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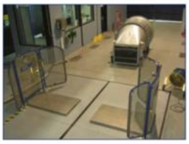

A Report from the Advanced Motor Fuels Technology Collaboration Programme

Sustainable Bus System (Phase 1)

Marcela Castillo, Sebastián Galarza, Gianni López
Centro Mario Molina Chile.

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3CV, Ministry of Transport and Telecommunications of Chile.

ADVANCED MOTOR FUELS
IEA-AMF

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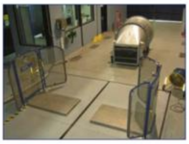
Annex 53-1



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March 2018

Presentation

During 2016 and 2017, a collaboration project was made between the international research centers and the Ministry of Transportation and Telecommunications, within the framework of the Technical Collaboration Program of the International Energy Agency called *Advanced Motors Fuels* (AMF), whose purpose was to generate a first bus technology evaluation system in Chile, which would serve as an example that can be replicated in other developing countries. This project, called the "Development of an Energy Efficiency and Emissions Labeling System for Transantiago Buses" was made possible thanks to the participation of the Chilean Ministry of Transportation and Telecommunication's 3CV, the Finnish Technological Development Center - VTT and the Swedish Transportation Authority - Trafikverket. It also involved the valuable cooperation of the Chilean Energy Ministry, Canada's *Environment and Climate Change* and the *Argonne National Lab* from the United States. All of this brought together under AMF's "*Sustainable Bus System*" project.

Executive summary

This report presents the results and conclusions of the "Development of an Energy Efficiency and Emissions Labeling System for Transantiago Buses" project, carried out under the CORFO technology contract modality between ENEL and Centro Mario Molina Chile. It has involved the active participation and interest of the Chilean Ministry of Transportation and Telecommunications (MTT). The project has contributed to the International Energy Agency's Technical Collaboration "Advanced Motor Fuels" program, which our country has participated with Finland, Sweden and Canada in the development of a first example of the bus evaluation procedure for developing countries.

The project's aim was to design a representative driving cycle for the city of Santiago, using laboratory measurements, along with a proposal for a labeling system which includes the procedures needed to certify energy efficiency and emissions from the different public bus technologies. This will allow promoting the adoption of advanced, innovative, clean and efficient technologies

The project has three components: 1) the design of a driving cycle and test procedures which represent the operating conditions of buses in the Santiago public transportation system, 2) the development of a testing program for buses with advanced technologies in Santiago and in Europe, using the Santiago buses cycle and finally, 3) the preparation of recommendations both for the use of the Santiago buses cycle, and for the test procedures which MTT carries out during the evaluation and selection of bus technologies that will enter the Santiago public transportation system's fleet, so that these contribute towards energy efficiency and reducing the system's emissions.

The Santiago buses cycle was made based on the statistical processing of operational information collected in a sample of bus routes from Santiago's public transportation system, mainly following methodologies of the United States Environment Agency.

A test program for the buses was also developed using the Santiago bus cycle in the VTT's heavy duty vehicles laboratories in Helsinki and

3CV's in Santiago. The program's goal was to compare the results of testing buses in the Santiago cycle with other similar ones done in other countries, along with the evaluation of the behavior of new bus technologies in the Santiago cycle[1]. The program considered collecting key operation parameters of the engine/vehicle during road tests and on the dynamometer.

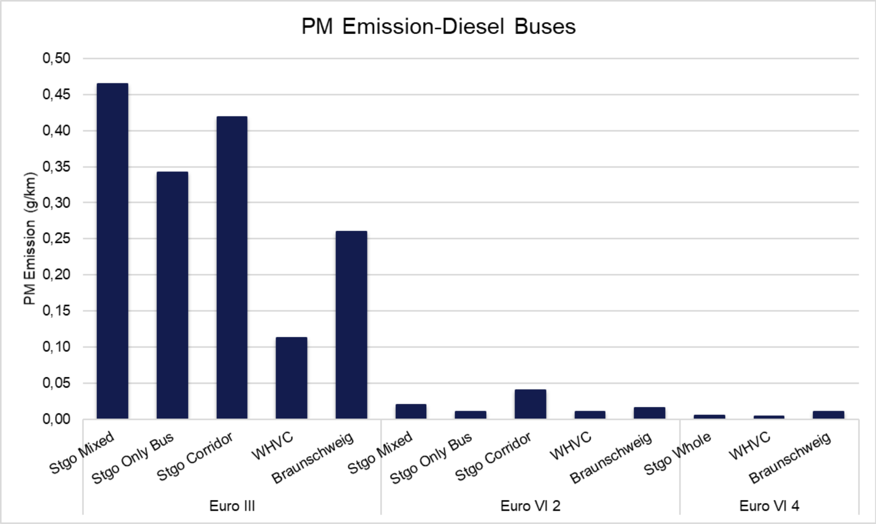
The laboratory tests addressed the following bus technologies:

- Euro III Diesel
- Euro V Diesel
- Euro VI Diesel
- Euro VI CNG
- Electric

Alongside this, the Autonomie vehicle modeling software was used to simulate the behavior of the different bus technologies being tested in VTT's laboratories with the Santiago bus cycle. During the modeling, changes were made in variables which are critical for the buses performance, like for example, passenger load and slopes.

In addition, a series of recommendations were made for the use of the Santiago buses cycle and its testing procedures, looking to improve the incorporation process of new technologies into the Santiago public transportation system. This section required an exhaustive review of similar international experiences, all within the framework which regulates the authorization and use of buses in Santiago.

[1] During the preparation, professionals from the Ministry of Transportation and Telecommunications and CMM were trained in VTT's laboratories, especially in testing vehicles with advanced technologies.



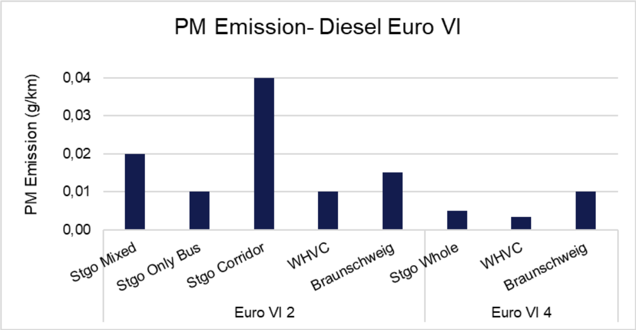


Figure 1: PM emission from Urban Buses under different driving cycles.

The project's results indicate that the operating conditions of buses in a city like Santiago are very demanding compared to cities in Europe or the United States. By calculating the method's parameters, using the Art.Kinema[2], it was possible to determine a broad range of descriptive values for defined driving cycles. These parameters allow quantitively analyzing and comparing driving cycles with different resolutions and lengths.

[2] Prepared by the Swiss organization, INFRAS

On comparing the parameters of the Santiago cycle with Braunschweig, it was seen that the average speed of both cycles is around 20 km/h. The average driving speed is similar (approx. 32 km/h), but the Santiago cycle is about 8km longer and with longer stopping times, which has an impact on the acceleration times and magnitudes. This is reflected in the relative positive and positive kinetic energy acceleration values which are considerably higher.

The bus testing program showed that buses operating in a developing city, like Santiago, can have high local contaminant emissions.

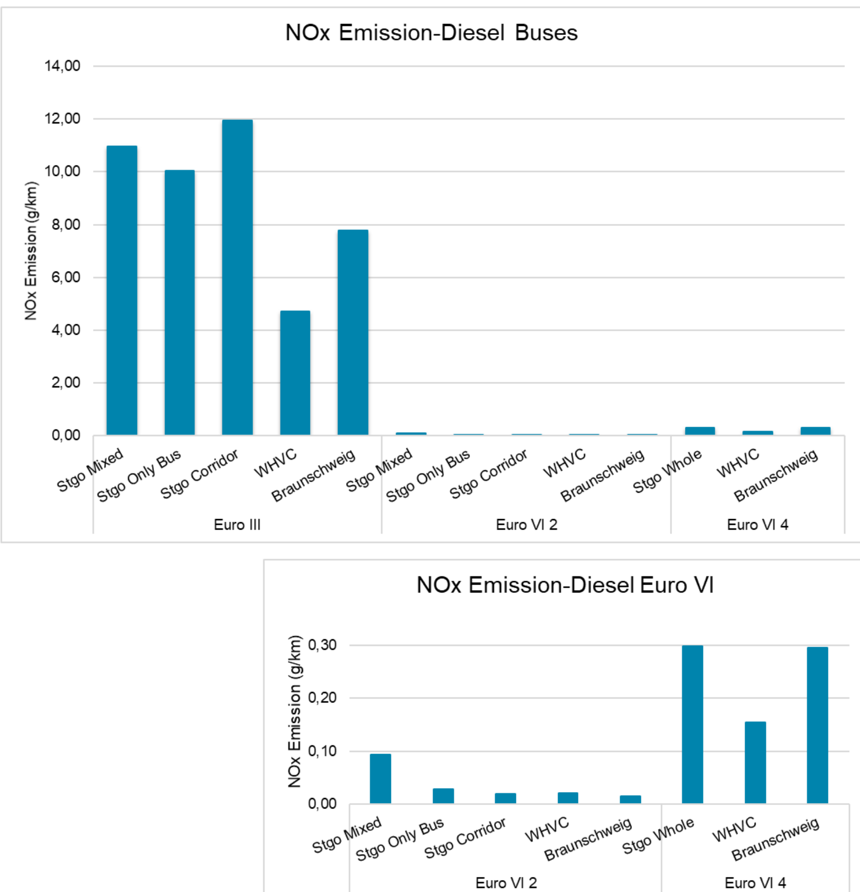


Figure 2: NOx emission from Urban Buses under different driving cycles.

Likewise, the results indicate that more advanced emissions control technologies in buses with diesel engines, like the Euro VI, produce very good results in PM control, even under complex conditions, similar to what was seen with buses with CNG engines.

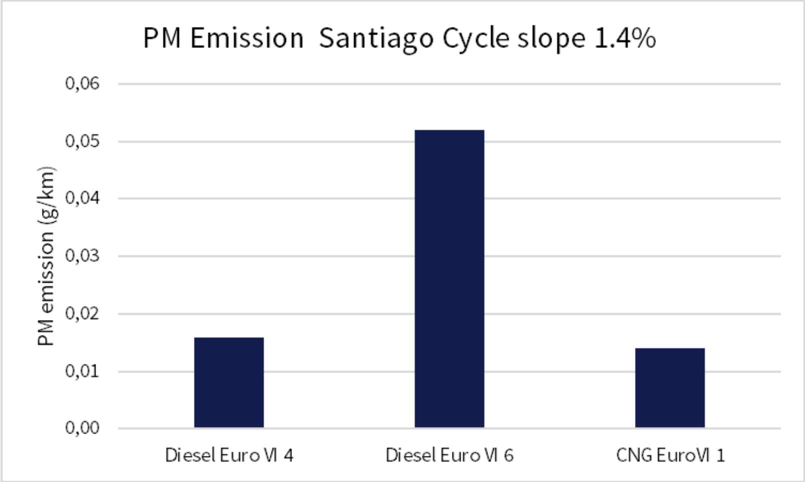


Figure 3: PM Emissions of Urban buses. Santiago Cycle - 50% payload and 1.4% slope

In regard to the energy efficiency of conventional buses, this does not greatly improve with diesel and more advanced CNG buses. A higher energy consumption is seen in the Santiago bus cycle than in Braunschweig, which is frequently used in Europe, due to the greater demands the former has.

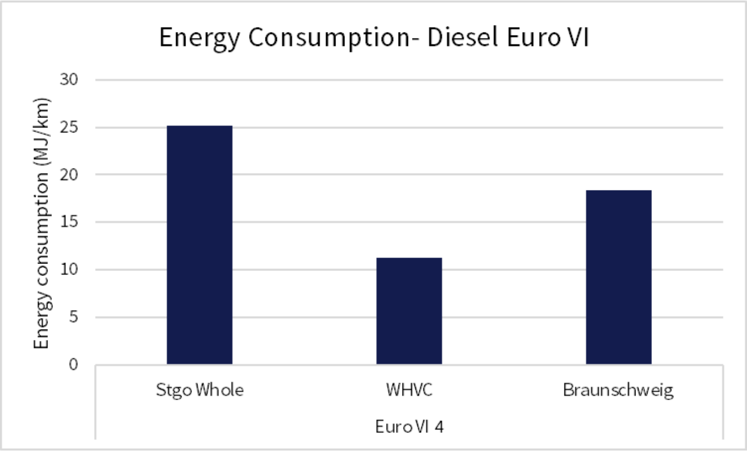


Figure 4: Energy consumption in a Euro VI Bus under different driving cycles

Electric buses are seen to be noticeably more efficient that conventional buses, even under demanding operating conditions during the Santiago bus cycle. Independent from this advantage, the energy consumption is higher than seen in other cycles with less demanding operating conditions; however, these differences may vary depending on the technology used by the electric bus.

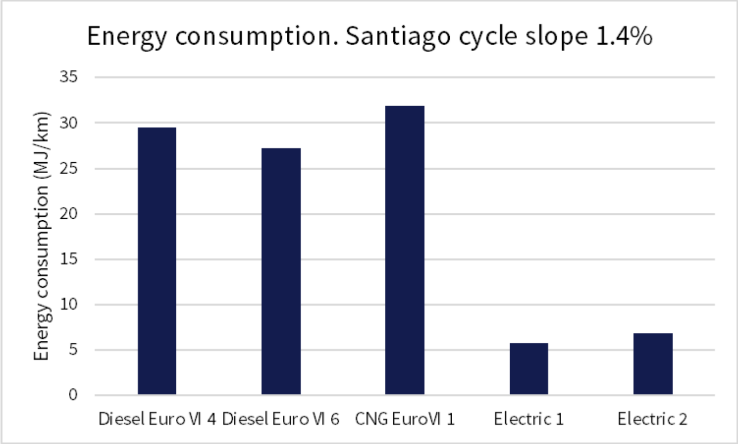


Figure 5: Energy consumption of urban buses. Santiago Cycle - 50% payload and 1.4% slope.

The passenger load and the slope the buses must overcome, has an important impact on the vehicle's energy consumption. The bus technologies have different results, mainly due to weight differences and differences in the capacity to store regeneration energy between the two electric bus technologies evaluated.

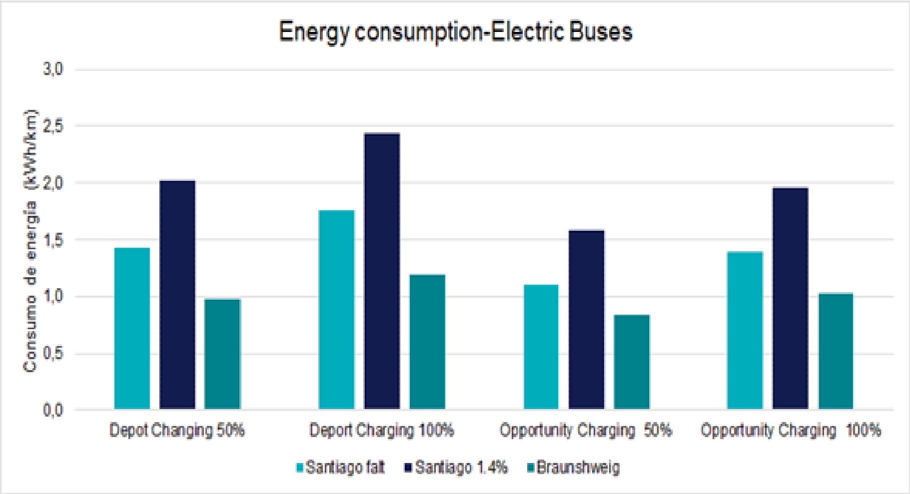


Figure 6: Modeling of energy consumption in urban electric buses under different conditions: cycles, payloads and slopes.

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Abbreviations

3CV	Vehicle Certification and Control Center
AAM	Alliance of Automobile Manufacturers
ACEA	European Automobile Manufacturers Association
AMF	Advance Motor Fuels
APTA	American Public Transportation Association
APU	Auxiliary Power Unit
BEB	Battery Electric Bus
BEVs	Battery Electric Vehicles
CARB	California Air Resources Board
CBG	Compressed Biogas
CCAC	Climate and Clean Air Coalition
CH4	Methane
CMMCh	Centro Mario Molina Chile
CO2	Carbon Dioxide
CORFO	Production Development Corporation
DPF	Diesel Particles Filter
DTPM	Metropolitan Public Transportation Board
Evs	Electric Vehicles
f0, f1, f2	Load Coefficients
FAS	Free acceleration smoke
GHG	Greenhouse Gas
GEM	Greenhouse Gases Emissions Model
CNG	Compressed Natural Gas
LNG	Liquid Natural Gas
LNG	Liquid Natural Gas
GPS	Global Positioning System
GVW	Gross Vehicle Weight
HDV	Heavy Duty Vehicle
HEVs	Hybrid Electric Vehicles
Hz	Hertz
I&M	Inspection and Maintenance
ICCT	International Council on Clean Transportation
IEA	International Energy Agency

IQR	Interquartile Range
JAMA	Japanese Automobile Manufacturers Association
JRC	Joint Research Center
kW	Kilowatt
LBG	Liquid Biogas
MJ	Megajoules
PM	Particulate Matter
MTT	Ministry of Transportation and Telecommunication of Chile
NEDC	New European Driving Cycle
Nm	Newton meter
NMHC	Non-Methane Hydrocarbon
NOx	Nitrogen Oxide
OBD	Onboard Diagnosis
OEM	Original Equipment Manufacturer
OICA	International Organization of Motor Vehicle Manufacturers
PEMS	Portable Emissions Measurement System
PHEVs	Pluggable Hybrid Electric Vehicles
PKE	Positive Kinetic Energy
AM Peak	Peak Hour - AM
BOL	Bus Only Lane
PM Peak	Peak Hour - PM
PTI	Periodic Technical Inspection
RPA	Relative Positive Acceleration
RPM	Revolutions per minute
SCR	Selective Catalytic Reduction
THC	Total Hydrocarbons
TRL	Transportation Research Laboratory (UK)
Trx	Transactions
EU	European Union
UITP	International Association of Public Transport
UNEP	United Nations Environment Program
US EPA	United States Environmental Protection Agency
VECTO	Vehicle Energy Consumption Calculation Tool
VTT	Finland's Technological Development Center
WHVC	World Harmonized heavy duty Vehicle Cycle
WLTP	Worldwide harmonized light vehicle test procedure

1 Introduction

In 2012, the AMF made a great contribution, at an international level, with the publication of the final report of the "*Fuel and Technology Alternatives for Buses*" project. This evaluated the energy efficiency, emissions and costs of several bus technology options, including diesel, Compressed Natural Gas (CNG), Hybrids and biofuels. The project shows that updates to emissions standards have provided a special reduction for particles, but at the same time, important improvements in energy efficiency have not been seen except in the case of hybrid buses and conventional buses built with light materials. It was also shown that the test cycles which represent the different operating conditions, have a very important effect on the results, being able to affect the emissions and energy consumption in a factor of 5 to 1.

Currently, the development of new vehicle technologies, which offer potential benefits in terms of reducing contaminant emissions is being seen, along with an increase in energy efficiency, which will bring major benefits for public transportation systems. The buses market has ever more options available, be these conventional with low emission diesel and with certificates under the Euro VI standard, to buses with CNG engines, hybrids and electric options. It is seen that electromobility is being deployed in nearly the entire spectrum of vehicle applications, with bus options with different types of batteries and charging solutions.

The major urban areas in developing countries have a high dependence on public transportation, as the result of lower motorization rates when compared to developed countries. It is for this reason that many cities in Latin America have large fleets of buses, some of them comprised by more than five thousand buses, as is the case of Mexico City, Bogota, Lima, Sao Paulo, Rio de Janeiro, Buenos Aires and Santiago. Most buses in these cities operate on routes with conditions that are very different to those seen in European cities. like the ones studied in AMF's "*Fuel and Technology Alternatives for Buses*" project. As such, having evaluation procedures which suitably represent these generally more complex differences, increases the possibilities of success in the deployment of new technologies.

Combined with this, it will allow evaluating the different bus technologies which are subjected to standardization processes for the domestic market, facilitating, in this way, more information of the behavior that they will have operating in the city of Santiago. This background information, along with the information facilitated by local representatives and manufacturers, will allow public transportation operators to make better decisions when incorporating new technologies in their fleets, while improving the monitoring of the evolution of emissions and energy efficiency standards in this relevant sector for the quality of life of the Capital's inhabitants.

2 Method

2.1 Development of a driving cycle for Santiago's public transportation

There is no single measurement pattern for fuel consumption tests. Although there are similarities in the measurement methods, there are important differences in the use of simulation models or chassis or engine dynamometers.

Figure 7 presents in a summarized manner, the different procedures which apply in the US, Japan, China and Europe. In terms of the payload factor, Europe, Japan and the US assume 50% of the entire payload that a vehicle can bear, while in China, they set a full payload. Regarding the aerodynamic and rolling coefficients, Japan is the only one that takes the standard values, while the rest of the countries are calculated through tests.

China is the only country that uses chassis dynamometers to measure the base vehicle fuel consumption, while the rest make tests on engine dynamometers. With regard to the cycles used, Japan includes the influence of the slope, though it is possible that Europe also includes it.

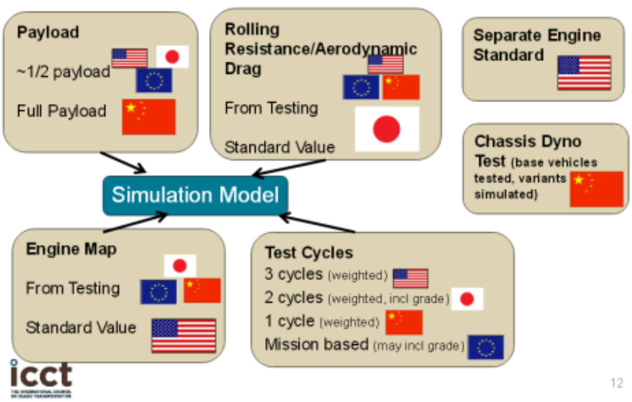


Figure 7: Comparison of the different measurement procedures, ICCT.

In particular, the driving cycles are used to make estimations of atmospheric contaminant emissions and fuel consumption, through procedures that involve programming these on an exhaust gas measurement system using chassis dynamometers. For this reason, if a good estimation of emissions or consumptions in a specific region is sought, it is essential that the driving cycles represent the real operating conditions of vehicles in this particular study area. If what is needed is to establish a standardized driving pattern to make comparisons or define norms which require specific conditions, then it is necessary to use a standardized driving cycle, which is accepted by all the parties involved in the regulatory process. In this last case, the cycle used does not necessarily have to represent real driving conditions, but it must allow for repetition under controlled laboratory conditions.

There are different cycles that have been approved internationally, which are potentially relevant for greenhouse gas emissions tests and for energy efficiency in urban buses. The following table presents the international cycles, highlighting that the Braunschweig cycle is the most commonly used one for emissions measurements of full buses, with an average speed of 22.6 km/h. On the other hand, the cycle which represents more stops, simulating a high traffic congestion, is the NY Bus cycle, where 65.2% of the measurement time is in idle mode (Barlow, Latham, & I S McCrae, 2009).

Table 1: Summary of driving cycles for buses.

Driving cycle	Distance (M)	Duration (s)	Average speed (km/h)	Idling (%)
Braunschweig City Driving Cycle	10,900	1,740	22.6	24.50
New York Bus Cycle	996	600	6.0	65.2
Manhattan Bus Cycle	3,333	1,089	11.0	35.90
Orange County Bus (OC Bus) Cycle	10,530	1,909	19.9	22.0
Millbrook London Transport Bus cycle (inner+outer London)	8,984	2,281	14.0	40.0
Helsinki 1			25.7	
Helsinki 2	857	1,503	19.5	29.0
Helsinki 3	10,300	917	40.6	16.0

Driving cycles have already been made for urban buses for Santiago. They highlight those of the study made for the Urban Transportation and Highway Program "SECTRA", which was developed considering the vehicle categories: trunk and feeder buses. Another study was made by the Foundation for Technological Transfer, which had the purpose of determining experimental emissions factors which consider service categories (Trunk-Feeder) (Mechanical Engineering Department, Universidad de Chile, 2007).

Developing a new driving cycle for Transantiago's buses is necessary, given that the operational conditions have changed as a result of the increase of the light car fleet, changes in bus technology, modification of routes and infrastructure.

2.1.1 Description of the fleet

The Transantiago fleet has approximately 6,500 buses, which cover around 370 services within Greater Santiago, without taking into account the short, nighttime or express routes, which cover around 460 million kilometers a year. The system currently operates three types of buses, which are classified by length: >14 meters, $11 \leq l < 14$ meters y <11 meters. The buses and their denominations are presented in the figure.

Clase	Largo (L) [m]
A1	8 ≤ L < 9
A2	9 ≤ l < 11
B	11 ≤ l < 14
C	l ≥ 14

Figure 8: Type of Buses, Article 2ºBis of SD 122

Bus type B is the most common one in the system. It represents around 62% of the fleet. It is also projected looking forwards, that this class of bus will continue to increase, due to the operational difficulties seen with class C buses. It is for this reason that the analysis made in this report is focused on this type of bus.

Santiago's public transportation system has 3 main types of infrastructure:

a) Mixed roads

Those where public transportation circulates with private vehicles and where there is no preference for buses. On the routes, 87% (on average) of the route is made along this type of road and these consider 92% of the highway network covered by buses (DTPM, 2014).

b) Bus only roads

These refer to streets where there is bus only roads, which do not have physical barriers and are generally painted red to recognize them. Around 4.3% of the public transportation highway network corresponds to these.

c) Corridor roads

These are roads that are physically separated, where only buses from the public transportation system run. There are approximately 70 km of these and they cover approximately 2.5% of the public transportation road network.

2.1.2 Selection of representative routes

First, the choice of routes which will represent the transportation system was made. A methodology to choose the routes that would later be equipped with buses for the study was made by the Ministry of Transportation and Telecommunication's 3CV with the Ministry of Energy. These were chosen based on the following parameters:

- Average driving speed
- Average length of each service
- Average occupation of the bus (using payment card transactions).
- Number of stops

2.1.3 Selection of time zone

Two timetable periods were determined, from which the routes would be chosen. These correspond to the Peak morning (AM-Peak) between 6.30am and 8:30am and Peak Afternoon (PM-Peak) between 5:30 pm and 8:30pm, according to the transport authorities. Then, the period with the lowest average speed and highest transaction period was chosen. It can be stated that the speed variation between timetable blocks[3] were not considered in the analysis, which is why the period of time which had most transactions with the payment card was adopted: Peak morning.

2.1.4 Selection of routes

The services which met the condition of being in the interquartile range (IQR) of all the key variables were chosen, such as the service length, number of stops, transactions with payment system, average speed and % on mixed roads (section2.1.3). Thus, in the case that the routes chosen were greater than 5 (case of mixed roads), the upper and

[3] Timetable classifications defined by the Metropolitan Public Transportation Board: pre-nighttime, nighttime, peak morning, off-peak morning, off-peak afternoon, peak afternoon, among others.

lower limits of the interquartile range were increased and decreased by 1% until obtaining 5 routes by each class of bus.

The interquartile ranges and minimum percentages values for the route selection are presented in the following tables.

Table 2: interquartile range which restricts the choice of representative routes for each variable

Class	Class B	
Percentile	$P_{37.5}$	$P_{62.5}$
Service length (km)	12.58	18.22
N° of Stops	34	49
Period transactions	8153	21949
Average speed (km/h)	17.12	18.75
Mixed	74.77	94.41

Table 3: Minimum condition to choose bus only and corridor routes.

Priority roads	Class B
Bus Only	>90%
Corridor	>60%

2.1.5 Data collection campaign

The data was collected between April and June 2016, during a campaign which measured the speed, geographical location and altitude above sea level with a geographical positioning device (GPS), meaning intervening in a bus was not necessary. The GPS models used have a 1Hz resolution and are Garmin Oregon 650, GPS Dual, Garmin Etrex Venture HC and Garmin GLO.

Apart from this, visual information was collated every 5 minutes through a site sheet which describes the following route parameters:

- Bus capacity: qualitative information which indicates the passenger capacity the bus carries (0, ½, 1).
- Stops: Information about extended stops on the route, corresponding to traffic, roadworks or accidents.

- Weather conditions: for example, rain.
- Type of public transportation infrastructure: general information about the roads the bus travels on: exclusive, corridors, bus only or mixed roads.
- General conditions of the bus's condition.

Table 4: dates of the information collection campaign.

Predominant infrastructure	Representative routes	Dates
Mixed	I14R	12-April/3-May 2016
	J16I	
	F01I	
	B19I	
	101c	
Corridor	507cI	17-May/31-May 2016
	519e	
Bus Only	201r	16-May/25-May 2016
	201I	

2.1.6 Identification of micro-trips

The methodology described by the Environment Protection Agency (EPA) for heavy vehicles (US EPA, 2003) was used to prepare the driving cycle, where the cycle's construction is based on micro-trips. The first step consists in the selection of micro-trips of the data. For this, the speeds and instantaneous accelerations of each piece of data had to be calculated (second by second).

During this process, the data with accelerations under -3.58 m/s^2 and over 2.42 m/s^2 (cycle limits of Braunschweig's urban buses) were discarded. In addition, the already filtered accelerations and speeds had to be approximated: speeds under 0.5 km/h were considered as 0 km/h and the accelerations of ± 0.1 m/s^2 = 0.

The following conditions must be met to identify a micro-trip.

$$t2<t1 \parallel t2-t1\neq 1 \parallel v2=0 \text{ and } v1\neq 0$$

It is underlined that the pieces of information that have the following characteristics are not considered as micro-trips.

1. Only values where speed = 0
2. ≤20 pieces of data
3. With only a speed value of ≠ 0

2.1.7 Speed-acceleration frequency distribution

The key point of the methodology to develop a cycle, is the selection and connection of the micro-cycles which can best represent the public transport bus's driving conditions. According to the methodology used, it is necessary to determine a target vector (T) to prepare the cycle. This represents the driving mode, in terms of speed and acceleration of the data collected onsite. Meanwhile, vector C is the result of the sum of vectors M_1, M_2 … M_n which represent the micro-trips. The strategy to prepare the cycle is to minimize the difference between these vectors (T-C).

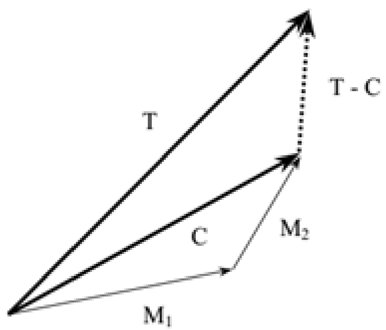


Figure 9: Graphical description of the methodology to prepare the driving cycle.

The vectors are representations of the frequency accumulated distribution both of the speed and the acceleration, SAFD. An SAFD is a combination of the two variables, where their continuous values were converted into frequency distributions by means of the classes, where each one of the values takes place in a determined class.

2.1.8 Selection of micro-trips

For this stage, the first micro-trip is sought, which has the smallest difference of minimum squares between the standardized elements, accumulated with the target elements. This means that the T-C is the smallest. The second micro-trip chosen corresponds to the one which, on adding this to the first, the distance between T and C was the least. For this, programming was done in MatLab. The code designed runs all the micro-trips until choosing the one that minimizes the difference between T-C. The code stops adding micro-trips when it completes the required number or the cycle's preset duration time.

2.2 Measurement program

A measurement program was made between 2016-2017 in the heavy vehicle laboratories of VTT and 3CV, where bus technologies were evaluated under the Santiago cycles in different slope and payload conditions. This allowed comparing the results under other driving cycles. To complement the measurements, CMMCh made energy consumption modeling with Autonomie[4], an advanced vehicle simulation tool which evaluates, among other parameters, the bus's performance. One of the advantages of developing simulations with Autonomie is having a virtual laboratory, where different urban bus setups can be modeled.

2.2.1 Chile

Before running the measurement program in 3CV's laboratory, a comparison of the cycle developed with the information of real routes was made. Its goal was to determine whether the bus was capable of operating within a normal range of operation, i.e., that the engine's parameters did not exceed the value observed in a regular operation of Transantiago's public transportation services.

[4] Developed by Argonne National Lab. of the University of Chicago and the US Department of Energy together with General Motors. It is also part of Siemens PLM Software.

2.2.1.1 Preliminary tests in the 3CV

To make the comparative analysis, a Mercedes Benz O500U Euro V bus was used for the test and data of two measurement sources: telemetry and scanner. The validations of each parameter were made comparing the results the two measurements produced. The first under normal operating conditions (telemetry) and the second in the laboratory with the developed cycle (scanner). The route chosen to analyze the parameters under normal conditions was 506 Maipu - Peñalolen of Metbus's business unit 5, which runs from west to east over 32.6 km and an average slope of 1.4%.

Figure 10: Characteristics of route 506: Route, distance covered, average slope.

It can be stated that the laboratory tests were run with a full cycle, warm start, without slope and with 50%, 70% and 100% payload capacity.

Figure 11: 3CV heavy vehicles laboratory, Chile

The telemetry system follows up on some of the bus's parameters like speed, turbo pressure, revolutions per minute, among others, so that the operation of the bus can be verified on route 506 and in the laboratory under the same demands of the driving cycle. The tests with the scanner are done in the same way. This collects information from a datalogger connected to the bus's CAN system where the parameters are stored.

Table 5: Telemetry and scanner parameters used to validate the Santiago cycle.

Parameters	
Telemetry	Scanner
RPM	RPM
Coolant temperature (˚C)	Power (kW)
Oil temperature (˚C)	Torque (Nm)
Fuel level (%)	Consumption (l/100km)
Diesel exhaust fluid (%)	
Oil pressure (bar)	
Speed (km/h)	
Turbo pressure (Pa)	

2.2.1.2 Dynamometer's adjustments and parameters

The adjustment of the dynamometer's load is made with the Artemis method, using theoretical load coefficients[5]. The chassis' dynamometer is a AVL Zoellner Gmbf, RPL 1220/12/ 28 M 25/APM 300 model. Its characteristics are presented in

Table 6.

Table 6: Characteristics of 3CV's chassis dynamometer.

Maximum power	300 kW
Maximum force	30,000 N
Maximum speed	150 km/h
Rolling diameter	48 inches
Maximum load per axle	10,000 kg
Maximum mass simulation	30,000 kg

[5] With theoretical load factors (F0, F1, F2)

2.2.1.3 Characteristics of buses and fuels

A summary table is presented below with the buses and fuels used in the Chile tests:

Table 7: Buses used in 3CV's tests

Emissions standard	Fuel	Length	Gross vehicle weight (GVW) Kg	After Treatment
Euro VI	Diesel	13.2m	18,000	SCR+DPF
Euro VI	Diesel	11.8 m	18,000	SCR+DPF
Euro V	Diesel	13.2 m	18,500	SCR
BEV	Battery electric	12 m	19,000	

The fuel used in the 3CV was commercial diesel with a density of 0.846 kg/l with a calorific value of 42.48 MJ/kg.

2.2.2 Finland

2.2.2.1 Dynamometer's adjustments and parameters

The VTT uses a load model for typical double axle buses, based on the measurement of the decelerations on a lane especially set up for the test to determine the dynamometer's adjustments (F0, F1, F2), the resistance to rolling of the rear tires and their axle, as well as deducing the total resistance value. This method is common to configure the values in a dynamometer.
It is really important to consider that the bus's mass is decisive for the driving resistance when a cycle is made in a typical transient city.

2.2.2.2 Characteristics of buses and fuels

In VTT's laboratory, diesel, CNG and electricity was used. The main characteristics of the buses tested are presented in the following table.

Table 8: Buses used in the VTT tests.

Emissions standard	Fuel	Length	Gross vehicle weight (GVW) Kg	After Treatment
Euro VI	Diesel			SCR+DPF
Euro VI	Diesel			SCR+DPF
Euro VI	CNG	12.14 m	19,000	
BEV	Battery electric	12 m	15,000	

2.2.3 Simulation with Autonomie

Its Applications cover energy consumption and performance analysis for different vehicle setups, including:

- Impact on the sizing of components for different propulsion systems, as well as how to define the requirements of the components like power and energy.
- Impact on component technologies (like advanced transmissions, engine, differentials, wheels, batteries, etc.)
- Comparison between different propulsion system setups like conventional electric vehicles vs. hybrid vehicles vs. pluggable hybrid electric vehicles vs. hybrid electric vehicles with fuel batteries, etc.

For Autonomie to work, it is necessary to input some entry data like the vehicle's components, including engine, transmission system, differentials, types of wheels, batteries, weights, sizes, etc. It is also necessary to input the driving cycle, including speed and slope per second. After this, the configuration of the components, engine map and performance must be defined. The data provided includes energy consumption and efficiency, CO_2 emissions and costs assessment.

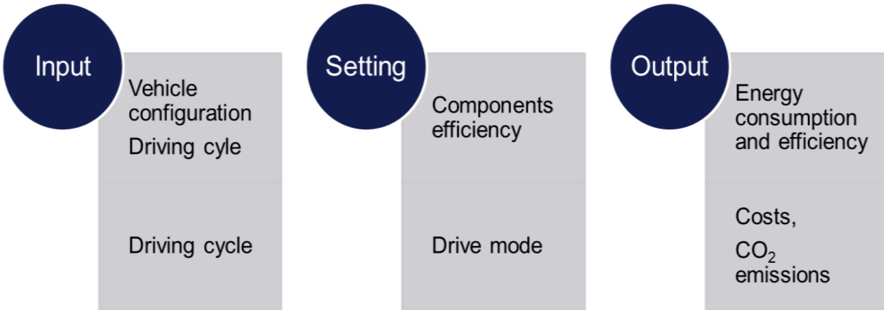


Figure 12: Simplified outline of the input, setup and output parameters needed to use Autonomie.

2.2.3.1 Input data: vehicle's setup

The characteristics of the simulated buses is presented below. This corresponds to one of the pieces of information required by Autonomie.

2 types of Mercedes Benz diesel buses have been setup, O500U Euro V and OC500LE Euro VI. The Euro V model is only considered for the purposes of the model's sensitivity analysis.

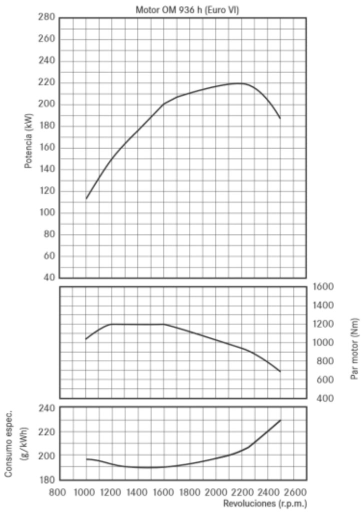
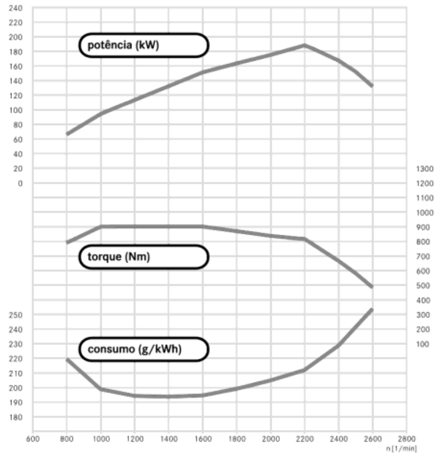
Table 9: Setup of the modeled buses (Kaufmann, 2017).

Brand	Mercedes Benz	
Technology	Euro V	Euro VI
Chassis	O500U	OC500LE
Gearbox	ZF Ecolife 6 AP 1200 B	ZF Ecolife 6 AP 1200 B
Engine	OM926LA	OM936
Cylinder arrangement	6 in line	6 in line
Cylinder capacity	7700 cc	7700 cc
Maximum power	188 kW	220 kW
Maximum pair	900 nm (1200 to 1600 RPM)	1200 nm (1200 to 1600 RPM)
Maximum authorized weight	18500 kg.	18600 kg.

Table 10: Specific setups of each bus model (Kaufmann, 2017)

Chassis Parameters							
Model	O500U			OC500LE			
Maximum vehicle length	13200 mm			13200 mm			
Maximum vehicle width	3000 mm			2400 mm			
Maximum distance between front axle and drive shaft	2486 mm			3000 mm			
Front overhang	3350 mm			2570 mm			
Rear overhang	2900 mm			3200 mm			
Tire size	295/80 R 22.5			295/80 R 22.5			
Front track width	1824 mm			2101 mm			
Rear track width	1780 mm			1803 mm			
Maximum authorized weight							
Total	18500 kg			18600 kg			
Front axle	7000 kg			7100 kg			
Drive Shaft	11500 kg			11500 kg			
Gearbox							
	1	2	3	4	5	6	R
ZF Ecolife 6 AP 1200 B	3.36	1.91	1.42	1.00	0.72	0.62	4.24

Table 11: Engine maps (Kaufmann, 2017) (Kaufmann, 2017).

<table>
<tr><td>OM936</td><td>OC500U</td></tr>
<tr><td>
</td><td>
</td></tr>
</table>

2.2.3.2 Input data: driving cycle

Apart from the vehicle's setup, to run Autonomie, it is necessary to introduce a driving cycle to the model. Primarily the driving cycle of Santiago developed for this project has been input (setup without slope, with slope of 1.4% and 50% payload) and then the Braunschweig cycle.

2.2.3.3 Input data: driving cycle, Transantiago routes

The routes input were the Transantiago 516 outbound and 201 inbound measured in the first half of 2017. These routes were chosen due to their length and demand (3CV, MTT Chile, 2016).

516 Route 201 Route

Figure 13: Maps of the 516 and 201 routes

The route's altitude profiles, the difference of the total altitude covered for the 516 outbound is 310 meters with maximum instantaneous slopes of 7.7 degrees, while the 201 inbound covered a height difference of 77 meters with maximum instantaneous slopes of 0.8 degrees as seen in Figure 14. With this information, it can be confirmed that the 516 outbound is considerably more demanding that the 201 inbound.

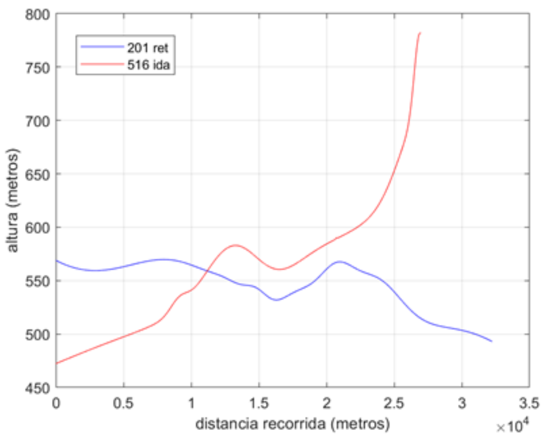


Figure 14: Distance covered versus height for the 516 outbound and 201 inbound routes.

3 Results

3.1 Development of the driving cycle

3.1.1 Selection of representative routes

The routes chosen and equipped with GPS are presented in the following table:

Table 12: Routes chosen with their variables

Road type	Route	% Mixed	% BOL	% Cor	L, Route [km]	N, Stops	Trx / hr.	<Spe> [km/h]
Mixed	B19I	93.24			13.62	45	13715	17.71
	F01I	90.09			14.29	49	9723	18.18
	101cI	84.21			12.75	44	9272	17.57
	I14R	83.36			14.89	43	19813	17.65
	J16I	84.34			14.32	47	12205	18.67
Bus Only	C01cI	9.49	90.51	0	11.58	33	245	18.89
	C01cR	7.33	92.67	0	11.34	35	1244	22.12
	406cR	2.87	97.13	0	8.53	23	1098	20.21
Corr.	507cI	10.67	19.60	69.73	14.01	30	33872	17.91
	507cR	13.84	19.67	66.49	14.05	30	65302	15.62
	519eI	14.39	17.14	68.48	15.34	23	13660	18.60
	519eR	11.46	17.80	70.74	15.34	24	32496	18.09

In the data collection campaigns, it was seen that on the routes chosen as representative of bus only lanes, type B buses do not run. As such, another variable had to be determined which offsets this unforeseen aspect, as well as a minimum percentage to choose routes: >70% on bus only lanes. Thus, the representative routes chosen for the bus only lanes were as follows:

Table 13: Second selection of routes on bus only roads

	Route	% Mixed	% BOL	% Corr	L, Route [km]	N, Stops	Trx / hr.	<Spe> [km/h]
Bus	201I	23.1	**72.1**	0	13.62	45	13715	17.71
Only	201R	25.8	**73.8**	0	14.29	49	9723	18.18

3.1.2 Identification of micro-trips

On implementing the considerations of section 2.1.6, 1356 micro-trips are obtained for analysis, which correspond to 70708 seconds of data.

As has already been mentioned, one of the goals of this project is being able to characterize, in driving pattern terms, the different infrastructure the public transportation buses drive along. Because of this, the criterion to choose micro-trips was that 100% of the data belongs to a same road type: mixed, corridor and bus only. In this way, 266 micro-trips were filtered which also include data groups which contain information about exclusive infrastructure. Data which will also be excluded in future analysis. The number of micro-trips per road type are presented below.

Table 14: Micro-trips by road type

Type of road	Number of micro-trips	Total seconds of the trip
Mixed	853	42534
Corridor	71	2692
Bus Only	166	8130
TOTAL	***1090***	***53356***

3.1.3 Speed-acceleration frequency distribution

To determine the distribution of these variables, the number and band of each class was determined. For the speed, 13 classes were defined with a band of 5 km/h and for the acceleration, 15 classes of 0.5 m/s^2. As an example, the frequency histograms for the speed and acceleration for the mixed road data are presented in the following figures.

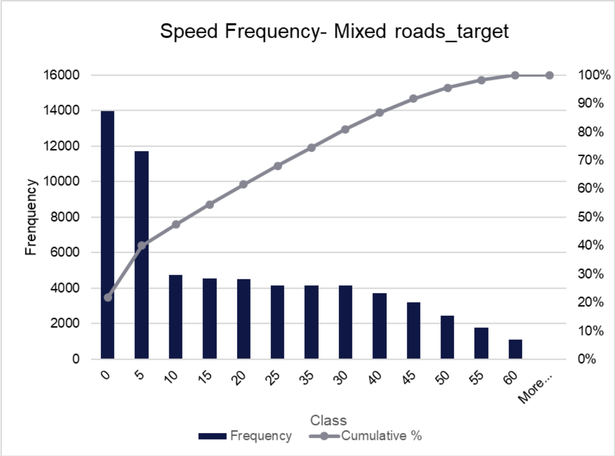


Figure 15: Speed frequency distribution of the mixed_target roads data.

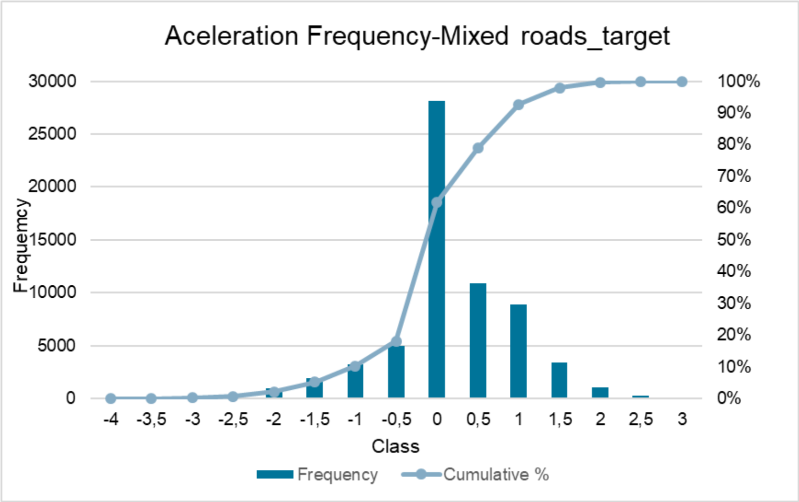


Figure 16: Accelerations frequency distribution of the mixed_target roads data.

For the case of corridors, a fraction of the data was considered. The frequency distribution is presented in the following figures:

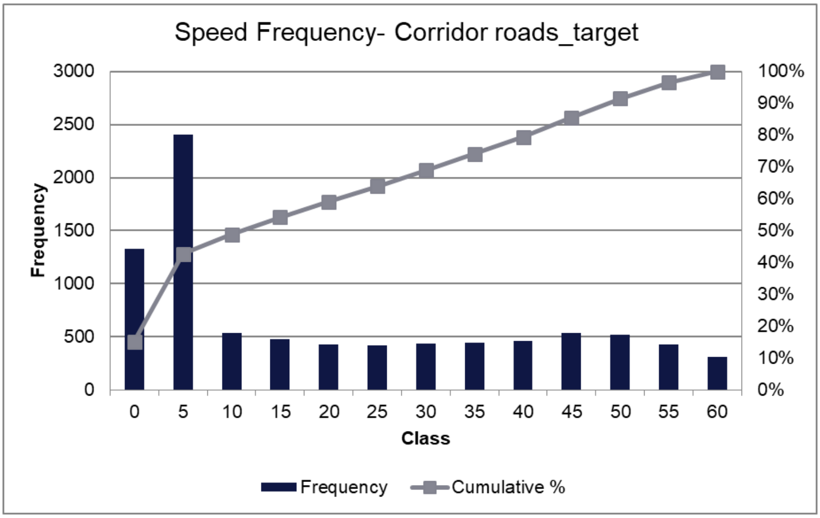


Figure 17: Speed frequency distribution of the corridor_target roads data.

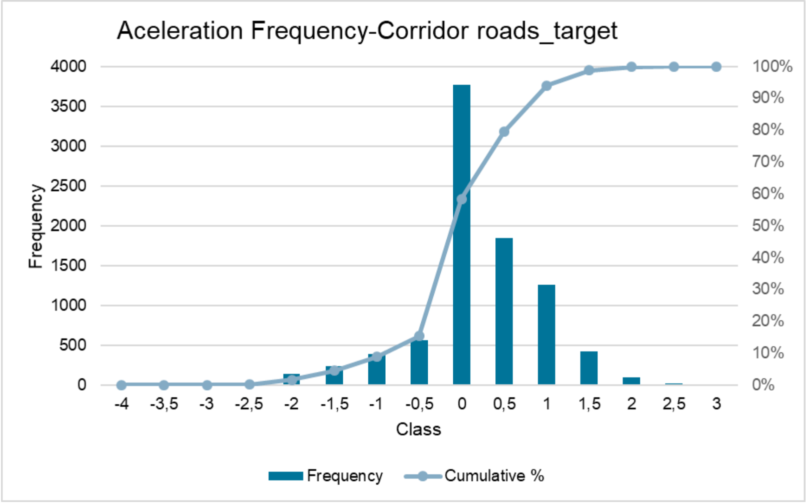


Figure 18: Accelerations frequency distribution of the corridor_target roads data.

Finally, for bus only lanes, the distributions are as follows:

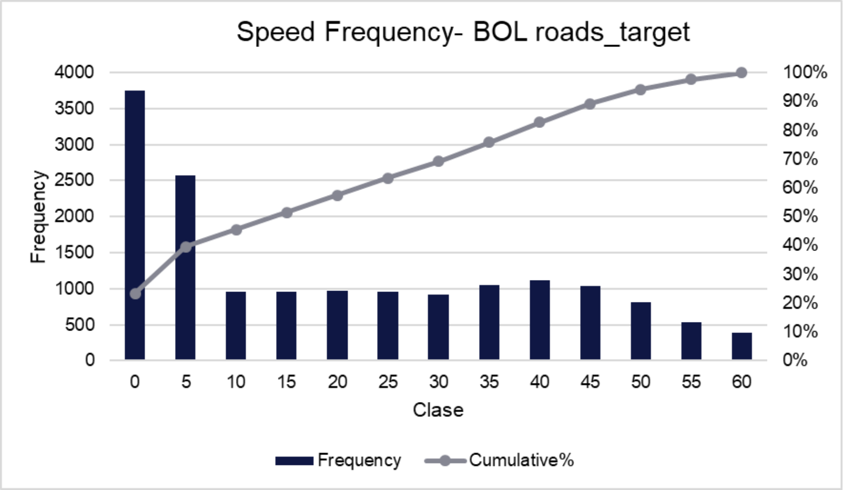


Figure 19: Speed frequency distribution of the BOL_target roads.

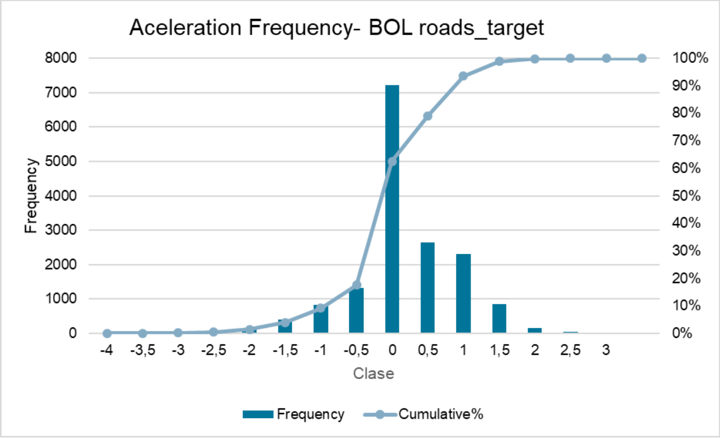


Figure 20: Accelerations frequency distribution of the BOL_target roads.

The frequency distributions for speed show differences between road types. In the case of the corridor, it was seen that there is a greater frequency in the data range (class) [5.10] km/hr. On the other two road types (bus only and mixed), higher values of between 0 and 5 km/hr. arose. It is seen in the case of the mixed roads, that frequencies fell as the class range increases. These results are as expected for a corridor.

On being a 2D space - speed and acceleration - a 13x15 element matrix is used, which contains the following information:

a) Observations per second in each class
b) Frequencies accumulated through each row
c) Frequencies accumulated from the observations by column
d) Standardization of the matrix elements

3.1.4 Selection of micro-trips, driving cycle

The resulting driving cycle, has three phases of approximately 600 seconds each one, as can be seen in the following figure. In the same way, the characteristics of each one of the phases are presented in Table 15, the same ones which are associated to the city's infrastructure types.

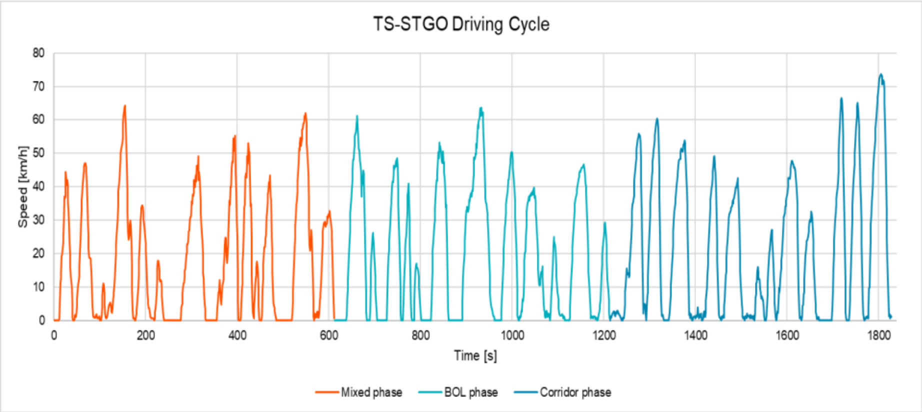


Figure 21: Speed vs time profile of the Santiago driving cycle.

The cycle has an average speed of 19.66 km/h and the corridor phase has the highest speed: 21.62 km/h. This is as a result of the association of the cycle to the characteristics of the infrastructure. However, higher speeds were expected in the corridor phase, but the road's conditions do not allow high speeds to be maintained for a long time. For example, the existence of stopping due to traffic lights and other factors. This characteristic can be verified on seeing the percentage of time that the bus is at a crossroads, 13%. The differences found between the travel and driving speed are explained by the congestion different infrastructures have. In the BOL phase, the average speed increase eliminating v=0 is explained by the high traffic levels or traffic lights. The difference between the two types of speeds mentioned is around 34% for BOL, while for the corridor phase, the increase is 12%.

Table 15: Art. Kinema parameters of the Santiago driving cycle.

ART KINEMA PARAMETERS	CTS-STGO	CTS-STGO MIX phase	CTS-STGO BOL phase	CTS-STGO COR phase
D_tot [m]	9977	3019	3272	3687
T_tot [s]	1827	612	601	614
T_stop [s]	345	129	151	65
% T_stop	19	21	25	11
T_drive [s]	1482	483	450	549
% T_drive	81	79	75	89
T_acc [s]	750	239	221	290
% T_acc	41	39	37	47
T_dec [s]	553	189	180	182
% T_dec	30	31	30	30
T_cruise [s]	179	55	49	77
% T_cruise	10	9	8	13
V_trip [km/h]	19.66	17.76	19.60	21.62
V_drive [km/h]	24.24	22.50	26.17	24.18
V_sd [km/h]	19.54	17.93	19.11	21.26
V_p25 [km/h]	1.00	0.78	0.00	1.35
V_p75 [km/h]	35.80	30.91	37.06	39.33
V_max [km/h]	73.61	64.39	63.75	73.61
A_av [m/s2]	0.0002	0.0004	0.0003	0.0005
A_pos_av [m/s2]	0.6507	0.6851	0.6828	0.5979
A_neg_av [m/s2]	-0.8824	-0.8676	-0.8349	-0.9523
A_sd [m/s2]	0.7977	0.7948	0.7489	0.8465

A_pos_sd [m/s2]	0.4154	0.4286	0.4321	0.3862
A_p25 [m/s2]	-0.2318	-0.2937	-0.2851	-0.1788
A_p75 [m/s2]	0.4492	0.4338	0.3934	0.4833
acc_pos_nr	173	56	53	64
acc_pos_rate	17	19	16	17
RPA	0.284	0.323	0.265	0.270
PKE	0.683	0.739	0.624	0.690
V_p50	13.93	12.23	15.08	14.76
A_p50	0	0	0	0

The Positive Kinetic Energy (PKE) values are also presented in the table. This is a parameter which represents the required acceleration energy for each one of the driving patterns; therefore, it is the indicator of the amount of energy that the engine is consuming. The bibliography indicates a direct relationship between the PKE and fuel efficiency values (OPUS, 2012):

- If PKE is high, inefficiency is presumed: A high PKE value means the driver has often accelerated and done so with intensity.
- If PKE is close to 0, efficiency is presumed: when the driver is efficient, the PKE value is low since his driving is soft (he does not accelerate sharply).

It is for this reason that this is one of the best energy/fuel consumption and contaminant emissions indicators of the driving cycle (Figure 22).

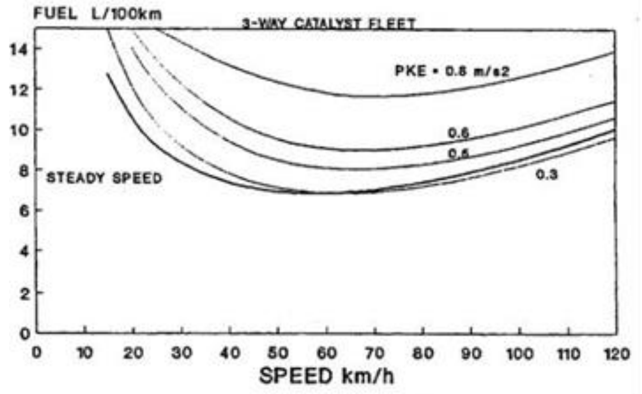


Figure 22 Fuel consumption at different PKE for light vehicles (OPUS, 2012)

The Mixed phase presents the highest PKE value, as such it would be expected that its fuel efficiency is the least, contrary to the BOL phase which has higher efficiency. It would be expected, a priori, that the Corridor infrastructure had the lowest PKE value, presuming lower fuel consumption due to a higher cruising speed. However, higher acceleration levels versus the other phases are also seen, which could affect the efficiency.

3.1.5 Cycle conditions

The conditions under which the driving cycle will run, are presented below. A warm start is considered, as one of the goals of this project is being able to represent, to some extent, the real driving conditions in Santiago, as it is presumed that the bus's engine is started before heading out. In regard to the payload, 50% is assumed, as the buses during the qualitative measurements onsite, traveled with 50% capacity most of the time. Finally, two conditions were considered for the slope: flat and with a 1.4% slope. The decision was made to use just fixed slopes due to the difficulties in making tests with variable slopes (3CV's dynamometer does not allow these tests). The slope's value corresponds to the 506 route which runs from west to east, which is a route used by bus operators and manufacturers to test their vehicles under the highest stress conditions.

Table 16: Test conditions of the Santiago cycle

Cycle startup	Warm start
Payload	50%
Slope	1.4%
Full cycle	

3.2 Measurement program

3.2.1 Chile

The information from 3CV's laboratory was used as a starting point to make the first comparison of the Santiago cycle with consumption data on real operation routes and with international urban bus cycles.

3.2.1.1 Comparison of driving cycle parameters with routes in operation.

A series of graphs are presented below which compare the results of the most important analysis parameters measured with telemetry and scanner, under the conditions specified in the previous sections. In Figure 23, primarily the telemetry results of the parameter results for the engine's revolutions per minute, turbo pressure and average speed are seen. In general, the cycle test's parameters running with a 100% payload are somewhat higher than those seen under the other two conditions.

Figure 23: 50 percentile of the parameters analyzed with telemetry under real driving conditions and Santiago driving cycle under different payloads.

The results of the analysis of the tests using the scanner are presented in Figure 24. The comparison of the speed, engine torque, performance and power parameters can be seen in this. Just like in the previous methodology, the values found on the 506-route fall within the expected range.

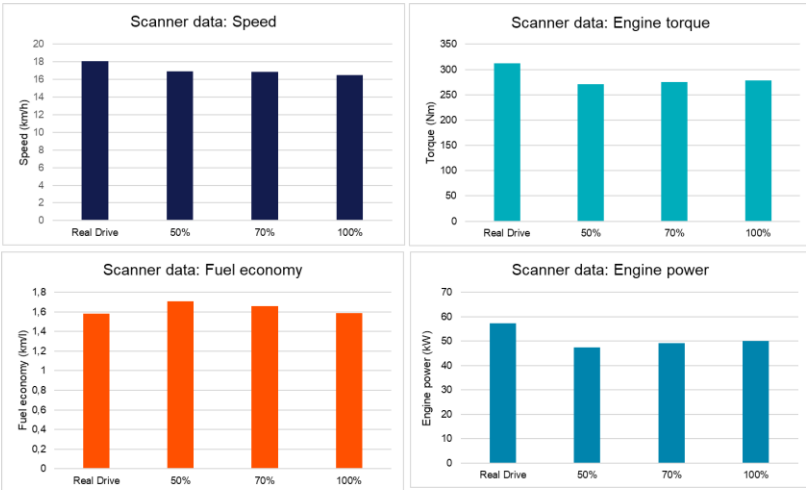


Figure 24: 50 percentile of the parameters analyzed with scanner under real driving conditions and Santiago driving cycle under different payloads.

To determine the degree of correlation between the data obtained during the tests and what is obtained through real driving on line 506, the difference of the square minimums method was calculated. The information from this analysis is presented in the following figure, where the values closest to 0 have more correlation with the conditions presented by the bus of the 506 route.

It was considered that the buses have a reasonable operation on running the Santiago driving cycle.

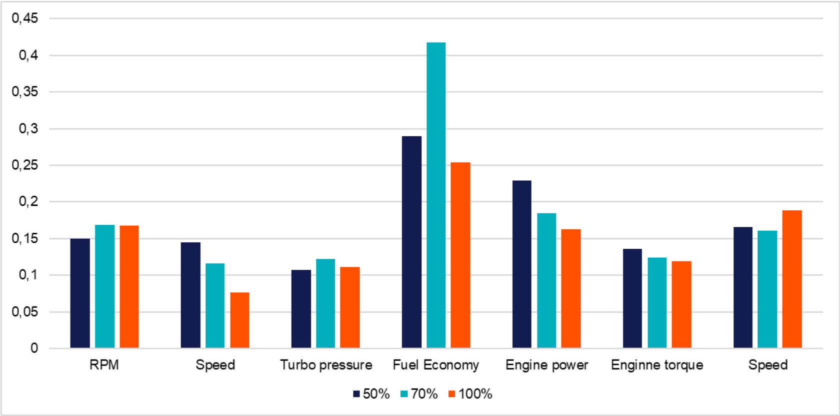


Figure 25: Difference of square minimums between the real driving condition and the Santiago driving cycle under different payloads.

3.2.1.2 Emissions and consumption results of the Santiago cycle by phase

Tests for each phase of the Santiago cycle were also made in the laboratory: Mixed, Bus Only and Corridor phase, to determine, in this way, the effect of each one of these, separately. The following figures, as a result, show the PM emissions and energy consumption of Euro VI buses under the different phases of the Santiago and Braunschweig cycle, under 100% payload conditions and in the case of the cycle's phases, with a 1.4% slope. A higher PM emission and energy consumption of the Santiago cycle versus the Braunschweig cycle is seen in the figures, with the PM 3 times higher than the emissions of the mixed phase. In must be kept in mind, that in the case of the PM, the emissions fall within a range of 0.01 and 0.05 g/km, compared with a Euro III bus, where the emissions are 10 times higher. In the case of the fuel consumption, a higher efficiency is seen in the Bus Only phase, which evidences what is mentioned in section 3.1.4, where some Art.Kinema parameters were analyzed, particularly the PKE value, with this having the lowest value among the 3 phases.

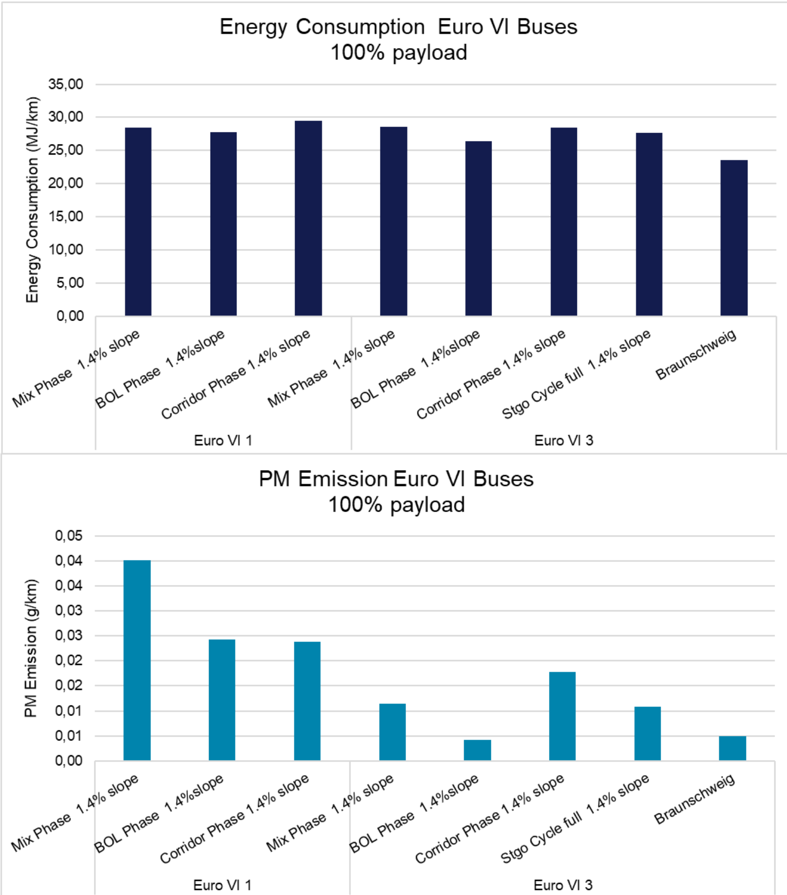


Figure 26: Energy consumption and PM emissions in Euro VI buses.

Measurements were also made to determine the effect of the slope on PM emissions and fuel consumption. In this case, buses were evaluated under 50% payload on the flat and with a fixed slope of 1.4%. As could be expected, the PM emissions are doubled or tripled when considering the bus on a constant 1.4% slope, and as was mentioned in the previous paragraph, the orders of magnitude of the PM emissions must be considered. In the case of fuel consumption, the increases are around 25%. These results can be explained as on experimenting a slope, the bus is subjected to higher payloads to reach the target speed. In this way, the engine runs harder, with the *kick down*[6] of the gear box being activated on occasions, thus increasing the revolutions per minute and the fuel injection. As a result of this, increases in the PM emissions are seen which noticeably vary depending on the phase of the cycle. In the mixed phase, the increase is around 260% and in this corridor phase, this is approximately 50%, along with a fall in the fuel performance.

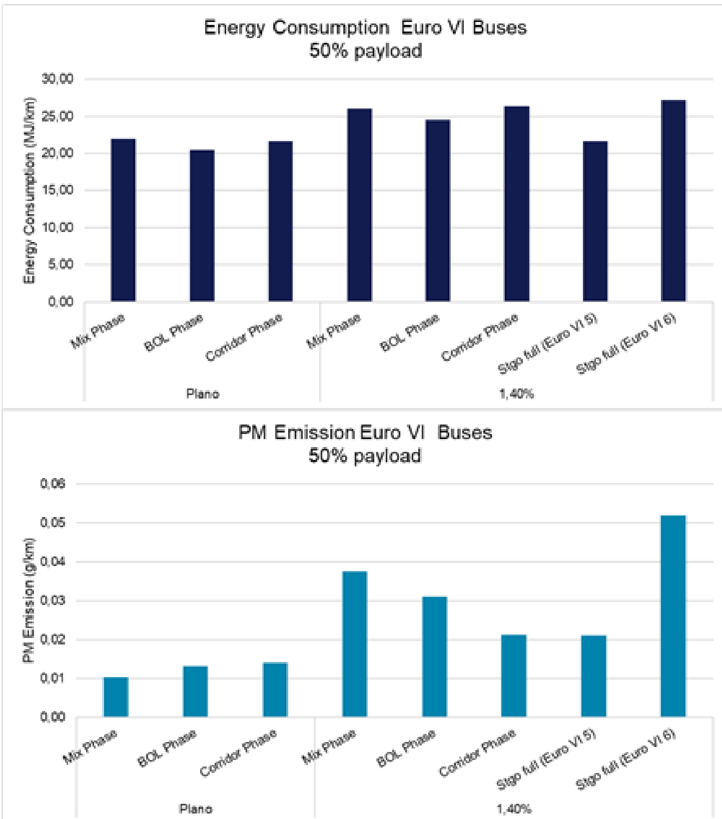


Figure 27: Effect of the slope on the performance and PM emissions in a Euro VI bus.

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6 System designed to obtain higher accelerations in a given moment, taking full advantage of the power the engine can provide. The device acts automatically, changing to a lower gear when the accelerator is floored. The engine increases its revolutions until approaching its corresponding maximum power, which is translated into a forceful acceleration.

The performance and PM emission information on varying the bus's payload between 50% and 100% is presented in the following figure. The first graph shows the clear performance reduction on increasing the vehicle's payload, which is clear at 10%. In the case of PM emissions, the effect is not directly seen, as the emission reduces for the Bus Only phase. These results are expected according to international experience (IEA-AMF, 2007) (IEA-AMF, 2016) (IEA-AMF, 2012), where studies are presented in which PM emissions do not show a clear trend in regard to the vehicle's payload.

Figure 28: Effect of the payload of a bus on the performance and PM emissions in a Euro VI bus.

3.2.1.3 Emissions and consumption results of the whole Santiago cycle

Finally, different bus technologies were assessed under the conditions of the Santiago cycle: Slope 1.4%, 50% payload, warm start and full cycle. The main results of the measurements made are presented below, where the buses were evaluated with Euro VI (Diesel) and electric technology, seeing variations of close to 25% in the energy consumption between the diesel buses, which should be explained by the weight and setup characteristics of the different buses.

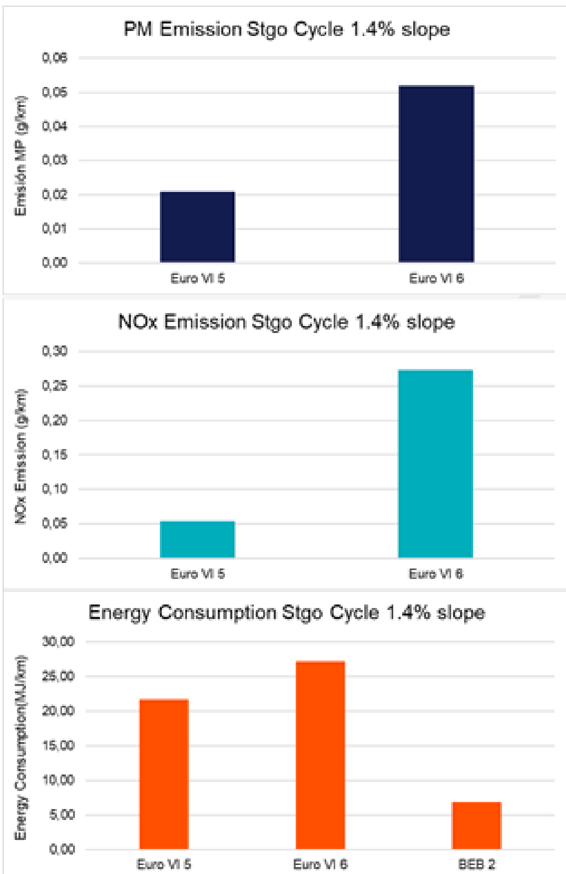


Figure 29: NOx emission, PM and energy consumption of urban buses under Santiago cycle (3CV).

3.2.2 Finland

The measurements in VTT's laboratory also initially included the evaluations of the Santiago cycle's phases and the comparison with different driving cycles.

3.2.2.1 Emissions and consumption results of the Santiago cycle by phase

It is clearly seen in the next figure that the Santiago cycle, in its three phases, is more demanding than the internationally used cycles, presenting performances close to -58% and -28% between the Harmonized cycle (WHVC) and Braunschweig cycle, respectively. The results are as expected, given that although the Harmonized cycle is developed for vehicles, it is thought mainly for trucks; therefore, the driving conditions are different. This is reflected in that the harmonized cycle has a phase on highways, 23% of the cycle's total, where speeds are higher and higher fuel consumption is expected. In the case of the Braunschweig cycle, which also has higher performance than the phases of the Santiago cycle, it may be due to first of all, that it has both positive and negative accelerations 7 that are lower than those presented in the developed cycle, which would mean that the Braunschweig cycle is less demanding that the Santiago cycle.

[7] Braunschweig Cycle: Positive acceleration average 0.424 m/s^2, negative acceleration average -0.595m/s^2.
Stgo Cycle - Mix phase: Positive acceleration average 0.6851 m/s^2, negative acceleration average -0.8676 m/s^2.
Stgo Cycle - BOL Phase: Positive acceleration average 0.6828 m/s^2, negative acceleration average -0.8349 m/s^2.
Stgo Cycle - Corr Phase: Positive acceleration average 0.5947 m/s^2, negative acceleration average -0.9523 m/s^2.

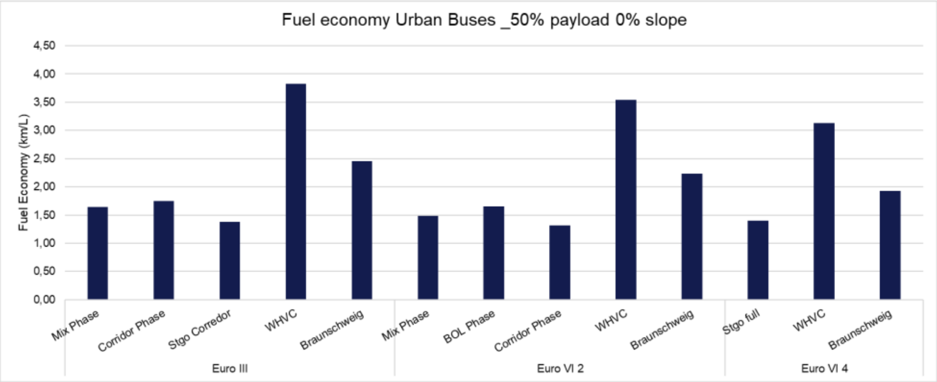
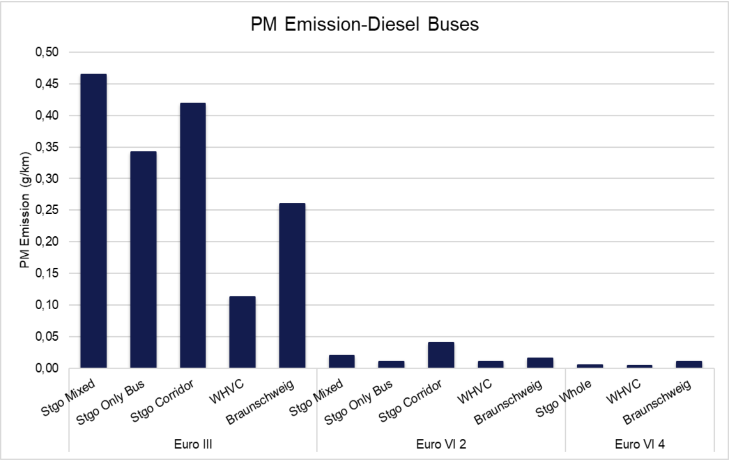


Figure 30: Fuel performance in Euro III and Euro VI buses. Condition: 50% payload and without slope

In the case of the local contaminant emissions, the reduction caused by the Euro VI (DPF+SCR) technology compared to the Euro III is notorious, close to 99% in the case of NOx and 95% for Particulate Matter. On comparing the emissions by driving cycle, the results indicate higher PM and NOx levels for buses under the Santiago cycle than under the international cycles and, in the case of comparison by phases of the cycle developed, it can end up with the same records reported in the previous paragraph.



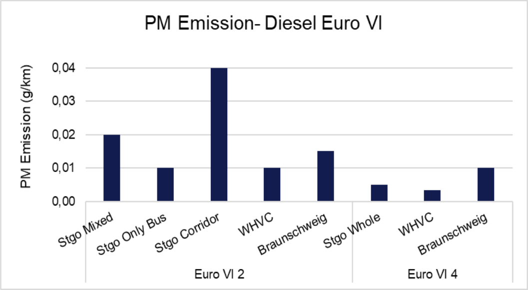
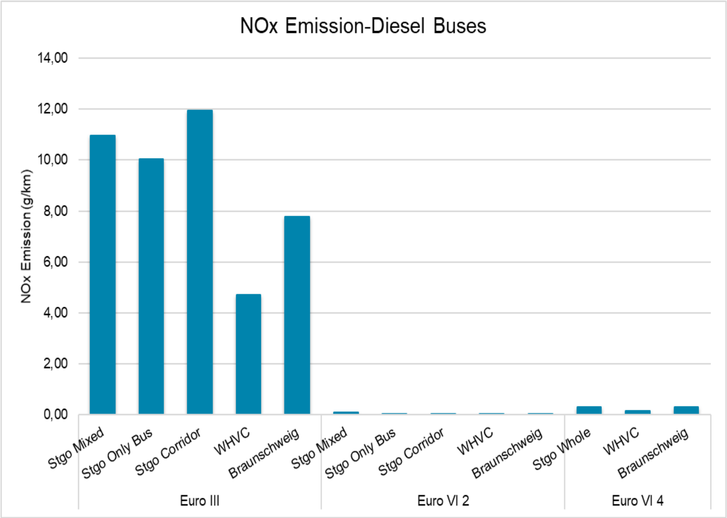


Figure 31: PM emission under different driving cycles and with different vehicle technologies (50% payload, without slope).



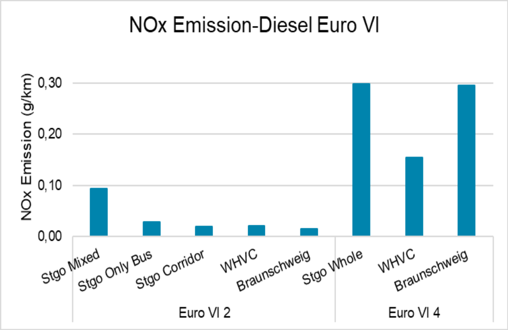


Figure 32: NOx emission under different driving cycles and with different vehicle technologies (50% payload, without slope).

3.2.2.2 Emissions and consumption results of the whole Santiago cycle

Finally, different bus technologies were assessed under the conditions of the Santiago cycle: Slope 1.4%, 50% payload, warm start and full cycle. The main results of the measurements made at VTT, where buses were evaluated with Euro VI (Diesel and Natural Gas) and one with electric technology are presented below.

It was seen that the most advanced technologies in diesel bus emissions control, like the Euro VI, produce good results in PM control, even under the aggressive conditions of the Santiago cycle, similar to those seen for the CNG. On the other hand, the energy efficiency of the conventional buses did not visibly improve with more advanced CNG and diesel buses. In addition, the electric bus has a noticeable efficiency when compared with conventional technology buses.

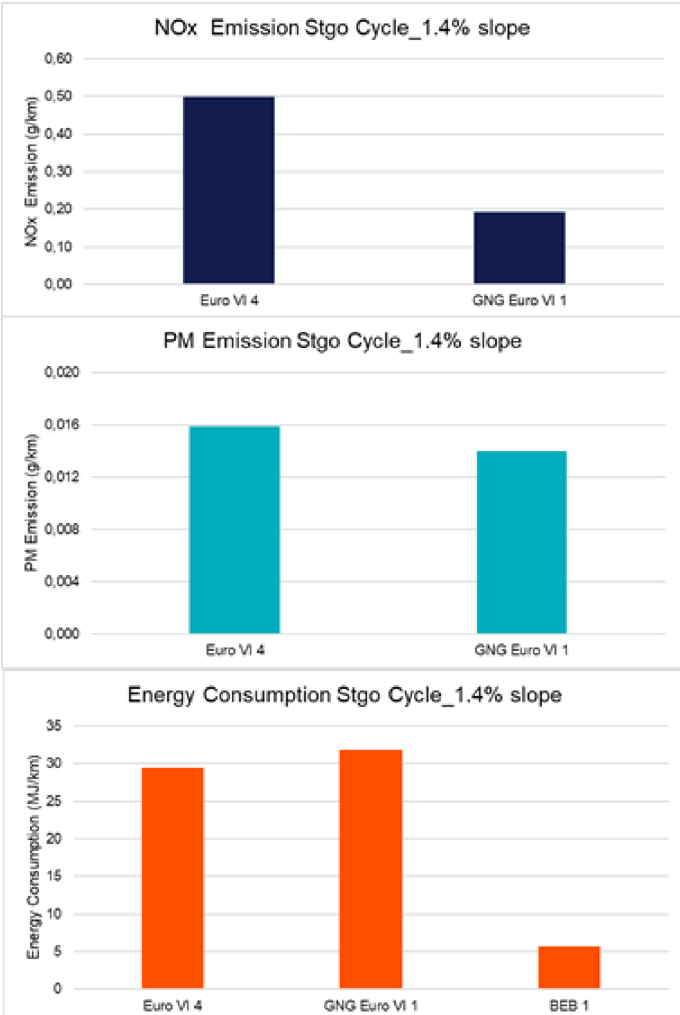


Figure 33: NOx emission, PM and energy consumption of urban buses under Santiago cycle (VTT).

3.2.3 Simulation in Autonomie

Just as was mentioned in section 2.2.3, the cycles loaded in Automonie were from Santiago and Braunschweig, setting up the first with a 1.4% slope and 50% payload.

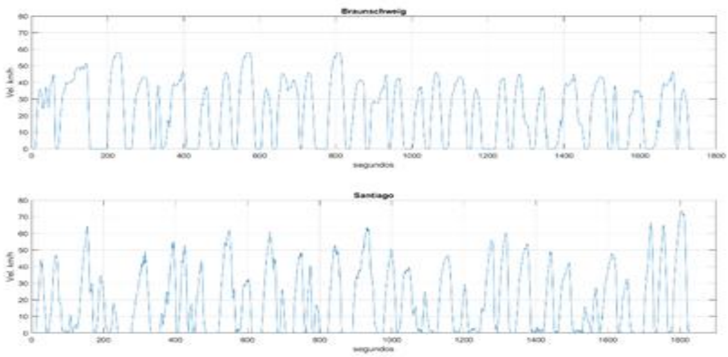


Figure 34: Comparison between Braunschweig and Santiago cycles.

Art.Kinema is a unit developed by the Swiss organization INFRAS, which allows calculating a broad range of descriptive parameters for defined driving cycles. These values called cinematic parameters, allow quantitatively analyzing and comparing different driving cycles with different resolutions and lengths.

Table 17: Some Kinema parameters of the Braunschweig and Santiago cycles.

Parameter	Braunschweig	Santiago
Distance covered	10873 m	18278 m
Average Speed	22.49 km/h	19.66 km/h
Maximum speed	58.2 km/h	73.60 km/h
Driving speed (Speed>5 km/h)	32.64 km/h	31.48 km/h
Average stopping time	15.46 sec.	26.38 sec,
Relative Positive Acceleration (RPA)	0.2351 m/s^2	0.3640 m/s^2
Positive Kinetic Energy (PKE)	0.1216 m/s^2	0.1898 m/s^2

As can be seen, the average speed of both cycles is around 20 km/h. The average driving speed is similar (approx. 32 km/h), but the Santiago cycle is about 8km longer and with longer stopping times, which has an impact on the acceleration times and magnitudes. This is reflected in the relative positive and positive kinetic energy acceleration values which are considerably higher.

In this document, the Braunschweig cycle is only considered for the purposes of sensitivity analysis.

3.2.3.1 Evaluation of the Santiago cycle

The simulated Santiago cycle (blue) is seen in Figure 35 along with the theoretical cycle (green). The Mercedes Benz OC500LE EURO VI bus was used for this simulation.

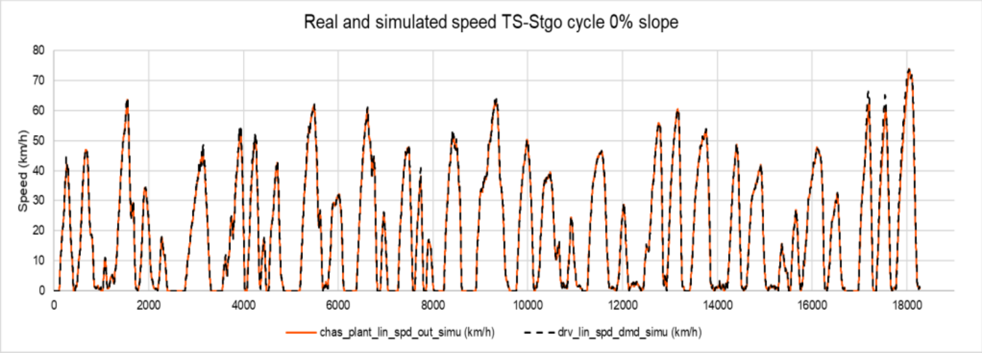


Figure 35: Simulation of the Santiago cycle in Autonomie without slope.

The simulated bus correctly reproduces the Santiago cycle. Only 2.68% of the data had a difference above 3.21 km/h. In the case of the cycle with a 1.4% slope, this value was reached in 4.23% of the data.

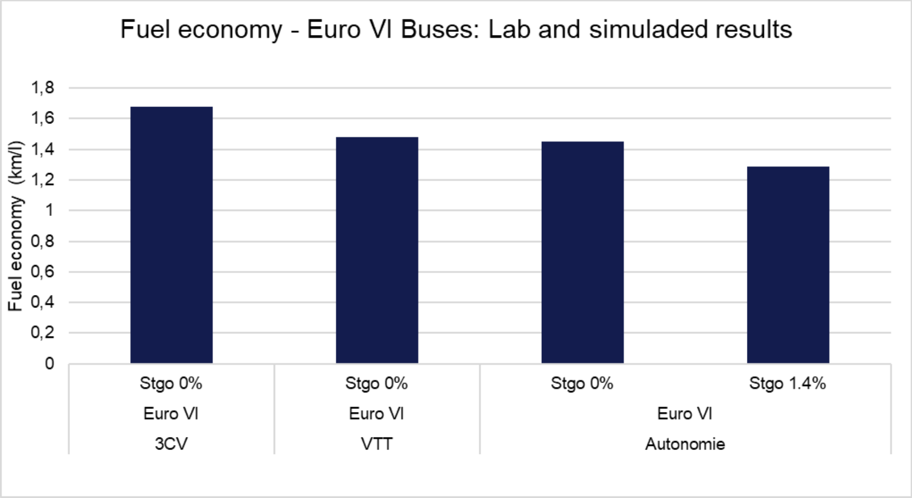


Figure 36: Performance of diesel Euro IV buses measured in laboratory and simulated, in units of km/l.

As can be seen in Figure 36, the Euro VI bus's performance in km/l, simulated in the Santiago cycle, was 1.5 km/liter which is a similar value to that measured in the VTT laboratory (1.48 km/l), but is slightly lower that the one measured in the 3CV Vehicle Certification and Control Center (1.68 km/l). When the slope is increased to 1.4%, the simulated performance falls to 1.29 km/l as can be expected.

3.2.3.1.1 Hot maps

To better visualize how the change in slope affects the bus's performance, two fuel consumption hot maps are presented in Figure 37, considering the torque and revolutions of the Euro VI bus's engine on the flat (a) and with the Santiago cycle's 1.4% slope (b).

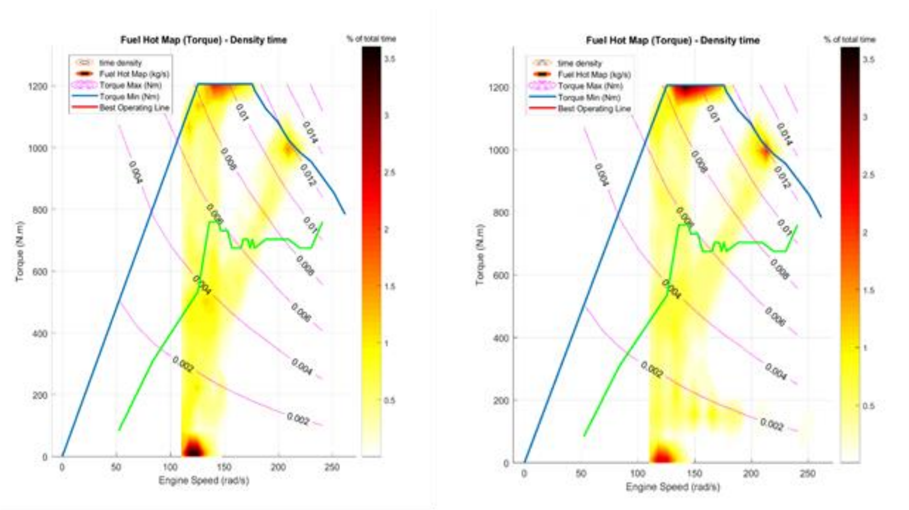


Figure 37: Hot map (Torque) - time density versus engine revolutions for: (a) flat Santiago cycle, (b) Santiago cycle with 1.4% slope.

The torque (Nm) is on the vertical left axis, while the time the engine remains in this range is on the vertical right axis, shown using the red and yellow areas. The revolutions per minute expressed in radians per second are on the horizontal axis.

The blue line indicates that the engine's torque map constantly increases the faster the engine rotates until reaching 1200 Nm, then after approx. 170 rad/s. it reduces in a variable manner to 800 Nm. The green line indicates the ideal torque demand for fuel consumption suggested by the program.

The demanding nature of the Santiago cycle is seen in both cases, but with the 1.4% slope, the red area dominates in the maximum torque value, i.e. more is being demanded from the engine than under the flat conditions.

3.2.3.1.2 Evaluation of operating routes, representative of the Santiago cycle

The real and simulated speed of the return 201 route can be seen in Figure 38. Only 0.2% of the data did not reach the target speed (>3.21 km/h).

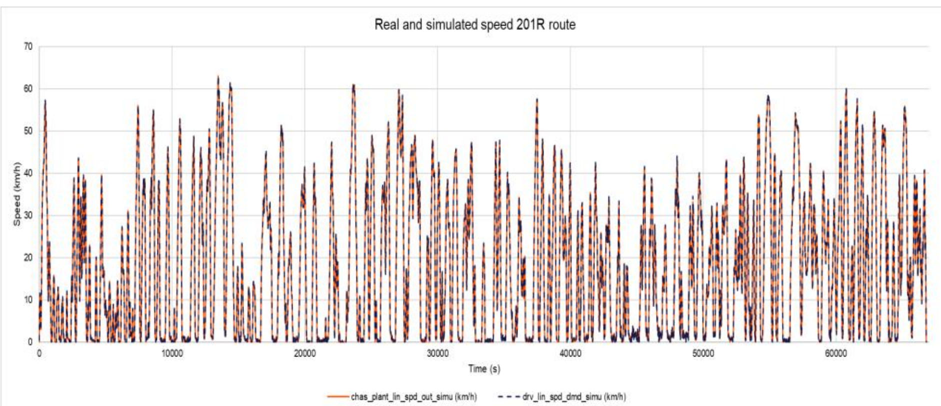


Figure 38: Real and simulated speed of the return 201 route.

The real and simulated speed of the 516-outbound route are seen in Figure 39, where 7.92% of the data did not reach the target speed (>3.21 km/h).

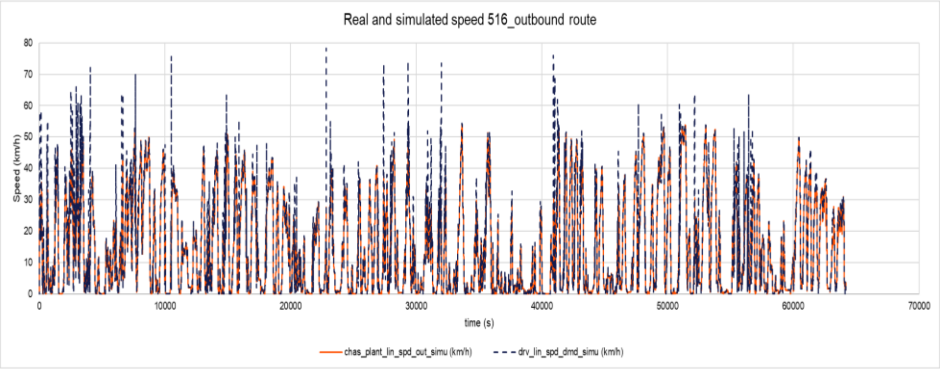


Figure 39: Real and simulated speed of the 516-outbound route.

The simulated performance of the Euro VI bus is 1.1 km/h on the 516-outbound route and 1.7 km/l on the return 201 route, which is in line with the preliminary analysis about the demands of the routes seen in the height profiles. A summary of the results is presented in Figure 40.

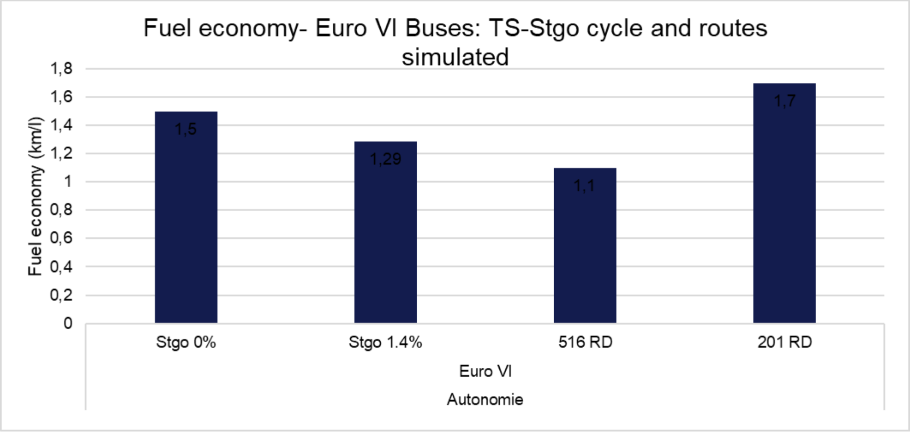


Figure 40: Performance in km/l of the Santiago cycle without slope, with 1.4% slope and of the 516 outbound and 201 return routes.

3.2.3.1.3 Sensitivity analysis

To visualize the effects in the results from the technology change, a sensitivity analysis is presented where the different setups have been modeled.

Table 18: The difference between the setups with regard to the first setup is marked in the different types of setup tested.

Parameter	Setup				
	Base	Change of differential	Light coachwork	Heavy coachwork	Lower Power
Engine	M.Benz OM936	M.Benz OM936	M.Benz OM936	M.Benz OM936	M.Benz OM926
Max Power	220kW	220kW	220kW	220kW	188kW
Max. Torque	1200Nm	1200Nm	1200Nm	1200Nm	1200Nm
Gearbox	ZF-Ecolife 6 AT	ZF-Ecolife 6 AT	ZF-Ecolife 6 AT	ZF-Ecolife 6 AT	ZF-Ecolife 6 AT
Differential ratio	5.875	4.330	5.875	5.875	5.875
Wheel size	295/80r22.5	295/80r22.5	295/80r22.5	295/80r22.5	295/80r22.5
Total Mass	15690	15690	14690	16590	15690

The fuel consumption results are presented in Table 19 in km/liter.

Table 19: Fuel economy as per vehicle setup and driving cycle.

Fuel economy (km/l)			
Setup	Cycle		
	Braunschweig	Santiago	Santiago 1.4%
Base	1.92 (100%)	1.47 (100%)	1.28 (100%)
Change of differential	1.84 (96%)	1.42 (97%)	1.20 (94%)
Light coachwork	2.03 (106%)	1.54 (105%)	1.35 (105%)
Heavy coachwork	1.84 (96%)	1.41 (96%)	1.22 (95%)
Lower power	1.83 (95%)	1.41 (96%)	1.21 (95%)

It is seen that the change in driving cycle does not significantly modify the percentage results. Separately changing the components has an approximate 10% effect on the performance value (between 85% and 105% approx.)

In regard to the model developed, Autonomie reproduces the results obtained in the VTT and 3CV laboratories with a certain margin of error (10% in comparison to the 3CV and 1% in comparison with VTT), which is within the acceptable range in this type of measurements. In addition, the modeled bus correctly reproduces the routes entered, with 2.68% of the data that does not reach the target speed in the Santiago cycle and 4.23% of the data in the Santiago cycle with slope. In the case of the routes, 0.2% in the 201 and 7.92 in the 516. These results depend on the slopes of these routes. In the case of the 516, this has a considerably more limited performance than the Santiago cycle (1.1 km/h versus 1.4 km/l), while the 201 has a considerably higher performance (1.9 km/l) as such, for the fuel consumption evaluation, the Santiago cycle cannot be used as representative of all Santiago's routes.

Upon analyzing the fuel consumption heat maps, it is seen that if the slope is increased, the engine remains for a long time at the maximum torque values, which affects the power requirements to reproduce the route correctly and the service life of the bus's internal components.

Finally, it can be concluded that changing the bus's components separately has an approximate effect of 10% on the performance's results.

4 Development of directives for buses in a sustainable transportation system

4.1 International experience

There are many methods to compare different bus characteristics, the difficulty is deciding which of these is more effective and how the exhaustive results of tests carried out in sophisticated emissions laboratories can be transferred to results in real driving conditions. One thing is testing the engine's efficiency, and the vehicle's performance is another thing entirely. The heavy vehicle's engines are tested in the laboratory separately as independent units, and in an autonomous cell with environmental parameters (temperatures, humidity, pressure) under strict control.

To approach the real-life performance when driving, the bus must be tested on a chassis dynamometer stand. The predetermined pattern used in the engine is now substituted for a representative driving cycle tracked from a (driver-auxiliary) screen by a trained driver. The results will normally be calculated as gram per vehicle kilometer / mile (g/km, g/ml) for the selected pattern. The question to answer is whether the driving pattern chosen is representative of the local situation.

The driving cycle is by default, one of the most trustworthy methods to measure the emissions and the fuel or energy consumption of a vehicle. The most common cycles are "transitory" as they represent the real-life operation including accelerations and decelerations, moments with moderate speed changes as well as including periods of inactivity which simulate being stopped at a red light or, making a stop as in the case of buses.

The driving cycles can be used for standards or to develop emissions factors. In most cases, the main goal is to determine the contributions towards the poor environmental air quality of a specific group of vehicles.

Hundreds of driving cycles have been developed to be used in chassis dynamometers, however there are still many characteristics of local highways and driving conditions that are not covered by the cycles that are available. More than 200 of these are presented in the report, "*A reference book of driving cycles for use in the measurement of road vehicle emissions*" published in 2009. From these, between 10 and 15 of these are internationally recognized and in spite of this, many cities / regions develop their own representative driving cycles, just like the case of Santiago. Some of the most used cycles on buses are presented below, together with the parameters that most affect the final emissions measurement results.

Table 20: Examples of driving cycles used in chassis dynamometer tests, considering a full bus.

Nombre ciclo de conducción	Distancia Total (metros)	Tiempo Total (segundos)	Tiempo conducción (segundos)	Tiempo detenido (segundos/%)	Velocidad promedio Viaje total (km/h)	Velocidad promedio conducción (km/h)	parada/km (número)
FIGE drive cycle (ETC on chassis dyno)	29 949	1 800	1 800	0 (0%)	59.0	59.0	0
New York Bus Cycle	996	600	272	328 (54.6%)	6.0	13.2	11.1
Brauschweig City Driving Cycle	10 900	1 740	1 452	288 (16.6%)	22.6	27.0	2.4
Millbrook London Bus Cycle Outer London	6 474	1 380	1 073	307 (22.2%)	16.9	21.7	3.7
Millbrook London Bus Cycle Inner London	2 509	901	620	281 (31.2%)	10.0	14.6	9.2
TNO Bus Cycle	5 248	898	706	192 (21.4%)	21.0	26.7	2.7

Along the same lines, a project "*Evaluation of duty cycles for heavy duty urban vehicles*" was run by 3 laboratories [8]. The main goal was to evaluate how the different driving cycles affect fuel consumption and the exhaust emissions figures. As could be expected, the results vary significantly, not only by test cycle, but also by vehicle technology. The reason could be that different cycles have a great impact on the engine's parameters and, therefore, change the exhaust temperature and the behavior of the exhaust gases after treatment devices. In some cases, the increase in fuel consumption or the payload of the vehicle results in an increase in emissions, while in other cases, these are reduced.

In total, 19 transitory driving cycles were tested in the project. An interesting observation of the results analysis, is that there seems to be

[8] Technical Research Center of Finland, VTT, Environment Canada and West Virginia University, USA.

a clear difference in the European vehicle emissions profiles (tested in Finland) and the North American ones (tested in Canada and the US). In Europe, emphasis is made on fuel efficiency, while in North America, attention focuses on the regulated exhaust emissions, especially the micro particles. The reason could be a European approach on fuel consumption to reduce operating costs, while the stricter application of emissions and the lower diesel fuel price changes the focus in North America.

A different approach to compare the fuel consumption of buses in a standardized way, is the *Standardized On-Road Test Cycle* (SORT) driving cycle, developed originally by the *International Association of Public Transport* (UITP) for 12-meter buses (standard double-axle buses), recognized by most European manufacturers, as well as by bus operators as a tool for reproducible tests in terms of highway fuel consumption measurements. This is normally used when different types/sizes of buses are compared in a tender process.

4.1.1 Parameters to consider in a methodology to evaluate emissions and energy consumption in buses

To test the efficiency of the engine of an urban bus, a test is made separately as an independent unit in an autonomous cell, with controlled environmental parameters (temperature, humidity, pressure). Immediately before the engine enters "test mode", the engine's operation is pre-conditioned until it is ready under non-specific heat conditions. During the test, the motor runs following a predetermined pattern, i.e. the motor's load and its speed are adjusted. The test sequence is made up of transitory and stationary status measures, along with a separate test to detect smoke emissions. In addition, the result of the tests following the European requirements is calculated following what is established in the standards, expressed in grams (of contaminants) per kWh (power in time). This has nothing to do with the contaminants emitted by a bus which operates under real driving conditions.

In terms of the vehicle's performance, there are still differences in the results of the exhaust emissions measurement and those of the fuel consumption. The difficulty is testing a bus on the highway under normal operation and the same bus tested on the chassis dynamometer using the same driving cycle. The origin of the difference may be air resistance, environmental temperature, the condition of the tires and, to a certain extent, the inclination of the real highway. However, special attention must be paid to the tires since the dynamometer's design can affect the properties of the tires which affect the resistance to rolling. A group of special tires prepared for use on the dynamometer must minimize the negative effect.

It is also very important to carry out a simultaneous measurement of a bus's exhaust emissions and fuel consumption, as there are possibilities that a lower fuel consumption results in high emissions of some components in the exhaust and vice versa. From the point of view of the manufacturers, it may be favorable for them to use different individuals to carry out tests with slightly modified adjustments, even within the tolerances established to reach more favorable results.

During recent years, a new testing method has been developed, "Portable Emissions Measurement System" (PEMS) which is not accepted internationally. It consists in analyzers placed inside a vehicle which is operating in a normal environment. The emissions emitted are analyzed and calculated during real driving. In a few years' time, this method will be part of a future testing procedure requirement to approve engines and vehicles, as well as for their follow up. The driving cycles used may be varied. They are recorded and stored for future use. The results consider real driving emissions and are different from the results obtained during the certification / standardization of the engine / vehicle. The differences are related with altitude, slopes, environmental temperature, humidity, vehicle's test weight (payload), the influence of the driver and the influence of the surrounding traffic. When vehicles are tested on highways during normal operation, it is must more difficult to manipulate the vehicle or the test procedure to present unrealistic results, unlike tests carried out in the laboratory.

Another approach for the highway measurement is installing an instrument on the vehicle which records the real driving pattern during the operation of a bus in real life. When sufficient data is sampled, the information is calculated and adjusted to simulate the same typical driving conditions to then be taken to tests on a dynamometric stand. These driving cycles, developed especially for specific ends, could be a substitute of the driving pattern recognized internationally to best represent the local conditions. The main disadvantage with this approach is that many types of vehicles need to be tested under a great variety of driving modes.

When the buses operated by electricity must be compared with conventional buses, another even more local criterion must be introduced. The estimation of the total energy consumption and the associated costs with how the electricity is produced must be considered, as this differs between countries. As a result, the total operational costs of the electric buses during their life will significantly depend on the origin of the electricity.

It is also worth highlighting that several studies made in the United States to determine the emissions related with the generation of electricity used by passenger vehicles, have a consensus that passenger vehicles charged with the dirtiest carbon-based networks have global emissions comparable to those of automobiles run on more fuel-efficient petrol. However, these emissions significantly fall when these vehicles are charged from the cleanest networks which use low carbon energy sources. The conclusions are based on light passenger vehicles but should also be valid for buses.

4.1.1.1 Vehicle technologies

The purpose of this project, as has been mentioned, is to develop methodologies to establish requirements for clean and energy efficient buses, which means that the buses are the only type of vehicles debated in depth. Between 2012 and 2015, a group of European projects were working on the so-called "Clean Fleets Project", whose main goal was to facilitate the acquisition of vehicles for public authorities and fleet owners. The Clean Buses - Experiences with Fuel and Technology Options report was published in November 2014, presenting different technologies for buses with their advantages and disadvantages. The report presents the following technologies:

- Clean diesel (conventional) (in this context from Euro III or its equivalent)
    - Significant improvements can be made by updating the bus fleet with newer models equipped with the latest technology and after-treatment systems. This option is destined mainly to the public authorities and transport operators who lack the resources to buy, test and/or develop infrastructure for innovative bus technologies. These authorities must also consider the rest of their fleet.
- Methane gas (in this context from Euro III or its equivalent)[9]
    - The bus manufacturer has to test the long-term stability of the buses supplied with methane in the certification documents. The buses designed to use CNG can also work with compressed bio-methane, biogas (CBG), as the engine's technology is the same. The engines used for heavy vehicles are often designed to use only gas, but there are "double fuel" engines which simultaneously burn petrol and diesel in a diesel engine. In 2014, the "double fuel technology" was not sufficiently well used (in Europe) to offer greater engine efficiency or reduce emissions performance and the operational costs. The main reason is that Europe regulates the maximum total hydrocarbon emissions (THC), including methane (CH4), a high GHG potential, while in the US, only the non-methane hydrocarbons (NMHC) are regulated, excluding CH4. The double fuel technology and the emissions performance are analyzed in three reports [10]

[9] Only the new buses designed originally to work with methane gas (OEM products) are discussed. The alternatives to convert the diesel buses used to work only with methane are not analyzed in depth, mainly because there is no international experience available where the improvement both of the emissions performance and the engine's efficiency can be verified.

[10] http://www.iea-amf.org/app/webroot/files/file/Annex%20Reports/AMF_Annex_39-2.pdf.

published by the International Energy Agency (IEA-AMF). The development of double fuel or "methane-diesel" technologies continues to be of interest to reduce the greenhouse gases and encourage the manufacturer to introduce new versions for the European market as of 2018.

- To avoid the cost implications and the impracticalities of long distance natural gas transportation by pipes or compressed in chutes, it can be converted into liquid natural gas (LNG), cooling the gas to a liquid at around -160°C. The origin of the LNG could also be non-fossil and the product will then be liquid biogas (LBG). However, a disadvantage in the use of liquid methane gas and the corresponding engine and storage technology could be the bleeding risk, where the methane could slowly vaporize and escape without control from the vehicle's LNG tank.

- Hybrid - Electric
  - A hybrid vehicle is a vehicle which uses two different sources of energy. Typically, this refers to hybrid electric vehicles (HEVs), which combine an internal conventional combustion engine with an electric motor. The batteries or super condensators that the electric motor uses are continuously recharged by the engine or by the energy generated during braking, energy which in another way would be lost as heat.
  - The "pluggable hybrid electric vehicles" (PHEVs) are developed so that the electric batteries can be charged by plugging them to the electricity network. These are equipped with the largest batteries that the vehicle can handle to travel further under solely electric mode. The passenger vehicles which are equipped with a distance extender are also included in this group. This is a small combustion engine that forms an auxiliary power unit (APU) with the key role of increasing the vehicle's scope. The device also helps relieve the anxiety of distance.
- Electric - Trolley
  - The trolleybuses are electric buses which normally use aerial cables for electricity supply. Similar technologies are also being

developed for trucks which operate on predefined driving routes. Other technologies for dynamic power transfer are being developed, such as inductive or conductive transfer from the side of the highway or aerial catenaries. Most of the modern trolleybuses have an Auxiliary Power Unit (APU) which allows them to operate independently. The APU may consist of a smaller diesel engine or a battery.

- Battery - Electric
  - The electric vehicles (EVs) which work exclusively with a rechargeable battery are known as fully electric, electric or battery electric vehicles (BEVs). Buses which use this technology do not have the need for an internal combustion engine, as they depend entirely on strong batteries which make an electric motor run. The charging can be done overnight or on the real route through a contact aerial line by inductive or conductive supply on the highway, as well as in the first and last stop.
- Hydrogen or fuel batteries
  - The basic operation of a bus supplied by hydrogen or a fuel cell is the same as for a battery electric vehicle.

4.1.1.2 Fuels

When the engines are certified / approved following emissions regulations, they have to use a well specified fuel for real engine tests. However, the specification is not completely identical for the certifications made in Europe, the United States and Japan. The advantage of using identical fuel when the vehicles / engines are certified for the European market in the United States, Japan or Europe is that fuel complying with the same requirements will minimize the number of parameters that affect the results on testing engines in different laboratories. The respective regulation is the one which normally specifies the fuel of reference.

There are differences between the fuel used in the laboratories for the certification test (reference fuel) and the one commercially available in the market. Likewise, there are differences between the fuels of different markets in the countries, especially in the introduction of biological components both in the petrol and in the diesel fuels. Different components can also affect the fuel's energy content. A risk to manipulate the commercially available fuel is by adulteration, that is to say, diluting the fuel supplied from an oil refinery with cheaper components like kerosene (for diesel) or solvent (for petrol). This type of fuel manipulation is a disaster both for the emissions performance and for the engine's durability. Fortunately, it is not very common nowadays. However, the risk of fuel adulteration could be minimized by introducing systems to control the fuel quality or improve the existing systems.

The Worldwide Fuels Charter, issued by the European Automobile Manufacturers Association (ACEA) and the Automobile Manufacturers Association (AAM) (JAMA), is an internationally accepted document which offers recommendations for the compatibility of fuel quality in different engine technologies. The document is available on the website of the International Motor Vehicle Manufacturers Organization, OICA (http://www.oica.net/worldwide-fuels-charter). There are additional documents included which deal with the mixtures of biological components, both in diesel and petrol.

Both petrol and diesel are divided into five different categories and as countries more towards stricter vehicle and engine requirements, the role of fuel quality in the preservation of the vehicles and engines continues to grow. The ultra-low sulfur and metal free fuels continue being prior critical requirements for ultra-clean, efficient and lasting emissions control systems. A brief description (for heavy vehicles) of different diesel categories is presented below:

- Category 5, used for more advanced engines and vehicles to solve their design potential.
- Category 4, used for advantage emissions control requirements, for example the US 2007/2010, Euro IV, Euro V, Euro VI and JP 2009 regulations or equivalent emissions standards. This fuel category allows for sophisticated NOx and particle after-treatment technologies.
- Category 3, used for stricter emissions control requirements, like

Euro VI and JP 2005 or their equivalent emissions standards.

- Category 2, used for emissions control requirements of Euro II, Euro III or equivalent emissions standards.

Normally, manufacturers develop and design engines to use fuel complying with a specific norm. If the fuel used is of a different type, for example 100% renewable in origin, this could have harmful consequences for the durability and the engine's emissions performance. However, many of the more recently developed engines which comply with the Euro VI emissions requirements, also accept the use of fuels included in bio components. The requirement is that the manufacturer verifies the use of biofuels in the owner's manual.

When renewable fuel is used, with the main goal of reducing the GHG, it is vital that the interested engine manufacturers accept the fuel and that the fuel has no negative impact for the engine. It is not obvious that the use of a non-fossil fuel will reduce the emissions and improve the fuel consumption. There is literature which shows that the toxicity of the exhaust gases could increase, as well as some regulated contaminant emissions too. The tests of the first versions of the diesel engines that use conventional fuels, biofuels and their mixtures have some unfavorable results for the biofuels (SOU1994: 64; Med raps i tankarna, delbetänkande från miljöklassutredningen, 1994). However, the results of the tests of the advanced technology engines using the latest biofuels could reach other conclusions.

For the engines designed to use methane gas as a fuel, the situation is different as there are still no internationally accepted standards. The quality (methane content and Wobbe index) of the natural gas varies depending on the gas's origin. To avoid any unacceptable emissions performance risk of the engines, the manufacturer must find ways so that the engines automatically adjusts (within specified limits) the engine's parameters to obtain the best performance.

A report was published in 2013 to highlight further still, the difference in the emissions and fuel consumption performance (CO_2), when different specifications are used for "similar fuels". In this case, the fuels were destined for diesel engines without modifications of the parameters. The Swedish Transportation Administration and the Swedish Transportation Agency presents the results of identical tests of a heavy truck (gross vehicle weight of 12,000 kg) approved under the Euro V emissions requirements and tested on a chassis dynamometer following the world harmonized vehicles cycle (WHVC). Different specifications were used for the diesel fuel and tests were done with cold and warm startup. Before each test, the vehicle's engine was identically conditioned. The regulated contaminants and the still unregulated contaminants were analyzed.

The report's conclusion is that none of the fuels investigated has an important negative impact on the components analyzed. However, the fuels included contain components that have the possibility of coming from renewable sources and therefore, contribute positively in the greenhouse gas emissions and in a more sustainable transportation system.

4.1.1.3 Approval of engines for heavy vehicles

Before engines which heavy vehicles use enter the market, the engine manufacturer must request the engine's homologation / certification. Approval may be granted based on the different regulations normally issued in Europe (EU, ECE) the US (Federal, California) and Japan, but they must not be completely identical. Other countries, like China and India, issue their own national regulations. The type of requirements set out in the regulations are, in principle, the same. The different regulations stipulate tests of engines as independent units and the test program is not designed to reflect the exhaust pipe emissions of a vehicle when it is in normal operation.

The latest European norm (582/2011 / CE and its later amendments, Euro VI) related with the emissions of heavy vehicles, includes the following basic elements to be done to receive the European standardization of an engine system or engine family as a technically independent unit:

- It states the type of fuel that can be used and whether it complies with the established requirements (fuel range).
- Demonstrate the conformity of the engines and vehicles in service (using PEMS).
- Verify the exhaust emissions (engine's emissions test).
- Measure the CO while idling (for engines with spark plugs).
- Verify the sump's gas emissions.
- Limit the outside cycle emissions (OCE) and the emissions during use.
- Verify the durability of the engine's systems.
- Measure the CO2 emissions and fuel consumption.
- Specify the fuel of reference (which will be used for the certification tests).
- Explain the onboard diagnosis (OBD).
- Explain the conformity of the engines and vehicles in service standardized following the 2005/55/CE Directive.
- Describe how to guarantee the proper operation of the NOx control measures (UREA, SCR).
- Measurement of the engine's net power.
- Provide access to the vehicle's OBD and to the information on vehicle maintenance and repair.

The manufacturer will show that the vehicles or the engine systems were subjected to tests and meet the requirements. They must also guarantee compliance of the specifications of the fuels of reference.

Most of the relevant components are covered by the requirements presented in the emissions legislation and it is essential that the vehicles (buses) are covered by a Conformity Certificate stating that all the requirements, upon the release, are met. It is important to inspect and maintain all the systems to guarantee an acceptable performance over time.

During the last two years, it has become clear that the gap between the certification test results, especially the fuel consumption and NOx emissions for passenger vehicles, compared with the driving experience in real life has been increasing. The special efforts that have been made during the development of the Euro VI emissions requirements for heavy vehicles has led to more detailed procedures which must be followed during the certification process along with new clauses in the Regulation making a misinterpretation of the requirements more difficult. Some examples to mention are a more detailed procedure for the pre-conditioning of the engine and better requirement for the use performance. All the details are found in the European legislation for heavy service engines[11]. In addition, new requirements have been introduced to measure "outside cycle emissions" (emissions in areas of the engine not included in the testing procedure) and the introduction of requirements for emissions in use (a more effective control of the emissions under a broad range of engine operation and environmental conditions during the normal operation of the vehicle in service). While, recent confirmations in the United States that passenger vehicle manufacturers have deliberately manipulated the electronic programming, have led to a European Commission proposal to improve the approval process further along with the type of surveillance of the engine powered vehicle market with the main goal of reducing the gap between operation in real life and the certification. When all the actions [12]are implemented, the results of the standardization tests could be trusted more.

4.1.1.4 Inspection and Maintenance I&M (Periodic Technical Inspection, PTI)

The development of new engines and sophisticated exhaust gas after treatment systems is a continuous process for the manufacturers to offer engines with lower fuel / energy consumption and a higher energy

[11] https://www.dieselnet.com/standards/eu/hd.php.
[12] http://europa.eu/rapid/press-release_IP-16-167_en.htm.

efficiency. Therefore, it is questionable to confirm that the methods designed 40 years ago are still suitable for today's and tomorrow's technologies, in spite that the maximum limits have been modified to check the results.

However, the need of checking the emissions performance is not questioned, and it is a common option that there must be some type of verification system or inspection to find high emission vehicles. It is estimated by the Pareto principle, that around 20% of the vehicle fleet cause 80% of the emissions. This ratio has been confirmed by several international projects. In addition, a project recently made by the University of Toronto[13], "analysis based on air contaminant emissions plumes of the vehicle fleet and the contribution of high emitters" found that 25% of the automobiles and trucks are causing around 90% of the vehicle fleet's contamination.

An inspection can be part of an obligatory program for vehicle inspection or be part of a separate activity which must be done, for example, by a bus or truck fleet owner. A well-designed inspection program could also be used as a supply for the inspected fleet's preventive maintenance through the detection of minor faults before a substantial one, which implies the maintenance and vehicle at a standstill. In addition, a program must guarantee a suitable operation during the vehicle's service life and, especially, the durability of the exhaust emissions control system. The recommendation is that any inspection program has to be profitable, at least to defend the introduction cost of vehicles with sophisticated exhaust emissions control systems.

In recent years, the emissions test requirements for periodic emissions tests have not followed the evolution rhythm of vehicle technology and the standardization procedures, like a major emphasis on NO_2, and in the mass and number of PM versus the air quality and human health.

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[13] http://www.atmos-meas-tech.net/8/3263/2015/ Amt-8-3263-2015-discussion.html.

Studies have been made to check whether it is necessary to improve the regulation applicable to the technical and regular inspection of vehicles which use modern technology or engines equipped with onboard diagnosis (OBD) and exhaust gas after treatment systems (EATS), such as exhaust gas recirculation (EGR), diesel particle filters (DPF), selective catalytic reduction (SCR), etc. Recently, the EPA presented a new proposal to improve the inspection program of diesel powered HDVs.

A study was done in 2011 by a consortium of nine organizations, with the International Motor Vehicle Inspection Committee, CITA, as the coordinator. The allocation was based on a contract with the European Commission, DG-MOVE. The following recommendations were preliminarily identified for future considerations:

- The free acceleration test, just as defined currently in the legislation, continues to be a suitable procedure for modern Euro 5/6 diesel cars. However, the way in which the engine's speed limiters are dealt with so that the free acceleration tests can be done for all the vehicles, must be kept in mind.
- The diesel emission limits in the current legislation, are expressed as "k values" expressed in m-1, which are the opacity meter units. The possibility of changing the PM mass concentration measurement (in mg/m3) for new vehicles which comply with a specific emissions standard, should be studied.
- While waiting for the results of new studies, the extension of the OBD's use in the emissions evaluation legislation or other pertinent parameters for the regular testing must be considered.
- The hybrid electric-petrol and diesel-electric vehicles are not considered in the European legislation for regular inspection. The revision of the legislation must be considered to include hybrid vehicles and suitable testing methods. For the PTI hybrid vehicle testing mode, it may be necessary to operate the motor at a specific charge level.

The change recommended to the particles measurement to mg/m3 will require modified maximum values and the introduction of new tools to measure mass concentrations.

Another study made in 2015, also made with CITA as coordinator, was considered as a follow-up to the aforementioned study. The main goal was to investigate the possibility of defining an improved testing procedure for particle measurement (PM), looking for it to be included in the regular inspection process of modern diesel vehicles with different types of exhaust gas after treatment systems and a test procedure to measure the carbon monoxide (CO) emissions of petrol powered automobiles. The use of OBD controls during the inspection was also investigated. The tests were run on vehicles with diesel engines, as well as on modern petrol engines, presented normally for regular obligatory inspections and including passenger (M1) and light (N1) vehicles.

This project has reached a series of recommendations:

- PM Emissions for M1 and N1 vehicles with diesel engines
    - There is no clear correlation between an emissions test and an OBD control for petrol or diesel-powered vehicles. Therefore, for Euro 4 or later vehicles, it is recommended that both the emissions test and the OBD control must be done instead.
    - For Euro 3 vehicles, the current limit is suitable.
    - For Euro 4 vehicles, given that some are equipped with DPF, while others are not, the limit must be the value that the plate indicates, but a maximum of 1.0 m-1 is required.
    - For Euro 5 vehicles or later, a general limit is practical for all diesel vehicles. It is recommended that a limit of 0.2 m-1 is used for future requirements.
    - During the project, it was left clear that the acceleration time over 2 seconds leads to lower k values. Increasing the time is the same as reducing the load on the engine, which results in a reduction of the emissions. Therefore, engine speed limiters must be considered.
- OBD check for M1 and N1 vehicles with diesel engine
    - During the OBD test, the vehicles with a diagnosis code (DTC) "P0..." must fail in the test.

An additional study made by the International Council on Clean Transportation (ICCT), published in 2015, summarizes the findings of the current I/M program for HDVs which is based mainly on two test methods, the free acceleration smoke (FAS) and the drag smoke test. "These tests are not suitable for newer vehicles with advanced after treatment systems due to the fact that there are not sufficiently sensitive to detect many of the possible faults of an advanced emissions control system". Normally, the tests are only used to measure the smoke, while the other contaminants like NOx are not measured.

The recommendations are to study new technologies to measure and test methods to improve the regular inspections programs. The measurement of nitrogen oxides (NOx) and nitrogen dioxide (NO2) could be done using non-dispersive ultraviolet absorption spectroscopy (NDUV) and laser light dispersion photometry (LLSP) could be used to measure particle concentrations and sizes. Another alternative is to include the use of onboard diagnoses.

An even more sophisticated system that could be used is the "on-road HDV emissions measurement system (OHMS). Said system collects the exhaust emissions of a heavy-duty vehicle during the vehicle's running (approximate acceleration of 8 seconds) under a partially closed tunnel structure.

The results and the methods presented briefly in the previous paragraphs, could be introduced in any program for obligatory vehicle inspection, as well as in programs run by large fleet owners to check the emissions and engine performance to, in the long term, reduce the operational costs via preventative maintenance.

4.1.2 Emissions performance statement

The European Directive 2009/33/CE about the development of transport vehicles for energy efficient and clean highways could be considered as the first general European document which considers the energy and environmental impacts during the service life (energy consumption, CO_2 emissions and NOx emissions, NMHC and particles) on buying highway transportation vehicles. The member states will guarantee that, as of the end of 2010, the adjudicating powers, entities and operators at the time of acquiring highway transportation vehicles will follow this directive.

The fuel consumption per vehicle kilometer will be based on the standardized community test procedures[14] and for vehicles not covered by standardized testing (buses), widely recognized testing procedures, like the information provided by the manufacturer could be used. The cost of the operational service life as well as the fuel consumption and emissions must be monetized and the life mileage must be determined for the cost's calculation. In the Directive, the life mileage is specified as:

- Passenger vehicles (M1 category) 200,000 km
- Light commercial vehicles (N1 category) 250,000 km
- Merchandise transportation vehicles (categories N2, N3) 1,000,000 km
- Buses (categories M2, M3) 800,000 km

The Directive also specifies the energy content of 8 types of fuels expressed in MJ/liter to be able to compare the energy consumption of a conventional fuel powered vehicle (diesel) versus a similar vehicle that uses electricity as its energy source.

All the demands should be applied upon procuring and only include the purchase of new vehicles as of the end of 2010. However, nothing is mentioned about the degradation of emissions performance over time. There are special requirements for the vehicle's servicing or whether the vehicles must receive maintenance following the manufacturer's information and the fuel specification that will be used during its service life (800,000 km). In this context, it is essential to know that, even if the vehicles are maintained as well as possible, a normal aging of the emissions control will be produced and with it, the fuel consumption and emissions will be increased. Thus, the total cost of the energy consumption and the emissions must be adjusted. Bear in mind that the

[14] For example, passenger vehicles according to the New European Driving Cycle (NEDC), and the "Worldwide harmonized light vehicle test procedure - WLTP.

European Regulation N° 582/2011, related to the emissions from heavy vehicles, establishes the emissions and service performance during the vehicle's service life (durability requirements).

In the case where standard tests are performed, it is essential to clarify how the buses are subjected to testing, as the results of the tests of different makes / types of bus are compared during the procurement process. Even if the driving cycle is the same during the tests, the conditions of the buses tested could be different. An example of parameters which significantly affects the result is the type of tires, the use of gearboxes, the use of air-conditioning and other devices which consume energy, the air resistance and the weight of the empty bus. Other parameters which represent "more local conditions" and that affect the results could be the altitude where the buses are operating, the slopes on the routes (up and downhill), the average number of passengers (i.e., the payload).

In the EU member states, a strategy has been introduced to reduce fuel consumption and CO_2 emission of heavy vehicles (buses and trucks) and an obligatory requirement is foreseen in 2018. Currently a simulation software is being developed which estimates the total fuel consumption and CO_2 emissions for the vehicle based on its length dynamic starting from the input data (transmission, aerodynamics, rolling and auxiliary resistance) and characteristics of the engine. The initial studies and the feedback received from those involved, suggest that the most suitable approach implies a combination of component tests and simulation. The European Commission, especially DG Clima and DG JRC (Joint Research Center), along with the industry's stakeholders, have developed over recent years, a VECTO (Vehicle Energy Consumption Calculation Tool) software tool and will continue supporting this work over the coming years.

The main goal of VECTO is not to use it as a legislation tool for public hiring matters. However, given that the public hiring in Europe must consider energy efficiency and environmental performance, the VECTO tool could be considered as a parameter for a more sustainable transportation system in Europe.

The report "*An experimental evaluation of the methodology proposed for the monitoring and certification of CO_2 emissions from heavy-duty vehicles in Europe* summarizes the findings in the following way: "the simulation's results coincide with those of the dynamometric tests. The final fuel consumption simulated deviates by approximately 2.4% in comparison with the value measured. For the tests run on the highway, the final fuel consumption is +3.5% of the measurement. Bearing in mind the real measurement variability (≥2%), it concludes that in the future, the official vehicle certification system may be based on this approach and achieve a better representation in the comparison of the vehicle's real performance and the high vehicle to vehicle accuracy".

The report also underlines that a greater development of the tool is required before it can be implemented in any certification process. As an example of areas not completely developed, the way to improve the quality of the entry data related with losses in transmissions, air drag coefficients, type/sizes of tires, etc. is found. The intention is to establish the first simulation-based certification outline for 2017 for delivery trucks and then continue with other HDV categories.

VECTO provides an estimation of the fuel consumption and CO_2 emissions for HDVs expressed in grams per kilometer. Given that the design of buses and trucks is very diverse due to the differing operation, the results could be presented as gram/ton-km, gram/passenger-km or gram/m^3-km. These values could be provided for each recently registered bus and could be reported and monitored. However, two legislative actions would need to be implemented in parallel.

- The certification of the fuel consumption and CO_2 emissions which requires the adaptation of the corresponding standardization legislation. This would imply that these values would be made available to the buyers.
- The notification of the CO_2 values is necessary to aid the follow-up and dissemination of certified heavy-duty vehicles, recently registered in the EU.

The *Recommended Practice* SAE J2711 issued by the *Society of Automotive Engineers* focused on measuring the fuel economy and the emissions of hybrid electric and conventional vehicle emissions was established in 2002 to provide an accurate, uniform and reproducible procedure to simulate the use of heavy service hybrids - electric vehicles (HEV) and conventional vehicles on dynamometers to measure emissions and fuel economy.

The Recommended Practice suggests the use of three cycles: the Manhattan cycle, which represents the low speed transit of a bus operation (average speed of 10.9 km/h, 6 stops per km, 3.3 km distance); the Orange county transit cycle, which represents the operation of a bus at an intermediate speed (average speed of 19.4 km/h, 3 stops per km, distance of 10.5 km); and the UDDS (Urban Dynamometer Driving Schedule) cycle which represents a high speed operation for buses and trailers (average speed of 30.3 km/h, 1.5 stops per km, and a distance of 8.9 km).

The Recommended Practice is not a document for procurement, but a document that presents a testing method. However, when the three previous driving programs are used, the results of the tests could be very well used to compare the fuel and energy consumption of different buses. The recommended practice does not specify how the auxiliary energy consuming devices must be handled during the tests.

A greenhouse emissions model (GEM) was developed by the EPA as a means to determine the compliance of GHG emissions requested by the EPA and the fuel efficiency standards of the NHTSA for heavy vehicles. The GEM v2.0 model itself is a part of the final legislation, and it is distributed as a freely available desktop application. Currently, a new version of GEM (v3.0) is being developed as part of the following phase of HDV GHG/FE standards, which will end in 2016. Under normal circumstances, GEM users may only enter a limited number of simulation parameters, and the model uses its integrated vehicle definitions library to run.

The International Council on Clean Transportation (ICCT) (www.theicct.org) compared the methods used to model emissions and fuel consumption in the US (GEM) and Europe (VECTO) and presented the results in a report dated April 2015. The result of the study described that the "Vehicle simulation tools can provide a reliable estimation of HDV fuel efficiency when the undesirable variation sources like the driver's behavior or the influence of environmental conditions are removed". The simulation model could be used as long the entry data quality is sufficient. For more advanced engine technology, with fuel saving potential like advanced transmissions, intelligent auxiliary management and for the hybrid vehicles, the models need to be developed even further. But, in general, computer simulation offers regulators and manufacturers interesting possibilities for the engine / vehicle's efficiency certification, as well as those of CO_2.

A new approach to reduce the carbon footprint of the transport sector, launched in USA in 2004, is SmartWay (https://www.epa.gov/smartway), a voluntary program started by the United States Environmental Protection Agency which helps the merchandise transportation sector to improve efficiency in the supply chain. The program is a voluntary association and helps companies to move more tons-miles of cargo with fewer emissions and less energy, and at a lower cost. The program generates carbon data with scientific methods based on EPA emissions factors and provides consistent and comparable metrics for the cargo emissions in all sectors of the industry. However, there is no intention to use the program for any procurement related process.

Japan was the first country to introduce the fuel consumption calculation and measurement requirement. The "Top Runner" program was introduced in 1998 with the main goal of reducing environmental impacts, especially CO_2 emissions, and of improving the national economy through technological advances in the industry. Since the beginning, 11 categories of products were included in the program and for 2014, the number of categories has increased to 31. Among the categories included in the program, are the passenger and cargo vehicles. The program is considered as one of the main pillars of the Japanese climate policy. There are three main models to determine the energy consumption efficiency standards: a system of minimum standardized values under which all equipment covered by this program must exceed the standard values. A system of medium-low standard values whose average value all the equipment covered by this program must exceed and; a maximum standard value (Top Runner Program) which considers the goals that are set for the most efficient equipment's values, from the energy point of view in the market at the time of the normal value's setting. The program is obligatory and based on the energy conservation law and is run by the Ministry of Economy, Commerce and Industry. The program is not meant to be used for procurement.

4.1.3 Procurement of vehicles / services

The European Union firmly promotes open international public hiring and has committed to granting access to the markets for determined goods and services. Information published by the European Commission's *DG Growth* (http://ec.europa.eu/growth/single-market/public-procurement/international/index_en.htm) estimates that the international public procurement accounts represent between 15 and 20% of the gross domestic product (GDP) and the Agreement on Government Procurement (GPA) represents alone, around 1.3 billion euros in business opportunities around the world. However, there are cases where companies have difficulties to access foreign public procurement markets due to protectionist or discriminatory measures.

To guarantee open, fair and transparent competition conditions in the public procurement markets, several members of the World Trade Organization (WTO) have negotiated the Agreement on Government Procurement (GPA) which will come into force in April 2014. Currently, the GPA has 18 parties which comprise 46 members of the WTO.

The European Commission (*DG Environment*) published a document in 2011 (*Green Public Procurement - Transport, Technical Background Report*), which is a voluntary instrument to purchase groups of vehicles used by the public authorities and they have prepared criteria for passenger and light vehicles, buses and garbage trucks. Most of the recommendations fully fit the different EU directives. However, for the vehicles subjected to special driving conditions, additional criteria have been considered and, in some cases, have also been developed.

The document related to the criteria for public transport vehicles (bus procurement) presents two levels of standards, called "basic criteria" and "exhaustive criteria". The technical specifications of the exhaust gas emissions for the basic criteria are that the engines used in heavy vehicles must comply with the EEV (*Enhanced environmentally friendly*) standards for the emissions level, while the criteria for the exhaustive criteria must comply with the Euro VI standards for emissions. In both cases, the bidder must present the vehicle's technical documents which indicate that the engine complies with the norms. However, to avoid misunderstandings, it may be preferable to confirm that the engines used in heavy vehicles are approved following the specified requirement (instead of complying with the norm, with an opening for the modification of older vehicles). In this project, the engines used in heavy vehicles approved following the Euro III emissions norms could fit the "sustainable bus systems", depending on the obligatory requirements for the engines authorized to enter the affected markets, these could be reformulated to also include these vehicles. In addition, the vehicles destined to satisfy exhaustive criteria must also comply with the exhaust pipe, lubricating oil and tire requirements. To qualify for the awarding criteria (additional points during the tender's evaluation), the basic criteria include alternative fuels, noise emissions and exhaust gas emissions. To qualify to the awarding of buses with exhaustive criteria, additional areas are included like tire pressure indicators, air-conditioning gases, vehicle's material (light, renewable) and automatic startup and stopping systems. In addition, it is recommended that the awarding criteria address at least 15% of the total available points.

A significant issue in the way the document presented is written, is that reference is made mainly to the engine's emissions performance when this is tested as an independent unit in a sophisticated emissions laboratory, as described above. No mention is made about the ratio between the vehicle's weight and the emissions performance during real life operation. A typical example is when a bus supplier designs a light chassis (for example, using mainly aluminum or a compound material) with a weight that is several hundred kilograms lighter than a conventional chassis (using more steel). Given that the engine's emissions performance is the same, the chassis lighter, and therefore there is a lower fuel consumption in real life operation, it may not have any advantage in the awarding process, since the assembled vehicle's performance does not form part of the procurement.

In addition, the document does not mention anything about the use of automatic transmissions in the buses being procured. In many cases, the gear change points in modern automatic gearboxes are adjusted by the manufacturer to better manage the bus's performance depending on the route the bus is going to run on. Normally, the low fuel consumption will then be the highest priority and, as a result, when the fuel consumption is also adjusted, the emissions performance will be positively or negatively affected.

It is vital that the basic criteria and requirements in any procurement are established so that they represent the whole vehicle and not just the components included in the vehicle.

The EU document also addresses the criteria for public transportation service, i.e., the contract to provide the services of an environmentally friendly bus. The criteria are the same as mentioned above, "basic" and "exhaustive". Both of these criteria must be introduced for a transport system for people in a designated area, using a variety of vehicles of different models and ages. The technical specifications for the exhaust gas emissions in the basic criteria are that all vehicles used for the service must have engines which comply with the Euro IV emission level norms, while for the exhaustive criteria, vehicles must have engines which comply with the Euro V emissions norms. It also accepts that vehicles with older engines could be improved to comply with the required standards. However, this does not fit this project's intentions, as the project only uses the OEM applications (and does not improve the engines). The contract compliance clauses also explain that information must be provided about the fuel consumption information, independent of what is used (petrol, diesel, biofuels, CNG, electricity, etc.) as well as a program to train all bus drivers throughout the contract. The training must be done by a recognized institution and not by the fleet's own operator.

The final disposal of lubricating oils and tires are also important questions and the contractor has to mention how they would be disposed of and guarantee that this is suitable. The environmental impacts at the end of the life must be considered, especially with regard to the electric vehicle batteries. In general, the batteries will be handled by the manufacturer to be suitably disposed of at the end of their service life. This could be an important future matter to consider, since an electric bus manufacturer as well as the conventional diesel bus manufacturer, deem that the demand for diesel (city) buses will fall within 10 years in Europe.

The Directive 2009/33/CE related to the promotion of energy efficient and clean highway transportation vehicles (*Clean Vehicles Directive*) demands that public authorities also bear in mind the life energy consumption and the environmental impacts.

The Directive does not impede the possibility of modernizing the vehicles, so that the engines, after treatment devices and moto propulsion groups are improved to obtain a better environmental performance. However, this document excludes any retrofit and deals only with new vehicles introduced in the market (original equipment manufacturer, OEM applications), since the real life driving experiences for several types of adaptation devices have not always been successful. The Directive also demands that at least the energy consumption, carbon dioxide emissions (CO_2), nitrogen oxide emissions (NOx), non-methane hydrocarbon emissions (NMHC) and particle emissions are kept in mind. In this context, it is not obvious that the energy consumption is the same as the emissions reduction.

For the lifetime environmental and energy impacts, reference is made to the following reports: *Environmental Impact of Products***,** (EIPRO) and to the Analysis of the life cycle environmental impacts related with the final consumption of the EU-25 (*EU Commission, Joint Research Center, JRC, Institute for prospective technological studies, IPTS*), where the transport CP07 is a sector (**http://ec.europa.eu/environment/ipp/pdf/eipro_report.pdf**).

In the United States, the *American Public Transportation Association* (APTA) published the documents, *Standard Bus Procurement Guidelines and Procurement Handbook*. The documents are very complete and include general recommendations, as well as detailed technical requirements to develop a bus package that is consistent throughout the industry. In addition, the role and responsibilities of the stakeholders is explained in detail.

The APTA *Procurement* manual presents different types of procurement, such as:

- Best price procurement (*proposal request*), not only bearing in mind the product's initial cost, but also the product's life cost, the quality and a variety of other factors. This process is essentially a negotiation which allows the agency to speak with the companies that offer competitive proposals. For complicated matters like the purchase of "systems" or "services", this type of procurement is preferred by the responsible agencies.
- *Procurement of the lowest offer*, in the cases where the products or services are relatively standard and easy to specify. Sometimes, specific companies are invited to the tender process as "prequalified".
- *Sole Source*, where only one price is requested to a single supplier or the contract is awarded without competition. Especially in the contracts which have a limited amount of money. This type of procurement needs a high level of transparency and a suitable control.

From a total of 267 pages, 153 pages (57%) are related with technical specifications. From the 153 pages, only a few are related with the engine's performance, the exhaust emissions or the fuel consumption.

Details are shown about the information requested in Appendix 2. It is worth stating that no follow-up is prepared in the recommendation document, but as common practice, all vehicles are inspected before delivery and entering service.

Appendix C of the Procurement Directives provides examples about the evaluation of proposals and recommends setting up an evaluation committee. The Committee will check and project the proposal based on several parameters and each one will be validated and classified by allocating points. The parameters are listed as follows:

- Meeting prior to the bid (maximum 5 points)
- Technical evaluation criteria (maximum 80 points), including
    - Product design and performance (maximum 30 points)
    - The bidder's performance and reputation (maximum 30 points), and
    - Delivery timeframes (maximum 20 points)
- Evaluation of the costs proposal (maximum 20 points)

Each one of the proposals must be evaluated so that it complies with the minimum established requirements, and each proposal will be rated following the specified designations such as: Outstanding, Acceptable, Marginal and Unacceptable. The performance risk is a way to evaluate the bidder's capacity to perform the contract tasks and is classified with the words: high (refers to significant doubts), moderate, low and not applicable. Appendix C also presents a list of factors that will be used together with the price, since the awarding will not necessarily be made to the cheapest offer. When all the tools are used, as well as the recommendations implemented in the process, there is a high probability that the procurement works very well.

The United States Transportation Department, Federal Transit Administration in their circular FTA C4220,.1F Revision 4 (March 18th 2013) provides basic information which is also related with third-party hiring directives, including federal assistance to finance procurement, and it is clear that there must be an integrated program running.

The document includes a chapter to guide the procedure to buy in an open market, as well as references to the federal regulation "*Buy American Rules*". The non-compliance of these regulations can result in the loss of federal funding for any determined procurement project.

In the State of California, the *Standard Bus Procurement Guidelines*, APTA, could be used, however the *California Air Resources Board* (CARB) started a "Fleet Rule" in 2000 for Transit Agencies which addresses the requirements for urban buses. The main goal is reducing the exposure to diesel particles (PM) and nitrogen oxide emissions (NOx) of the transit fleet's vehicles. In addition, the advanced clean transit project took place with even stricter requirements for the fleets. It also promotes advanced technologies for transit buses, such as battery electric and electric buses with fuel cells, hybrid bus and clean combustion engines. As many bus fleets are not working in California using advanced technologies, these could be classified as part of a Sustainable Bus System and, fall in line with the scope of Annex 53[15].

An example of the national requirements for bus procurement is the document used in Sweden "*Buss 2014 – Common Sector, Functional Requirements for Buses*" published by the *Partner Cooperation for Improved Public Transport*[16]. The same reference is also included in the *UN ECE Regulation 107* related to the definition of buses. General definitions of some types of buses are presented in Appendix 1 of this report.

The document, *Bus 2014* specifies the functional requirements that the sector has jointly agreed as being in the passenger's interest and that are applied on top of the current legislation. The purpose of the document is to serve as a standard for bus procurement in Sweden. Therefore, the *Swedish Public Transport Association and the Swedish Bus and Coach Federation* recommend that buyers do not make exceptions

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[15] Public procurement is not part of the new bus system, but more information about the fleets and California bus activities can be found at **https://www.arb.ca.gov/msprog/bus/bus.htm**.

[16] http://www.svenskkollektivtrafik.se/globalassets/partnersamverkan/dokument/mallavtal-och-kravbilagor/buss-2014/buss-2014-english-version.pdf.

and that they fully use this document.

For the common recommendations of the sector with regard to environmental requirements, like fuel, emissions, energy efficiency and noise, etc., reference is made to the most recently published common sector document titled "*Environmental requirements in connection with transport procurement*". Also included in the package as an orientation document. In total, all the documents comprise 100 pages and 1/3 is related with environmental issues like emissions, fuels, noise and follow-up requirements or recommendations.

General recommendations and three levels of requirements are presented in the orientation document. The requirements are set normally as "Minimum" recommended for areas with limited population levels or for small fleet owners, "Basic", recommended for the normal use of buses and "Extended", recommended for areas with high demand of strict requirements, but in some cases, specific requirements do not need to be presented. As an example, special emissions requirements are not demanded for buses with 22 passengers or less (Class A and B), since the existing obligatory requirements (Euro classes) and the vehicle's age seem to be sufficient. On the other hand, the emissions requirements for buses with more than 22 passengers (Class I, II and III) require the "Minimum" and "Basic" requirements are values measured for the particles and nitrogen oxide (NOx) emissions expressed as g/kWh. The average given for NOx is valid for the calendar year as of 2014 (3.0 Minimum, 2.4 Basic) through to 2020 and beyond (2.1 Minimum, 1.0 Basic). The corresponding requirements for PM are 0.02 and 0.015 g/kWh, respectively.

The energy use requirements are related with SORT driving cycle (discussed previously) and are quite unique for the procurement. For the Class I bus, 2 driving cycles must be used (*Easy Urban*, average speed of 18 km/h), while for the class A, B, II and III buses, the SORT 3 classification cycle (*Easy Suburban*, average speed of 25.3 km/h) must be used. The maximum admissible energy consumption for class A and B buses (which came into force in July 2011) is 24 liters of diesel/100 km or 24 kWh/10 km in the case of electrical powered buses. The value must be considered as the total consumption of the vehicle fleet in question (class A and B buses). Where buses run on electricity, this must be renewable in origin. It is highlighted that for Class I, II and III buses, the situation is more complicated.

An interesting observation, based on the conditions of Sweden, is the fact that the very special requirements of those responsible for procurement, could reduce the bus's economic life. The technical service life of a bus is estimated at 16 years, while the contract between the fleet operator and the council generally lasts 8. This will imply that the fleet owner must depreciate the buses more quickly than needed when considering the bus's technical status. If the buses, as an alternative, could not be reallocated as a result, there would be higher costs for the taxpayers or this would be passed onto the passengers.

5 National proposal

5.1 Proposals to include laboratory test information in the promotion of cleaner and more efficient buses

Most of the instruments described are already available and used internationally and could be used in Chile in a slightly different way to better fit the procurement intentions, that is to say, identifying the most profitable technology or bus used but also the technically most suitable one.

The selected alternatives will imply, of course, different efforts for the bidder and, therefore, add additional costs to supply the buses or to supply the public transportation service. However, the general approach is an attempt to maintain that "additional costs" are as marginal as possible. Affecting the total cost which depends on the number of buses being supplied. The most suitable alternatives for Chile are described below.

It is recommended that the Ministry of Transportation and Telecommunications adopts approach 2, "Good enough", because it allows taking advantage of the existing capacities in Chile, especially at the 3CV, reducing the gap between the information provided by the engine emissions certification and the behavior of vehicles on the public highway, which can produce a transformation of the bus market towards cleaner and more efficient buses. For this, it is necessary to adopt the Euro VI standard at a national level, already required in Santiago, along with the promotion of energy efficiency in the Renew your Bus (Renueva tu Micro) program. In the case of the tender process for new services in Transantiago, it is necessary to formally adopt the new Santiago cycle developed in this project, along with the procedures to run the tests, and demand the presentation of information in this test cycle for bus models which comprise the fleet included in the offer proposed by interested parties in the next tender process.

To promote energy efficiency, it must be demanded that all new buses present the performance information and emissions measured in the WHVC cycle on their registration in the National Passenger Transportation Services Register, and in the case of the vehicles already registered to operate in the Santiago public transportation system, demand information of the performance and emissions results in tests done with the Santiago cycle.

To make this requirement possible, SD212 which regulates the services and vehicles which provide public transportation in the country must be modified, and the test cycles for Santiago buses and the WHVC must be formalized, along with the conditions to run the emissions and performance certification tests. The test procedures must consider the differences in the conditions on being applied on buses with different technologies, namely: diesel, CNG, hybrids and electric. The most important ones are stated below.

- Preparation of the test:
  - Preparation of the laboratory.
  - Preparation of the vehicle.
  - Preparation of the dynamometer.
  - Test of the instruments.

- Test procedure:
  - Turning on of vehicle and dynamometer.
  - Preliminary run.
  - Emissions test.
  - End of the test.
  - Information recorded.
  - Test validation.

The following chapter presents recommendations about the bus test procedures in the Santiago Cycle, considering the different technologies.

The requirement of reporting the energy efficiency and the emissions must be made upon requesting the vehicle's registration in the Passenger Transportation Services Registry. For this, the vehicle's owner must attach a certificate with the results of the test made in the Santiago Cycle issued by 3CV under the conditions

5.2 Test procedure

5.2.1 General

To decide among similar products, information is required about their performance so that a decision is made on selecting which one of these provides the "*best value for money*"; as a result, complex analysis and tests must be done. In many cases, manufacturers are responsible for requiring tests or presenting evidence so that their vehicle is approved by the internationally accepted standards and meets the established requirements. Sometimes, when test results are really important or the tests are complicated and the results are crucial for the sale, it is common that final tests are done by an independent third-party laboratory. These are usually accredited for the related test procedures and comply with international standards for testing laboratories.

This chapter presents recommendations of how to run fuel consumption and emissions tests for buses in laboratories with dynamometric chassis. In contrast with the passenger vehicle tests on dynamometers using specific regulations and procedures established in internationally accepted standards, in the case of heavy vehicles, only the engines as an independent unit of the vehicle, are subjected to fuel consumption and emissions requirements. Independently, the results of tests on an engine made under strict laboratory conditions have little to do with the vehicle's emissions performance when operating in real life.

It is acknowledged that testing heavy vehicles on a chassis dynamometer is complicated, especially when results of different laboratories must be compared. To be able to make a ranking of the vehicles based on tests run in different laboratories, the test procedures that act as a guide must be made available.

5.2.2 Basic requirements

The international regulations for engine emissions used on heavy vehicles, guarantee an acceptable emissions performance for new engines, as well as an acceptable deterioration during their service life (just as the standards set out). They have added requirements for an onboard diagnosis (OBD) to this. These indicate the failures of vital components included in the emissions control systems. Finally, the standards have also included the measurement of emissions with the vehicle operating in real conditions, using the portable emissions measurement systems (PEMS). Finally, the standards also require that the manufacturers follow some best practices, which include the quality control of their procedures and components. It is demanded that for engines approved following the international standards (USEPA, EU, ECE, etc.), the manufacturer guarantees that the basic requirements are met. It is recommended to demand from the manufacturers, that they provide approval certificates from the competent authorities. Statements from the manufacturer themselves about a certain engine complying with the standards or the requirements sought, must not be accepted. In the case of prototypes when a formal approval is not available, a formal arrangement must be established.

There are differences between the European and US emissions legislations which must be considered. In Europe, limits have been introduced for the number of particles (PM). For the engines which use CNG, emissions limits for methane (CH_4 are used, while in the US, there are values for non-methane hydrocarbons (NMHC). This implies that the US does not regulate methane emissions for CNG buses and Europe considers methane as a Greenhouse (GHG) gas, and thus regulates it. CNG or liquid natural gas (LNG) buses, approved in the US will not be approved in the EU unless the methane emissions requirements are met.

It is important to mention that this chapter only refers to new buses complying with the latest emissions norms. Used buses that are converted or modified to meet the current emissions norms, or used buses converted or modified to use another type of fuel for which the original engine was not designed, are not considered in this document. For example, used diesel buses converted to run on CNG or a mix of diesel and CNG are not accepted. The buses with *retrofit* emissions control systems (catalytic converters, particle filers, SCR systems) need special considerations and a different discussion to that of the new vehicles.

5.2.3 Vehicle

- When a bus is presented in a laboratory it must be clean, even on its undercarriage to avoid increasing the contamination levels of the laboratory's environmental air, which could affect the test results.
- Depending on the laboratory's type of chassis dynamometer (simple or double rolling), the third axle's wheel (of the axle without traction) must be removed to give space to the traction wheels.
- For new buses, it is recommendable to connect the OBD system to check if there are failure codes or if the emissions control system is in perfect working order.
- Depending on the test ratio (where it is "as built" or "to show the potential of the technology"), it is recommendable to change the oil and its filter. In the case of the SCR additive (*AdBlue*), it must be checked that the appropriate liquid is being used. In some cases, it is recommendable to run some minor maintenance on the engine.
- To avoid discussions, the fuel must be changed for a reference or commercial fuel. When the buses are tested in laboratories outside the country and the fuel of the same quality is not available, it must be sought that the laboratory uses the fuel tests that represent the specifications of the country where the bus is going to operate.

- The implications of biofuels must be considered in the tests, since in Chile, unlike other countries, these are not present in commercial fuels (the energy contents of biofuels differ from conventional fuels as they have an impact on the consumption, affecting, along with the composition differences, the emissions results).

- Loading the vehicle with a representative weight considering the passenger numbers. The buses are normally loaded in Europe with 50% of their maximum passenger capacity (25 people x 70 kg/person). For trucks and traction trucks, ballast must be used to guarantee sufficient traction on the chassis dynamometer. For the case of buses, sacks of sand or drums with water can be used as ballast, while in the case of the trucks, blocks of concrete can. It is recommendable to use the number of passengers which represent the real operation condition. For the case of Santiago, it has been determined that the maximum payload of the bus is set at 50%.

- If the vehicle is equipped with new tires, it is recommended to change them for more suitable ones (preferably "bald") to minimize the risk of damage to the tires. The vehicle must not, of course, be run on the public roads with illegal tires.

- The vehicle must be placed on the dynamometer with the traction wheels on the roller(s) and aligning them, guaranteeing that they are sufficiently anchored and in the correct position so that they cannot slip outside the dynamometer during the test.

- Connect the vehicle to the measuring equipment, using a flexible tube on the exhaust and avoid broken connections and contacts. It is recommendable to use a several meter-long exhaust pipe to reduce the vibrations.

- Equipment must be installed to measure the exhaust temperature, whose role is to be used as reference to check the operation of the catalytic converter, filters and SCR system.
- Assemble a suitable air supply to the engine but checking that this does not affect the vehicle's additional systems (sump's ventilation, etc.).
- Couple the fuel consumption measurement system. Two alternatives can be used: using a flow meter system incorporated on the vehicle's fuel system or the use of a separate system which includes a scale to measure consumption during the test. It must be checked that there are no bubbles in the system and the fuel return hose to the tank is not forgotten. It is recommendable to ask the vehicle's manufacturer how to connect extra fuel hoses without affecting the pressure. The importance of bearing in mind that a fall in the volumetric flow may affect the final results due to heating the fuel, is underlined. The technicians must guarantee the system's water tightness and that there are no influences of other systems.
- The use of a cooling fan on the front of the vehicle and on the traction wheel is strongly recommended. The capacity of the fan on the front of the bus (with the open compartment) must allow cooling the engine under normal operation conditions.
- After the vehicle's preparation, the bus must be run on the dynamometer and check that the vehicle acts as planned. Accidents may be produced if the bus cannot be driven with open doors, when

all the wheels are not rotating, or when the front wheels rotate at a different speed to the rear ones.

5.2.4 Dynamometer (type)

- Dynamometers of a larger size can be used, or one of the two with smaller wheels.

- In the case of two roller dynamometers, it is recommendable to increase the traction wheel pressure to avoid greater rolling resistance due to heating of the tires.

- Some dynamometers can represent the condition of rising or falling slopes. This possibility is not commonly available, unless representing a particular driving pattern is wished.

- It is recommendable to contact the chassis dynamometer supplier to become familiar with its capacities, including all the adjustments and data and information storage possibilities for future requirements.

5.2.5 Dynamometer (setup)

- To simulate the road's condition, the dynamometer must be adjusted to the rolling and wind resistance. This is usually transmitted by inertia (representing the vehicle's weight) and the coast down coefficients (represented by the weights and rolling and wind resistance).

- The coast down must be done using a flat road, suitably measuring the time the bus takes to go from a high to a low speed (for example, from 80 km/h to zero), rolling freely. The dynamometer is adjusted to reach the same effect in a same amount of time. After testing buses for a good period, the possibility exists of making a database of different coast down curves for several bus manufacturers / models / setups, which makes adjusting the dynamometer easier for each bus in particular.

- Coast down tests must be run on the dynamometer to compare the times obtained with the same intervals on the road. The procedure must be repeated until the coast down time is the same, adjusting the dynamometer accordingly.

5.2.6 Instrumentation

- The instruments used must comply with the specifications defined in the internationally accepted emissions standards (EU Euro VI, ECE R49, USEPA 2010). All the relevant instruments for the tests must be calibrated following the demands of these standards, including the calibration gases.

- Before calibration, the instruments must be heated to be stabilized following their manufacturer's recommendations. The calibration must be done before and after the analysis. If the differences between the calibrations are greater than specified, the calibration must be done again.

5.2.7 Preparation test

- As part of the preparation test, the bus must be driven on the route to allow the driver to become familiar in terms of the engine's performance, gear changes (mechanical gearbox), brake's response, etc. The temperature of the vital components could also be recorded as a reference, to check before the test whether the bus is at the correct temperature for a warm test. These temperatures may be compared with the temperatures measured on route, as a reference.

- The tests can be run with the bus cold or warm. The buses are normally running 18 hours a day; therefore, most of the tests must be run warm. The energy consumption and emissions tests are normally run at environmental temperatures between 20 and 30°C, the same range as specified for passenger vehicles. However, the tests may be run at low temperatures (-7°C) to represent cold starts under these conditions, especially for heavy vehicle tests, which implies different requirements for the test cells.
- The chassis dynamometer must be conditioned before the tests, using another vehicle (or via an electric motor), rolling at a constant speed of 70 km/h for 30 minutes.
- A preparation cycle, for example, the world harmonized vehicle cycle (WHVC), must be run on the dynamometer by the driver, to determine the best strategic for the driving, braking and gear changing in the case of a mechanical gearbox. It is useful to record the gear changes when many tests are run on the same bus or an identical one, to minimize the impact on the results.
- The temperatures must also be recorded during the preparation cycle to achieve identical cycles.

5.2.8 Tests

- After the preparation, the bus is ready for the test. The following procedure must be considered to run the test:
    - Start the sample system at a constant volume.

- Start the laboratory cell's ventilation system.
- Turn on the front cooling fans and traction wheels.
- Activate auxiliary equipment.
- Check that the driving cycle loaded in the driver support system is correct.
- Turn on the driver support system.
- The driver must follow the driving indicated on the screen by the support system's curve. The driver cannot "soften" the driving route and must follow it as closely as possible. If the vehicle cannot follow the route during the accelerations, the driver must floor the pedal until the vehicle returns to the route indicated on the help system's screen. The tolerance for an acceptable driving on the dynamometer is ±1 km/hr. for passenger vehicles driving at a constant speed. Given that there are no standardized driving cycles for heavy vehicles on dynamometers, there are no specified limits for driving. However, the use of the same approximation as the passenger vehicles is recommended with a tolerance of ±1 km/hr. to constant speed. It is recommendable to register the driving pattern during the test to verify whether large discrepancies are produced between "what happens" and "what should happen".

* After finishing the test, the dynamometer's setup must be checked again. The same aforementioned procedure must be followed.

* The final results must be calculated after finishing the test and the emissions analysis.

* The number of tests being run has to be enough to provide reliable and representative results. Based on testing experience in

conventional buses done in international laboratories, 2 to 3 tests may be enough. In the case of tests on hybrid and battery electric buses, the number of tests must be higher as there are variations in the different systems that work together, such as the batteries and the charging systems.

5.2.9 Calculation of Results/Report

- The calculation of the exhaust emissions measurements must be made to present the results expressed in mass by distance. The results are usually presented in grams per kilometer, according to the common practices in Europe.

- The calculations from the fuel consumption measurements must be made to present the results expressed in volume by distance. Again, following common European practices, the results are usually presented in liters / 100 km, but can also be presented in km/lt.

- The results of the Santiago cycle's tests must be expressed in gr/km, indicating that they represent a "tank to wheel" methodology, to avoid confusion, given that it is common to also express results in broader analysis, like "well to wheel" (where the emissions associated to fuel transportation and production used by the vehicle are also included).

- The heavy vehicles are not subject to fuel consumption / energy report demands. However, the European Union is in the process of introducing the VECTO tool (*vehicle energy consumption calculation*) for energy/fuel consumption and CO_2 emissions statements for heavy vehicles.

- To make the comparison of results possible at a more detailed level, the emissions calculated can be divided by the maximum number of passengers the bus can transport, making it possible to estimate the energy consumption and emission per passenger carried.

5.3 Hybrid Buses

- The coast down tests for hybrids require special considerations, given that these buses have regenerative brakes, meaning they do not also roll freely, requiring a solution to uncouple the regeneration system.

- These buses are equipped with a smaller conventional engine, working together with an electric battery fed motor. The batteries are being recharged during the operation. There is always a trade-off between battery size and behavior and the combustion engine's performance. Because of this, it is necessary to establish a procedure that measures the total consumption of the conventional engine along with the electric motor. In the case that both the engine and motor work on the same axle, the total energy can be calculated by measurements on this common axle.

- It is important to verify the battery's charge status (SOC), especially the changes between the fully charged batteries at the start of the test and their status at the end.

- Given that most of the tests are run with a warm start, it must be completely clear how to deal with the battery's energy during the motor's heating before starting the test.

- A major complication is produced when the front axle of a vehicle is driven by the electric motor and the rear by the combustion engine.

In this case, a dynamometer is needed with the capacity to measure heavy vehicles with two drive axles.

- To make the total energy consumption of a hybrid bus comparable to a conventional one, it is recommendable to identify the most important parameters and to discuss them with the bus supplier to agree on how to measure these parameters. Given that there are different technologies, the means to measure these parameters differ among vehicles.

5.4 Battery electric buses

- Experience shows that battery electric buses operate differently to conventional buses, as the slopes and mean and maximum speeds have an important effect on the bus's performance, affecting its autonomy.

- When an electric bus is tested, the status of the batteries at the start is important. Normally the battery is fully charged and the bus's autonomy can be verified by running the bus, repeating the test cycle on several consecutive occasions.

- The use of the bus's auxiliary systems or devices, like air-conditioning, assisted steering and door operation, can have an important effect on the consumption.

- The capacity of the batteries is reduced with the room temperature, as such it is recommendable to consider a set of tests under winter conditions and others under summer conditions.

- The bus's payload may be of great importance in the energy consumption results, therefore, it is important to also consider tests at full and half payload.

5.5 Report

The test results must be presented in a format like the one proposed below, where the laboratory where they were run, the person responsible and the identification of the vehicle that was presented for testing, must be identified.

<table>
<tr><td colspan="7">TEST RESULTS OF EMISSIONS OF BUSES MEASURED IN SANTIAGO CYCLE</td></tr>
<tr><td colspan="7">VEHICLE</td></tr>
<tr><td></td><td colspan="2">Chassis</td><td colspan="2">Engine</td><td colspan="2">Coachwork</td></tr>
<tr><td>Brand</td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td></tr>
<tr><td>Model</td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td></tr>
<tr><td colspan="4">Serial number of vehicle subjected to evaluation</td><td colspan="3"></td></tr>
<tr><td colspan="7">The vehicle was subjected to testing under the cycle for Santiago de Chile's buses</td></tr>
<tr><td colspan="4">The vehicle was inspected by</td><td colspan="3"></td></tr>
<tr><td colspan="4">Norm of the Laboratory that ran the tests</td><td colspan="3"></td></tr>
<tr><td colspan="4">Test date</td><td colspan="3"></td></tr>
<tr><td colspan="7"></td></tr>
<tr><td colspan="4">Number of standing passengers</td><td colspan="3"></td></tr>
<tr><td colspan="4">Number of seated passengers</td><td colspan="3"></td></tr>
<tr><td colspan="4">Total</td><td colspan="3"></td></tr>
<tr><td colspan="7"></td></tr>
<tr><td colspan="7">Emissions results at 50% payload and standard environmental conditions</td></tr>
<tr><td>Test number</td><td>MP [gr/km]</td><td>Nox [gr/km]</td><td>CO_2 [gr/km]</td><td>Fuel Performance [km/lt]</td><td>Energy consumption [joule/km]</td><td>CO_2 Emission per nominal passenger [gr/pax-km]</td></tr>
<tr><td>1</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>2</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>3</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Average</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
</table>

6 Conclusions

Based on the project's results, it is possible to establish that the operation conditions of a bus in a developing city, like Santiago de Chile, are different to those used internationally to evaluate buses, especially those in Europe. The emissions and energy efficiency observed in the test program reflect this, being different to those available internationally for the same bus technologies evaluated, thus justifying the development of *ad-hoc* test procedures and cycles.

The differences in the operation conditions are due, among other causes, to a less developed road infrastructure, to more demanding payload conditions, to less well-trained drivers, to different standards for the vehicles, and to higher levels of congestion. There are also local factors, like the topography of Santiago, which has areas with very important slopes.

The emissions of a Euro VI bus measured in the Santiago cycle are different to the results seen in the Braunschweig cycle, independent from the control technologies allowing substantial reductions on comparing these with engine-powered buses certified under previous standards. It is seen that in the Santiago cycle, a same Euro VI bus can have double the NOx and PM emissions compared to the Braunschweig cycle. It is probable that a more congested cycle like Santiago, does not allow reaching the same exhaust temperatures as a cycle with longer sections operating at higher speeds like the Braunschweig cycle, which affects the efficiency of the selective catalyzer reduction (SCR) and the diesel particles filters (DPF). It is recommended to run a measurements program for the Euro VI buses that will enter the Santiago fleet in real operation conditions, to study these differences in more depth, and to check the compliance of the emissions levels required by this standard.

The energy consumption is higher in the Santiago bus cycle versus the Braunschweig cycle, seeing consumptions that are 60% higher for the same Euro VI diesel bus, which has important implications on the operation costs of these vehicles, and on the CO2 emissions of the Santiago public transportation system. The bus manufacturers must take this information as justification to develop versions of their buses optimized for operation in a city like Santiago, adapting and setting up the powertrain of their bus chassis to these more demanding conditions, and developing lighter coachwork.

Battery electric buses consume less than a quarter of the energy that a diesel bus requires per kilometer under the Santiago cycle conditions, but it is also seen that their consumptions are higher than those seen in other cities. The charging and the slope of the routes are very important factors in the energy consumption, and it is seen that the extra energy consumption needed to climb a route with a slope is not offset in going downhill, as the batteries cannot be recharged at the same speed with the energy regenerated in the braking, as if there is an excess energy, it cannot be accumulated. The electric consumption obtained, indicates that manufacturers must optimize their vehicles to operate in a complex city, to guarantee that vehicles do not have autonomy issues operating in Santiago's public transportation services.

The United States of America and the European Union present a series of useful experiences in the use of energy consumption and emissions testing information to promote cleaner and more efficient buses. These are base demands for this type of results in guidelines to purchase buses, in technical requirements for the buses and in incentive programs for buses with low local contaminant and CO2 emissions.

The Ministry of Transportation and Telecommunications has already generated the conditions for the first use of the Santiago bus cycle in the route's tender process, demanding that the new public transportation service concessionaries must report the energy consumption upon registering their new buses in the National Public Transportation Services Registry, measured in the world harmonized vehicle cycle (WHTC and WHSC) or in a cycle that the Ministry indicates. This second option corresponds to the Santiago buses cycles, which must be made official by a resolution of the same Ministry, indicating the cycle and the testing conditions. In the future, the Ministry must modify the decree that regulates the operation of public transportation services, demanding that all new buses registered to operate in Santiago must report their energy consumption in the Santiago bus cycle.

This demand of reporting the energy consumptions under a representative cycle of the operation conditions in Santiago, will allow that the fleet renewal with Euro VI buses and the progressive introduction of electric buses, produces the highest possible reductions in energy consumption and emissions with the available technologies.

7 References

3CV MTT Chile. (2015). *Selection of Representative Routes of Transantiago (in Spanish)*

3CV, MTT Chile. (2016). *Selection of Transantiago Routes which are Mainly Covered on a Bus Only Lane and Corridor (in Spanish)*

Barlow, T. J., Latham, S., & I S Mc Crae, P. B. (2009). *A reference book of driving cycles for use in the measurement of road vehicle emissions.* TRL Limited. Obtained from Dieselnet.

Departamento de Ingenieria Mecánica, Universidad de Chile. (2007). *Update of emissions factors for buses and cargo transportation in the Metropolitan Region (In Spanish).*

DTPM. (2014). *Management report*

IEA-AMF. (2007). *Advance Motor Fuels.* Taken from Evaluation of duty cycles for heavy-duty urban vehicles, Annex 29: The loadís (work load) effect on the specific fuel consumption was in the early stages of

IEA-AMF. (2012). *Fuel and Technology Alternatives for Buses.*

IEA-AMF. (2016). *CONVEC: Fuel and Technology Alternatives for Commercial Vehícles, Final Report of EIA AMF Annex 49* .

Kaufmann. (2017). Taken from http://www.kaufmann.cl/kf_data/buses/1011/catalogo.pdf

Kaufmann. (2017). Taken from http://www.kaufmann.cl/kf_data/buses/1173/catalogo.pdf

Kaufmann. (2017). Taken from http://www.kaufmann.cl/buses/

OPUS. (2012). *AA Research: Standard Metrics for Transport and Driver Safety and Fuel Economy.*

U.S. EPA. (2003). *Roadway-Specific Driving Schedules for Heavy-Duty Vehicles.*