the parameters used and their values.

Table 7: Parameters and Values Used to Determine GHG Emissions

Parameter	Value	Source
NCV of diesel	43 MJ/kg	IPCC Guidelines for National GHG Inventories, 2006, table 1.2,average
CO_2 emission factor of diesel	74.1 gCO_2/MJ	IPCC Guidelines for National GHG Inventories, 2006, table 1.4,average
Density of diesel	0.844 kg/l	IEA, Energy Statistics Manual, 2005
Well-to-tank emission factor diesel	22%	JRC-Study study 22%, CEC 23%, GREET model 25%, GHGenius model 29%; lower end value was taken to be conservative[16]

The following table shows the GHG Tank-to-Wheel (TTW) and the Well-to-Wheel (WTW) emissions of hybrid versus fossil fuel units. TTW emissions are those caused by fuel combustion i.e. they are the direct emissions caused by the vehicle. WTW emissions include the upstream emissions (extraction, refinery, transport) caused by fossil fuels. WTW include the indirect emissions caused by using fossil fuel and thus show a more comprehensive picture of total GHG emissions caused by different technologies.

Table 8: GHG Emissions 12m Euro V Buses in Bogota in gCO_2/km

Operator	Diesel		Hybrid		GHG Reduction
	TTW	WTT	TTW	WTW	
A	1,060	1,290	800	970	25%
B	1,200	1,460	890	1,090	25%

Source: calculation by Grütter Consulting based on data of Table 6 and 7

GHG emission reductions are thus, idem to fuel savings, 25% for hybrid buses.

On average 12m standard buses circulate per annum around 65,000 km in Bogota. Per bus GHG savings are therefore around 22 tCO_2/annum. With 500 hybrids operating Bogota thus avoids annually more than 10,000 tCO_2.

Local Environmental Impact

The local environmental impact assessed is NO_x and PM emissions. Hybrid buses have basically the same emissions as conventional buses when comparing identical technologies e.g. Euro V hybrids with Euro V conventional units. Hybrid as well as conventional buses will have the PM and NO_x emissions based on their Euro standard. Differences could arise due to having more constant engine

[16] JRC - Joint Research Centre-EUCAR-CONCAWE collaboration, Well-to-Wheels Analysis of Future Automotive Fuels and Powertrains in the European Context Version 3c, 2011 (used by EU RED); California Energy Commission, Full Fuel Cycle Assessment Well to Tank Energy Inputs, Emissions, and Water Impacts, 2007; LLC, Assessment of Direct and Indirect GHG Emissions Associated with Petroleum Fuels, 2009; Nylund et.al, Fuel and Technology Alternatives for Buses, VTT Technology 46, 2012; GHGenius was developed by Natural Resources Canada: NRC, GHGenius model version 4.02, 2013; http://www.ghgenius.ca/; GREET model was developed by the US Department of Energy: US DOE, GREET The Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation Model Version GREET1 2012 rev2 http://greet.es.anl.gov/

operations with hybrids. However various international studies comparing in-vehicle emissions of hybrid and conventional vehicles come to the result that emission differences are attributable to the Euro category and do not differ significantly between hybrids and conventional units[17].

4.2.3. Environmental Performance of Hybrids in Zhengzhou

Fuel Efficiency

The comparison of fuel consumption is made between diesel hybrids and diesel buses of the same size and CNG hybrids and CNG conventional buses also of the same size. Data included was bus fuel consumption and distance driven per month per bus for the entire year 2013 thus allowing for a large data base. The following table shows the specific fuel consumption based of different hybrid and conventional buses in Zhengzhou.

Table 9: Hybrid and Conventional Bus Fuel Efficiency Zhengzhou (average for 2013)

Bus Type	Fuel efficiency in l/100km or m^3/100km	% savings versus conventional
Standard (12m) Diesel Hybrid	29.5	26%
Standard (12m) Diesel conventional	40.0	
Articulated (18m) Diesel Hybrid[18]	43.9	34%
Articulated (18m) Diesel conventional[19]	66.5	
Standard (12-14m) CNG Hybrid	39.0	19%
Standard (10-11m) CNG conventional[20]	47.9	

Source: Zhengzhou Bus Communication Company, 2014; data collection and calculations by Grütter Consulting; based on monthly fuel consumption per bus

Hybrid buses were between 20% and 35% more efficient than their conventional counterpart. The improvement of CNG hybrid buses versus conventional CNG buses might thereby be slightly understated as CNG hybrid buses are all between 11.7 m and 13.7 m long with a passenger capacity of between 86 and 112 passengers whilst conventional CNG units are 10.2-10.6 m long with a capacity of around 60 passengers. Whilst the conventional CNG consumption was adjusted for the size difference this might only capture partially the load difference of on average 40% thus understating the fuel savings of CNG hybrids. Also conventional CNG buses in Zhengzhou are without AC whilst hybrid units have AC. Overall however fuel savings of 20-30% with hybrids can be confirmed from the experience of Zhengzhou.

All buses experienced significantly higher fuel consumption during hot summer months. The following figures contrast the average monthly temperatures in Zhengzhou with the specific fuel consumption of buses showing a clear correlation.

[17] See e.g. B. Holmén et.al., Particulate Matter Emissions from Hybrid-Electric and Conventional Diesel Transit Buses, CTTRANSIT, 2005
[18] on BRT trunk routes
[19] on BRT trunk routes
[20] Fuel consumption adjusted to larger CNG hybrid buses

Figure 9: Temperatures 2013 Zhengzhou (average monthly in °Celsius)

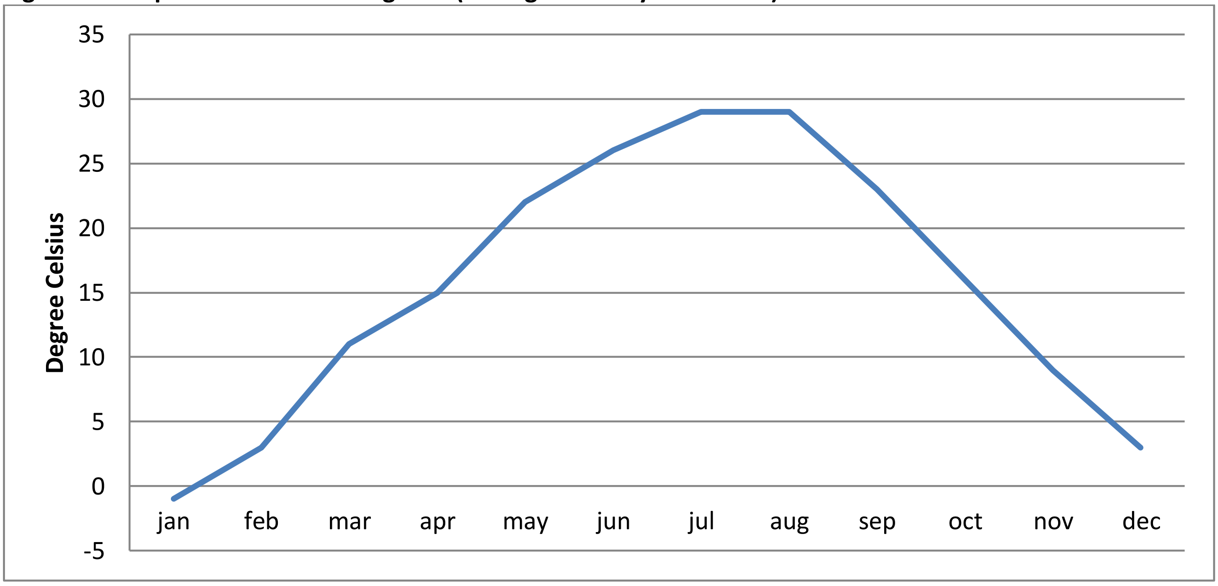
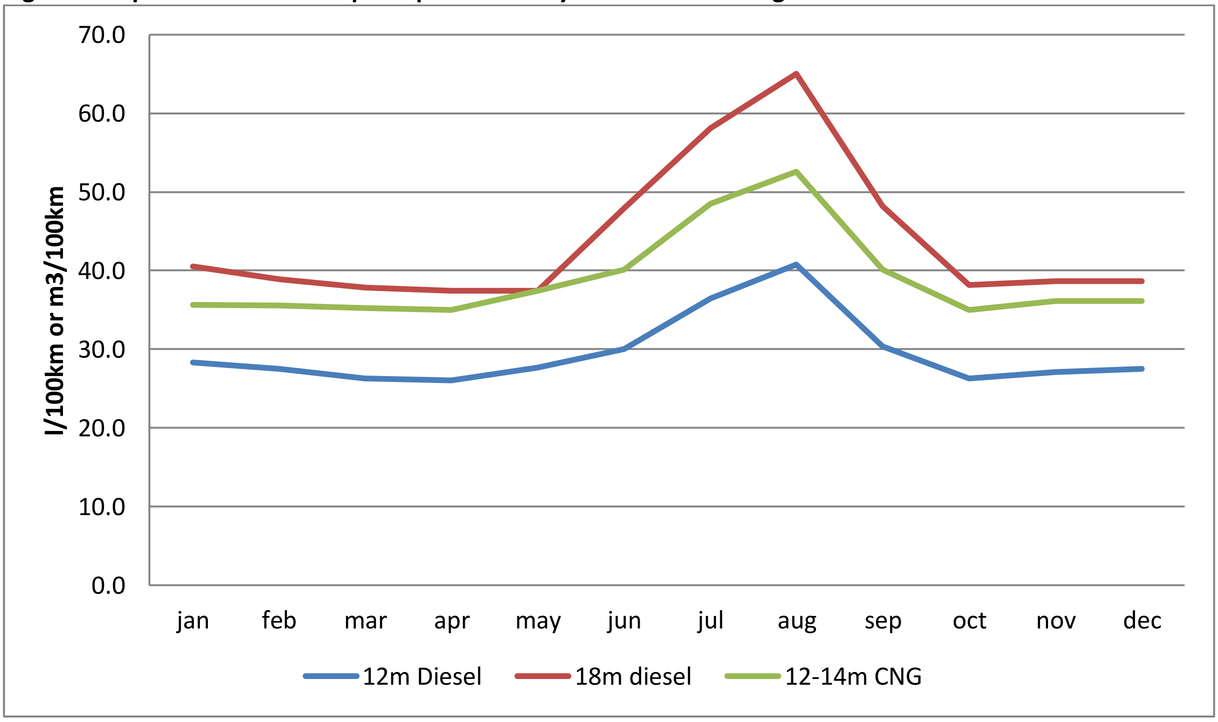


Figure 10: Specific Fuel Consumption per Month Hybrid Buses in Zhengzhou 2013

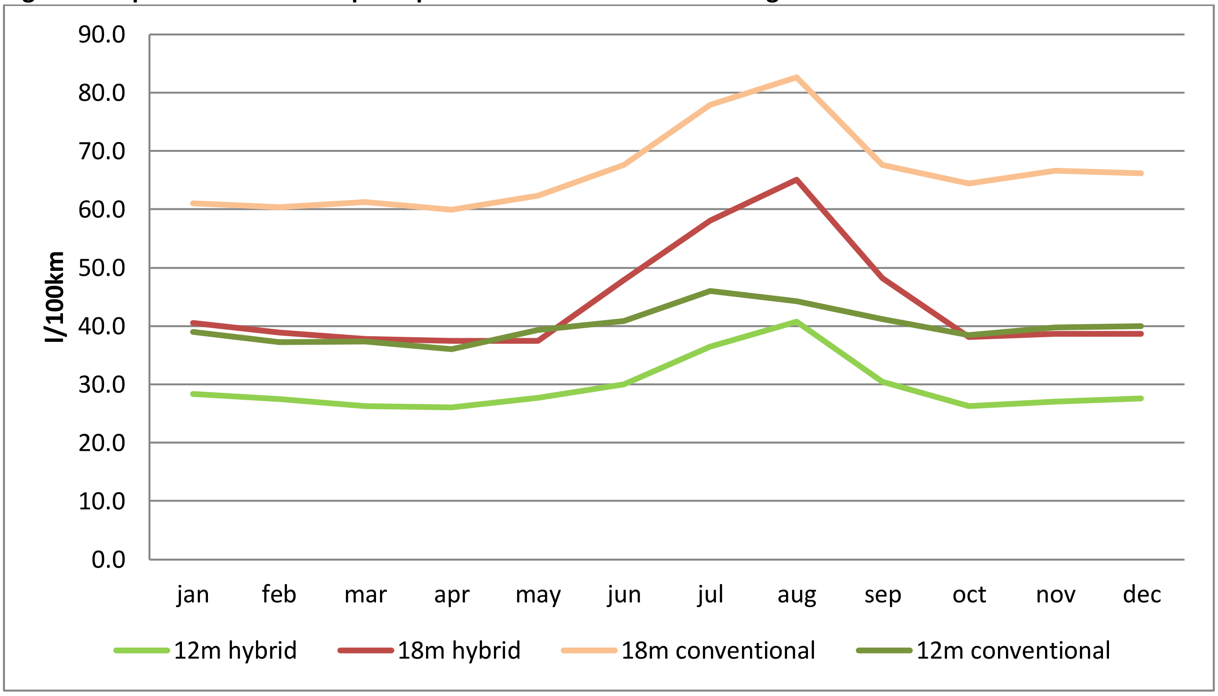


Source: Zhengzhou Bus Communication Company, 2014; data collection and calculations by Grütter

During August the specific fuel consumption of hybrids was 35-50% higher than the annual average. Conventional diesel buses[21] had in summer months increases of around 20% of fuel consumption i.e. the specific fuel consumption of hybrids is more affected by high temperatures and the usage of AC than the fuel consumption of conventional buses. The following graph shows for conventional diesel and hybrid buses the fuel consumption over the entire year.

[21] Conventional CNG buses have no AC in Zhengzhou

Figure 11: Specific Fuel Consumption per Month Diesel Buses in Zhengzhou 2013



Source: Zhengzhou Bus Communication Company, 2014; data collection and calculations by Grütter

Whilst overall hybrid diesel buses were 25-35% more efficient than conventional diesel units in the summer months of July and August the difference was only 10-25%. In the cold winter months December and January with temperatures near the freezing point and thus usage of heating in buses no such impact on fuel consumption could be observed. Two conclusions can be reached:

- In countries with year-round high temperatures which require heavy-duty AC service the fuel savings of hybrids will be lower than in countries in more moderate climate zones or with cooler summers.
- The investment in a good insulation of buses including e.g. double glazed windows is in countries with hot summer months important, especially for hybrid buses.

Plug-in hybrids, in service in Zhengzhou since early 2014, can reduce fuel consumption by another 10-15% if charged daily thus having fuel savings compared to conventional diesel buses of 30-45%.

GHG Emissions

The same approach is used as for Bogota. The following table shows the parameters used and their values[22].

Table 10: Parameters and Values Used to Determine GHG Emission Factors

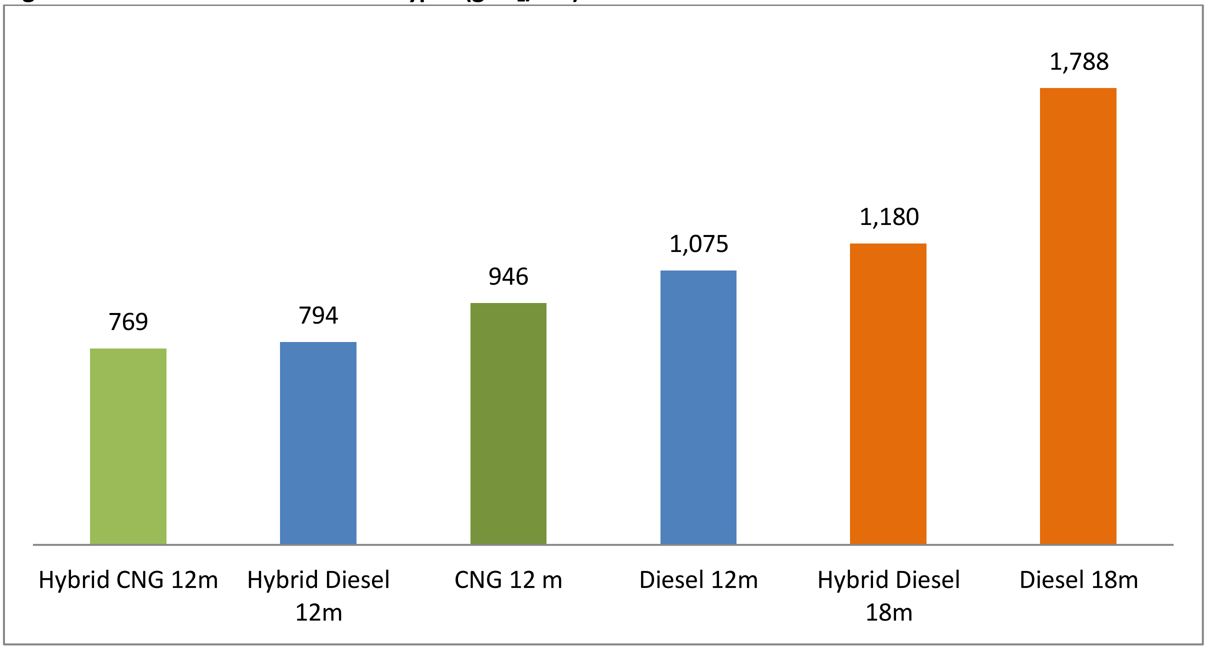
Parameter	Value	Source
NCV of CNG	48 MJ/kg	IPCC Guidelines for National GHG Inventories, 2006, table 1.2,average
CO_2 Emission factor of CNG	56.1 gCO_2/MJ	IPCC Guidelines for National GHG Inventories, 2006, table 1.4,average
CH_4 emission factor of CNG buses[23]	25 gCO_{2e}/km	IPCC Guidelines for National GHG Inventories, 2006,

[22] Parameters already included in Table 7 are not repeated.
[23] The CH_4 emission factor of diesel buses is marginal and is therefore not included; The N_2O emission factor of diesel and CNG buses are not included as these are also marginal.

		table 3.2.5 based on EU Copert IV model for Euro IV and later for CH_4 factor and GWP from IPCC AR5, 2013[24]
Density of CNG	0.714 kg/m^3	Based on molar mass
Well-to-tank emission factor CNG	11%	IPCC 1996 default Rest of the World 11%[25], CEC 17-37% depending on pipeline length, GHGenius model 18%, JEC-Study 15-40% depending on pipeline length, GREET model 45%; lower end value was taken to be conservative[26]
CO_2 emission factor of electricity based on Combined Margin	0.72 kgCO_2/kWh	NDRC China for Central China Power Grid, 2013

The following graph shows the GHG Tank-to-Wheel (TTW) emissions of hybrid versus fossil fuel units i.e. the emissions caused only by the fossil fuel burning process in the engine.

Figure 11: GHG TTW Emissions Bus Types (gCO_2/km)



Source: Grütter Consulting based on fuel consumption data 2013 provided by Zhengzhou Bus Communication Company

The following table shows the Well-to-Tank (WTW) emissions i.e. this includes the upstream emissions caused by fossil fuels. The table also includes CNG plug-in hybrids as used in Zhengzhou since early 2014.

[24] 900 mg CH_4/km with a Global Warming Potential (GWP) of 28 based on 2013 IPCC AR5 p. 714 excluding climate-carbon feedbacks

[25] 296 tCH_4 /PJ Table 1-63 and 1-64; EF_{CO2} for fuel combustion is according to IPCC 56.1 gCO_2/MJ; GWP based on UNFCCC is 21 for CH_4

[26] Conservative in the context that baseline emissions are potentially more underestimated than project emissions as more fossil fuel is used in the baseline than in the project situation;

Table 11: GHG Emissions WTW Buses

Buy Type and Technology	Emissions in gCO_2/km	GHG Reduction Compared to Conventional
12 m conventional diesel	1,310	
12 m hybrid diesel (no plug-in)	970	26%
12 m conventional CNG	1,050	
12 m hybrid CNG	850	19%
12m hybrid CNG plug-in	720	31%
Articulated 18m conventional diesel	2,181	
Articulated 18m hybrid diesel (no plug-in)	1,440	34%

Source: Calculation by Grütter Consulting based on tables 9 and 10

GHG emission reductions are on average between 20% and 35% for hybrid buses.

On average 12m buss circulate in Zhengzhou annually 55,000 km whilst articulated buses circulate around 65,000 km. Each 12m bus reduces therefore GHG emissions by 11-13 tCO_2/annum (CNG hybrids), 19 tCO_2/annum (diesel hybrids) and 48 tCO_2/annum for articulated diesel hybrids. Based on the number of hybrid units in operations Zhengzhou avoided GHG emissions of more than 40,000 tCO_2 in the year 2013.

Local Environmental Impact

As already mentioned hybrid buses have basically the same emissions as conventional. Plug-in hybrids can however operate in pure electric mode over a longer distance, e.g. in polluted downtown areas. The plug-in hybrids used in Zhengzhou have an electric drive range of around 30 km when fully charged and are thus 0-emission vehicles in this area.

4.3. Economic Performance of Hybrid Buses

4.3.1. Introduction

Following cost components are used to compare the financial performance of hybrids versus conventional units:

- Bus availability rate: This criteria is based on how much time the bus spends at the workshop or in non-productive usage. A lower availability rate is transformed financially in additional bus investment e.g. if a hybrid bus is only available 50% of the time a conventional bus is available the bus operator needs to buy 2 hybrid units per conventional unit for the same service level;
- Investment cost;
- Maintenance cost;
- Fuel price cost.

Driver cost and bus management cost is not included as this cost is independent of the bus type used. To realize a financial comparison costs are annualized based on standard interest rates and the life-span used for buses in the respective country.

4.3.2. Bus Availability

International reports on hybrids do not offer much information on bus availability. The study realized in Germany[27] indicates a 10% lower availability rate of hybrids versus diesel buses. This is not surprising as only 2-5 hybrid buses were deployed per city thus making maintenance and repairs more time-consuming due to lack of know-how and spare parts. In London, with a much larger hybrid bus fleet (600 units) bus availability of hybrids is identical to conventional units. Zhengzhou with a hybrid bus fleet of nearly 3,000 units also reports the same bus availability for hybrid as for conventional units. Bogota is only operating hybrids since ½ a year. During this time no difference in availability rates could be recorded.

4.3.3. Investment and Operational Cost

To make comparisons meaningful the same bus make, model and Euro standard is compared. In the case of Bogota this refers to Volvo buses and in the case of Zhengzhou to Yutong units. The following table compares the investment cost of buses in Bogota based on Volvo Euro V units.

Table 12: Investment Cost 12m Bus Bogota in USD (Euro V Bus)

Diesel	Diesel Hybrid	Sur-Cost Hybrid	Comment
155,000	290,000	90%	Excluding battery set the hybrid bus costs 250,000 USD. The battery is leased in the case of Bogota at 0.15 USD per km

Source: based on Volvo 12m Euro V buses with entry doors on both side; cost excludes VAT

Volvo buses have Lithium-Ion Phosphate battery-sets with an investment value of 40,000 USD and with a life-span of 4 years[28]. Hybrid bus operators in Bogota estimate that maintenance costs are comparable to conventional units. This excludes battery maintenance as operators have realized a leasing arrangement for batteries i.e. the batteries have not been acquired by the operator and a payment per kilometre has been agreed upon (0.15 USD per km).

The following table shows the investment cost for conventional and hybrid 12m and 18m units in Zhengzhou based on Yutong Euro V units.

Table 13: Investment Cost Buses Zhengzhou in USD (Euro V Bus)

Bus Type	Diesel	Diesel Hybrid	Diesel Plug-In Hybrid	CNG	CNG Hybrid	CNG Plug-In Hybrid	Sur-Cost Hybrid	Sur-Cost Plug-In Hybrid
12m	145,000	185,000	210,000	155,000	200,000	230,000	25-30%	45%
18m	315,000	390,000	440,000	n.a.	n.a.	n.a.	25%	40%

Source: Based on Yutong, 09/2014; exchange rate USD to RMB 1: 6.1; Hybrid LNG are available for 18m at the same cost as 18m diesel hybrids

The batteries respectively capacitors have a life-span of 8 years which is equivalent to the life-span of buses in China (based on national regulations). Therefore no battery replacement cost is included. Batteries used are Lithium-Ion. The investment cost for a charging station for plug-in hybrids is around 3,000 USD. The station can charge 2 buses simultaneously and requires 40 minutes per charge i.e. one station is sufficient for around 20-30 buses i.e. the unitary investment cost per bus is

[27] PE International, Abschlussbericht Plattform Innovative Antriebe Bus, realized for BMVBS, 2011

[28] See IDB, Analisis Economico para el Financiamiento de Autobuss Hibridos y Electricos en el Marco del "Sistema Integrado de Transporte" de la Ciudad de Bogota, 2013

less than 150 USD and therefore not further considered[29]. According to the bus operator in Zhengzhou the maintenance cost of hybrids and conventional units are comparable. This includes also spare parts and repairs as well as time required for maintenance.

4.3.4. Profitability

The following table shows main parameters taken into consideration for the determination of the profitability of hybrid versus conventional units.

Table 14: Parameters Used to Determine Profitability (Status June 2014)

ID	Parameter	Value Zhengzhou	Value Bogota
1	Investment cost	See table 13	See table 12
2	Maintenance cost per annum	Identical hybrid and conventional and thus not considered	Cost of battery 0.15 USD/km[30]
3	Fuel cost	Diesel: 1.16 USD/l CNG: 0.52 USD/m^3 Electricity: 0.08 USD/kWh	Diesel: 1.12 USD/l
4	Fuel savings	See table 9	See table 6
5	Annual distance driven	12m: 55,000 km 18m: 65,000 km	65,000 km
6	Electricity usage plug-ins per operational day	12m: 40 kWh 18m: 60 kWh	n.a.
7	Electric distance driven plug-ins per operational day	30 km	n.a.
8	Operational days per bus	300	Not required
9	Life-span of bus (usage years)	8[31]	12-15[32]
10	Real interest rate[33]	3.4%	9%

Source: data collected by Grütter Consulting from operators

The following table shows the profitability of hybrid buses versus their conventional units in Bogota.

Table 15: Profitability of 12m Diesel-Hybrids in Bogota in USD

Parameter	Diesel	Hybrid-Diesel	Comment
Additional investment		95,000	Excludes battery investment
Annualized cost per km	0.80	0.98-1.03	Lower value with a life-span of 15 years[34]

Source: Grütter Consulting based on above data

Fuel plus maintenance cost for hybrids including the battery leasing costs lead to slightly higher annual costs than for a conventional diesel unit. The investment surplus cost can thus not be repaid with the current cost structure, mileage and fuel consumption of buses in Bogota.

The following table shows the profitability of different types of hybrids in Zhengzhou.

[29] Additionally the charging station in Zhengzhou is provided for by the electricity company.
[30] Based on a service contract with Volvo
[31] Fixed by the government
[32] Conventional diesel buses are allowed to operate for 12 years and hybrid units for 15 years
[33] Based on the nominal interest rate minus inflation of 2013: see as data source for the lending rate: http://data.worldbank.org/indicator/FR.INR.LEND/countries and for the inflation rate: http://data.worldbank.org/indicator/FP.CPI.TOTL.ZG
[34] Bogota allows conventional units to be used for 12 years and hybrids for 15 years

Table 16: Profitability of Hybrids Zhengzhou in USD

Parameter[35]	12m diesel	12m diesel-hybrid	12m diesel plug-in hybrid	12m CNG	12m CNG hybrid	12m CNG plug-in hybrid	18m diesel	18m diesel hybrid	18m diesel plug-in hybrid
Additional investment		40,000	65,000		45,000	70,000		75,000	120,000
Annualized cost per km	0.85	0.83	0.86	0.66	0.73	0.79	1.47	1.38	1.44
Payback time (years)[36]		6	7		18	22		4	6

Source: Grütter Consulting based on above data

In the case of Zhengzhou diesel hybrids are profitable with a payback time of between 4 and 7 years – the most profitable being 18m diesel hybrids. CNG hybrids are not profitable due to CNG prices being far lower than diesel prices thus resulting in lower financial savings due to fuel savings whilst the investment differential is comparable to diesel units. The Internal Rate of Return IRR for diesel hybrids is between 0% and 10% for a 12m diesel hybrid and between and 7%-23% for 18m hybrids. Plug-in hybrids have a lower profitability rate than non-plug-ins. However if plug-ins are charged twice daily i.e. after the morning tour and again in the evening, the profitability would be in the range of normal hybrids.

Overall it can be said that diesel hybrids are profitable with a payback time of around 5 years if distances driven are 55,000 km/year or more, if fuel prices of diesel are 1.2 USD or higher and if the differential price between hybrids and conventional units is around 50,000 USD for standard 12m units or 80,000 USD for 18m articulated units (for plug-ins 40% more). If operators circulate more or fuel prices are higher the investment differential can be higher and a hybrid would still remain profitable.

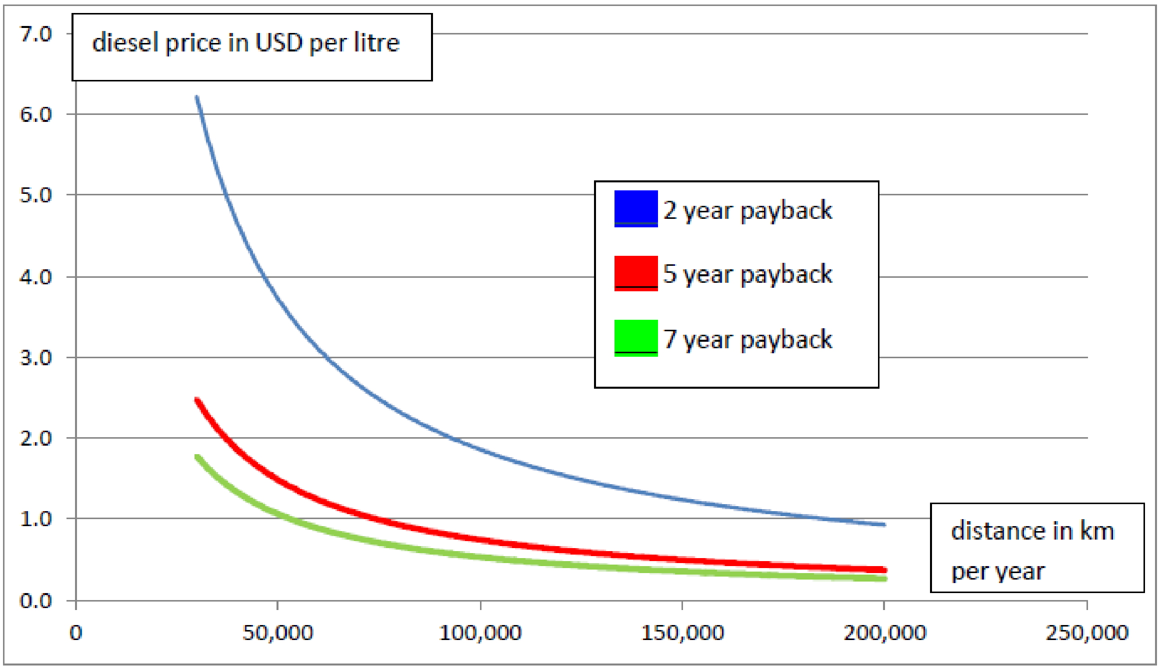
Main criteria which will affect the profitability of hybrids are:

1. Investment differential in absolute terms between hybrids and non-hybrids: A reduction of the investment differential between a hybrid and a conventional unit of 20% reduces the payback time by around 1 year.
2. Distance driven annually: An increase of the distance driven by 20% reduces the payback time by around 1 year.
3. Fuel price increase: An increase of fuel prices by 20% reduces the payback time by around 1.5 years.
4. For plug-in hybrids charging electricity twice per day instead of only once reduces the payback time by around 1 year.

The following figure shows for 12m diesel hybrids the constant payback curves for variations of diesel fuel prices and annual distance driven of buses.

[35] Compared with their same fuel conventional units same size
[36] Payback of additional investment compared to conventional unit same fuel and same size

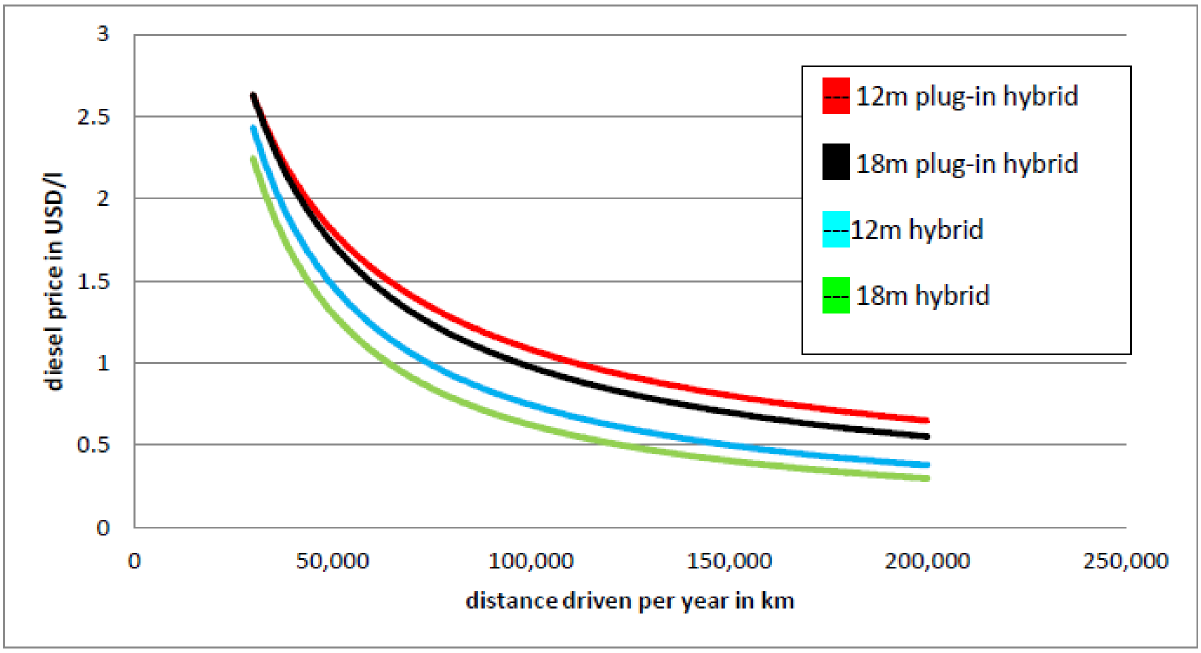
Figure 12: 12m Hybrid-Diesel Constant Payback Combinations of Diesel Price and Distance Driven



Source: Grütter Consulting; based on price differential hybrid to conventional diesel for Zhengzhou

The following figure shows for different diesel hybrids the combinations fuel price/distance driven which result in a payback time of 5 years based on the investment price differentials between hybrids and conventional buses for Zhengzhou i.e. any combination of diesel price and annual distance driven on each curve results in a payback time of 5 years. All combinations of diesel price and distance driven to the right of the curve result in shorter payback times.

Figure 13: 5-Year Payback Combinations Price/Distance for Diesel Hybrids



Source: Grütter Consulting; based on USD 40,000 price differential between hybrid and conventional unit

The excel tool[37] provides a calculation base for bus operators to insert location specific data (country specific fuel prices, bus investment costs, electricity prices and average distance driven of units) to determine the profitability of hybrids.

4.4. Conclusions Hybrid Buses

Hybrid buses clearly have significant fuel savings. This is true for different bus sizes (12m, 18m), different fuels (diesel, CNG and LNG) as well as for different manufactures. Real world performance of hybrids shows fuel and corresponding GHG savings of on average 25-35%. Plug-in hybrids can further reduce fuel consumption and lead to fuel savings of 40-50% compared to conventional units. The fuel savings of plug-ins depend basically on the frequency of charging the battery units (once or twice daily).

In economic terms modern hybrid buses show the same availability rate as conventional units. Maintenance costs are reported to be comparable. Battery replacement costs or battery leasing costs are a significant cost component and can offset fossil fuel savings. The differential investment between hybrids and diesel units is, next to the fossil fuel price, the core factor determining the profitability of hybrid buses. Price differences between manufactures of hybrid buses are significant and influence greatly the profitability. Overall it can be said that the additional investment in hybrids can be paid back in 5-6 years if the diesel price is at least USD 1.10/litre and the annual distance driven is 60,000 km or more.

5. Electric Bus Performance

5.1. Introduction

Standard 12m electric buses are still only used on a singular base. Also no study exists which has compared operational performance of a fleet of large electric buses with conventional units. Such units have only become commercially available recently but it is expected that this will be a mature technology soon[38]. The largest producer of 12m fully electric buses is BYD and the largest fleet is located in Shenzhen which started using electric buses January 2011 and now runs around 1,300 full electric buses produced by BYD and Wuzhoulong basically. Electric fleets considered in this report are those from Shenzhen and Zhengzhou. As mentioned Shenzhen operates by far the largest fleet of electric buses worldwide while Zhengzhou operates since 2011 a fleet of 10 electric buses which was expanded to 110 units end 2013.

Zhengzhou operates since 2011 10 electric Yutong buses with a length of 12m and a passenger capacity of 80 persons. These buses have no AC, which resulted in limited usage of units during summer months. End 2013 100 new units were acquired with AC. Under standard traffic conditions the electric buses have a range of 120 km with an overnight charging time of 8 hours. The new buses and charging stations allow for fast-charging with a duration of 2.5 hours. The system used by Yutong is based on battery racks with Lithium Ion batteries which can be changed within max. 10 minutes i.e.

[37] Grütter Consulting, Tool to Determine Profitability of Hybrid and Electric Buses, 2014
[38] See EU clean fleets program

the bus changes its batteries and continues to operate whilst batteries are re-charged in a central facility. This system, used also by other electric bus producers, has following major advantages:

- Total bus cost can be reduced significantly as the bus requires less batteries. The number of battery packs required will not be proportional as battery charging time is only 2 hours and bus usage can be phased. Based on standard peak-off peak hours with a fleet of 100 buses the total amount of batteries required could be reduced by minimum ¼ comparing buses with 200 km range battery sets and such with interchangeable 100 km battery sets.
- Bus weight can be reduced considerably whilst increasing the available space for passengers. A 12m bus with a range of 200 km or more includes a battery weight of around 3 tons. The weight itself can reduce the number of passengers allowable on the bus due to axle-weight restrictions. Also battery placement can result in structural problems (when putting batteries on the roof-top) or loss of space for passengers (if batteries are placed within the vehicle).
- Battery re-charging can be made with less space in optimum conditions and optimizing the number of charging facilities.
- Range is no core issue anymore as buses can replace their batteries in off-peak hours within 10 minutes.

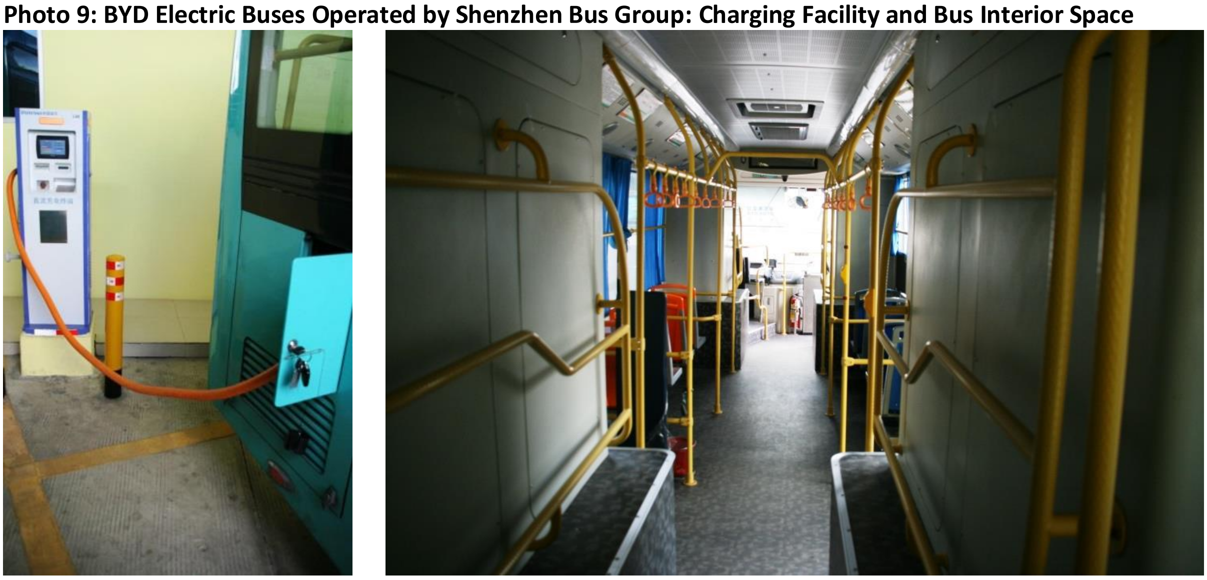
Photo 7: Yutong 12m pure Electric Bus

Shenzhen operates the largest fleet worldwide of electric battery buses with currently around 1,300 12m units. Bus makes are basically BYD and Wuzhoulong. The government office for promoting new energy vehicles in Shenzhen has been instrumental for this achievement. The central government pays for around ¼ of the bus, the local government finances ¼ and the bus operator pays the remaining 50% which in terms of investment costs equals in-about a conventional diesel unit. In the next 2 years the city plans to introduce another 2,000 electric buses of a 2^{nd} generation with lower energy consumption and more space for passengers.

Photo 8: BYD Electric Buses Operated by Shenzhen Bus Group

Source: Grütter

Photo 9: BYD Electric Buses Operated by Shenzhen Bus Group: Charging Facility and Bus Interior Space



Source: Grütter

The photo above shows the significantly decreased interior space of the 1st generation BYD full electric buses, which have their battery compartment within the bus thus reducing the passenger carrying capacity to around 50 passengers compared to 80 of a conventional diesel unit. The new generation of BYD electric buses have batteries primarily on the roof thus reducing this problem. The weight of batteries in the bus is around 3.5 tons. Batteries are Lithium-ion Iron-Phosphate FE batteries with a charging time between 2 and 4 hours and a driving range of around 180-200 km with AC. This driving range is based on the experience of Shenzhen Bus Group whilst the producer states a driving range of 250-280 km. Batteries cannot be removed quickly from the bus i.e. the entire bus must be re-charged. Based on the manufacturer batteries should with 3 years still have a capacity of minimum 90% and after 10 years still 80%[39]. The experience of the operator has however been that after 3 years batteries only retain 80% of their original capacity thus limiting also effectively the vehicle range.

5.2. Environmental Performance of Electric Buses

5.2.1. Environmental Performance of Electric Buses in Zhengzhou

The following table compares the electricity consumption of electric 12m buses with the fossil fuel consumption of comparable conventional diesel buses used by Zhengzhou.

Table 17: Comparison Average Energy Consumption Standard 12m Electric and Diesel Bus

Bus Type	Electric Bus	Conventional diesel
Energy consumption	100 kWh/100km	40 l/100km

Source: Zhengzhou Bus Communication Company, 2014; data collection and calculations by Grütter Consulting; based on monthly fuel consumption per bus; data for electric buses based on an average for 3 years; the larger time period is taken due to the lower number of buses

The consumption is based on the older electric bus model. The new models which also have AC have recently entered service during 2014 and therefore no performance data is yet available.

To determine GHG emissions calculation methods based on IPCC are used. For electric buses the upstream emissions of electricity generation are included. The correct figure to compare the carbon emission factor of electricity would be with the weighted average emission factor plus Transmission and Distribution Losses (TDL)[40]. The weighted average emission factor describes the average CO_2 emitted per unit of electricity generated in the grid. This factor is in general significantly lower than the Combined Margin (CM) used frequently for CDM projects, due to the fact that the CM is based on the average of the Operating Margin (OM) and the Build Margin (BM) whereby the Operating Margin does not include so-called “low-cost must-run” power plants which are basically hydropower and nuclear power plants. In other words the OM reflects the weighted average emissions rate of the thermal power plants. As example in India for 2011-2012 the weighted average emission factor of the grid was 0.78 $kgCO_2/kWh$, whilst the Operating Margin was 0.97, the Build Margin 0.90 and the Combined Margin 0.93 for the same period i.e. the CM was around 20% above the weighted average[41]. TDL is on average 5-10% in most grids, higher values reflecting basically a problem of theft. As CM data is fairly widely published it is used as a first approximation per country for upstream GHG emissions associated with the usage of electricity. However the weighted average emission factor is significantly lower than the CM in the case of countries relying basically on renewables i.e. actual GHG emissions of electric buses in such countries should be based on the weighted factor and not on the CM. The CM used for Zhengzhou is 0.72 $kgCO_2/kWh$[42]. The following figure compares the GHG Well-to-Wheel (WTW) emissions of standard 12m buses in Zhengzhou for the year 2013.

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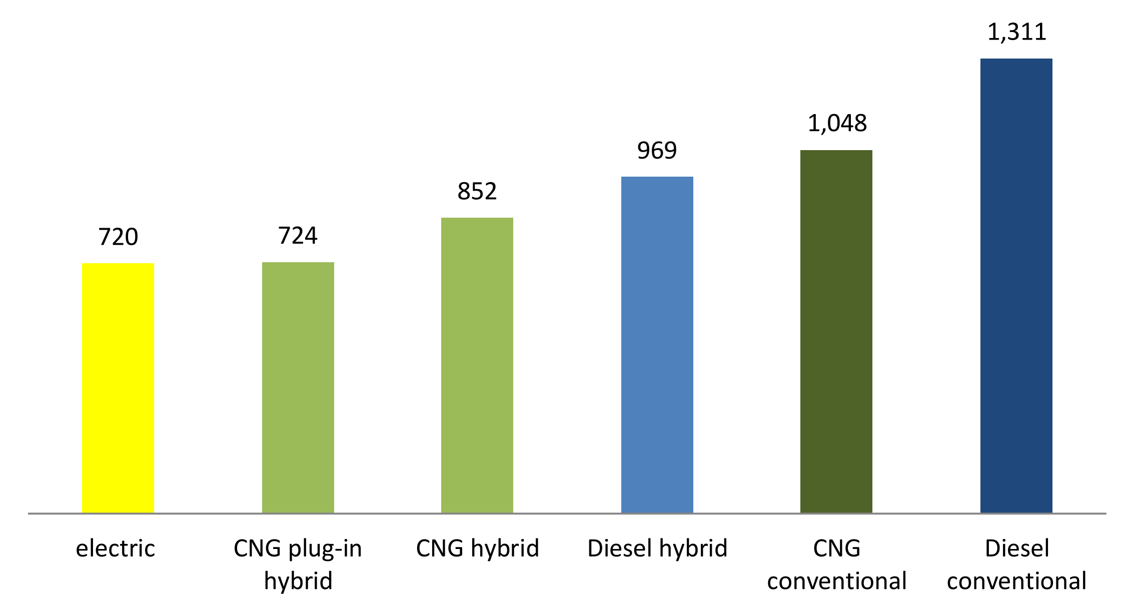
[39] Minimum 1,000 charging cycles with 90% and 3,000 cycles with 80% of capacity.

[40] This is the approached used by the CDM for consumers of electricity see e.g. approved CDM methodology ACM0016 for Mass rapid Transit systems

[41] GOI, Ministry of Power, Central Electricity Authority, CO_2 Baseline Database for the Indian Power Sector, Version 8.0, 2013

[42] NDRC China for Central China Power Grid, 2013

Figure 14: GHG WTW Emissions 12m Buses Zhengzhou Year 2013 (gCO_2/km)



Source: Grütter Consulting

GHG well-to-tank emission reductions for electric buses in Zhengzhou are between 0% and 25% compared to hybrid units, and between 30% and 45% compared to conventional fossil units. This reduction is achieved although electricity generation relies heavily on coal.

Local emissions of electric buses are 0. They therefore have significant advantages compared to fossil units in terms of particle matter, NO_x emissions as well as other local pollutants and also significant advantages concerning noise levels. However plug-in hybrids also have the possibility, albeit within a reduced range, of running as 0-emission vehicles.

The electric buses currently used in Zhengzhou cover basically shorter routes and are also used basically in peak hours and not as frequently as conventional buses. This is reflected in their average annual mileage which is 4,500 km/month for diesel, 4,000 km/month for CNG and only 2,000 km/month for electric buses. With the new electric buses available the mileage of electric buses is expected to increase. Based on the current annual mileage of electric buses in Zhengzhou and the usage of 110 units these have resulted in emission reductions of around 1,000 tCO_2 (around 10 tCO_2 per bus[43]), 10 t of NOx and 0.1 t PM[44].

5.2.2. Environmental Performance of Electric Buses in Shenzhen

Data is used from the Shenzhen Bus Group which operates around 500 of the currently 1,300 electric buses in the city, all of which have AC. Electricity consumption of buses is around 1.2 kWh/km. Compared with the average diesel fuel consumption of 40 l/100km for 12m comparable buses and the Southern China power grid which has a CM of 0.66 $kgCO_2$/kWh this results in GHG emissions of around 790 gCO_2/km i.e. around 10% more than in the case of Zhengzhou due to the higher electricity consumption of the buses used in Shenzhen. Compared to the WTW emissions of diesel unit this still results in emission reductions of around 40%. However taking into account the reduced

[43] Compared with a conventional fleet of 50% diesel and 50% CNG units; based on WTW; the relatively low reduction per bus is due to the low mileage of electric buses
[44] Compared with Euro V units

passenger carrying capacity of 40% the emissions per passenger (based on carrying capacity) of the electric bus is comparable to a diesel unit. However other producers or also the new generation of BYD buses have placed batteries on the roof and have thus resolved at least partially the passenger carrying capacity issue. Assuming the same passenger carrying capacity and an annual mileage of electric buses of around 40,000 km the GHG offset of the 1,300 units used in Shenzhen is around 27,000 tCO_2 per annum, 2 tons of PM and around 200 tons of NO_x.

5.2.3. Conclusion Environmental Performance of Electric Buses

A core element when determining the GHG impact of electric buses is how electricity is produced in the country and the resulting carbon emission factor of electricity. As CM data is fairly widely published it is used as a first approximation per country for upstream GHG emissions associated with the usage of electricity.

Table 18: Combined Margin Emission Factor of Electricity Production Selected Countries

Asia	EF $kgCO_2$/kWh	Americas	EF $kgCO_2$/kWh	Africa	EF $kgCO_2$/kWh
Bangladesh	0.64	Argentina	0.52	Egypt	0.54
Cambodia	0.67	Bolivia	0.58	Ghana	0.55
China	0.89	Brazil	0.30	Iran	0.61
India	0.90	Chile	0.60	Israel	0.72
Indonesia	0.76	Colombia	0.34	Ivory Coast	0.66
Malaysia	0.67	Cuba	0.87	Jordan	0.58
Mongolia	1.06	Dominican Republic	0.65	Kenya	0.60
Pakistan	0.54	Ecuador	0.59	Lebanon	0.65
Philippines	0.51	El Salvador	0.68	Libya	0.79
South Korea	0.63	Guatemala	0.65	Madagascar	0.55
Singapore	0.49	Honduras	0.67	Morocco	0.66
Sri Lanka	0.69	Mexico	0.53	Namibia	0.92
Thailand	0.55	Nicaragua	0.69	Nigeria	0.58
Viet Nam	0.56	Panama	0.62	Rwanda	0.65
		Peru	0.60	Saudi Arabia	0.65
		Uruguay	0.57	Senegal	0.68
				South Africa	0.95
				Tanzania	0.31
				Tunisia	0.53
				Uganda	0.55

Source: IGES database, 2014

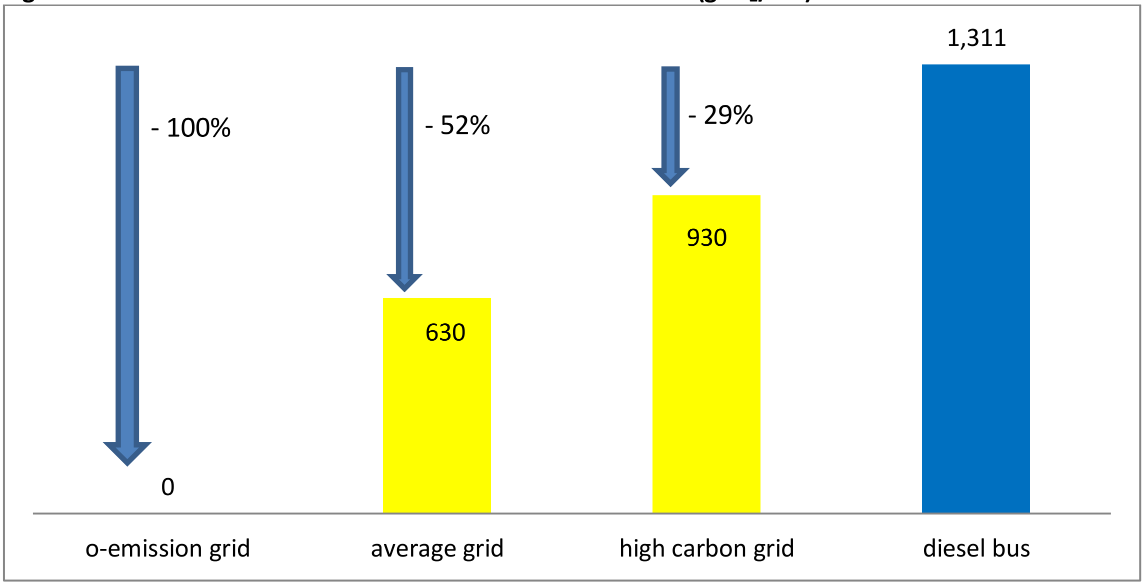
Some countries like Bhutan, Costa Rica, Lao PDR and Paraguay have a weighted emission factor of 0 due to producing all electricity based on renewables[45]. The following graph shows the GHG emissions of an electric bus grouped into 0-emission grid, average carbon grid[46], high carbon grid[47] and compares this to the average WTW GHG emissions of a conventional diesel bus.

[45] The combined margin is not 0 as it includes in the operating margin only fossil plants and therefore the existence of some very small back-up plants can create a relatively high CM – albeit this does not reflect, especially in these countries, actual overall CO_2 emissions of the power grid.

[46] Based on median of countries listed

[47] Based on average of top 10% of countries listed

Figure 15: GHG WTW Emissions 12m Electric versus Diesel Bus (gCO_2/km)



GHG emission reductions are highly dependent on the electricity source of the country. Average emission reductions of 50% and more can however be expected against conventional diesel buses. It is noteworthy that even with a grid based primarily on coal power electric buses are still distinctively better than diesel units.

An important aspect to consider is the actual carrying capacity of electric buses. Some bus producers use significant interior space for batteries thus reducing the passenger carrying capacity significantly. This in effect means that a 12m electric bus must be compared with a smaller conventional bus with the same passenger capacity. However the trend of producers has been to put batteries basically on the roof and thus maintain a comparable passenger carrying capacity for electric versus conventional fuel buses of the same size.

5.3. Economic Performance of Electric Buses

5.3.1. Introduction

The same cost components are used to compare the financial performance of electric versus conventional units as for hybrid buses.

5.3.2. Bus Availability

Zhengzhou as well as Shenzhen show a significantly lower availability rate of electric versus conventional fuel buses. On average electric buses are only 70% as much available as diesel units. Reasons are more breakdowns of the bus and longer standstill time for maintenance and repair due to lack of spare parts. Electric buses are still an “exotic” product resulting in more technical difficulties, less trained maintenance staff and not readily available spare parts due also to the limited amount of units. As a result operators currently require for each diesel bus 1.4 electric buses to ensure the same level of operations.

5.3.3. Investment and Operational Cost

The investment cost for a conventional diesel 12m in China is around 150,000 USD whilst an electric 12m bus has around double the cost i.e. 300,000 USD. Prices for an electric bus are thereby based on Yutong and BYD in China. Outside China the BYD bus is known to be sold at 650,000 USD. The investment cost for a battery set is thereby around 50% of the bus investment. The electric fast-charging stations are owned by the electricity companies which thereafter sell the electricity.

In general the bus manufacturer leases the batteries or even the entire bus to the bus operator. This includes also the entire maintenance service. In theory maintenance costs should be lower for electric buses due to less revolving parts and less maintenance requirements. In practice however the experience of the operators has been that maintenance costs are higher for electric buses due to fewer suppliers of electric buses and spare parts and non-standardized spare parts which result in costlier repairs. More competition and a growing market for electric buses will bring down differential costs but at the current stage electric buses in practice cost more to maintain and repair than diesel units. This cost has therefore been included in the bus availability rate.

The batteries have a life-span of minimum 8 years which is equivalent to the life-span of buses in China (based on national regulations). Therefore no replacement cost is included. For a longer usage of buses however a battery replacement after around 10 years would need to be included.

5.3.4. Profitability

The following table shows main parameters taken into consideration for the determination of the cost and profitability of electric versus conventional units.

Table 19: Parameters Electric Versus Diesel 12m Bus Shenzhen/Zhengzhou (Status June 2014)[48]

ID	Parameter	Electric Bus	Diesel Bus
1	Investment cost	300,000	150,000
2	Availability rate (index)	70	100
3	Maintenance cost per annum	Identical electric and conventional and thus not considered	
4	Fuel cost	Electricity: 0.08 USD/kWh	Diesel: 1.16 USD/l
5	Fuel usage	1.1 kWh/km	40 l/100km
6	Annual distance driven	60,000 km	60,000 km
7	Life-span of bus (usage years)[49]	8	8
8	Interest rate	3.4%	3.4%
9	Standardized investment[50]	430,000	150,000
10	Annualized cost per km	1.12 USD/km	0.83 USD/km

Source: data collected by Grütter Consulting from electric bus operators in Zhengzhou and Shenzhen

Actual differential investment for the same usability is around 300,000 USD i.e. the electric bus has in reality around triple the price of a diesel unit due to the lower availability rate of the unit which results in requiring more units to maintain the same service level. Annual operational savings of electric versus diesel units amount to around 20,000 USD. This figure is however insufficient to cover

[48] Based on average figures between Shenzhen and Zhengzhou
[49] Fixed by the government
[50] Based on providing the same service level i.e. an indexed availability rate of 100

the differential investment for the electric bus. Annualized costs[51] per km including investment cost and fuel cost but excluding cost components which are identical between the two vehicles like driver cost are around 35% higher for the electric bus compared to a conventional diesel Euro V unit.

5.4. Conclusions Electric Buses

The main advantage of electric buses is there 0-emission of local pollutants in cities. Upstream air pollution will occur if electricity is produced by fossil means – however power plants can control such emissions more effectively than small engines and also pollution of power plants occurs in less critical pollution zones than where buses operate. The advantage of 0-GHG emissions is only available in countries with a non-fossil grid. In most countries electric buses will reduce GHG emissions – however also modern hybrid buses, especially plug-ins, come in the range of electric buses concerning GHG emissions, especially in average and higher carbon grids.

Concerning finance electric buses require a significant surplus investment. Buses cost around double of conventional units and clearly have a lower availability rate due to more breakdowns and more time required for servicing and repairs. This is typical of new technologies and was also observed with first generations of CNG buses. Due to the battery load – directly related to the vehicle range – the vehicle weight increases considerably, which - depending on the manufacturer solution chosen - can result in a significantly reduced passenger capacity (either due to weight allowance restrictions or due to space being taken up by batteries thus reducing space for passengers). Reduced availability of buses and reduced passenger capacity result in equivalent investment costs being not only double but triple of a conventional diesel bus, if the same level of service is compared. Annual operational costs due to fuel cost savings will be lower for electric buses than for diesel units. How much lower depends on the relative diesel versus electricity costs per country and the annual distance driven. However electric buses, due to range limitations, will be used more on shorter downtown routes and thus will in general have a below-average annual mileage. The annualized investment and fuel cost per km of an electric bus is therefore around 30-40% higher than that of a conventional diesel bus.

6. Climate Finance Opportunities

Hybrid and electric buses receive currently in various countries additional finance either climate related (e.g. UK, Switzerland[52]), driven by environmental considerations (e.g. Bogota) or in relation to industrial policies (e.g. China). In the international scenario the CDM (Clean Development Mechanism) used to be a good instrument to attract climate finance with payment being made per tCO_2 reduced. 4 electric vehicle projects, albeit not for buses, have been registered under this mechanism in India. However the drastic fall of prices has made this market since 2013 unattractive. New market mechanisms like NAMAs (Nationally Appropriate Mitigation Actions) are posed to be more promising and already various NAMA proposals have been made for electric vehicles and recently also for hybrid ones. However the instrument is still new and no proposal has yet succeeded in ensuring finance. The following table gives an overview of some interesting climate finance available potentially for hybrid and electric buses.

[51] Annualized costs include the cost of capital and, based on the interest rate, calculate the annual discounted investment value together with the annual operational costs

[52] A program was registered by Myclimate and Grütter Consulting where payment is made per tCO_2 reduced for each hybrid and electric bus within the domestic emission reduction program.

Table 20: Climate Finance Opportunities

ID	Name	Description	Link
1	NAMA facility	An initial €120 million of funding to support developing countries for implementing NAMAs. In the 1st round 2 transport NAMAs received approval (TOD Colombia and sustainable urban transport in Indonesia)	http://www.nama-facility.org/news.html
2	Regional development banks e.g. IDB, ADB, AFD, CAF	Example: Within Latin America IDB is supporting the formulation of various transport NAMAs and is also involved directly in the promotion of alternate technology buses in Bogota as well as in Quito	www.iadb.org
3	Clean Technology Fund	The CTF through IDB financed for example hybrid and electric buses in Bogota	https://www.climateinvestmentfunds.org/cif/node/2
4	Global Environment Facility	The GEF has specifically identified hybrid and electric buses in its program for sustainable transport; It has approved e.g. in Philippines a program which includes investment for a limited number of electric/hybrid buses	http://www.thegef.org/gef/home
5	General links to climate finance opportunities: http://www.climatefinanceoptions.org/cfo/cfo_search/type%3Afunding_sources%20category%3A219 http://www3.unfccc.int/pls/apex/f?p=116:1:2895636133177913		

7. Conclusions

The real-world performance of operators with large fleets of hybrids show clearly that fuel savings of 25-35% with conventional hybrids and 40% or more with plug-in hybrids can be expected. The reliability of hybrids is comparable to conventional fossil fuel buses and also maintenance costs, with exception of battery costs, are comparable. The differential investment, depending on make and model, can however be significant. Under normal annual operating conditions and fuel prices of USD 1.20 or more per litre, hybrids can be profitable recovering the initial differential investment within 5-6 years. Carbon finance can play an important role in reducing the differential investment cost of hybrids and thus making latter more popular.

Electric battery buses are still less well established. Various options are being tried to resolve the problem of range, battery weight and battery cost such as buses carrying along large battery racks (e.g. BYD), buses with fast-change battery racks (e.g. Yutong) or opportunity charge bus systems like TOSA. Such systems have a good potential of replacing electric trolley buses. Currently reliability of electric buses is still significantly below conventional diesel units therefore leading to additional investment costs (more buses are required to fulfil the same peak service level). Also maintenance costs, which theoretically should be lower compared to diesel units, is in practice higher due to less availability of spare parts, spare parts art higher costs and more stand-still time with repairs. These problems are typical of new technologies. Energy usage of electric buses is low and fuel savings can be significant. However battery costs are still very high and life-span of batteries is limited thus resulting in significant additional costs of electric buses which cannot be recovered currently with energy savings. Therefore electric buses, even with carbon finance, are not yet financially considered as viable compared to conventional units. However electric buses compared to conventional trolleybuses can be an interesting option. At the same time it is previewed that the cost of electric buses will come down and that battery capacity will increase whilst costs decrease. With larger fleets reliability should also improve and maintenance costs should decrease.

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