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Annex 22b:

Program: E-Motion: E-Mobility and Low Carbon Transportation

GHG and SD Emission Reduction Methodology and Calculations

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Abbreviations

AC	Air Conditioning
ADB	Asian Development Bank
AFD	French Development Agency
BAU	Business as Usual
BC	Black Carbon
BEB	Battery Electric Bus
BRT	Bus Rapid Transit
CAPEX	Capital Expenditures
CDM	Clean Development Mechanism
CM	Combined Margin
CNG	Compressed Natural Gas
EEA	European Environmental Agency
EF	Emission Factor
ER	Emission Reduction
EV	Electric Vehicle
EVI	Electric Vehicle Initiative
FA	Financial Assistance
FIRR	Financial Internal Rate of Return
FOB	Free On Board
GCF	Green Climate Fund
GDP	Gross Domestic Product
GHG	Greenhouse Gases
GWP	Global Warming Potential
HDV	Heavy Duty Vehicle
IEA	International Energy Agency
IMF	International Monetary Fund
IPCC	Intergovernmental Panel on Climate Change
LCMR	low-cost/must-run
LCV	Light Commercial Vehicles
NCV	Net Calorific Value
NG	Natural Gas
OECD	Organisation for Economic Co-operation and Development
OPEX	Operational Expenditures
PM	Particle Matter
PPP	Purchasing Power Parities
PT	Public Transport
SCC	Social Cost of Carbon
SD	Sustainable Development
STDEV	Standard Deviation
TA	Technical Assistance
TCO	Total Cost of Ownership
TTW	Tank to Wheel
UNFCCC	United Nations Climate Change Convention
WACC	Weighted Average Capital Cost
WTT	Well to Tank
WTW	Well to Wheel

1. Introduction

The e-Motion Program of AFD has as goal to accelerate Electric Vehicle (EV) deployment through financial and technical assistance. The Program implements interventions to kick-start EV mass deployment significantly earlier than under a Business as Usual (BAU) scenario by reducing the risk profile of investments and by comprehensive technical assistance. The Program fills the gap between initial pilots and long-term targets. These interventions are made in a time where e-mobility is commercially not yet viable and thus require initial investment support -like is the case in all countries which have a significant uptake of e-mobility.

The Program focuses on pure electric commercial vehicles i.e. buses, taxis and urban freight vehicles together with the required charging infrastructure and grid upgrades. No private usage vehicles are financed. The main investment area is on electric buses. Investments are linked with new business models and service delivery structures which enhance the attractiveness and sustainability of the public transport sector and thereby is an important component to ensure that current public transport ridership levels are sustained or even increased. The Program has thus also an important contribution towards mode shift.

The Program is implemented by AFD in Argentina, Brazil, Colombia, Costa Rica, Dominican Republic, Ecuador, Mexico, and Peru. Investment projects with calculated GHG reduction are in Brazil, Colombia, Mexico and Peru.

This report establishes the base for determining the expected impact in terms of climate change or Greenhouse Gas (GHG) emissions and of local pollutants including $PM_{2.5}$ and NO_x. Poor air quality is detrimental to health with vehicle emissions being an important source of pollutants. The report also shows the base for the determination of economic costs related to emissions.

For GHG as well as pollutants and the economic benefits a direct impact calculation is made based on the expected emission reductions from vehicles directly financed by the Program plus the expected impact from public transport interventions.

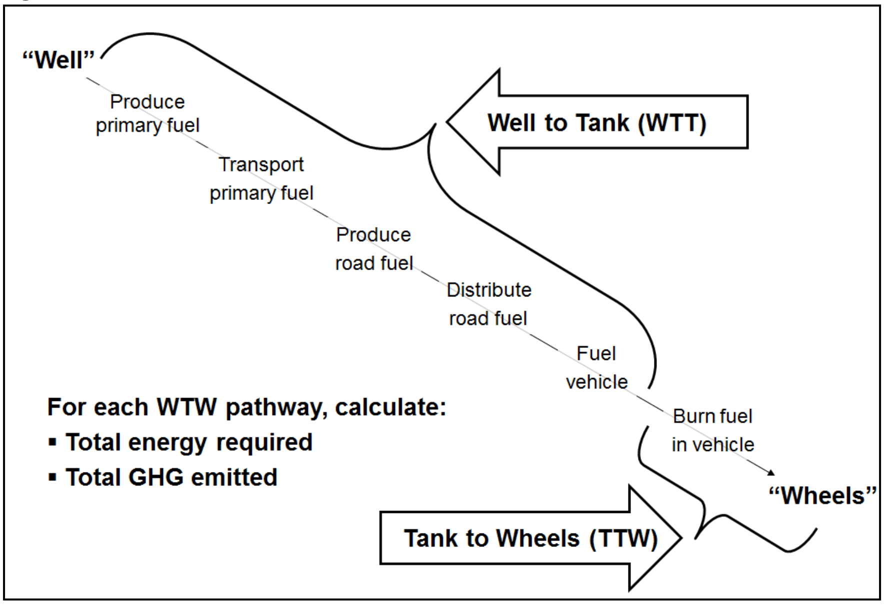
2. General Considerations on GHG Emissions

2.1. Levels of Analysis

GHG emissions are differentiated in 3 levels:

- Direct emissions equivalent to combustion or tank-to-wheel (TTW) emissions;
- Direct plus indirect or well-to-wheel (WTW) emissions;
- Life-cycle or cradle-to-grave emissions.

Figure 1: Tank-to-Wheel, Well-to-Tank, and Well-to-Wheels



Source: (European Commission, 2016); https://ec.europa.eu/jrc/en/jec/activities/wtw

The GHGs included under the 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, N_2O emissions are marginal and therefore only CO_2 and CH_4 emissions are included (IPCC, 2006). An important recognized GHG is also Black Carbon (BC). However, it is not a GHG as included in the Paris agreement and is thus not included in calculations.

All Global Warming Potentials used in the report are for a 100-year timespan (GWP_{100}) as used by IPCC.

2.2. Direct Emissions (TTW)

Direct emissions are defined as combustion related emissions. This is equivalent to the term TTW.

Emissions of CO_2 are calculated on the basis of the amount and type of fuel combusted and its carbon content. For annual emissions of the vehicle the distance travelled is multiplied with the specific emission factor per unit of distance. This approach is used by IPCC (IPCC, 2006) and by approved Clean Development Methodologies (CDM) methodologies for the transport sector of the UNFCCC. For vehicles using different fuel types (e.g. passenger cars using gasoline or diesel) the Emission Factor (EF) is calculated per fuel type and weighted based on the number of vehicles per fuel type[1]. For gaseous vehicles, as used in some countries, methane slip caused during combustion within the vehicle is included also based on default values from ICCT (ICCT, 2015). Methane slip is caused within the vehicle in the crankcase and the exhaust pipe. Leakage of unburnt methane is important due to the high GWP of CH_4. Methane slip emissions are calculated in the following manner:

[1] More precise would be to weight it per distance driven per fuel type; however, such data is not available.

$$EF_{km,MSV,i} = SFC_{CNG,i} \times MS_V \times GWP_{CH4} \times 10^3 \quad (1)$$

Where:

$EF_{km,MSV.i}$	Emission factor per km of CNG vehicle category *i* due to methane slip within vehicle (gCO_{2e}/km)
$SFC_{CNG,i}$	Specific fuel consumption of CNG vehicle category *i* (kg/km)
MS_V	Default factor for methane slip within vehicle (%)
GWP_{CH4}	Global Warming Potential of CH_4 (no unit)
i	vehicle category

The full equation for TTW emissions is therefore:

$$EF_{km,i,TTW} = \sum_y SFC_{i,y} \times NCV_y \times EF_{CO2,y} \times S_{i,y} + EF_{km,MSV,i} \times S_{i,CNG} \quad (2)$$

Where:

$EF_{km,i,TTW}$	Tank-to-wheel emission factor per kilometre of vehicle category *i* (gCO_{2e}/km)
$SFC_{i,y}$	Specific fuel consumption vehicle category *i* using fuel type *y* (kg/km)
NCV_y	Net Calorific Value of fuel type *y* (MJ/kg)
$EF_{CO2,y}$	CO_2 Emission Factor of fuel type *y* (gCO_2/MJ)
$S_{i,y}$	Share of vehicle category *i* using fuel type *y* (%)
$EF_{km,MSV,i}$	Emission factor per km of CNG vehicle category *i* due to methane slip within vehicle (gCO_{2e}/km)
i	vehicle category
y	fuel type

Direct emissions include only combustion emissions.

Direct or combustion emissions of electric vehicles are 0.

2.3. Direct plus Indirect Emissions (WTW)

Direct plus indirect emissions are defined as combustion plus upstream emissions. This is equivalent also to the term well-to-wheel emissions (which is the sum of TTW plus well-to-tank emissions).

For ***fossil vehicles*** WTW emissions are based on direct emissions multiplied with an upstream default factor for the extraction, refinery and transport of diesel. Upstream methane emissions related to the gas pumps are also included.

$$EF_{km,i,WTW} = \sum_y EF_{km,i,y,TTW} \times UEF_y + EF_{km,MST,i} \times S_{i,CNG} \quad (3)$$

Where:

$EF_{km,i,WTW}$	Well-to-wheel emission factor per kilometre of vehicle category *i* (gCO_{2e}/km)
$EF_{km,i,y,TTW}$	TTW emission factor per kilometre of vehicle category *i* using fuel type *y* (gCO_2/km)
UEF_y	Upstream emission factor for fuel type *y* (no unit)
$EF_{km,MST,i}$	Emission factor per km of CNG vehicle category *i* due to total methane slip (gCO_{2e}/km)
i	vehicle category
y	fuel type

Total methane slip emissions are calculated in the following manner:

$$EF_{km,MST,i} = SFC_{CNG,i} \times MS_T \times GWP_{CH4} \times 10^3 \quad (4)$$

Where:

$EF_{km,MST,i}$	Emission factor per km of CNG vehicle category *i* due to total methane slip (gCO_{2e}/km)
$SFC_{CNG,i}$	Specific fuel consumption of CNG vehicle category *i* (kg/km)
MS_T	Default factor for total methane slip (%)
GWP_{CH4}	Global Warming Potential of CH_4 (no unit)

For ***electric vehicles*** WTW emissions include the emissions caused by electricity production, transmission and distribution losses.

$$EF_{km,EVi,WTW} = EC_i \times CF_{elec} \quad (5)$$

Where:

$EF_{km,EV,WTW}$	Well-to-wheel emission factor per kilometre of EV category *i* (gCO_{2e}/km)
EC_i	Electricity consumption of EV category *i* per kilometre (kWh/km)
CF_{elec}	Carbon factor of electricity grid (gCO_{2e}/kWh)

2.4. Life Cycle Emissions

Life-cycle emissions (cradle to grave) include vehicle manufacturing and disposal. Related infrastructure (roads) are not included, also due to the reason that an EV replaces an identical category fossil vehicle which results also in identical infrastructure requirements. The determination of life-cycle emissions is much less precise than of direct and indirect emissions. Their determination serves primarily for informative purposes. The two sources included for life-cycle emission are vehicle and battery manufacturing. To determine emissions per kilometre the lifetime of the vehicle and of batteries and the annual mileage is determined. The lifespan of fossil and EVs are thereby not necessarily the same: EVs have less vibrations and moving parts and therefore can be used technically for a longer period than fossil vehicles and on the other hand legal or concession regulations in some countries have differential lifespans in which fossil or electric vehicles can be used (e.g. concession contracts for bus operators are differentiated in various countries for electric and diesel buses).

The Program does not consider life-cycle emissions.

3. General Considerations on Local Pollutants

3.1. Levels

Pollutants are emitted at different levels:

- Tailpipe (combustion emissions);
- Non-combustion direct emissions of the vehicle;
- Upstream indirect emissions caused by fuel/energy production and transport;
- Indirect emissions caused by vehicle and related infrastructure production and disposal from a cradle to grave perspective (not further discussed in this report).

The project includes for all calculations only tailpipe (combustion) emissions. However, a short discussion of non-combustion and fuel-related upstream emissions is made.

3.2. Tailpipe Emissions

Tailpipe or combustion emissions are determined based on the emission category of the vehicle using the latest version of the European Environmental Agency emissions model COPERT with a Tier 2 approach i.e. the emissions are determined relative to the vehicle type, the fuel used, and the emission category (EEA, 2019).

3.3. Non-Combustion Emissions

Vehicles not only have combustion emissions but also PM emissions from brake, tire and particle re-suspension. Measurements of PM_{10} in the city of Zurich, Switzerland in 2007 showed that 16% of PM emissions from heavy duty vehicles in urban areas were brake, 53% re-suspension and only 31% combustion related (BAFU, 2009)[2]. 40% of PM emissions from braking corresponds to $PM_{2.5}$ particles, and 70% of PM emissions of tyres (TRL, 2014)[3]. There are however no regulations for non-combustion emissions and data on actual emission levels for road vehicles is scarce. Electric vehicles are expected to have lower non-combustion emissions as they use much less brake pads due to braking energy recovery systems. Non-combustion emissions are therefore not considered in the report.

3.4. Upstream Emissions

Upstream emissions of pollutants are related partially to the energy production. For vehicles using fossil fuels upstream emissions are related basically to the refinery and the transport of fuels. A detailed assessment made by Grutter Consulting for ADB in Kyrgyz Republic showed that upstream emissions of $PM_{2.5}$ emissions from refineries are insignificant (<5%) compared to combustion emissions of Euro IV vehicles comparable to those used in most of the Program countries. NO_x and SO_2 emissions however can be significant and higher even than combustion emissions, depending on the pollution control devices installed at the refinery.

Refineries are in general not located in densely populated areas and thus emissions from refineries do not result in the same impact as those emitted from urban transport vehicles.

Upstream emissions of pollutants are therefore not further considered in this report.

4. Economic Cost of Emissions

The economic cost of pollution is calculated by assigning a monetary value to emissions of $PM_{2.5}$, NO_x, and SO_2. The economic cost of air pollutants is based on an IMF (International Monetary Fund) publication and dataset (IMF, 2014). All values are updated to USD of 2019 by updating the GDP/capita of each country (Purchasing Power Parity approach) based on latest available data from the World Bank. The cost of pollutants calculated by the IMF are based on local levels of pollution at the ground level and the impact on health and costs caused by this type of pollution in each country. This is based

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[2] (BAFU, 2009), Figure 1-5

[3] TRL, 2014, p.10

on the exposure of the population to contamination and how increased pollution increases mortality risks using the World Health Organization's dose response functions to concentration. The greater risk of mortality or, more precisely, the cost of premature death is valued economically on the basis of stated preference studies as performed by the OECD. An annual cost increase of 2% in real terms is used (ADB, 2017). The following table shows resultant values of cost of pollutants per country for 2019 and for 2030.

Table 1: Economic Costs of Pollutants 2019 and 2030 (USD of 2019; USD per ton of pollutant)

Country	2019		2030	
	$PM_{2.5}$	NO_x	$PM_{2.5}$	NO_x
Brazil	167,000	1,310	207,644	1,629
Colombia	246,000	1,890	305,870	2,350
Mexico	267,000	2,060	331,981	2,561
Peru	85,000	650	105,687	808

Source: IMF, 2014, updated to USD 2019; annual cost increase of 2% in real terms (ADB, 2017)

The global warming externality cost is expressed through the social cost of carbon (SCC). Latter is an estimate of the economic damages associated with an increase in CO_2 emissions. Valuating the economic damage of CO_2 emissions is complex and very much dependent on discount rates. A review of empirical estimates of the global social cost of carbon reported by the IPCC reports a unit value of USD 36 per ton of CO_{2e} in 2016 prices for 2016 emissions, to be increased by 2% annually in real terms to allow for the potential of increasing marginal damage of global warming over time (ADB, 2017). This results in around 40 USD per ton CO_{2e} for 2020.

5. Carbon Factor Electric Grid

Electric mobility causes upstream emissions due to usage of electricity which has production related emissions as well as transmission and distribution losses. The carbon emission factor of the grid is calculated based on the net energy production (total domestic production minus energy losses) and the total GHG emissions for electricity production i.e. the actual carbon factor of the country[4]. The latest available grid factor is used. An alternative would be to use the projected future carbon grid factor based on the projections concerning electricity production in the country.

The grid factor is based on the International Financial Institutions (IFI) latest version database for electricity consumption as published on the UNFCCC website.

Table 2: CO_2 Grid Emission Factor

Country	Value in $kgCO_{2e}/kWh$
Argentina	0.288
Brazil	0.150
Colombia	0.208
Costa Rica	0.039
Dominican Republic	0.426
Ecuador	0.280
Mexico	0.359
Peru	0.252
Median	**0.266**

Source: IFI, version 3.1, 02/2022

[4] Exports and imports are not considered i.e. this is the grid factor of nationally produced electricity.

6. Impact of EVs

6.1. Introduction

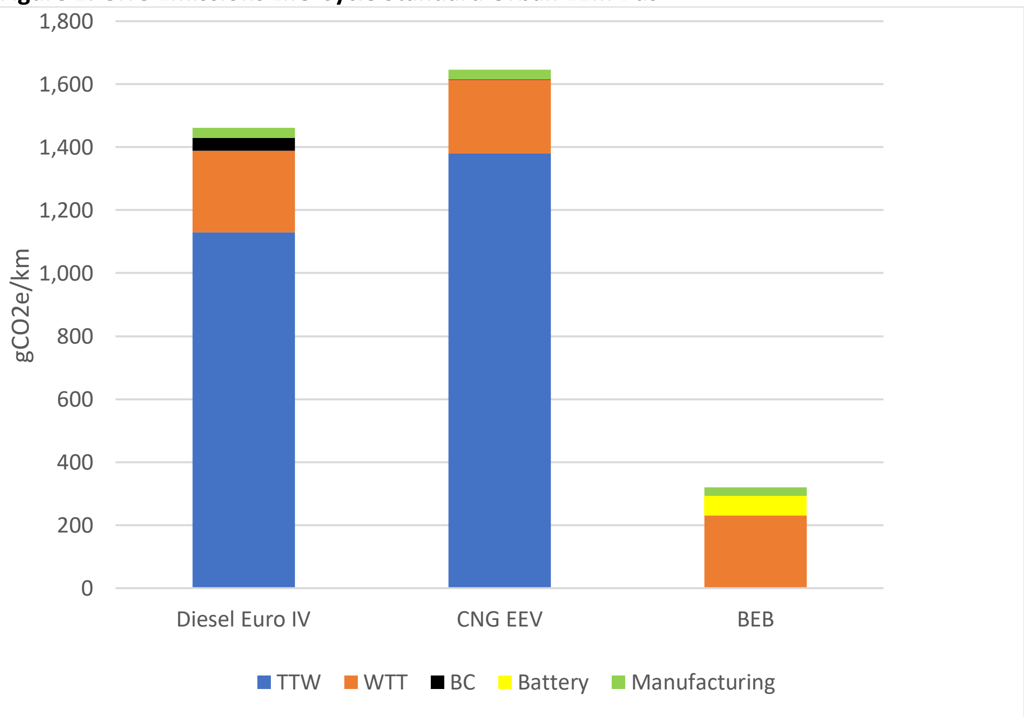
The calculated impact of EVs refers to the impact of EVs financed through the Program with GCF funds.

6.2. Source of Emission Reductions

The emission reductions (ERs) are due to EVs having lower WTW GHG emissions than fossil units. Operating EVs instead of fossil units thus reduces GHG emissions. This impact is due to switching the energy base of the vehicle from fossil fuels to electricity.

EVs will be used identical to the existing fossil vehicle. EVs are purchased instead of acquiring a new fossil vehicle. Usage rates and usage purpose are identical. The following graphs show in an exemplary manner for 12m urban buses the magnitude of GHG reductions based on the median grid factor of Program countries. GHG reductions of electric buses compared to Euro IV diesel or CNG buses are on average 80%. Notable is that CNG buses, in contrary to frequent claims, do not reduce GHG emissions compared to diesel units. This is primarily due to their inefficiencies (high energy usage) as well as the methane slip occurring in the vehicle and at the filling station.

Figure 2: GHG Emissions Life-Cycle Standard Urban 12m Bus



TTW = tank-to-wheel; WTT = well -to-tank; CNG = Compressed Natural Gas; EEV = Enhanced Environmentally Friendly Vehicle; BEB = Battery Electric Bus
Source: Grutter Consulting; see Excel sheet Annex 22b for details

The figure is for illustrative purposes and to show that indirect or leakage emissions are lower for e-buses than for fossil units. **For Program GHG calculations the comparison is between WTW GHG emissions of fossil versus electric units without including Black Carbon, methane slip or vehicle manufacturing related emissions.**

For pollutants EVs have 0 combustion emissions and thus reduce these pollutants by 100%. The absolute magnitude of reduction depends on country circumstances (primarily prevalent vehicle emission standard and mileage).

6.3. Vehicle Scrapping

Calculated emission reductions (ERs) in the framework of the E-mobility Program are fully independent and non-related to the existence or not of a vehicle scrapping program. Vehicles are purchased due to requiring a new unit. What type of vehicle is being replaced is irrelevant. Relevant is the comparison between the Business as Usual (BAU) purchased vehicle and the EV. The comparison in terms of emission reductions is thus made with a new fossil vehicle and not with the old replaced vehicle.

The investor has basically 2 options for a replacement investment:

- Replace the old fossil vehicle with a new fossil unit (baseline or BAU);
- Replace the old fossil vehicle with a new electric unit (project case).

For an expansion investment the options are similar:

- Purchase a new fossil unit to expand services (baseline or BAU);
- Purchase a new EV to expand services (project case).

In the baseline case (1) and in the project case (2) we have exactly the same amount and type of old fossil vehicles which are replaced. Implementing the project does not change this situation i.e. the vehicle would continue to circulate if a new fossil bus was purchased or if a new EV was purchased. There is no logic in an argument that if a new fossil unit would be purchased the old vehicle discontinues operations not however if a new EV is purchased. As a consequence, the Program implementation, does not have an incremental positive or negative impact derived from what happens with the old fossil units. If these are continued to be used, scrapped or sold is exactly the same in the BAU scenario as in the project scenario. Whatever happens to the old vehicles is thus materially irrelevant.

The confusion created by some organisations and persons derives from being focused on the replaced vehicle and comparing “new” with “old” instead of comparing a baseline or BAU situation against a project situation where the alternatives are in both cases to purchase a new vehicle irrespective of what happens to the old unit. No units are retired prior their remaining commercial lifespan – neither in the baseline case of fossil vehicles nor in the Program case with EVs.

One could theoretically argue that scrapping will increase ERs beyond the simple comparison of fossil and EVs i.e. a Program with scrapping would have more ERs than one without. First, the proposed Program does not claim any ERs which go beyond a simple vehicle comparison of BAU vehicle with EV. Secondly such a scrapping program could be realized, and has been realized, with pure fossil vehicles i.e. is not related to the vehicle technology. Whilst scrapping programs are acclaimed for obvious reasons by vehicle manufacturers their actual impact on GHG emissions is however very questionable due to:

- New vehicles are used more and have higher mileages than old ones[5]. This is clear with passenger cars, but also the case in commercial vehicles due to higher reliability rates and lower operating costs of new units versus old ones. Whilst the new vehicle might have lower emissions per km, the total mileage might increase resulting in higher emissions than in absence of a scrapping program.
- In terms of fuel usage new vehicles are not necessarily more fuel efficient than old units. The fuel usage of Heavy Duty Vehicles is for example since the vehicle emission standard Euro I constant[6]. Vehicle deterioration factors for fuel usage and emissions are very low (Borken-Kleefeld, 2015) (Rexeis, 2005) - newer versions of the EU COPERT model have therefore also downward adjusted deterioration rates.
- Old units might have replaced even older units in rural areas or for less frequently used vehicles. A typical pathway is followed e.g. by the Indonesian bus operator DAMRI (state owned entity) which uses their buses in urban settings like Jakarta for 8 -10 years and then moves these buses to smaller rural sites where they are used for another 8 years before being sold for usage as low-mileage units by schools or for company staff transport. If vehicles are scrapped this trickle-down effect is not given and rural sites might end up without public transport services as new buses would be too expensive especially given the low annual mileage.
- If service demand exists old units might enhance service supply levels and convenience for public transport users resulting in additional passengers being transported.
- Scrapping reduces the commercial lifespan of scrapped vehicles thus increasing upstream vehicle manufacturing emissions per unit of distance.

Whilst scrapping might have some limited merits for pollutants (as newer vehicles comply with more stringent emission standards) their impact on GHG emissions is considered to be negative in general.

6.4. Project Boundary

The geographic boundary is, in accordance with the CDM methodology AMS.III.C, the geographic area where the project activity vehicles are operated. The project boundary also includes the power plants connected physically to the electricity system that supply power to the project. This is reflected in the carbon grid factor (see chapter 5).

6.5. Emission Sources

In accordance with other CDM transport methodologies (see e.g. table 2 of ACM0016) only CO_2 emissions are included for liquid fossil fuel vehicles and for gaseous units additionally CH_4. For baseline vehicles using liquid fossil fuels CH_4 emissions are a minor emission source of the total CO_{2e} emissions. Neglecting these emissions in baseline as well as project emissions is conservative as fuel consumption and thus also CH_4 emissions are reduced through the project. N_2O emissions are a minor source of the total CO_{2e} emissions in transport vehicles. Neglecting these emissions in baseline as well as project emissions is conservative as fuel consumption and thus also N_2O emissions are reduced through the project.

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[5] See national vehicle registration data related to age and mileage e.g. Germany, UK, USA or (Goel, 2015)

[6] See 2016_09_Blog_20_years_no_progress_methodological_note_final.pdf (transportenvironment.org)

6.6. Baseline Determination and Additionality

The baseline scenario is defined in accordance with paragraph 22 of the UNFCCC CDM methodology AMS-III.C, Version 15 "Emission reductions by hybrid and electric vehicles" as the operation of comparable vehicles that would have been used to provide the same transportation service. In the same methodology the additionality is proven either through a barrier approach (Option 1; paragraph 20) or through showing that the market share of electric/hybrid vehicles of the same category is less than 5% in the region (Option 2, Paragraph 21). All program countries have only pilot fleets of EVs which are far less than 1% of vehicle stock of the same vehicle category with exception of Colombia for buses. However also in this case the share of e-buses is below 1%: Colombia has 588 e-buses[7] of a total of 111,000 buses (Ministerio de Transporte, 2020) i.e. a share of 0.5%.

6.7. Mitigation Period

The mitigation period is based on the commercial and legal vehicle usage lifetime (whichever earlier). This is county and vehicle category specific due to differing regulations, concession contracts and vehicle usage rates (vehicle mileage). Emission reductions are claimed for the entire commercial vehicle lifespan[8].

6.8. Methodological Approach

The methodological approach to determine vehicle emissions is based on IPCC as used also by the UNFCCC for transport methodologies. It is based on fuel consumption multiplied with the Net Calorific Value of the Fuel and the CO_2 Emission factor of the fuel used (IPCC, 2006).

A WTW approach excluding Black Carbon and Methane slip emissions is used. The same approach is used for fossil fuels as for electricity. It would be inconsistent to include for electricity upstream emissions and not so for fossil fuels. The CDM includes them as leakage emissions[9], and the Upstream Emission Factors are taken from the UNFCCC/CDM. A WTW approach independent of the energy source is methodologically consistent and as realistic as possible neither under- nor overestimating GHG impacts.

EVs are purchased instead of fossil vehicles in the implementation period of the Program. The most advanced vehicle emission standards of the respective country is used as baseline case. In the baseline situation the same vehicle would be purchased in the same year as the EV and therefore will not have during its lifespan an improvement factor. For the 5-year sourcing period the same average fuel consumption of new units is considered as baseline vehicles do not get automatically more efficient[10].

The equations used for calculations are (see for details chapter 2):

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[7] E-BUS RADAR - E-BUS RADAR (ebusradar.org)

[8] Differences of lifespan of vehicles do not result in proportional differences of GHG emission reductions as in general longer lifespans are coupled with lower usage rates i.e. the lifespan mileage is relevant for GHG impacts but the vehicle age is relevant for attribution of GHG reduction per annum.

[9] Basically due to being a trading regime and as such only ERs which occur in the country can be traded

[10] (EEA, 2020) uses constant fuel consumption values for vehicles since Euro 1/I; For heavy duty vehicles including buses see 2016_09_Blog_20_years_no_progress_methodological_note_final.pdf (transportenvironment.org); see also (Green for Growth Fund, 2018)

For ***fossil vehicles*** : $EF_{km,i,WTW} = \sum_y EF_{km,i,y,TTW} \times UEF_y$ (4)

Where:

$EF_{km,i,WTW}$	Well-to-wheel emission factor per kilometre of vehicle category *i* (gCO_{2e}/km)
$EF_{km,i,y,TTW}$	TTW emission factor per kilometre of vehicle category *i* using fuel type *y* (gCO_2/km)
UEF_y	Upstream emission factor for fuel type *y* (no unit)
i	vehicle category
y	fuel type

For ***battery electric vehicles:*** $EF_{km,BEVi,WTW} = EC_i \times CF_{elec}$ (5)

Where:

$EF_{km,BEV,WTW}$	Well-to-wheel emission factor per kilometre of BEV category *i* (gCO_{2e}/km)
EC_i	Electricity consumption of BEV category *i* per kilometre (kWh/km)
CF_{elec}	Carbon factor of electricity grid (gCO_{2e}/kWh)

Emission reductions are the product of number of vehicles, lifetime mileage and differential EF. For BEVs:

$$ER_i = BEV_i \times DD_i \times LS_i \times \left(EF_{km,i,WTW} - EF_{km,BEVi,WTW}\right) \times 10^{-6} \quad (6)$$

Where:

ER_i	Emission reduction lifespan of BEV category *i* (tCO_{2e})
BEV_i	Number of BEVs purchased with Program funds of category *i* (no unit)
DD_i	Annual distance driven BEV category *i* (km)
LS_i	Lifespan of BEV category *i* (no unit)
$EF_{km,i,WTW}$	Well-to-wheel emission factor per kilometre of fossil vehicle category *i* (gCO_{2e}/km)
$EF_{km,BEVi,WTW}$	Well-to-wheel emission factor per kilometre of BEV category *i* (gCO_{2e}/km)
i	Vehicle category (buses, taxis, LCVs, trucks, vessels)

The major **assumption** used is that EVs and fossil vehicles are of the same usage type and can be used for the same purposes with a comparable service level.

6.9. Data Sources

The calculations are based for the 4 projects on local values for baseline vehicles. For overall calculations default values per vehicle category are used. The following table lists parameters used for calculations and data sources.

Table 3: Standard Values Used for Calculations

Parameter	Value	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
NCV of CNG	48 MJ/kg	(IPCC, 2006), table 1.2
CO_2 emission factor of CNG	56.1 gCO_2/MJ	(IPCC, 2006), table 1.4
Density of NG	0.714 kg/m^3	(IEA, 2005)
Well-to-tank mark-up factor CNG	18%	(UNFCCC, 2014), Table 3
GWP_{100} of CH_4	29.8	IPCC AR6[11]

[11] IPCC Sixth Assessment Report (AR6) Global Warming Potentials - (ercevolution.energy)

Carbon grid factor	Per country	IFI, Version 3.1, 2022

7. Impact of Mode Shift to Public Transport

7.1. Introduction

The impact of Public Transport (PT) refers to measures taken to increase the PT ridership and make PT usage more attractive thereby contributing to mode shift.

7.2. Source of Emission Reductions

The emission reductions (ERs) are due to an increased number of PT users with PT having a lower emission factor per passenger-kilometre than cars, taxis of motorcycles.

7.3. Project Boundary

The geographic boundary is, in accordance with the CDM methodology for Mass Rapid Transit Systems ACM0016, the larger urban zone of the city in which the project takes place. It is based on the origins and destinations of passengers using the project system. As the project cannot control the trip origins or destinations of passengers the spatial area of the project is the entire larger urban zone of the city in which the project operates. The project boundary also includes the power plants connected physically to the electricity system that supply power to the project. This is reflected in the carbon grid factor (see chapter 5).

7.4. Emission Sources

In accordance with other CDM transport methodologies (see e.g. table 2 of ACM0016) CO_2 is included for baseline vehicles CO_2 and for countries using as baseline vehicles gaseous units CH_4. For baseline vehicles using liquid fossil fuels CH_4 emissions are a minor emission source of the total CO_{2e} emissions. Neglecting these emissions in baseline as well as project emissions is conservative as fuel consumption and thus also CH_4 emissions are reduced through the project. N_2O emissions are a minor source of the total CO_{2e} emissions in transport vehicles. Neglecting these emissions in baseline as well as project emissions is conservative as fuel consumption and thus also N_2O emissions are reduced through the project.

7.5. Methodological Approach

The methodological approach to determine vehicle emissions is based on the UNFCCC methodological tool 18: “Baseline emissions for modal shift measures in urban passenger transport”. This is used to determine the emission factor per pkm per baseline mode. Baseline modes are thus non-public transit. The project increases the scope of public transport and the bus ridership.

A WTW approach is used. The same approach is used for fossil fuels as for electricity.

The equations used for calculations are:

$$EF_{km,i,WTW} = \left\{\sum_y SFC_{i,y} \times NCV_y \times EF_{CO2,y} \times UEF_y + EC_i \times CF_{elec} \times \frac{N_{i,y}}{N_i}\right\} \quad (7)$$

Where:

$EF_{km,i,WTW}$	Well-to-wheel emission factor per kilometre of vehicle category *i* (gCO_{2e}/km)
$SFC_{i,y}$	Specific fuel consumption of vehicle category *i* using fuel type *y* (g/km)
NCV_y	Net calorific value of fuel type *y* (MJ/g)
$EF_{CO2,y}$	CO_2 emission factor of fuel type *y* (gCO2/MJ)
UEF_y	Upstream emission factor for fuel type *y* (no unit)
EC_i	Electricity consumption of EV category *i* per kilometre (kWh/km)
CF_{elec}	Carbon factor of electricity grid (gCO_{2e}/kWh)
$N_{i,y}$	Number of vehicles of vehicle category *i* using fuel type *y* (no unit)
N_i	Number of vehicles of vehicle category *i* (no unit)

The emission factor per pkm results from the emission factor per km divided by the occupation rate per vehicle category:

$$EF_{pkm,i} = \frac{EF_{km,i,WTW}}{OC_i} \quad (8)$$

Where:

$EF_{pkm,i}$	Emission factor per passenger-kilometre of vehicle category *i* (gCO_{2e}/pkm)
$EF_{km,i,WTW}$	Well-to-wheel emission factor per kilometre of vehicle category *i* (gCO_{2e}/km)
OC_i	Average occupation rate of vehicle category *i* (passengers)

Baseline emissions are then the additional pkm on public transport multiplied with the differential emission factor of baseline modes with bus-based public transport.

$$ER_{PT} = \sum_i (S_i \times (EF_{pkm,i} - EF_{pkm,PT})) \times AP_{PT} \times TD_{PT} \quad (9)$$

Where:

ER_{PT}	Emission reduction due to increased usage of public transport (tCO_{2e})
S_i	Share of additional PT passengers which would have used vehicle category *i* (%)
$EF_{pkm,i}$	Emission factor per passenger-kilometre of vehicle category *i* (gCO_{2e}/pkm)
$EF_{pkm,PT}$	Emission factor per passenger-kilometre of public transport (gCO_{2e}/pkm)
AP_{PT}	Additional passengers on public transport (million passengers)
TD_{PT}	Average trip distance of public transport user (km)
i	Baseline vehicle category (cars, taxis, motorcycles)

The additional passengers on PT are directly due to usage of electric buses and due to measures taken with programs to improve PT. Customers will appreciate an EV more due to less noise and due to a positive image and therefore ridership of electric buses could increase resulting in a positive mode shift towards EVs. A report found for example that e-buses could attract 1.9% additional ridership compared to diesel units (Currie G. , 2018).

A meta-study looking at the impact of integrated ticketing (including ease of interchange and simplified fares) including 14 cities from different countries showed that this measure increased patronage by 24% (median value of all cities involved) (booz&co, 2009). A Swedish study focusing on PT improvement measures such as route re-restructuring resulted in average increases of patronage of 18.5% (Khan, 2021). For calculation purposes a 20% increase of bus ridership was assumed due to measures for PT enhancement, which means the downward trend of PT usage could be stopped.

7.6. Data Sources

The calculations are based on the PT passenger numbers per city and the default factors listed below.

Table 4: Defaults PT GHG Emission Calculations

Parameter	Value	Source
Projected additional patronage due to multiple measures	20%	Khan, 2021 and booz&co, 2009
Additional patronage from cars	100%	Conservative assumption as other motorized modes excluding PT are higher emitting (taxis/ride-hailing), or do not have a significant mode share for private usage (motorcycles are used more for commercial purposes); NMT mode change is modelled in NMT
Assumed lifespan	25 years	Standard infrastructure lifespan

The same approach is used for pollutants as for GHGs. For energy savings fossil fuel and electricity is converted to TJ.

8. Monitoring

Monitoring of GHG parameters is discussed in detail in Annex 11b Monitoring Manual

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