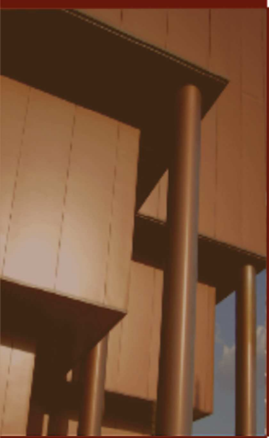
Trabajo fin de Máster
Máster en Ingeniería industrial

Reducción del consumo de combustible y emisiones en zonas de tráfico congestionado

Autor: Reyes Fernández Navarro
Tutor: Ricardo Chacartegui Ramírez



Dep. Ingeniería Energética
Grupo de máquinas y motores térmicos
Escuela Técnica Superior de Ingeniería
Universidad de Sevilla
Sevilla, 2017

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Proyecto Fin de Carrera: Reducción del consumo de combustible y emisiones en zonas de tráfico congestionado

Autor:

Tutor:

El tribunal nombrado para juzgar el Proyecto arriba indicado, compuesto por los siguientes miembros:

Presidente:

Vocales:

Secretario:

Acuerdan otorgarle la calificación de:

Sevilla, 2017

El Secretario del Tribunal

A mi familia

A mis profesores

Agradecimientos

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Gracias a todos,

Reyes Fenández Navarro

Sevilla, 2017

Resumen

La naturaleza está mostrando evidencias del cambio climático con consecuencias que ya influyen en la vida animal y vegetal de nuestro planeta. Estudios científicos han demostrado la gran influencia que tiene sobre el cambio climático los gases de efecto invernadero inherentes a distintas actividades humanas. Así mismo, la presencia de concentraciones de estos gases por encima de los estándares habituales en la naturaleza, se ha relacionado directamente con distintas enfermedades cada vez más presentes en los núcleos urbanos con mayores índices de concentración de contaminantes en aire. La presencia de estos contaminantes se relaciona con el consumo de combustible para la generación de energía final para distintos fines. Según datos estadísticos obtenidos de la *Agencia Andaluza de la Energía* (AEE), el 42% de la energía final se consume en actividades de transporte (siendo el sector que más energía final consume), y el 80% de la energía final consumida en actividades de transporte se asocia al transporte por carretera. A su vez, el 95% del consumo de combustible, de los vehículos que circulan por carretera, lo constituyen combustible fósiles. Con estos datos, puede deducirse la fuerte relación existente entre los valores de concentración de contaminantes en el aire y las actividades de transporte por carretera.

La evaluación del transporte de carretera con el objetivo de analizar el consumo de combustible, las emisiones de gases de efecto invernadero y el ruido (factor directamente relacionado con la salud y confort de la población y estrechamente relacionado con el tráfico en carretera), no resulta una evaluación sencilla, sin embargo, es un paso fundamental con el objetivo de impulsar estrategias encaminadas a mejorar la calidad del aire y condiciones de confort en los núcleos urbanos.

A lo largo de este proyecto se desarrolla una metodología para la evaluación y propuesta de medidas de reducción de emisiones de gases contaminantes y ruido en zonas de alta densidad de tráfico en ciudades. La metodología desarrollada en el proyecto pasa por describir la generación de escenarios de forma sencilla, pero con la rigurosidad suficiente como para poder realizar un análisis cualitativo y cuantitativo del tráfico de forma realista, para la posterior simulación de una flota de vehículos conocida en el escenario de referencia a través del software *Sumo,* cuyas bondades para esta aplicación serán explicados a lo largo de la memoria. Fruto de la simulación bajo diferentes escenarios, se establece el análisis de los resultados de la simulación; consumo de combustible, emisiones y niveles de ruido asociados. La validación se realiza mediante la comparación de los resultados con modelos teóricos conocidos que permiten calcular los mismos resultados.

Como ejemplo de aplicación de la metodología, el análisis y verificación de resultados se aplica a un caso concreto, una de las principales vías de Thessaloniki, Grecia, una de las ciudades con mayor concentración de tráfico de Europa. Se comprueba sobre este caso práctico el consumo de combustible y emisiones se ajusta a las curvas de motores de vehículos establecidas por el modelo *PHEMLight*, y los niveles de ruido se verifican mediante la aplicación de la metodología *CNOSSOS.*

Los resultados obtenidos sobre el caso práctico permiten vislumbrar las consecuencias asociadas al tráfico en la ciudad y permiten identificar acciones destinadas a mitigar sus efectos sobre el medio ambiente y la salud de las personas. Las acciones se han implementado en distintas simulaciones obteniendo resultados favorables en términos de consumo de combustible emisiones de CO_2 y ruido. Todos estos factores se han visto reducidos.

Abstract

The environment is highlighting the climate change through effects that actually influence over the animal and plant life of our planet. Scientifics studies reveal the strong influence that Green House Gases (GHG), which are inherent to different human activities, have over the climate change. Thus, the presence of these gases in higher concentrations than nature standards, is been directly related to different diseases, which have growing presence in urban areas, where index of pollutant concentrations are higher. The presence of these pollutants is been related to fuel consumption destined to final energy generation to be used by different sectors. Based on statistical database provided by the *Andalusian Energy Agency,* the 42% of final energy is consumed in transport activities (the higher consumer sector), and the 80% of final energy is consumed in transport activities associated to road transport. Furthermore, the 95%, of the fuel consumed by vehicles driving along roads, is been represented by fossil fuels. Thanks to this information is possible to deduce the strong relation existing between concentration of pollutants in air and road transportation activities.

The evaluation of road transport with the main objective of analysing the fuel consumption, GHG emissions and noise (factor which is been related to population health and comfort and to road traffic), do not result an easy task; however, it is a fundamental step to promote politic strategies taken to improve air quality and comfort conditions within urban areas.

Along this project, a methodology has been developed aiming to evaluate and propose measures to reduce GHG emissions and noise within high traffic density urban areas. This methodology firstly describes the scenarios generation in an easy way, but enough detailed in order to realize a quantitative and qualitative realistic traffic analysis. Then, the known fleet for the scenario is simulated though the software *Sumo*, which strengths for this application are explained along this report. As result of simulations under different scenarios, simulations results analysis has been performed: analysis of fuel consumption, emissions and noise pressure levels. These results have been verified through their comparison to obtained results by applying known theoretical models, which allow realizing same calculations.

As an example of the methodology application, the analysis and verification of results have been applied to a particular case, one of the main Thessaloniki roads, Greece, which is one of highest traffic concentration cities in Europa. It has been proved within this case that emissions and fuel consumption results, obtained by simulation, follow vehicles engine curves implemented by PHEMLight, and noise results are verified by application of CNOSSOS methodology. Obtained results within the implemented case, allow for identifying consequences associated to urban traffic, and identifying action plans taken to mitigate their effects over environment pollution and population health. These actions have been implemented achieving favourable results: fuel consumption emissions and noise reductions.

Index

TABLES INDEX

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FIGURES INDEX

1 INTRODUCTION

Transportation issues

Transportation activities play a crucial role in society, but also have negative outcomes, which must be internalized by the user. Particularizing to the case of road transportation, associated road traffic outcomes has several impacts over population daily life. Time lost by citizens during their transportation activities as well as noise problems associated to traffic sources are some of those problems which cause immediate consequences over citizens daily life.

1.1.1 Fuel consumption and air pollutant emissions

Fuel consumption and air pollutant emissions are closely related to road traffic; until today these issues are direct consequences of transport; however, in last years the interest in protecting environment and reduce energy dependency is resulting in new vehicles launching such as electric vehicles, hybrid vehicles, etc. This way the European Union has been realizing efforts in order to reduce fuel consumption and CO_2 emissions. Last published is *Directive 1999/94 CE (European Parliament and Council of the European Union,1999)*, which aims to report about fuel consumption and CO_2 emissions of most energy efficient vehicles in order to make future buyers consider acquiring most efficient vehicles. Other important European Directive which is related to transport consumption is *Directive 2012/27/UE (European Parliament and Council of the European Union,2012)* where are included objectives stablished in "*Objective 20/20/20: climate and energy targets*". This objective stablished three different goals: reducing greenhouse gas emissions (GHG) by 20 %, increasing energy efficiency by 20% and increasing renewable energy consumption by 20% from 1990 values.

To have an idea about the role that road transport plays in worldwide total energy consumption, **Table 1** shows accumulate values by different sectors and percentage values:

Table 1 Balance of worldwide final energy consumption by sectors (2015)

Final energy (2015)	Coal	Fuels	Gases	Waste	Renewable energy	Electricity	Total
Industry (ktep)	1.397,38	2.717,09	6.897,04		1.345,90	6.539,87	**18.897,28**
Transport (ktep)		31.650,65	311,72		960,90	522,19	**33.445,46**
Other uses (ktep)	117,35	5.954,96	6.009,61	2,41	2.983,17	12.893,21	**27.960,70**
Total (ktep)	**1.514,72**	**40.322,69**	**13.218,38**	**2,41**	**5.289,97**	**19.955,27**	**80.303,44**
Industry (%)	92%	7%	52%	0%	25%	33%	**24%**
Transport (%)	0%	78%	2%	0%	18%	3%	**42%**
Other uses (%)	8%	15%	45%	100%	56%	65%	**35%**
Total (%)	100%	100%	100%	100%	100%	100%	**100%**

Fuente: MINETUR/IDAE[4]

As has been shown in Table 1, transport represents the most intensive sector in terms of energy consumption, representing the 42% of the total worldwide energy consumption. This way, efforts to reduce energy consumption and emissions within this sector will be essential in order to protect environment and population health. Another critical point, which is included in above table, is transport fuel consumption, which represents the 78% of the total fuel consumed around the world. These values are huge and a signal to be aware about the evolution of this sector and environmental strategies to be applied.

By other hand, **Table 2** includes transport final energy consumption data broken down by transport typology.

Table 2 Balance of worldwide final energy consumption in transport (2015)

Final energy (2015)	Fuels						NG	Biofuels	EE	TOTAL
	GLP	Gasolin	Keros.	Diesel	Fueloil	TOTAL				
Road (ktep)	47	4.426		20.939		25.412	287	958	105	**26.763**
Railway (ktep)				88		88			238	**327**
Marine (ktep)				340	106	446				**446**
Air (national) (ktep)		4	1.778			1.783				**1.783**
Air (international) (ktep)			3.859			3.859				**3.859**
oil pipeline (ktep)										
Other (ktep)		1		62		63	25	3	178	**269**
Transport (ktep)	**47**	**4.431**	**5.637**	**21.429**	**106**	**31.651**	**312**	**961**	**522**	**33.445**
Road (%)	100%	100%		98%		80%	92%	100%	20%	**80%**
Railway (%)									46%	**1%**
Marine (%)				2%	100%	1%				**1%**
Air (national) (%)			32%			6%				**5%**
Air (international) (%)			68%			12%				**12%**
oil pipeline (%)										
Other (%)							8%		34%	**1%**
Transport (%)	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**

Fuente: MINETUR/IDAE[4]

As the **Table 2** shows, the road transport represents the 80% of the total energy consumed in transport activities.

It is also interesting to be aware about the relative consumption of different fuel typologies in road transport. As it is shown in figure below fossil fuels represent the most final energy consumption. So, energy consumption and emissions associated to this kind of transport, typical from urban areas, is critical and consequences of road transport characteristics, not only environmental issues, but also health issues, monuments damage, etc are resulting in a huge problem to be solve.

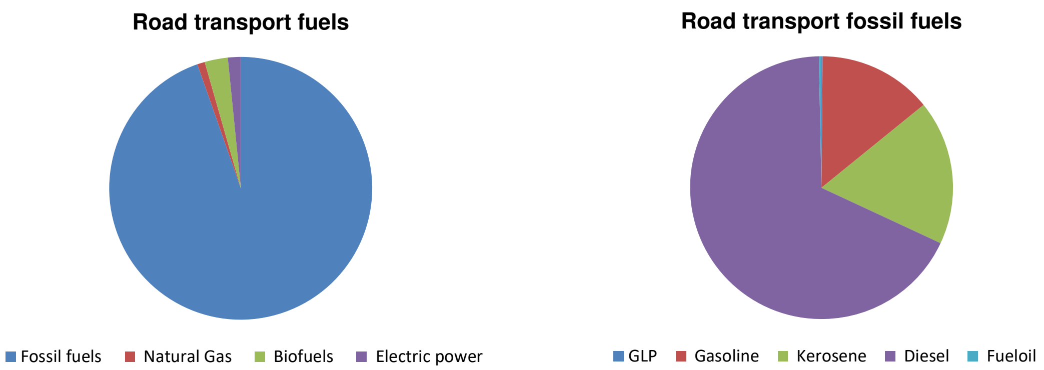

Figure 1. Road transport. Energy consumption by fuel typology[4]

1.1.2 Noise

Another outcome of road transportation is noise. Noise is an agent that can delay in several problems for inhabitants [6]. Road traffic noise is analysed along this project as a line source stablished through the contribution of different vehicles flows in the road [7]. This source line represents the most stable noise source in the city [8]. According to the relevant importance and effects that noise has over health and environmental conditions; in 2002, Directive 2002/49/CE is published in order to stablish a common approach intended to avoid, prevent or reduce on a prioritised basis the harmful effects, including annoyance, due to exposure to environmental noise [9]. Following this directive, in 2008 The European Commission started to develop a methodological framework for the common noise assessment [10]. Common Noise Assessment Methods in Europe (CNOSSOS –EU) was performed to be used by the Member States for strategic noise mapping following adoption as specified in the *Environmental Noise Directive 2002/49/*EC-*END* [9].This directive requires Member States to prepare and publish, every 5 years, noise maps and noise management action plans for different scenarios, including major roads (more than 3000 vehicles per year). This methodology also follows the article 6.2 of the END which urges the European Commission to stablish common assessment methods for the determination of noise indicators stablished in ANEX 1 of the Directive.

Air pollutant, human health and environment

Exposed data confirm the direct relation existing between road transport and air pollution, considered as one of the main issues the current world has to face to.

The *European Environment Agency* (EEA) Executive Director, Hans Bruyninckx confirmed above consideration, written in the EEA webpage [10] the following:

"Air pollution is causing damage to human health and ecosystems. Large parts of the population do not live in a healthy environment, according to current standards. To get on to a sustainable path, Europe will have to be ambitious and go beyond current legislation"

In fact, European Institutions are working together to get on to "that sustainable path", in order to achieve 20/20/20 [3] and even improve expected results. The objective is creating a sustainable philosophy on population, as only way to protect human health and environment.

Some of most important damages air pollution occasion the environment are the following:

- Acidification. It takes place in Europe's sensitive ecosystem areas that suffer acid deposition of excess sulphur and nitrogen compounds.
- Eutrophication. This is a typical environmental problem caused by the input of excessive nutrients into ecosystems. The area of sensitive ecosystems affected by excessive atmospheric nitrogen loses its indigenous way of life.
- Crop damage. Most agricultural crops are exposed to high ozone levels areas. High ozone levels cause damage on vegetation, which could end dying.
- Climate change. Climate change is happening now and is expecting to continue with its associated consequences: temperatures are rising, drought and wild fires are starting to occur more frequently, rainfall patterns are shifting, glaciers and snow are melting, and the global mean sea level is rising. Extreme weather and climate related events resulting in hazards such as floods and droughts will become more frequent and intense in many regions. Impacts and vulnerabilities for ecosystems, economic sectors, and human health and well-being differ across Europe. Even if global efforts to reduce emissions prove effective, some climate change is inevitable, and complementary actions to adapt to its impacts are needed.

  Recent evidences of the Climate change are collected from *Nasa* web page [11] and are shown below. **Figure 2** shows actualized indicators collected from the reference source, which indicate critical values for the future of the Earth life as it is know.

Figure 2. Global climate change indicators [11]

Figure 3 introduces figures taken from a recent scientific paper published by Nasa [12], which also shows recent indications of climate change. Specifically, it shows anomalous climatological phenomenology which actual takes place in tropical regions of the world, those associated to high carbon air concentrations.

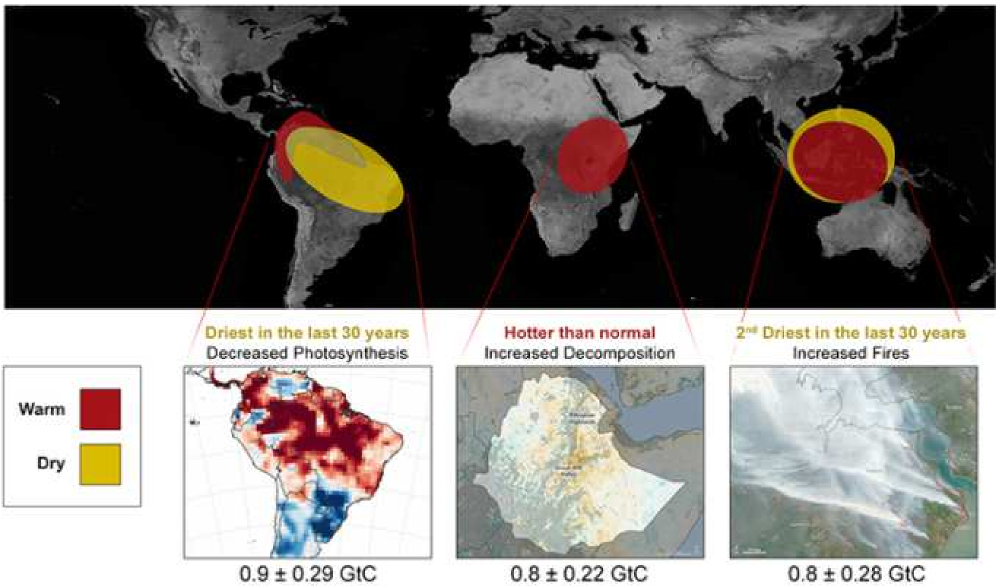

Figure 3. Climate change indicators. Three tropical regions releasing 2.5 gigatones more carbon into they did in 2011[12]

In the case of Europe, institution and population efforts have lie in on a substantially decrease of emissions of many air pollutants over the past decades, resulting in improved air quality across the region. However, air pollutant concentrations are still too high and air quality problems persist. A significant proportion of Europe's population live in areas, in particular cities, where exceedances of air quality standards occurs [10].

This way, health effects on air population have been subjected to intense study in recent years. Exposure to air pollutants has been associated with increases in mortality and hospital admissions due to respiratory and cardiovascular diseases [13].

The following interesting values have been obtained from [13]: For the Netherlands (16 million inhabitants and around 140.000 deaths per year) the number of deaths attributes to day-to-day air pollutants exposure is, at least, 2.100 deaths (almost twice the number of deaths due to traffic accidents). For Austria, France, and Switzerland (74,5 million inhabitants), 40.000 deaths per year are estimated to be attribute to air pollution. Similarly, high numbers have been indicated, in the reference source, for respiratory and cardiovascular hospital admissions, bronchitis episodes, and restricted activity days.

Conclusions

This brief introduction highlights the critical role that road transport plays over environment and human health. Three fundamentals outcomes from transportation activities have been indicated: energy consumption, air pollutant emissions and noises.

Firstly, the final energy consumption all over the world has been broken down in order to obtain the role that transportation plays on it. Once detecting that transportation is the most intensive sector in terms of final energy consumption, transportation activities has been divided into different means of transport, resulting again the road transportation the most intensive mean.

Once detecting that road transport consumes the most of final energy in the sector, it resulted interesting to break this consumption down into different energy sources. The result is that most of road transport consumes fossil fuels, which are one of the most critical sources of air pollutant emissions. This way, road transport and air pollution are directly related.

Otherwise, referenced sources indicate that the core of transport activities is concentrated on urban areas, where also the most worldwide population lives. So, the air pollution in urban areas is concluded to be highly related to road transport, and also health problems detected on population living in those areas. But not only air pollution is a transport outcome which has consequences over population health, noise is referenced in different sources as other source of diseases. In the noise case, road traffic is also considered as the most relevant source.

In order to mitigate environmental and human health issues directly associated to road transport, European Institutions have been implementing directives aiming to mitigate these consequences.

2 PROJECT SCOPE

As it has been concluded in previous introduction, road transport and environmental and health issues are strongly related. This relation is, mostly caused by road transportation outcomes, such as energy consumption, air pollutant emissions and noise.

Following previous conclusions, the main goal of this project is stablishing an easy and consistent methodology able to obtain energy consumption, emissions and noise levels associated to a road traffic configuration. To achieve this methodology, it has been also stablished the way to generate the road scenario and the traffic configuration, including the fleet generation according to European standards. For the scenario generation, open source simulation software has been selected and implemented models have been compared to theoretical models in order to detect variables of influences over models and the accuracy among them.

Theoretical models have also been implemented in Excel tools in order to be able to reproduce simulated results from available database. This way, it is possible to analyse other variables included in models which are not easy detected just through direct simulation.

To end up, the methodology has been tested in a reference scenario in order to verify the easy and consistency of the method. Results have been analysed regarding fuel consumption, CO_2 emissions and noise effects. From these analyses, different actions have been proposed in order to mitigate traffic effects. These actions have been implemented within the traffic simulation and results have been analysed.

Separately, another expected goal of this project is to analyse relevant bibliography associated to transport and its outcomes in order to be a reference for future related project. As the biography shows is not easy to find in references, which collect the transport problems and its outcomes, which are here analysed.

3 METHODOLOGY

In order to cover the disclosed objectives, the project has been divided into seven different chapters and an additional annex section, which includes tables of results data, and another chapter, which includes references. Different chapters are been explained below:

1. **Introduction**. Firstly, a brief analysis has been realized summing up main transport characteristics and outcomes in order to obtain a relation between health and environmental issues and transport.
2. **Project scope**. Objectives of the project have been disclosed in this chapter in order to limit boundaries of the project and makes easier the reader understanding.
3. **Methodology**. It includes description of project chapters and followed methodology.
4. **Scenarios generation**. This chapter stablishes the way to generate the road scenario and the traffic configuration to be able for analysing traffic outcomes in an easy and accuracy way. Firstly, it has been realized a description of what a reference scenario is. Then, the software chosen for the traffic simulation is been briefly described, including its main characteristics. Next step is a description of how creating a reference scenario in the chosen software. At this point, a reference scenario has been selected in order to test methodology and implemented models. Needed database for the simulation and models evaluation is been also explained and disclosed for the chosen scenario. Traffic configuration has been then explained and disclosed methodology has been applied over the selected scenario. To end up with this chapter, needed steps for realizing the traffic simulation through the software are been explained too.
5. **Traffic analysis**.

   Firstly, results of simulation are analysed taken into account different models and operating points of the vehicle fleet in order to detect the influence of main traffic configuration parameters. Results have been analysed for different traffic configuration and implemented models. To be consistent with first chapters, main road traffic outcomes, such as energy consumption, air pollutant emissions and noise have been analysed. This chapter shows the reader the sensitivity of the simulation and implemented models, differences obtained through simulation under different implemented models, and the relative importance of different parameters. Total fuel consumption and emissions results associated to the simulation of the reference scenario are also included in this analysis.

   Once traffic results obtained from the simulation are been analysed, two theoretical models are explained for obtaining same analysed road traffic outcomes.

   The PHEMLight theoretical model is been explained within this chapter for determining energy consumption and emissions associated to traffic configuration. The model has been also applied in the analysed scenario and results are been compared to simulation outputs.

   The CNOSSOS [10] is been also implemented in an excel tool in order to obtained the noise associated to the road which is considered a source line. The model has been explained along this chapter and applied into the reference scenario in order to compare obtained results with simulated results.
6. **Conclusions**. Conclusions obtained from traffic analysis are collect within this chapter in order to conclude obtained proposed goals.
7. **Outlook**. Conclusions obtained from the project allow the reader to conclude most relevant future developments in order to follow the methodology and being able to characterize quantitatively

different transportation scenarios and its outcomes in order to establish politic strategies to mitigate the associated impact over environment and human health.

4 SCENARIOS GENERATION

This chapter stablishes the way to generate the road scenario and the traffic configuration to be able for analysing traffic outcomes in an easy and accuracy way. Firstly, it has been realized a description of what a reference scenario is. Then, the software chosen for the traffic simulation is been briefly described, including its main characteristics. Next step is a description of how creating a reference scenario in the chosen software. At this point, a reference scenario has been selected in order to test methodology and implemented models. Needed database for the simulation and models evaluation is been also explained and disclosed for the chosen scenario. Traffic configuration has been then explained and disclosed methodology has been applied over the selected scenario. To end up with this chapter, needed steps for realizing the traffic simulation through the software are been explained too.

4.1 Reference scenario

The reference scenario is a simplified representation of the analysed road which include most important element that define the traffic. It will be a known scenario which allows the reader to analyse main factors of influence over the traffic and its consequences.

Other reason to stablish a reference scenario is comparing, under well-known conditions, the simulation realized in Sumo and its outputs, and results obtained when theoretical models, explained along this project, are implemented. Main outputs to be evaluate because are considered to be the most significant when evaluating the traffic of a road are energy consumption (fuel consumption), emissions and noise.

4.2 Sumo

Simulator of Urban MObility

SUMO is an open source, highly portable, microscopic and continuous road traffic simulation package designed to handle large road networks. So to start with, it seems to be the expected software for realizing a traffic analysis. It also allows modelling of intermodal traffic systems including road vehicles, public transport and pedestrians. Included with SUMO is a wealth of supporting tools which handle tasks such as route finding, visualization, network import and emission calculation. SUMO can be also enhanced with custom models, such as PHEMLight models for calculating emissions and fuel consumption.

The simulation platform SUMO offers many features. Most interesting features within this project are enumerated below:

- Microscopic simulation: vehicles, pedestrians and public transport are modelled explicitly.
- Simulation of multimodal traffic: vehicles, public transport and pedestrians.
- Time schedules of traffic lights can be imported or generated automatically by SUMO.
- No artificial limitations in network size and number of simulated vehicles.
- Supported import formats: OpenStreetMap.
- SUMO is implemented in C++ and uses only portable libraries

4.3 Generating the reference scenario in Sumo

The traffic microsimulation a road and associated effects evaluation under software Sumo, which goodness has already been explained, is possible after a scenario generation which represents in a simplified way main characteristics of the analysed road.

The complexity of the scenario to be generated could be as high as the user aims, however, one of the key points of this project is to being able to stablish a methodology in Sumo for the quick an easy generation of scenarios, not refusing main characteristics of the real road.

4.3.1 Road representation

To start with the representation of the road, geographical coordinates of the nodes should be specified. These nodes are the minimum number of point necessary for the representation of the road.

Nodes includes will be those which have consequences on the traffic simulation: nodes located at that geographical points where the vehicles direction or the road gradient change, points where there are crossing with other streets or traffic elements, such as traffic lights, pedestrian crossing, roundabouts, intersection with other streets… This way, if there is a straight road segments without traffic elements or intersection and constant gradient, it is not necessary includes different nodes along it.

Figure 4 includes an image, taken from google maps [5], of a generic road segment, indicating the road to be represented (red lines) and the selected points to be chosen as road nodes.

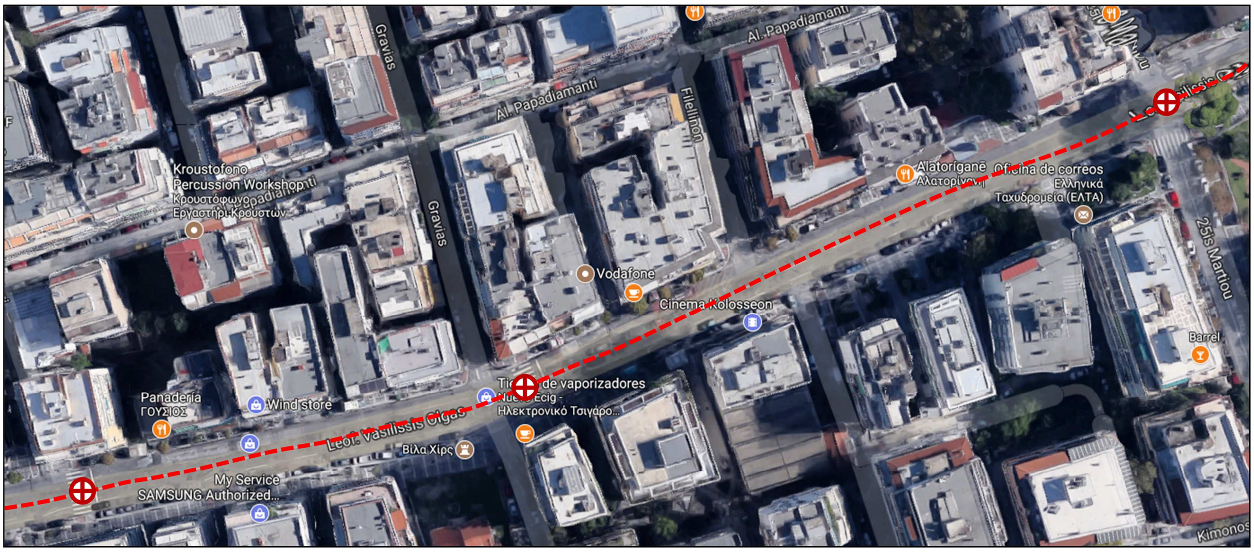

Figure 4 Example of nodes definition for the road representation

As is represented in Figure 1, just three nodes have been included for representing the road segments. All of those nodes are associated to traffic elements, which have an impact on traffic simulation: pedestrian crossings and crossing with a main street (25's Martiou).

Road representation though nodes definition allows the user to build the traffic scenario in an easy way taken into account all needed traffic elements or the traffic simulation.

Figure 5 includes Sumo representation of a road build by nodes definition as is shown in the applied zoom.

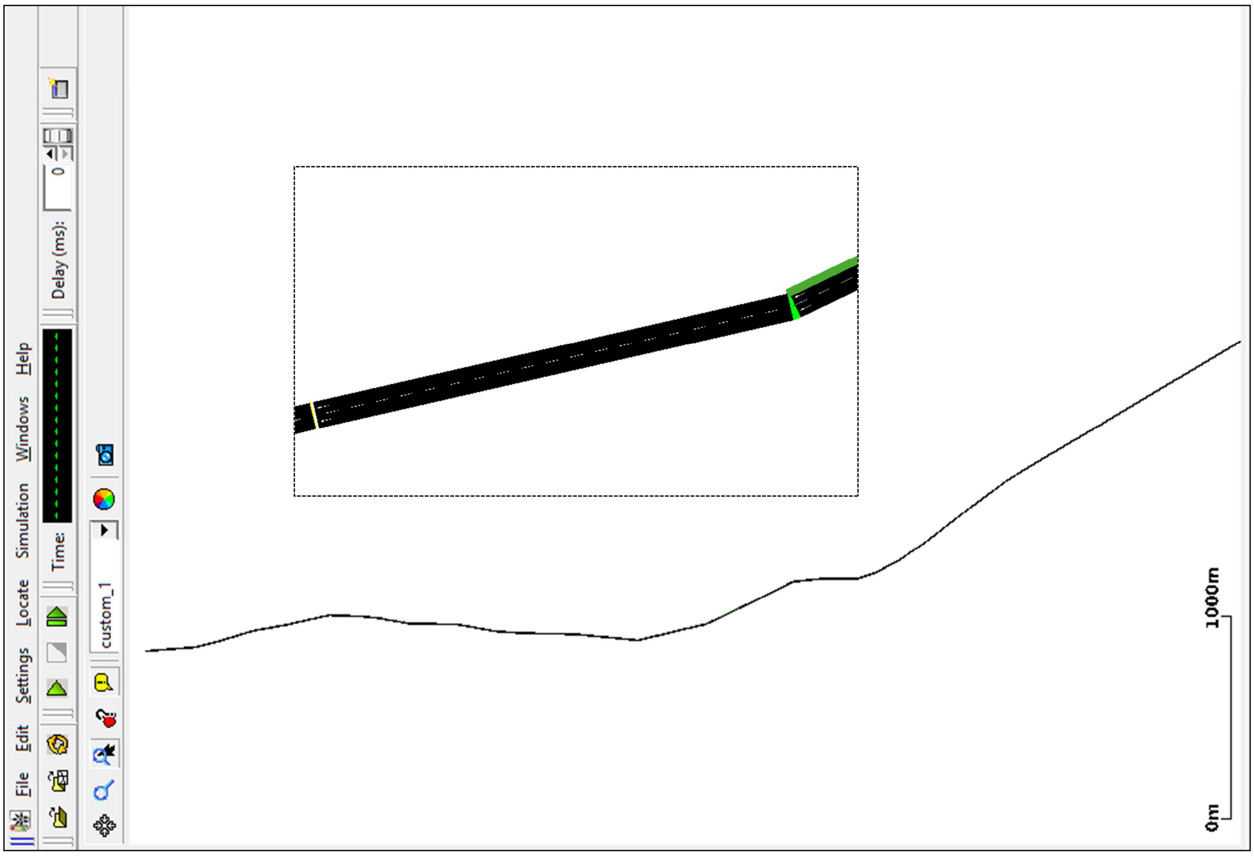

Figure 5 Sumo representation of a defined road thorough nodes

Steps for building the scenario though Sumo, from nodes definition until road representation, as it is shown in Figure 5, are explained below:

Step1. Nodes definition

A XML file: *nombre.nod.xml* is generated in order to specify nodes in SUMO simulation. The structure of the XML code is the following:

```
1   <nodes>
2           <node id="1" x="longitude_id=1" y="latitude_id=1"/>
3           <node id="2" x="longitude_id=2" " y=" latitude_id=2" type="traffic_light"/>
4   </nodes>
```

Node typology (*type*):

In case one of the nodes is considered as special node, as a traffic light, a roundabout or a crossing, this fact will be indicated next to geometrical coordinates of the node as its *type*. This indication is shown in the third line of the code represented above.

Each of the different node types should be characterized. In the case of traffic lights, these nodes are defined through another xml file: *nombre.tll.xml*. This file defines parameters that characterize the traffic light performance as below:

```
1       <additional>
2               <tlLogic id="2" type="static" programID="0" offset="0">
3                       <phase duration="t1" state="GGGyyy"/>
4                       <phase duration="t2" state="yyyrrr"/>
5                       <phase duration="t3" state="rrryyy"/>
```

```
        <phase duration="t4" state="yyyGGG"/>
</tlLogic>
</additional>
```

Attributes defined for the traffic light case are the following:

- *Type* (static, actuated o delay_based):
    - *Static*: Duration of fixed phases.
    - *Actuated*: Phase extension based on space between vehicles (level of congestion)
    - *Delay-based*: Phase extension base don lost time in congestion by vehicles.
- *Offset*: The initial time to the beginning of the program.
- *Actuated*: Space-based phase extension between vehicles (congestion level).

Step2. Edges definition

Once nodes are defined, the next step consists on the definition of different edges in which the road is divided. This edges results in the connection of different nodes. This step is implemented in the file *nombre.edg.xml*, as the structure below:

```
<edges>
    <edge id="1" from="1" to="2" numLanes="2">
    <lane index="1" allow="bus">
</edges>
```

The edge is defined through the specification of initial and final nodes and an indication of the number of lines per edge. If one of the lines is special, Sumo allows to specify which type of vehicle can flow by that line and which are not allowed. This is the case of a bus lane as is indicated in the code above.

Index indicates the considered lane number, being *index="0"* the one which is located in the right of the edge.

The road definition consists on the connection of defined edges.

There are other elements, part of the road, which are not defined as node types, but as edges connections. This is the case of pedestrian crossing. Edge connections are defined as a new XML file: *nombre.con.xml*.

```
<connections>
    <crossing node="3" edges "2 3"/>
</connections>
```

Type of connections, connection edges and node in which the connection is located, are defined in the connection file.

Once nodes, edges and connections are defined, Sumo generates the scenario in a new xml file: *nombre.net.xml* by "netconvert" function.

If nodes are been defined by geographical coordinates, it will be necessary to use the function *proj.utm* for turn GPS coordinates into Sumo coordinates.

The Sumo application NetEdit, allows the user to open the file *nombre.net.xml.*

4.3.1.1 Thessaloniki – Reference scenario

Thessaloniki is the second-largest city in Greece and is characterized by severe pollution and traffic problems. The evolution of the Thessaloniki pollution sources is dominated by the continuous increase of the vehicles fleet (mainly passenger cars). This direct relation between traffic problem and pollution problem makes

Thessaloniki a real candidate to be evaluated within this kind of problems. Otherwise, the *Aristote University of Thessaloniki*, is one of the participants within REMEDIO project[1], in which Seville University is currently working in as coordinator and technical participant. Within project, Thessaloniki has been selected as one of the pilot zones to be evaluated, so real traffic fleet data is available. These are some of the reasons why Thessaloniki has been selected as the reference scenario.

Thessaloniki is the capital of Thessaloniki Regional Unity and of the region of Central Macedonia, and it is the second largest city in Greece. It plays an important role in the national and greater Balkan region, especially as a commercial centre and a transportation hub.

According to the General Secretariat of Ministry of Infrastructure, Transport and Networks, the total number of vehicles in the city exceeds 777. 544, including private cars, heavy vehicles and motorcycles. It is estimated that more than 400.000 urban trips take place per day, close to 25% of that trips take place in the city centre. Daily, around 94.500 vehicles cross the main arterials of the city with an average peak hour speed in the centre of about 60 km/h. In Thessaloniki, there are almost 2.2 million passengers' daily trips taking place by all travel modes and Public Transport (PTransp.) share is approximated to 27%.

Figure 6 represents the selected areas to be evaluated within this project. This area includes the main street of Leof.Vasilissis Olgas from its beginning (Cleaning Worksite of Municipality of Kalamaria) till its end, and strees Ethnikis Antistatis, until intersection with Makedonias, and Leof.Vasileos Georgiou, until intersection with Leof.Stratou. The total length of the selected streets is close to 6.5 km. Selected area is represented by red lines, delimited by two nodes, marked in red colour within Figure 6.

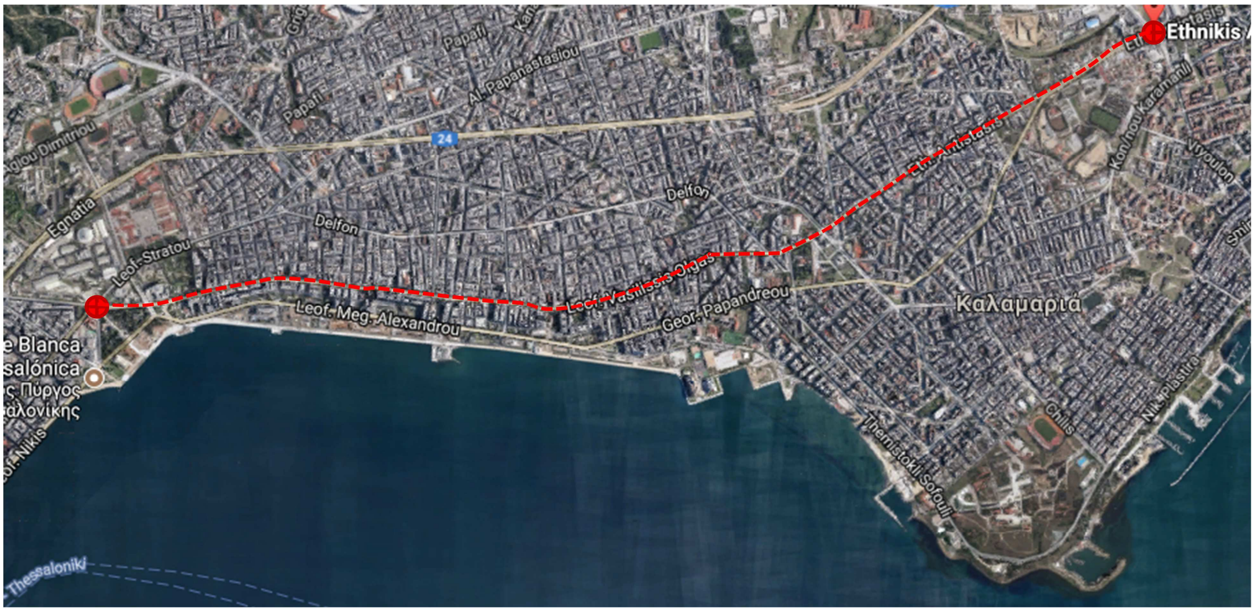

Figure 6. View of the pilot-area in Thessaloniki (Google maps)

In order to represent the selected road (Figure 6) through Sumo, as it has been explained at the beginning of section 4.3.1, nodes and edges have been defined along the road following its real characteristics.

Step1. Nodes definition

Nodes, the minimum number of necessary points for the representation of the selected road (Figure 6), have been defined through their GPS coordinates.

Table 3 includes all defined nodes along the selected road, indicating GPS coordinates as well as the node

[1] *REMEDIO: REgenerating mixed-used MED urban communities congested by traffic through Innovative low carbon mobility sOlutions*

type.

Table 3 Defined nodes along the selected road (Thessaloniki) Reference scenario

Node id	Latitude	Longitude	Node type
1	40,57637	22,96995	
2	40,58203	22,96575	
3	40,58327	22,96481	traffic_light
4	40,58405	22,96424	
5	40,58626	22,96262	
6	40,58748	22,96169	traffic_light
7	40,58937	22,95994	
8	40,5912	22,95814	
9	40,59175	22,95771	
10	40,59235	22,95718	traffic_light
11	40,59345	22,95646	
12	40,59419	22,95616	
13	40,59585	22,95619	traffic_light
14	40,59712	22,95605	
15	40,59792	22,95554	traffic_light
16	40,59944	22,95461	
17	40,60103	22,95367	traffic_light
18	40,60207	22,95339	
19	40,60406	22,95282	traffic_light
20	40,6068	22,95325	
21	40,60933	22,9534	
22	40,61041	22,95353	traffic_light
23	40,6121	22,95398	
24	40,61426	22,9541	
25	40,61553	22,95443	traffic_light
26	40,61635	22,95457	
27	40,61779	22,95468	
28	40,61969	22,95418	
29	40,62119	22,95387	traffic_light
30	40,62264	22,95334	
31	40,62372	22,953	traffic_light
32	40,62603	22,95283	

Along the selected road just traffic lights have been considered (Table 3), in this simplified scenario, as traffic elements to have consequences over the traffic simulation.

Step2. Edges characterization

<u>Bus stops of the road:</u>

As it was previously explained, bus stops along the road have been defined indicating the edge and lane in which they are located in. The following code shows the xml file associated to bus stops definition within the reference scenario:

```
<additional>
        <busStop id="stop1" lane="8_0">
        </busStop>
        <busStop id="stop2" lane="16_0">
        </busStop>
        <busStop id="stop3" lane="24_0">
        </busStop>
```

8 </additional>

<u>Other road characteristics:</u>

- One way road.

<u>SUMO representation of the road:</u>

Figure 7 shows the representation realized in Sumo of the selected road (defined in Figure 6) next to a real image obtained from Google Maps [5]. Nodes and traffic lights (in red colour) have been also indicated within the image.

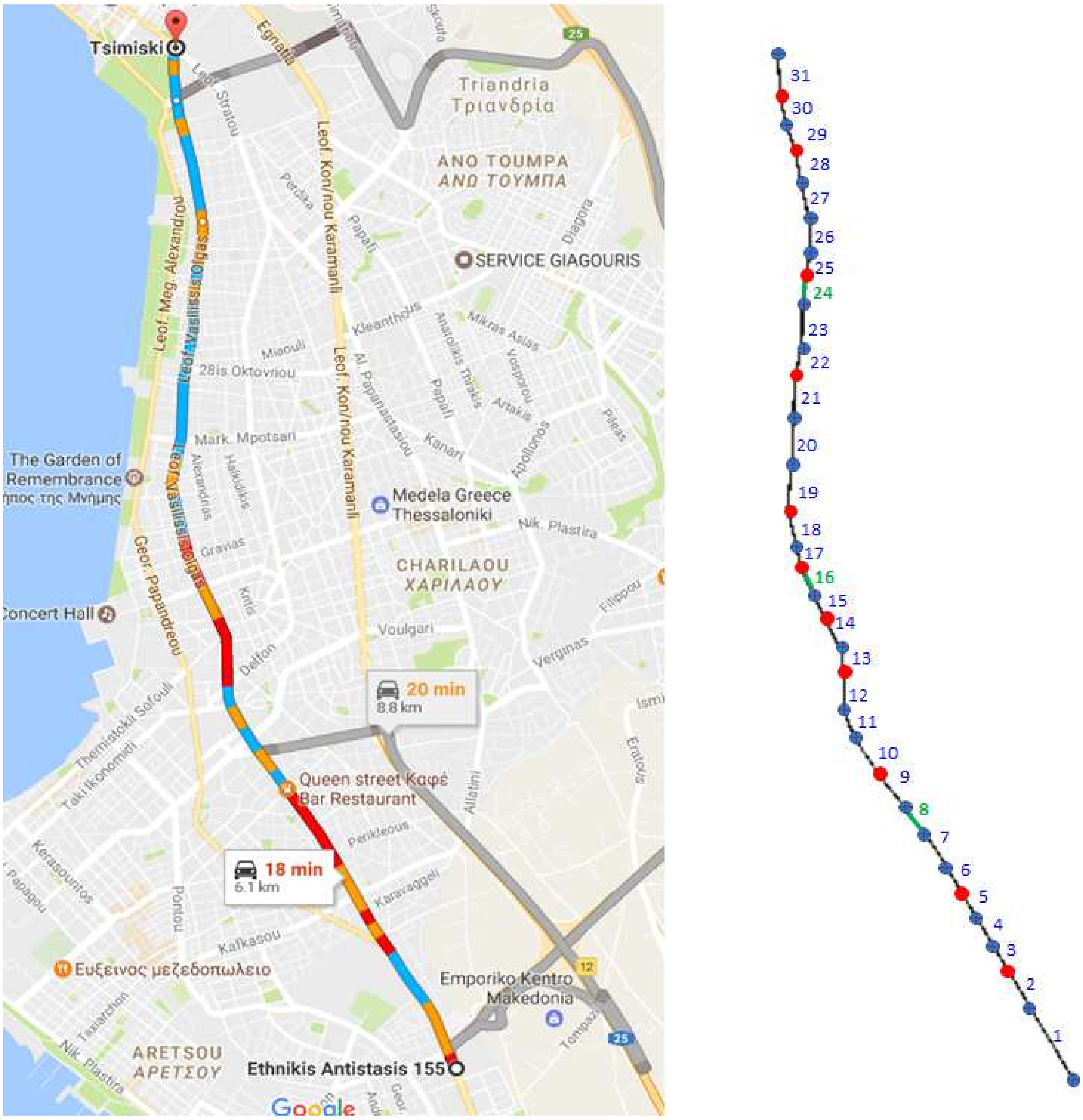

Figure 7. Scenario-0 – SUMO representation

From Figure 7 is concluded the accurate representation of the real road, performed by Sumo. The 2D geometrical description of the road is perfectly performed just by defining nodes and edges along the road.

4.3.2 Traffic flow representation

Sumo defines the traffic flow along the road through the file *nombre.rou.xml*. In this file the traffic flow of different vehicle typologies per lane are defined; as well as main characteristics of the different vehicle typologies, which define the fleet.

4.3.2.1 Definition of the vehicle typology

The first step consists on the definition of the different vehicles. Sumo allows the user to define several characteristics of the vehicle: speed characteristics, acceleration, size of the vehicle, colour, driver behaviour… The next code is an example of a vehicle type definition implemented in the file *nombre.rou.xml*. The code also shows most important vehicle attributes in relation to their effects over traffic simulation per vehicle typology. Default values used by Sumo are also indicated.

```
<routes>
<vType id="type1" vClass=”passenger” length="5" maxSpeed="70" accel="2.6"
decel="4.5" />
</routes>
```

Table 4 extracted from Sumo tutorial, indicates the rest of parameters that Sumo uses for the vehicle characterization and their default values.

Table 4. Vehicle characterization – Sumo attributes

Attribute name	Default value	Description
id	-	The name of the vehicle type
accel	2.6	The acceleration ability of vehicles of this type (in m/s^2)
decel	4.5	The deceleration ability of vehicles of this type (in m/s^2)
sigma	0.5	Driving imperfection
tau	1.0	Stablished in the "carFollowModel"
length	5.0	The vehicle's netto-length (length) (in m)
minGap	2.5	Empty space after leader [m]
maxSpeed	70.0	The vehicle's maximum velocity (in m/s)
speedFactor	1.0	The vehicles expected multiplicator for lane speed limits
speedDev	0.0	The deviation of the speedFactor; see below for details
color	"1,1,0" (yellow)	This vehicle type's color
vClass	"unknown"	Vehicle class ("passenger", "taxi", "bus", "truck", "motorbike"...)
emissionClass	"P_7_7"	Emission class
width	2.0	The vehicle's width [m] (only used for drawing)
laneChangeModel	'LC2013'	The model used for changing lanes
carFollowModel	'Krauss'	The model used for car following
personCapacity	4	The number of persons (excluding an autonomous driver) the vehicle can transport.
containerCapacity	0	The number of containers the vehicle can transport.
boardingDuration	0.5	The time required by a person to board the vehicle.
loadingDuration	90.0	The time required to load a container onto the vehicle.
latAlignment	*center*	The preferred lateral alignment when using the sublane-model (left, right, center, compact, nice, arbitrary).
minGapLat	0.12	The minimum lateral gap at a speed difference of 50km/h when using the sublane-model
maxSpeedLat	1.0	The maximum lateral speed when using the sublane-model

The explanation of two of the attributes included within Table 4, which need a deeper comprehension, is performed below:

EmissionClass:

Sumo realizes its own classification of vehicles taking as reference the emission vehicle classification available in the “Handbook emission factors for road transport” [16]. Two independent classifications are included. One associated to passenger cars and light duty vehicles and another one for heavy duty vehicles.

This attribute allows the user to increase the diversity of the vehicle fleet.

CarFollowModel:

Sumo allows the user to define the model, which characterizes the driving behaviour, per type of vehicle. Characterizing this attribute, identifying the most accuracy model to the traffic characteristics by the vehicle type, is a project in itself. In our case Krauss model has been chosen because is the most common used in Sumo simulations [17].

CarFollow models available in Sumo are included within Table 5:

Table 5 CarFollowModels-SUMO

Element	Attribute	Description
carFollowing-Krauss	Krauss	The Krauß-model with some modifications which is the default model used in SUMO
carFollowing-KraussOrig1	KraussOrig1	The original Krauß-model
carFollowing-PWagner2009	PWagner2009	A model by Peter Wagner, using Todosiev's action points
carFollowing-BKerner	BKerner	A model by Boris Kerner Caution: currently under work
carFollowing-IDM	IDM	The Intelligent Driver Model by Martin Treiber Caution: Problems with lane changing occur
carFollowing-IDMM	IDMM	Variant of IDMM Caution: lacking documentation
carFollowing-KraussPS	KraussPS	the default Krauss model with consideration of road slope
carFollowing-KraussAB	KraussAB	the default Krauss model with bounded acceleration (only relevant when using PHEM classes)
carFollowing-SmartSK	SmartSK	Variant of the default Krauss model Caution: lacking documentation
carFollowing-Wiedemann	Wiedemann	Car following model by Wiedemann
carFollowing-Daniel1	Daniel1	Car following model by Daniel Krajzewicz Caution: lacking documentation

Attributes associated to each model are shown within Table 6:

Table 6 CarFollowModels associated attributes - SUMO

Attribute	Description	Models
accel	The acceleration ability of vehicles of this type (in m/s^2)	SUMOKrauß, SKOrig, PW2009, Kerner, IDM
decel	The deceleration ability of vehicles of this type (in m/s^2)	SUMOKrauß, SKOrig, PW2009, Kerner, IDM
sigma	The driver imperfection (between 0 and 1)	SUMOKrauß, SKOrig
tau	The driver's desired (minimum) time headway. Exact interpretation varies by model. For the default model Krauss this is based on the net space between leader back and follower front). For limitations, see Car-Following-Models#tau).	all Models
minGap		SUMOKrauß, SKOrig, PW2009, Kerner, IDM
k		Kerner
phi		Kerner
delta	acceleration exponent	IDM
stepping	the number of iterations per second when computing follow speed	IDM
security	desire for security	Wiedemann
estimation	accuracy of situation estimation	Wiedemann

Definition parameters are difficult to characterize due to the deep level of detail required in the road traffic definition. By default Sumo implements the Krauß car following model, which consists on a simplification of the model developed by Stefan Krauß[18]. In the traffic characterization of the road, particularizing for the studied scenario within this project, this model is used by default too since we have not analysed the other models due to the level of complexity of this analysis.

Krauß model let vehicles drive as fast as possibly while maintaining perfect safety (always being able to avoid a collision if the leader starts braking within leader and follower maximum acceleration bounds).

4.3.2.2 Traffic definition

There are different ways to define traffic flow along the road: one of them consists on defining routes and force vehicles to flow along them. This definition requires the characterization of the different vehicle types, which define the fleet. Another way of defining the traffic flow consists on stablishing different traffic flows per vehicle type and specifying the number of the initial and final edge which define the route where the flow pass through.

Once analysed different ways of defining traffic flow along the road and taken into account available database (Thessaloniki) for realizing the micro-simulation of the studied road, it has been decided to define the traffic flow through the definition of the traffic flow in the road. In the case of public vehicles or other special vehicles, it is necessary to define the route where the vehicles can flow through; this way, it is possible to associate different vehicles flows by category to different routes. Routes can be defined in another code or within the code where the traffic flow is defined.

Routes definition

Two different ways are possible for explicitly defining the traffic route where a vehicle typology can flow through.

1. Defining the route in a previous step to the vehicle flow definition.

```
<route id="route0" color="1,1,0" edges="1 2 3"/>
```

2. Defining the route within the same code where the vehicles flows are defined.

```
<route edges="1 2 3"/>
```

Defining the vehicle flow:

The vehicles flows have been defined through attributes included within Table 7:

Table 7. Attributes included in the vehicles flow definition

Attribute Name	Value Type	Description
id	id (string)	Vehicle flow identification
type	id	The id of the vehicle type to use for this vehicle flow
route	id	The id of the route the vehicle shall drive along
color	color	This vehicle's color
depart	float (s) or one of triggered, containerTriggered	The time step at which the vehicle shall enter the network; see **#depart**. Alternatively the vehicle departs once a **person enters** or a **container is loaded**
departLane	int/string (≥0, "random", "free", "allowed", "best", "first")	The lane on which the vehicle shall be inserted; see #departLane. default: "first"
departPos	float(m)/string ("random", "free", "random_free", "base", "last")	The position at which the vehicle shall enter the net; see #departPos. default: "base"
departSpeed	float(m/s)/string (≥0, "random", "max")	The speed with which the vehicle shall enter the network; see #departSpeed. default: 0
arrivalLane	int/string (≥0,"current")	The lane at which the vehicle shall leave the network; see #arrivalLane. default: "current"
arrivalPos	float(m)/string (≥0[1], "random", "max")	The position at which the vehicle shall leave the network; see #arrivalPos. default: "max"
arrivalSpeed	float(m/s)/string (≥0,"current")	The speed with which the vehicle shall leave the network; see #arrivalSpeed. default: "current"
line	string	A string specifying the id of a public transport line which can be used when specifying person rides
personNumber	int (in [0,personCapacity])	The number of occupied seats when the vehicle is inserted. *default: 0*
containerNumber	int (in [0,containerCapacity])	The number of occupied container places when the vehicle is inserted. *default: 0*
reroute	bool	Whether the vehicle should be equipped with a rerouting device (setting this to false does not take precedence over other assignment options)
departPosLat	float(m)/string ("random", "free", "random_free", "left", "right", "center")	The lateral position on the departure lane at which the vehicle shall enter the net; see Simulation/SublaneModel. default: "center"
arrivalPosLat	float(m)/string ("left", "right", "center")	The lateral position on the arrival lane at which the vehicle shall arrive; see Simulation/SublaneModel. by default the vehicle does not care about lateral arrival position
begin	float(s)	first vehicle departure time
end	float(s)	end of departure interval
vehsPerHour	float(#/h)	number of vehicles per hour, equally spaced (not together with period or probability)
period	float(s)	insert equally spaced vehicles at that period (not together with vehsPerHour or probability)
probability	float([0,1])	probability for emitting a vehicle each second (not together with vehsPerHour or period), see also Simulation/Randomness
number	int(#)	total number of vehicles, equally spaced

An example of a code for defining the vehicle flow driving along the road is shown below:

```
<routes>
    <vType id="car" vClass="passenger" sigma="0" speedDev="0"  minGap="1"/>
    <flow id="1" type="car" from="1" to="31" vehsPerHour="781" begin="0"
    departLane="0" departSpeed="max"/>
    </flow>
</routes>
```

The code above, instead of indicating explicitly the route where a vehicle drive along, indicates the edges where vehicles flow through by including attributes *from* and *end,* that indicate depart edge and final edge of circulation of the flow.

<u>Bus line definition</u>

In order to define the bus traffic in the characterized road, Sumo offers different options. The chosen one for this project is shown below:

- Defining for each bus line:
  - The route where buses drive along, specifying initial and final circulation edges.
  - Scheduled bus stops[2] for each bus line.
  - The flow of buses by line. Each flow is defined through the attribute *period*, which indicates the waiting time in the stop for next bus arrival.
  - Each bus line is defined in the file *nombre.rou.xml*.
  - Code below shows an example of bus line definition :

```
<routes>
    <vType id="bus" vClass="bus" sigma="0" speedDev="0"
    minGap="1"/>
    <flow id="lin1" type="bus" period="480" begin="0"
    departSpeed="max" departLane="best" from="1" to="31">
        <stop busStop="stop1" duration="30"/>
    </flow>
</ routes >
```

- Defining different bus stops in along the bus lane:
  - Bus stops are defined in the file *nombre.bus.xml.*
  - The definition code includes enumerated bus stops, including an indication of edges where they are located.
  - Code below shows an example of bus stops definition:

```
<additional>
    <busStop id="stop1" lane="30_0">
    </busStop>
</additional>
```

The example shown above through the XML file code, that defines the buses flow of a bus line, includes the following information:

- Defined Bus line: lin1.
- Waiting time in the bus stop for the next bus arrival: 480 seconds (8 minutes).

[2] *The analyzed road could include several bus stops but lines just have to stop in scheduled bus stops for the particular bus lane.*

- Circulation initial edge: edge 1.
- Circulation final edge: edge 31.
- Bus stop duration: 30 seconds (stop 1).
- Bus stop location: edge number 30, right lane.

4.3.2.3 Thessaloniki – Reference scenario

Selected road, located in Thessaloniki and geographically defined through GPS coordinates, has already been represented in Sumo through the nodes definition, lanes definition and indication of traffic lights location.

Once the road has been defined, the next step consists on the simulation of the road. This has been implemented for a reference scenario which represents a base line of comparison.

A reference scenario has been built by defining the fleet of vehicles driving along the road for the current situation of Thessaloniki, characterized by the available database included within section 4.3.2.3.1. The traffic simulation has been performed for this scenario and obtained results has been analyzed (chapter 5) and compared with other models, not included within Sumo tool. One the reference scenario has been analyses, actions over the reference scenario have been proposed taken into account conclusions obtained from traffic analyses

4.3.2.3.1 Available data base

As it was mentioned within section *4.3.1.1* one of the reasons to select Thessaloniki road as reference scenario is the data base already available thanks to the participation of *Aristote Thessaloniki University* within REMEDIO project. So, the available data comes from the evaluation of Thessaloniki as pilot zone within that project.

The available database has been explained below:

<u>Hourly database – Passenger cars:</u>

The only available hourly database corresponds to passenger cars flow and provides the vehicles flowing along the road, an average yearly day. This database has been included within Table 8.

Table 8 Hourly database – Reference scenario

Time period	Cars/hour
00:00-01:00	731
01:00-02:00	474
02:00-03:00	277
03:00-04:00	226
04:00-05:00	224
05:00-06:00	455
06:00-07:00	1171
07:00-08:00	2361
08:00-09:00	2772
09:00-10:00	2655
10:00-11:00	2699
11:00-12:00	2479
12:00-13:00	2408
13:00-14:00	2229
14:00-15:00	2161
15:00-16:00	2406
16:00-17:00	2356
17:00-18:00	2420
18:00-19:00	2418
19:00-20:00	2291
20:00-21:00	2314
21:00-22:00	1939
22:00-23:00	1339
23:00-24:00	1035

Values included within Table 8 have been represented in *Figure 8*, following the main objective of distinguishing a pattern. The representation shows the expected pattern; the traffic flow decreases at night.

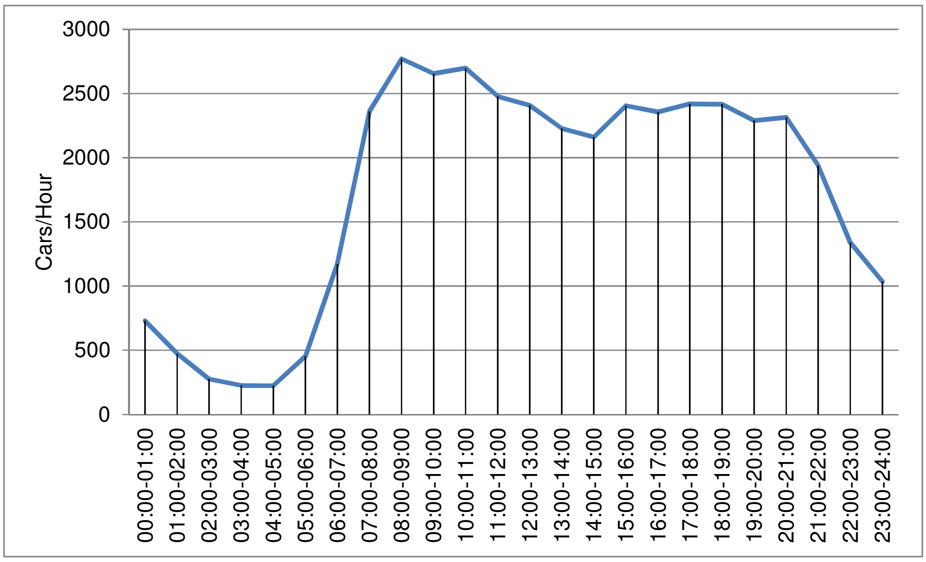

Figure 8 Hourly representation of the passenger cars flow in the road along a typical yearly day.

The period from 22:00 p.m to 7:00 a.m of the next day, in which the traffic flow is considerably reduced (less than 1500 cars/h), has been clearly identified as NIGHT. The associated ambient temperature is also lower than in others day periods. Both parameters have influence over the traffic analysis realized within this project.

The remaining day period (7:00-22:00) has been divided into two different periods: DAY (7:00-19:00) and EVENING (19:00-22:00). The traffic flow at EVENING decreases in comparison with DAY. This period segmentation is necessary in order to realize the traffic noise analysis exposed in following sections.

Taking into account previous explanation, is possible to calculate the average traffic of vehicles flowing through the road per each of the identified periods; considering the duration of each period: 12 hours DAY, 4 hours EVENING and 8 hours NIGHT.

Passenger cars flow rates by periods have been totalized by summing flow rates per hours of each period. Results have been included within Table 9:

Table 9 Cars/ hour by period– Scenario_0

Period	Cars/h
Day	2447
Evening	1971
Night	574

Public transport:

The bus fleet, flowing along the road, is given in the database as the periodicity of buses flowing along the road. It is also known, that there is only bus service during DAY and EVENING periods, while during night there is no bus circulation along the road.

Buses driving along the road, periodicity of each bus line and scheduled buses stops, are all included in Table 10, summing up the buses database:

Table 10 Bus lines dataBase – Scenario_0

Bus line id	Periodicity (s)	BusStop1	BusStop2	BusStop3
3	480	x	x	x
5	600		x	
6	840		x	
8	960	x		x
33	960			
39	600			
78	1920	x	x	x

Public transport service is only available during DAY and EVENING period; so, there is no bus typology of vehicles defined for the NIGHT simulation.

Vehicles fleet:

Thanks to the fleet database available for Thessaloniki (fleet distribution within the city), it has been considered that the vehicle fleet (distribution) flowing along the analysed road is equal to the vehicles fleet within Thessaloniki city. This way, it is possible to determine the number of cars and motorbikes driving along the road.

The fleet database available for Thessaloniki has been included within Table 11.

Table 11 Vehicles fleet - Thessaloniki

Vehicle typology	nº
Cars	519.478
Motorbikes	137.505
Trucks	98.290

In order to performance the traffic simulation, it is necessary to have an available database that includes the traffic flow by vehicle typology and period. This way Table 12 has been completed as below:

Table 12 Vehicles/h per period– Scenario_0

Period	Cars/h	Trucks/h	Motorbikes/h
day	2447	463	648
evening	1971	373	522
night	574	109	152

Vehicle technologies and fleet distribution:

Road traffic implications, in terms of noise emission, fuel consumption and pollution, will depend strongly on the technology of vehicles driving along the road, as well as EU-classification associated to pollution emission. In this regard, the vehicles fleet in the road is classified by vehicles technology, so a deeper breakdown of the fleet (Table 12) has been obtained. The fleet classification has been performed considering that fleet distribution by technology available for Thessaloniki is homogeneous in the whole city, so it is also the same at the analyzed road. Thessaloniki fleet classification is obtained from software COPERT[3].

Following tables show reference database obtained from COPERT, which has been used for characterizing each vehicle fleet per technology and typology. The percentage of the fleet associated to different fuels, consumed by vehicle typologies, is available, as well as the percentage of the fleet associated to different emission levels classification per type of fuel consumption.

- **Passenger cars:**

Table 13 Passenger cars fleet classification

Passenger cars	
Fuel	%
Gasoline Leaded	5,48
Gasoline unleaded	88,14
Diesel	5,27
LPG	0,18
Hybrid Gasoline	0,57
CNG	0,36
Bioethanol	0

3 COPERT is a MS Windows software program aiming at the calculation of air pollutant emissions from road transport. The software has been developed for use from the National Experts to estimate emissions from road transport to be included in official annual national inventories. It includes actualized vehicles fleets for different European cities, including Thessaloniki.

Table 14 Passenger cars fleet by different vehicle technologies

Gasoline leaded		*Gasoline unleaded*		*Diesel*	
Technology	%	Technology	%	Technology	%
PRE ECE	0	EU1	15,06	Conventional	0,52
ECE 15/00-01	0	EU2	26,35	EU1	8,61
ECE 15/02	0	EU3	32,25	EU2	7,6
ECE 15/03	18,06	EU4	15,51	EU3	23,15
ECE 15/04	81,94	EU5	8,13	EU4	26,4
Improved conventional	0	EU6	2,27	EU5	23,81
Conventional	0	EU6+	0,43	EU6	8,44
				EU6+	1,47
LPG		***Hybrid Gasoline***		***Bioethanol***	
Technology	%	Technology	%	Technology	%
Conventional	3,78	EU6	100	EU4	25
EU1	5,81			EU5	25
EU2	22,72	***CNG***		EU6	25
EU3	42,88	Technology	%	EU6+	25
EU4	11,35	EU4	89,85		
EU5	10,57	EU5	8,76		
EU6	2,55	EU6	1,36		
EU6+	0,34	EU6+	0		

- **Trucks:**

Table 15 Trucks fleet classification

Heavy duty truck	
Fuel	%
Gasoline Leaded	2,92
Diesel	97,08

Table 16 Trucks fleet by different vehicle technologies

Gasoline leaded		*Diesel*	
Technology	%	Technology	%
Conventional	100	Conventional	16,02
		HD EU I	36,53
		HD EU II	12,15
		HD EU II	15,01
		HD EU IV	8,6
		HD EU V EGR	2,53
		HD EU V SCR	5,91
		HD EU VI	3,25

- **Buses:**

Table 17 Buses fleet classification

Buses	
Fuel	%
Diesel	100
CNG	0
Biodiesel	0

Table 18 Buses fleet by different vehicle technologies

Diesel	
Technology	%
Conventional	11,26
HD EU I	39,16
HD EU II	12,75
HD EU II	20,9
HD EU IV	7,06
HD EU V 2008 Standards	0
HD EU V EGR	1,83
HD EU V SCR	4,27
HD EU VI	2,77

- **Motorbikes:**

The only consider technology is gasoline as fuel. Motorbikes are classified by size: motorbikes <49c.c and motorbikes >49c.c.

Table 19 Motorbike fleet classified by size

[<49cc] Gasoline leaded		*[<49cc] Gasoline leaded*	
Technology	%	Technology	%
Conventional	14,86	Conventional	14,96
Mop-Euro I	40,92	Mot-Euro I	10,32
Mop Euro II	31,08	Mot Euro II	45,98
Mop Euro III	13,14	Mot Euro III	28,74

4.3.2.3.2 Traffic definition

Tables (from Table 13 to Table 19) characterize the fleet at the simulation scenario, stablishing the scope of the analysis in terms of definition level of the traffic in the road. The fleet definition along the road, disaggregated by vehicles technology, allows the simulation to achieve a deep detail level at the scenario definition. In this regard, the database and models of PHEMLight [4] have been included within Sumo tool in order to define the vehicle fleet per technology (fleet clasification) at the simulation.

PHEMLight offers an extensive vehicles database, which allows the user characterizing different flows of vehicles driving along the evaluated road, taken into account the fleet classification for the analyzed scenario.

Followed methodology, for characterizing the vehicle fleet previously defined for the simulated road per period (DAY, EVENING and NIGHT), is based on calculating different vehicles flows per technology by

[4] *(Allé, 2011)*

attributing percentages associated to different vehicles technologies (included within COPERT database) to absolute vehicles flows driving along the road. Once vehicles fleet has been defined by technology, these technologies are identified and associated to PHEMlight classification in order to achieve a real simulation of the road though PHEMLight models.

PHEMlight[5] available vehicles database has been included in tables below:

Table 20 Available vehicles in PHEMlight

Vehicle	Otto Engine		Diesel Engine		BEV	CNG
	Conventional	Hybrid	Conventional	Hybrid	Conventional	Conventional
PC	EU0-EU6c	EU5-EU6	EU0-EU6c	EU6	available	EU5-EU6
LCV	EU0-EU6c (I-III)	EU6 (I-III)	EU0-EU6c (I-III)	EU6 (I-III)	EU6 (I-III)	EU6 (I-III)
HDV_RT	-	-	EU0-U6c (I-II)	-	-	-
HDV_TT	-	-	EU0-EU6	-	-	-
HDV_CO	-	-	EU0-EU6	-	-	-
HDV_CB	-	-	EU0-EU6	-	-	-

Table 21 PHEMlight Vehicle description code

Vehicle category	Size class	Technology	Emission standard
PC	I	G	EU0
LCV	II	D	EU1
HDV-RT	III	G_HEV	EU2
HDV-RTT		D_HEV	EU3
HDV_CB		CNG	EU4
HDV_CO		BEV	EU5
			EU6
			EU6c

Table 22 Explanation Vehicle category and size class

Code	Explanation		
PC	Passenger cars		
LCV	Light commercial	Size class I	RM<1305 kg
		Size class II	1305<RM<=1760 kg
		Size class III	1760<RM<=3500 kg
	RM: Reference mass		
HDV-RT	Heavy duty vehicle - rigid trucks		
	Size class I	2 axle trucks	
	Size class II	3+ axle trucks	
HDV-TT	Heavy duty vehicle - truck - trailer (incl. Articulated trucks = tractor + semitrailer)		
HDV_CB	Heavy duty vehicle - city bus		
HDV_CO	Heavy duty vehicle - coach		

[5] *(Allé, 2011, sec. 4) Table 20 Available vehicles in PHEMlight*

Table 23 Explanation Vehicle technology

Code	Explanation
G	Gasoline engine (conventional powertrain)
D	Gasoline engine (conventional powertrain)
G_HEV	Gasoline engine (parallel hybrid powertrain)
D_HEV	Diesel engine (parallel hybrid powertrain)
CNG	CNG Engine
BEV	Battery electric vehicle

Once PHEMLight vehicles have been defined, the vehicles fleet obtained for the analysed road (from Table 13 to Table 19) is associated to PHENLight classification (Table 20). Thus, vehicles fleet per PHEMLight technology has been calculated (results included within Table 24, Table 25 and Table 26).

Table 24 Passenger cars fleet classification by technology at the analysed road

Fleet passenger cars [veh/h]									
Gasoline									
Period	PC_G	EU0	EU1	EU2	EU3	EU4	EU5	EU6	EU6+
Day	***2290,8814***	134,0956	324,8119	568,3131	695,5634	334,5175	175,3467	48,9590	9,2742
Evening	***1845,2502***	108,0108	261,6283	457,7626	560,2597	269,4458	141,2376	39,4353	7,4701
Night	***537,3788***	31,4552	76,1921	133,3109	163,1604	78,4688	41,1316	11,4845	2,1755
Diesel									
Period	PC_D	EU0	EU1	EU2	EU3	EU4	EU5	EU6	EU6+
Day	***128,9569***	0,6706	11,1032	9,8007	29,8535	34,0446	30,7046	10,8840	1,8957
Evening	***103,8717***	0,5401	8,9434	7,8942	24,0463	27,4221	24,7319	8,7668	1,5269
Night	***30,2498***	0,1573	2,6045	2,2990	7,0028	7,9859	7,2025	2,5531	0,4447
CNG									
Period	PC_CNG	EU4	EU5	EU6					
Day	***13,2138***	11,8726	1,1575	0,1797					
Evening	***10,6434***	9,5631	0,9324	0,1448					
Night	***3,0996***	2,7850	0,2715	0,0422					
Hybrid-Gasoline									
Period	PC_G_HEV_EU6								
Day	***13,9479***								
Evening	***11,2347***								
Night	***3,2718***								

Table 25 Trucks fleet classification by technology at the analysed road

Fleet Heavy Duty Vehicle Rigid Truck 2 axes (1/3 of the trucks fleet) [veh/h]								
Diesel								
Period	HDV_RT_I_D	EU0	EU1	EU2	EU3	EU4	EU5	EU6
Day	***154,3333***	24,7242	56,3780	18,7515	23,1654	13,2727	13,0257	5,0158
Evening	***124,3333***	19,9182	45,4190	15,1065	18,6624	10,6927	10,4937	4,0408
Night	***36,3333***	5,8206	13,2726	4,4145	5,4536	3,1247	3,0665	1,1808
Fleet Heavy Duty Vehicle Rigid Truck 3 axes (1/3 of the trucks fleet) [veh/h]								
Diesel								
Period	HDV_RT_II_D	EU0	EU1	EU2	EU3	EU4	EU5	EU6
Day	***154,3333***	24,7242	56,3780	18,7515	23,1654	13,2727	13,0257	5,0158
Evening	***124,3333***	19,9182	45,4190	15,1065	18,6624	10,6927	10,4937	4,0408
Night	***36,3333***	5,8206	13,2726	4,4145	5,4536	3,1247	3,0665	1,1808
Fleet Heavy Duty Vehicle: Truck + trailer (1/3 of the trucks fleet) [veh/h]								
Diesel								
Period	HDV_TT_D	EU0	EU1	EU2	EU3	EU4	EU5	EU6
Day	***154,3333***	24,7242	56,3780	18,7515	23,1654	13,2727	13,0257	5,0158
Evening	***124,3333***	19,9182	45,4190	15,1065	18,6624	10,6927	10,4937	4,0408
Night	***36,3333***	5,8206	13,2726	4,4145	5,4536	3,1247	3,0665	1,1808

Table 26 Buses fleet classification by technology at the analysed road

Buses fleet - Heavy Duty Vehicle City Bus [veh/h]										
					Diesel					
Line 3	Period	HDV_CB_D	EU0	EU1	EU2	EU3	EU4	EU5	EU6
	Day	***7,5***	0,8445	2,9370	0,9563	1,5675	0,5295	0,4575	0,2078
	Evening	***7,5***	0,8445	2,9370	0,9563	1,5675	0,5295	0,4575	0,2078
	Night	***0***	0	0	0	0	0	0	0
Line 5	Period	HDV_CB_D	EU0	EU1	EU2	EU3	EU4	EU5	EU6
	Day	***6***	0,6756	2,3496	0,7650	1,2540	0,4236	0,3660	0,1662
	Evening	***6***	0,6756	2,3496	0,7650	1,2540	0,4236	0,3660	0,1662
	Night	***0***	0	0	0	0	0	0	0
Line 6	Period	HDV_CB_D	EU0	EU1	EU2	EU3	EU4	EU5	EU6
	Day	***4,2857***	0,4826	1,6783	0,5464	0,8957	0,3026	0,2614	0,1187
	Evening	***4,2857***	0,4826	1,6783	0,5464	0,8957	0,3026	0,2614	0,1187
	Night	***0***	0	0	0	0	0	0	0
Line 8	Period	HDV_CB_D	EU0	EU1	EU2	EU3	EU4	EU5	EU6
	Day	***3,75***	0,4223	1,4685	0,4781	0,7838	0,2648	0,2288	0,1039
	Evening	***3,75***	0,4223	1,4685	0,4781	0,7838	0,2648	0,2288	0,1039
	Night	***0***	0	0	0	0	0	0	0
Line 33	Period	HDV_CB_D	EU0	EU1	EU2	EU3	EU4	EU5	EU6
	Day	***3,75***	0,4223	1,4685	0,4781	0,7838	0,2648	0,2288	0,1039
	Evening	***3,75***	0,4223	1,4685	0,4781	0,7838	0,2648	0,2288	0,1039
	Night	***0***	0	0	0	0	0	0	0
Line 39	Period	HDV_CB_D	EU0	EU1	EU2	EU3	EU4	EU5	EU6
	Day	***6***	0,6756	2,3496	0,765	1,254	0,4236	0,366	0,1662
	Evening	***6***	0,6756	2,3496	0,765	1,254	0,4236	0,366	0,1662
	Night	***0***	0	0	0	0	0	0	0
Line 78	Period	HDV_CB_D	EU0	EU1	EU2	EU3	EU4	EU5	EU6
	Day	***1,8750***	0,2111	0,7343	0,2391	0,3919	0,1324	0,1144	0,0519
	Evening	***1,8750***	0,2111	0,7343	0,2391	0,3919	0,1324	0,1144	0,0519
	Night	***0***	0	0	0	0	0	0	0

4.3.3 Traffic simulation

Once the traffic along the reference scenario has been defined; the complete simulation of the scenario by period (DAY, EVENING and NIGHT) is performed.

The following XML files should be generated for being used as inputs of the simulations (one simulation by period):

nombre.nod.xml

nombre.edg.xml

nombre.tll.xml

nombre.net.xml [6]

[6] *Generated through NetEdit command, taking the files nod.xml, edg.xml and tll.xm as inputs.*

nombre.bus.xml

nombre.rou.xml

The XML file *nombre.cfg.xml* has been generated for configuring the simulation. This file takes as inputs the files previously exposed. The code included in the configuration file presents the following structure:

```
<configuration>
        <input>
                <net-file value="nombre.net.xml">
                <route-files value="nombre.rou.xml"/>
                <additional-files value="nombre.bus.xml,nombre_noise.add.xml,nombre.add.xml"/>
        </ input>
        <time>
                <begin value="0"/>
                <end value="1000"/>
                <step-length value="0.5"/>
        </time>
        <output>
                <emission-output value="emissions.xml"/>
        </output>
</configuration>
```

The following attributes have been included withinn the configuration file code:

- ***Input:*** Input files to the simulation. These files are those that define the road and the traffic, as well as three additional files. The additional file .bus.xml defines bus stops in the road; the other two files are generated to specify the outputs[7] files configuration. These two files codes are shown below:
  Nombre_noise.add.xml

  ```
  <additional>
          <edgeData id="noise" type="harmonoise" file="noise_tramos.xml"/>
  </additional>
  ```

  Solicita como output el nivel de ruido por tramos calculado según el método del Harmonoise.

  Nombre.add.xml

  ```
  <additional>
          edgeData id="ed" type="emissions" file="emissions_tramos.xml"/>
  </additional>
  ```

  Solicita como output los resultados del archivo emissions.xml, obtenidos por tramo.

- ***Time:*** This attribute defines the initial and final time of the simulation and the step time between simulations.

- ***Output:*** This attribute indicates the output file, which collects the whole dataBase obtained from the simulation. The emission file includes pollution emission and fuel consumption obtained from the simulation.

-

[7] *Simulation results.*

5 TRAFFIC ANALYSIS

In this chapter are presented the results of the simulation obtained for the reference scenario in order to determine current traffic characteristics (fuel consumption, emissions and noise profiles) under different periods of day and implemented models. These models are also compared with theoretical models, described at the end of this section, in order to establish relation between them and inputs taken into account in Sumo models. This comparison helps to determine what is behind the software interface, conceived as a black box for the end user.

5.1 Sumo

The simulation of the reference scenario has been performed through Sumo for three periods: Day, Evening and Night. Energy, emissions and noise results (road traffic outcomes) have been obtained by implementing different fuel consumption and emission models: PHEMLight and HBEFA. Furthermore, taken this fact into account, the results analyses show the behavior of the traffic flow (overall vehicle fleet) under different operating points without having to simulate each vehicle typology flow neither using engine curves. However, if the interest of the user lies in realizing a quantitative analysis, not qualitative; then it would be interesting to evaluate different vehicles consuming same fuel separately, in order not summing different fuel consumptions.

Simulation is performed with a time step of one hour. This is been established since traffic characteristics are supposed to be the same for all the hours of a period, so the behavior will be the same for all the period. Also values included in database are given hourly. In case the objective of the analysis is determining results per day, hourly results by period would have to be multiplied by hours of the period and then periods results would be summed in order to obtain daily results.

5.1.1 Energy consumption

The energy consumption is directly related to vehicles fuel consumption and it depends strongly on vehicles fleet and particular characteristics of each fuel. This way, PHEMLight offers the user the possibility to establish the complete fleet (broken down by vehicle typology and European emission class) already defined in 4.3.2, while HBEFA just distinguish by vehicle typology (motorbike, car, truck, bus). So, results will be significantly different for both models.

5.1.1.1 PHEMLight results

PHEMLight results are obtained for day, evening and night period and are included in this section within tables and graphs.

Tables below show fuel consumption by edge in which the road is divided, identifying the length of the edge, average speed over the edge, number of vehicles along the edge and average speed of vehicles driving along the edge. By other hand, fuel consumption values are given as absolute values, as normed values per km and as liters per vehicle per km. Since edge lengths are different, in order to compare results under different operating points, resuming in different edges conditions, it seems to be more representative to compare fuel consumption in liters per vehicle and per km length of the edge. So, fuel consumption in liters per vehicle and per km is included within represented graphs.

Black rows in tables are associated to edges where traffic lights and bus stops are located.

5.1.1.1.1 Day results:

Table 27 Fuel consumption by edge – Base Line of day results – PHEMLight (Sumo)

Edge	Length	Speed		Vehicles		Fuel abs	Fuel normed	Fuel per Veh		
	m	m/s	km/h	nº veh	nº veh/m	ml	l/km/h	ml/veh	l/h/veh	l/veh/km
1	721,97	12,30	44,29	1.261,37	1,75	332.849,29	461,03	263,90	16,19	0,37
2	**158,73**	**4,87**	**17,53**	**1.294,52**	**8,16**	**134.281,24**	**845,97**	**103,74**	**8,62**	**1,08**
3	98,83	11,92	42,92	1.313,45	13,29	83.394,38	843,82	63,46	6,81	0,88
4	280,86	12,58	45,28	1.254,31	4,47	115.736,98	412,08	92,26	10,08	1,35
5	**156,57**	**4,06**	**14,63**	**1.262,32**	**8,06**	**159.568,41**	**1.019,15**	**126,40**	**13,64**	**0,80**
6	256,88	12,24	44,08	1.245,28	4,85	151.922,92	591,42	122,02	11,90	1,60
7	**253,63**	**10,48**	**37,73**	**1.230,91**	**4,85**	**111.410,80**	**439,27**	**90,51**	**8,82**	**0,92**
8	70,75	4,14	14,89	1.290,34	18,24	50.158,24	708,95	38,87	9,76	1,34
9	**79,90**	**2,30**	**8,27**	**1.280,41**	**16,03**	**118.807,96**	**1.486,96**	**92,78**	**31,05**	**0,73**
10	135,54	2,22	7,98	1.865,43	13,76	273.191,22	2.015,58	146,46	11,93	0,79
11	84,43	2,16	7,77	1.891,02	22,40	140.040,91	1.658,66	74,06	14,18	0,63
12	**183,31**	**2,07**	**7,46**	**1.800,98**	**9,82**	**446.129,23**	**2.433,74**	**247,72**	**11,45**	**0,65**
13	141,53	4,71	16,95	1.782,15	12,59	202.995,72	1.434,29	113,90	8,81	1,06
14	**98,60**	**2,06**	**7,43**	**1.786,67**	**18,12**	**282.138,16**	**2.861,44**	**157,90**	**11,96**	**1,54**
15	185,89	2,68	9,64	1.711,69	9,21	291.159,61	1.566,30	170,11	12,88	0,71
16	**192,76**	**2,02**	**7,26**	**1.658,25**	**8,60**	**429.339,93**	**2.227,33**	**258,90**	**8,56**	**0,88**
17	117,04	11,87	42,73	1.668,35	14,25	141.858,63	1.212,05	85,06	11,44	1,41
18	**224,94**	**4,20**	**15,13**	**1.617,41**	**7,19**	**286.774,92**	**1.274,90**	**177,30**	**30,85**	**0,74**
19	305,31	6,23	22,43	1.580,30	5,18	305.024,97	999,07	193,00	21,40	0,48
20	281,01	2,31	8,31	1.857,78	6,61	553.268,09	1.968,86	297,82	21,11	0,47
21	**119,86**	**2,16**	**7,78**	**1.855,73**	**15,48**	**341.862,15**	**2.852,18**	**184,22**	**19,71**	**1,11**
22	191,13	5,05	18,19	1.805,89	9,45	244.450,56	1.278,98	135,38	23,87	0,57
23	239,56	2,71	9,77	1.741,48	7,27	365.392,80	1.525,27	209,83	27,57	0,64
24	**143,26**	**2,25**	**8,10**	**1.717,92**	**11,99**	**347.624,42**	**2.426,53**	**202,35**	**13,82**	**1,37**
25	91,82	11,64	41,90	1.736,30	18,91	117.389,18	1.278,47	67,59	29,12	0,66
26	160,18	12,29	44,26	1.684,90	10,52	130.513,57	814,79	77,48	14,88	0,33
27	214,99	12,37	44,53	1.657,16	7,71	168.858,32	785,42	101,88	11,81	0,81
28	**168,42**	**4,94**	**17,79**	**1.664,36**	**9,88**	**310.579,93**	**1.844,08**	**186,63**	**20,93**	**0,47**
29	166,96	11,69	42,09	1.651,19	9,89	156.369,97	936,57	94,72	13,46	0,36
30	**122,56**	**2,81**	**10,11**	**1.650,15**	**13,46**	**276.517,48**	**2.256,18**	**167,58**	**8,18**	**0,55**
31	256,32	12,25	44,11	1.589,38	6,20	268.965,47	1.049,33	169,22	9,61	1,16

Included values within Table 27 (fuel consumed by vehicles driving along the particular edge per vehicle per km length of the edge) are represented at **Figure 9** , distinguishing fuel consumption by vehicles driving along different edges where traffic lights or bus stops are located and along those edges free of traffic lights or bus stops.

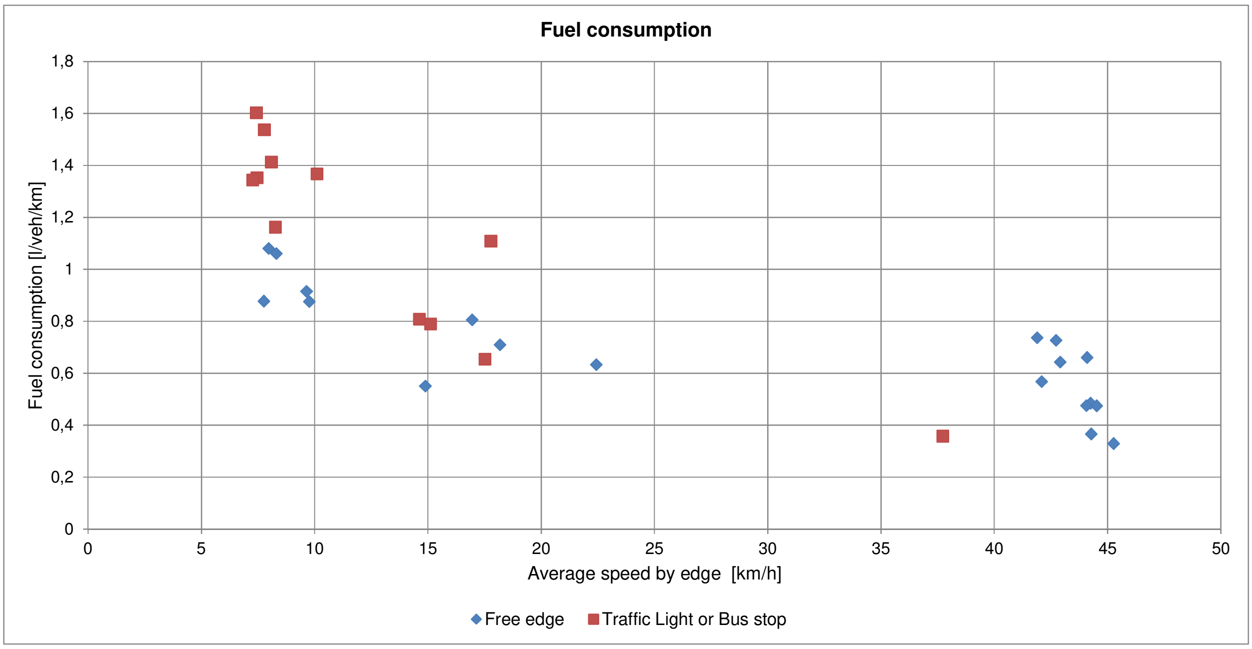

Figure 9 Fuel Consumption by edge – Base Line of day results – PHEMLight (Sumo)

The fuel consumption by vehicles driving along edges, where traffic lights or bus stops are located (represented by red dots within Figure 9), are in most cases associated to edges where the average speed of vehicles driving along is low. However, despite the average speed is lower, the unitary vehicles fuel consumption along these edges is, in most cases, higher than in free edges (edges free of traffic lights and bus stops (green dots)). This is explained as vehicles are under acceleration and deceleration conditions along these edges, this results in an increase of the output engine power of vehicles and consequently on higher fuel consumption.

5.1.1.1.2 Evening results:

Table of results included in Annex 1.

Figure 10 includes fuel consumption (fuel consumed by vehicles driving along the particular edge per vehicle per km length of the edge) results obtained for evening simulation. Fuel consumption at different edges is represented per average speed of vehicles driving along the edge, distinguishing free edges and edges where traffic lights or bus stops are located in.

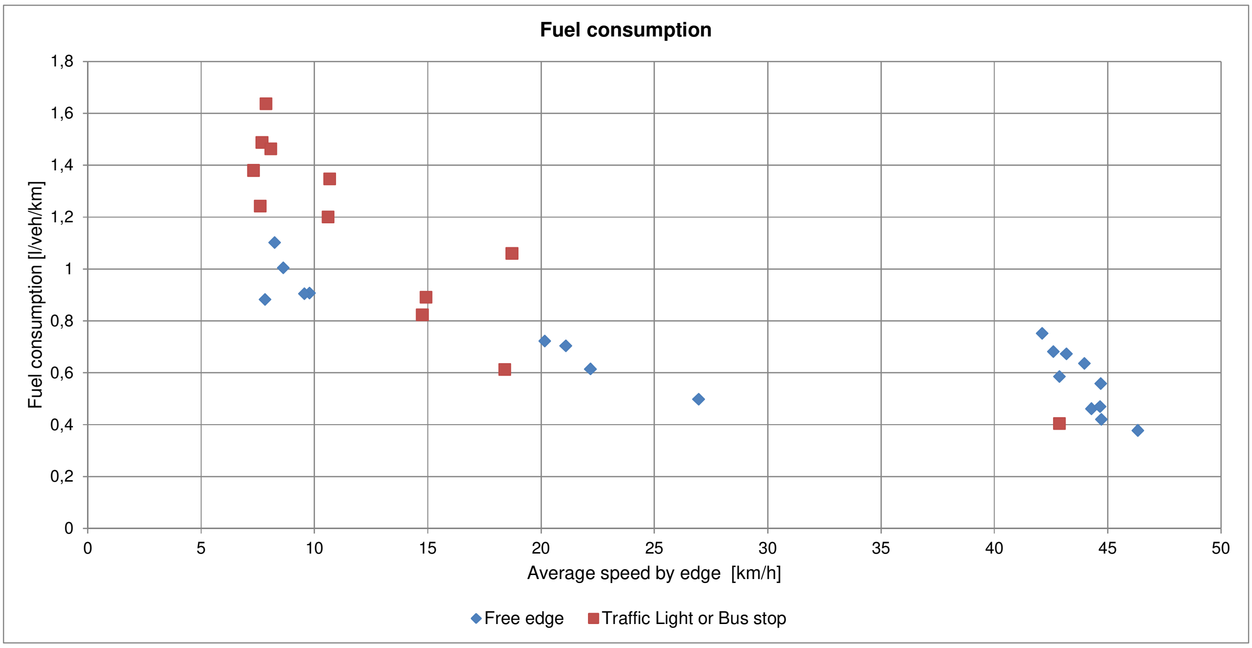

Figure 10 Fuel Consumption by edge – Base Line of evening results – PHEMLight (Sumo)

As it is concluded from Figure 10, evening results are closed to day results, quantitatively and qualitatively. Same observations have been realized for both simulations; most traffic-light edges are associated to a lower average speed and higher fuel consumption, which is again result of deceleration and acceleration conditions within the edge.

5.1.1.1.3 Night results:

Table of results included in Annex 1.

Figure 11 includes fuel consumption (fuel consumed by vehicles driving along the particular edge per vehicle per km length of the edge) results obtained from night simulation. Fuel consumption at different edges is represented per average speed of vehicles driving along the edge, distinguishing free edges and edges where traffic lights or bus stops are located in.

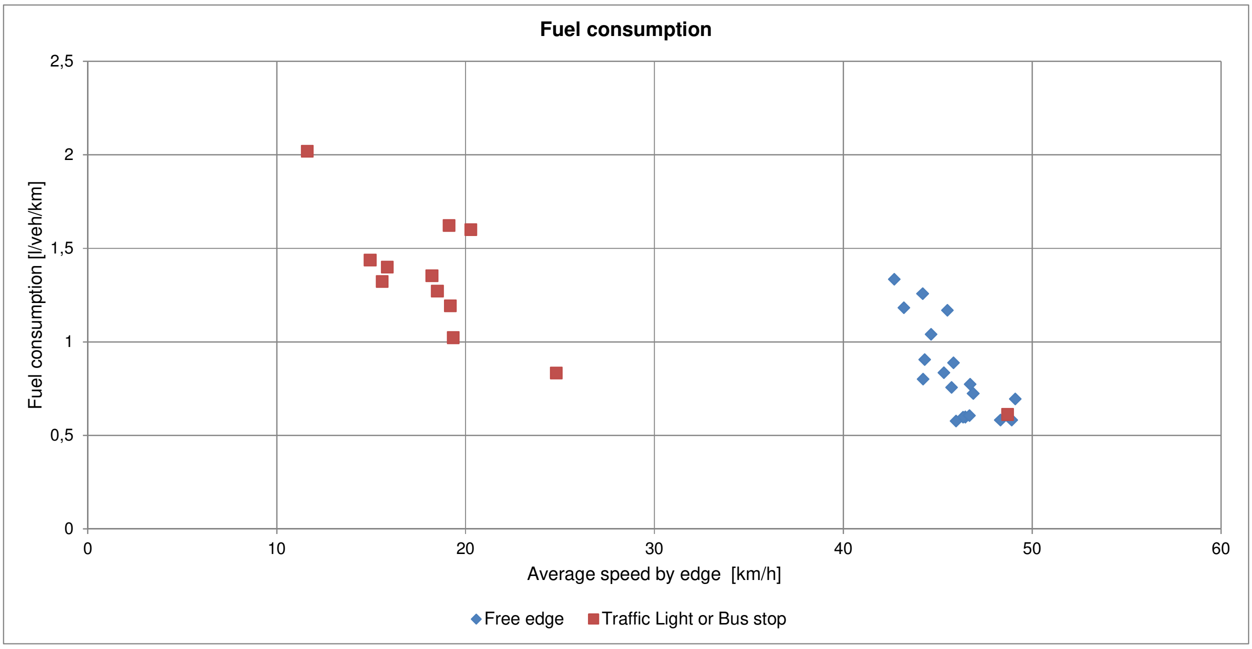

Figure 11 Fuel Consumption by edge – Base Line of night results – PHEMLight (Sumo)

Figure 11 presents differences in comparison to day and evening graphs (Figure 9 and Figure 10). To start with, there exist two operating condition clouds of points: one associated to traffic lights edges (characteristics operating points of these edges) and the other one associated to free edges. It seems to be one operating point, associated to traffic light or bus stop edge, within the operating condition cloud associated to free edge. Actually, this edge is a free edge under night operating conditions because it is associated to a bus stop and in the analysis road there are no bus lines operating during night. This fact, the absence of buses during night, is also the reason for the existence of these two completely separate clouds of operating points.

5.1.1.1.4 Day, evening and night results:

Once fuel consumption results have been briefly analysed for different periods, it results interesting to realize a comparison of these three results. For these purpose, **Figure 12** and **Figure 13** represent the absolute fuel consumption per vehicles driving along the particular edge per average edge speed, in order to consider speed and acceleration and deceleration influence (related to traffic-light or bus stop presence) over fuel consumption.

Figure 12 represents the speed influence over fuel consumption (fuel consumed by vehicles driving along the particular edge per vehicle per km length of the edge) per period. Fuel consumption at different edges is represented per average speed of vehicles driving along the edge, distinguishing free edges and edges where traffic lights or bus stops are located in.

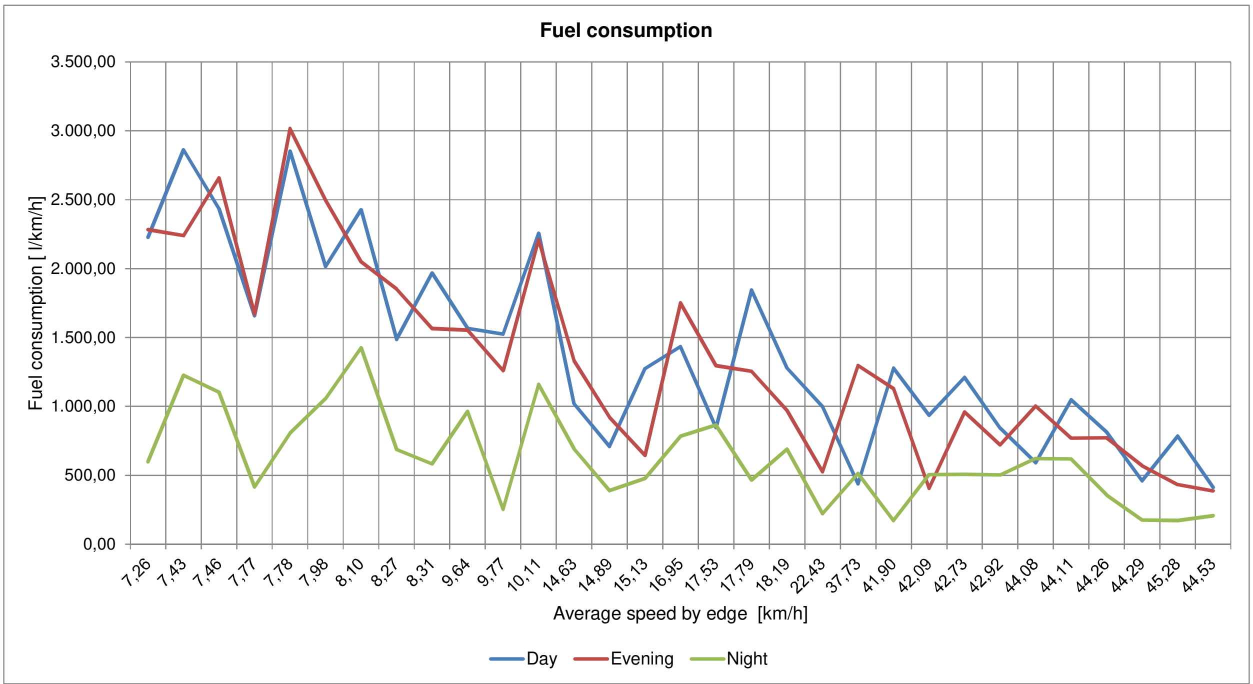

Figure 12– Fuel consumption base line under different periods and speed influence over results (PHEMLight (Sumo))

From Figure 12 it is observed that absolute fuel consumption values over day and evening periods are very similar each other, being considerably higher than night results. By other hand, speed influence over fuel consumption is clear at day and evening cases; however, under night conditions the speed effect is not so significant, mainly because of the no presence of buses, which have important influence over low speed edge, being one of the reasons of higher values at low speeds. In fact, another observation to be mentioned is the high fuel consumption values over low speed edges. It could be though that fuel consumption should be lower as speed decreases; however, operating points are not just conditioned by speed but also by other factors such as acceleration and deceleration or idle conditions. This is why at low speed edges fuel consumption is also high, because these edges are mainly associated to traffic lights and bus stops presence, associated to acceleration and deceleration conditions, which result in higher output engine power of vehicles and consequently higher fuel consumption.

Figure 13 represents same results than Figure 12 but, instead of representing results per average edge speed, results are represented per edge. Drawn yellow lines in graph below represent traffic lights or bus stops edges.

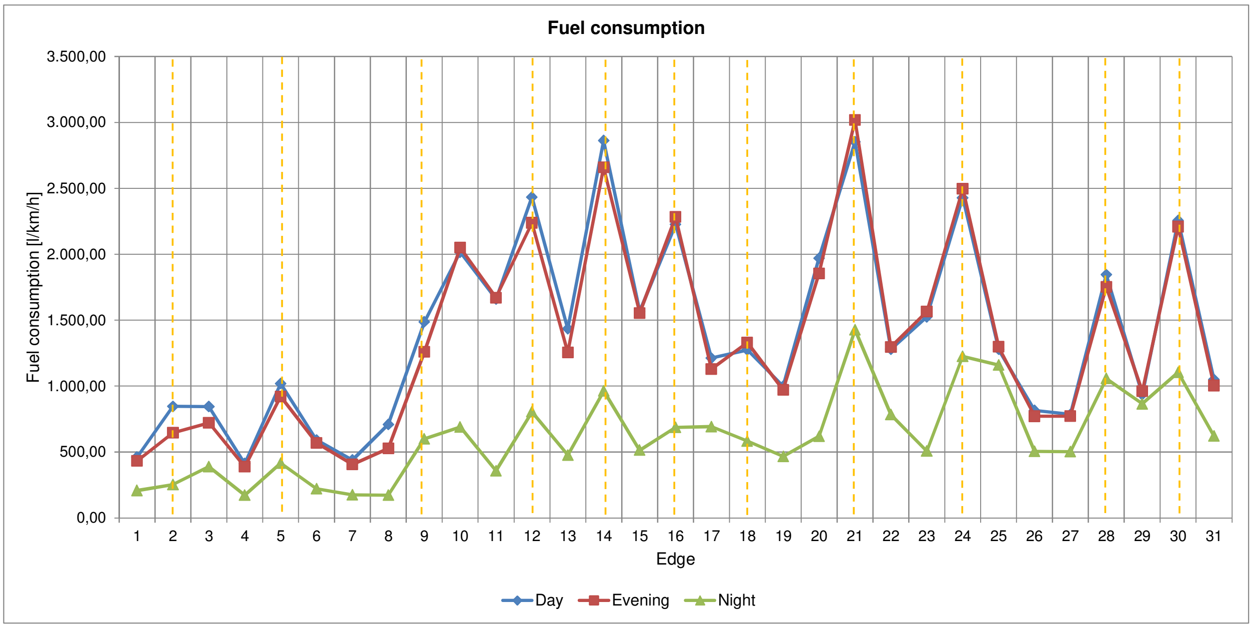

Figure 13– Fuel consumption base line under different periods – Results by edge (PHEMLight (Sumo))

From Figure 13 same conclusions than obtained from Figure 12 have been concluded.

5.1.1.2 HBEFA results

HBEFA results are obtained for day, evening and night period and are included in this section within tables and graphs.

Tables below show fuel consumption by edge in which the road is divided, identifying the length of the edge, average speed over the edge, number of vehicles along the edge and average speed of vehicles driving along the edge. Black rows within tables are associated to edges where traffic lights and bus stops are located.

Fuel consumption values are given as absolute values, as normalize values per km and as unitary values in litters per vehicle and per 100kilometers. This represents the first difference in comparison to PHEMLight results. Unitary results in PHEMLight are given in l/veh/km, but results obtained through HBEFA simulation are too low to be included as l/veh/100km. Differences between results, obtained from PHEM and HBEFA simulation, lies in the considered fleet for each simulation and, consequently, in considered fuels. So the comparison between both models should be quantitative and not qualitative since results are the sum different fuels consumption.

5.1.1.2.1 Day results:

Table 28 Fuel consumption by edge – Base Line of day results – HBEFA (Sumo)

Edge	Length	Speed		Vehicles		Fuel abs	Fuel normed	Fuel per Veh		
	m	m/s	km/h	nº veh	nº veh/m	ml	l/km/h	ml/veh	l/h/veh	l/veh/100km
1	721,97	12,30	44,29	1.261,37	1,75	102.498,09	141,97	81,26	4,99	11,26
2	**158,73**	**4,87**	**17,53**	**1.294,52**	**8,16**	**77.023,26**	**568,27**	**41,29**	**2,43**	**30,46**
3	98,83	11,92	42,92	1.313,45	13,29	48.263,65	571,64	25,52	2,35	30,23
4	280,86	12,58	45,28	1.254,31	4,47	119.278,86	650,69	66,23	2,70	36,13
5	**156,57**	**4,06**	**14,63**	**1.262,32**	**8,06**	**61.853,76**	**437,04**	**34,70**	**4,16**	**24,52**
6	256,88	12,24	44,08	1.245,28	4,85	68.669,26	696,44	38,43	2,90	38,98
7	**253,63**	**10,48**	**37,73**	**1.230,91**	**4,85**	**86.251,49**	**463,99**	**50,39**	**2,61**	**27,11**
8	70,75	4,14	14,89	1.290,34	18,24	116.792,86	605,90	70,43	2,65	36,54
9	**79,90**	**2,30**	**8,27**	**1.280,41**	**16,03**	**36.097,19**	**308,42**	**21,64**	**7,90**	**18,49**
10	135,54	2,22	7,98	1.865,43	13,76	70.615,30	313,93	43,66	2,94	19,41
11	84,43	2,16	7,77	1.891,02	22,40	77.134,60	252,64	48,81	3,59	15,99
12	**183,31**	**2,07**	**7,46**	**1.800,98**	**9,82**	**39.443,00**	**248,49**	**30,47**	**3,36**	**19,20**
13	141,53	4,71	16,95	1.782,15	12,59	154.816,50	550,93	83,34	2,46	29,66
14	**98,60**	**2,06**	**7,43**	**1.786,67**	**18,12**	**84.529,30**	**705,23**	**45,55**	**2,96**	**38,00**
15	185,89	2,68	9,64	1.711,69	9,21	63.621,92	332,87	35,23	3,35	18,43
16	**192,76**	**2,02**	**7,26**	**1.658,25**	**8,60**	**100.992,79**	**421,58**	**58,00**	**2,37**	**24,21**
17	117,04	11,87	42,73	1.668,35	14,25	86.742,32	605,49	50,49	2,85	35,25
18	**224,94**	**4,20**	**15,13**	**1.617,41**	**7,19**	**32.355,95**	**352,38**	**18,63**	**8,50**	**20,30**
19	305,31	6,23	22,43	1.580,30	5,18	27.599,23	172,30	16,39	4,53	10,23
20	281,01	2,31	8,31	1.857,78	6,61	35.420,72	164,76	21,37	4,43	9,94
21	**119,86**	**2,16**	**7,78**	**1.855,73**	**15,48**	**58.705,15**	**348,56**	**35,28**	**3,72**	**20,94**
22	191,13	5,05	18,19	1.805,89	9,45	43.325,80	259,50	26,24	6,61	15,72
23	239,56	2,71	9,77	1.741,48	7,27	25.401,97	257,03	19,33	8,40	19,57
24	**143,26**	**2,25**	**8,10**	**1.717,92**	**11,99**	**55.456,56**	**452,48**	**33,61**	**2,77**	**27,42**
25	91,82	11,64	41,90	1.736,30	18,91	64.082,08	250,01	40,32	6,94	15,73
26	160,18	12,29	44,26	1.684,90	10,52	33.886,69	120,65	27,01	4,36	9,62
27	214,99	12,37	44,53	1.657,16	7,71	42.474,71	271,28	33,64	3,14	21,49
28	**168,42**	**4,94**	**17,79**	**1.664,36**	**9,88**	**45.408,35**	**176,77**	**36,47**	**6,26**	**14,20**
29	166,96	11,69	42,09	1.651,19	9,89	33.466,35	131,95	27,19	4,04	10,72
30	**122,56**	**2,81**	**10,11**	**1.650,15**	**13,46**	**16.252,47**	**229,72**	**12,59**	**2,65**	**17,80**
31	256,32	12,25	44,11	1.589,38	6,20	29.451,04	368,60	23,00	2,38	28,79

Included values within Table 28(fuel consumed by vehicles driving along the particular edge per vehicle per 100km length of the edge) are represented at **Figure 14**, distinguishing fuel consumption by vehicles driving along different edges where traffic lights or bus stops are located and along those edges free of traffic lights or bus stops.

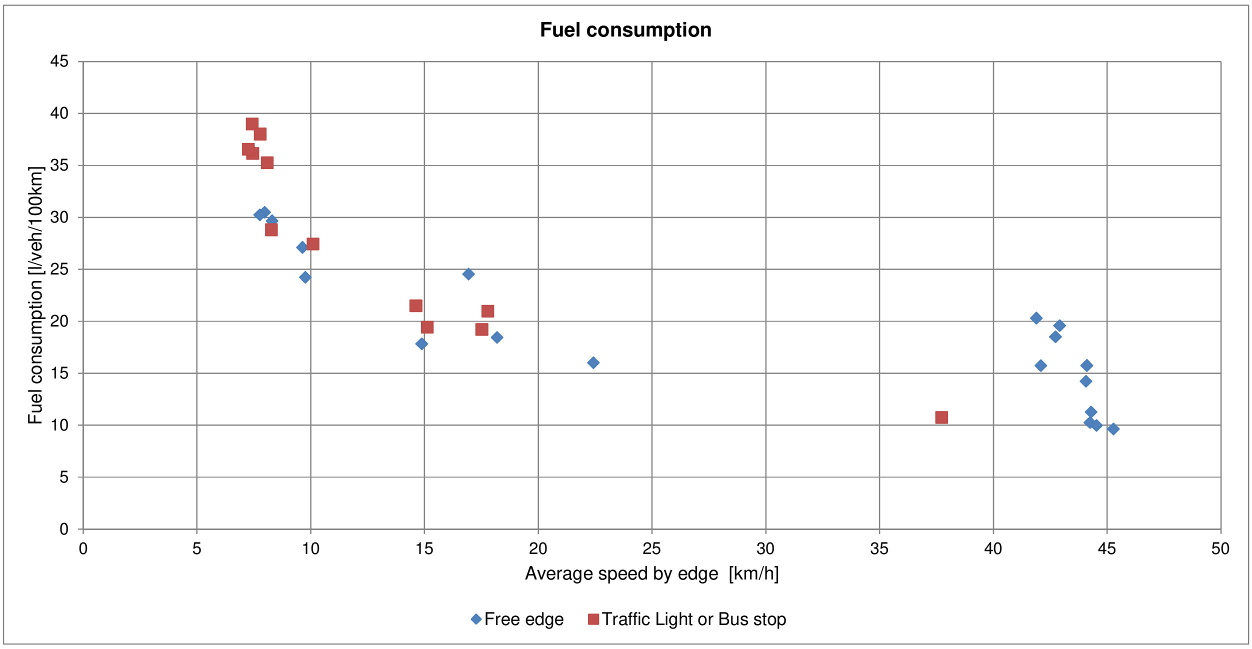

Figure 14 Fuel Consumption by edge – Base Line of day results – HBEFA (Sumo)

From Figure 14 same conclusions than in the PHEMLight simulation have been obtained; the fuel consumption by vehicles driving along edges, where traffic lights or bus stops are located (represented by red dots), are in most cases associated to edges where the average speed of vehicles driving along is low. However, despite the average speed is lower, the unitary vehicles fuel consumption along these edges is, in most cases, higher than in free edges (edges free of traffic lights and bus stops (green dots)). This is explained as vehicles are under acceleration and deceleration conditions along these edges, this results in an increase of the output engine power of vehicles and consequently on higher fuel consumption.

Once detected the speed influence over the fuel consumption, **Figure 15** has been included in order to represent fuel consumption evolution with speed, distinguishing between free edges and traffic light edges.

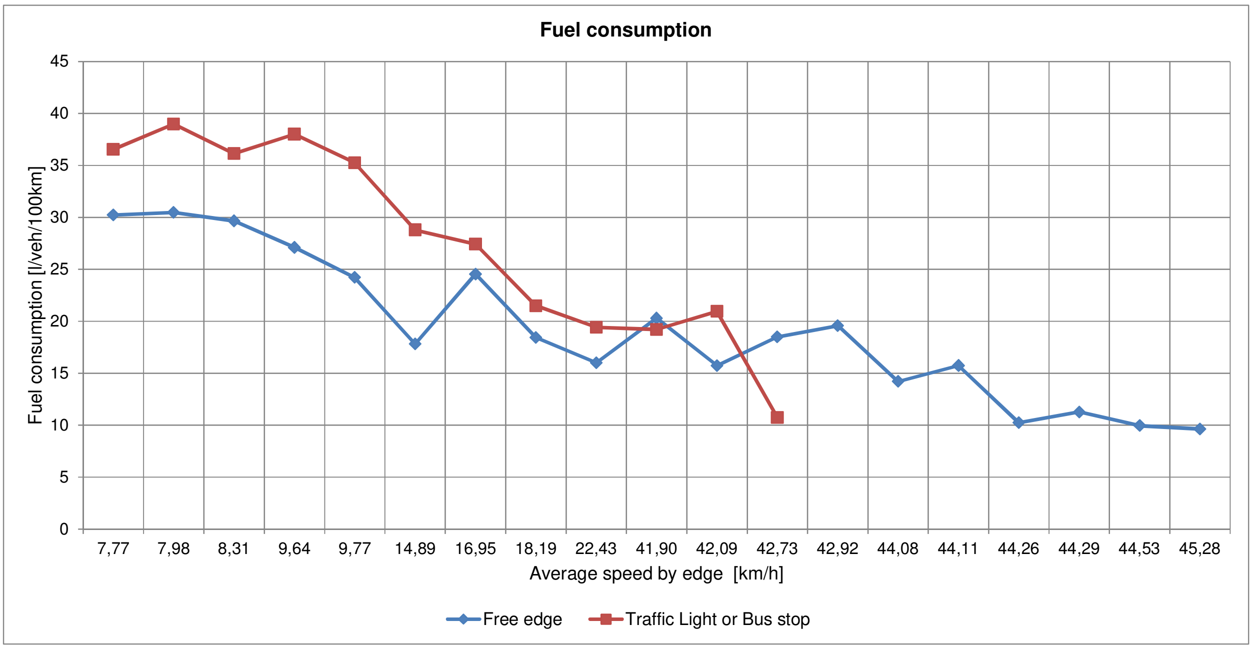

Figure 15 Fuel Consumption by edge – Base Line of day results – HBEFA (Sumo) [Normalized scale]

Figure 15 represents same results than Figure 14 but changing the x-axis. This way the effect of acceleration and deceleration conditions, over fuel consumption per edge, has become independent from average edge speed. It is observed that acceleration conditions (traffic lights presence) increase fuel consumption by vehicles, even if vehicles are driving at same speed rate. Thus, red dots are in most cases represented above blue dots, mainly at slow edges.

5.1.1.2.2 Evening results:

Table of results included in Annex 1.

Figure 16 includes fuel consumption values (fuel consumed by vehicles driving along the particular edge per vehicle per 100km length of the edge), distinguishing fuel consumption by vehicles driving along different edges where traffic lights or bus stops are located and along those edges free of traffic lights or bus stops. . Fuel consumption at different edges is represented per average speed of vehicles driving along the edge, distinguishing free edges and edges where traffic lights or bus stops are located in.

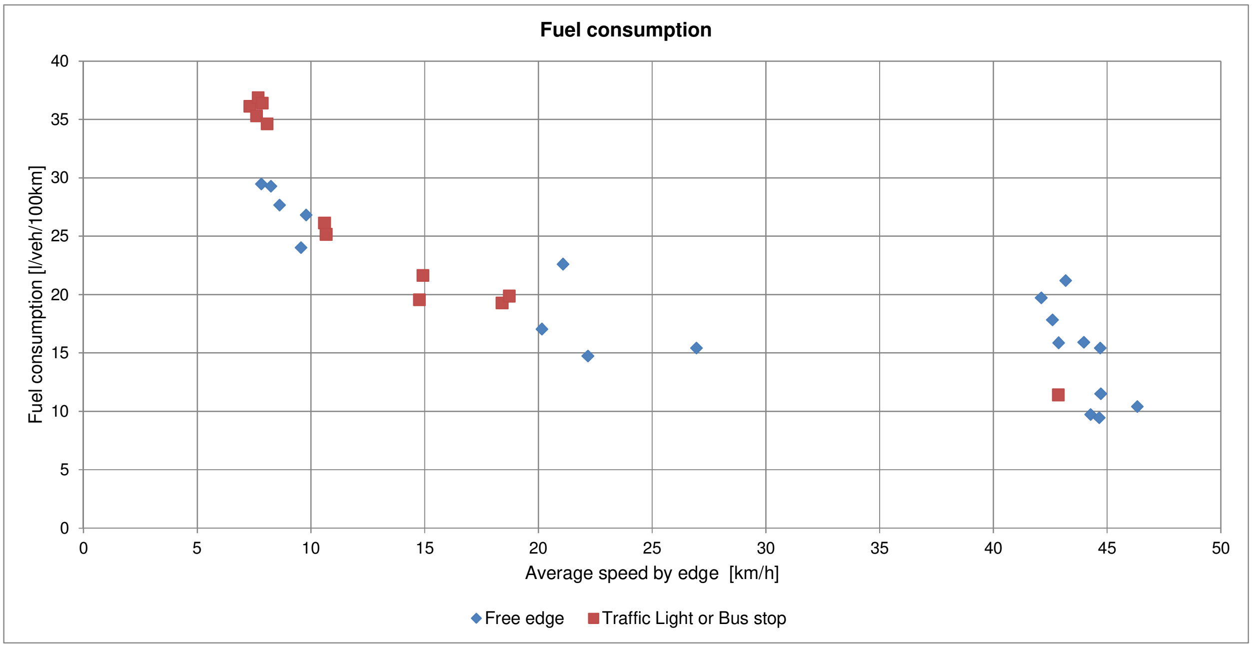

Figure 16 Fuel Consumption by edge – Base Line of evening results – HBEFA (Sumo)

From Figure 16Figure 14 same conclusions than in the PHEMLight simulation have been obtained; the fuel consumption by vehicles driving along edges, where traffic lights or bus stops are located (represented by red dots), are in most cases associated to edges where the average speed of vehicles driving along is low. However, despite the average speed is lower, the unitary vehicles fuel consumption along these edges is, in most cases, higher than in free edges (edges free of traffic lights and bus stops (green dots)). This is explained as vehicles are under acceleration and deceleration conditions along these edges, this results in an increase of the output engine power of vehicles and consequently on higher fuel consumption.

Once detected the speed influence over the fuel consumption, **Figure 17** has been included in order to represent fuel consumption evolution with speed, distinguishing between free edges and traffic light edges.

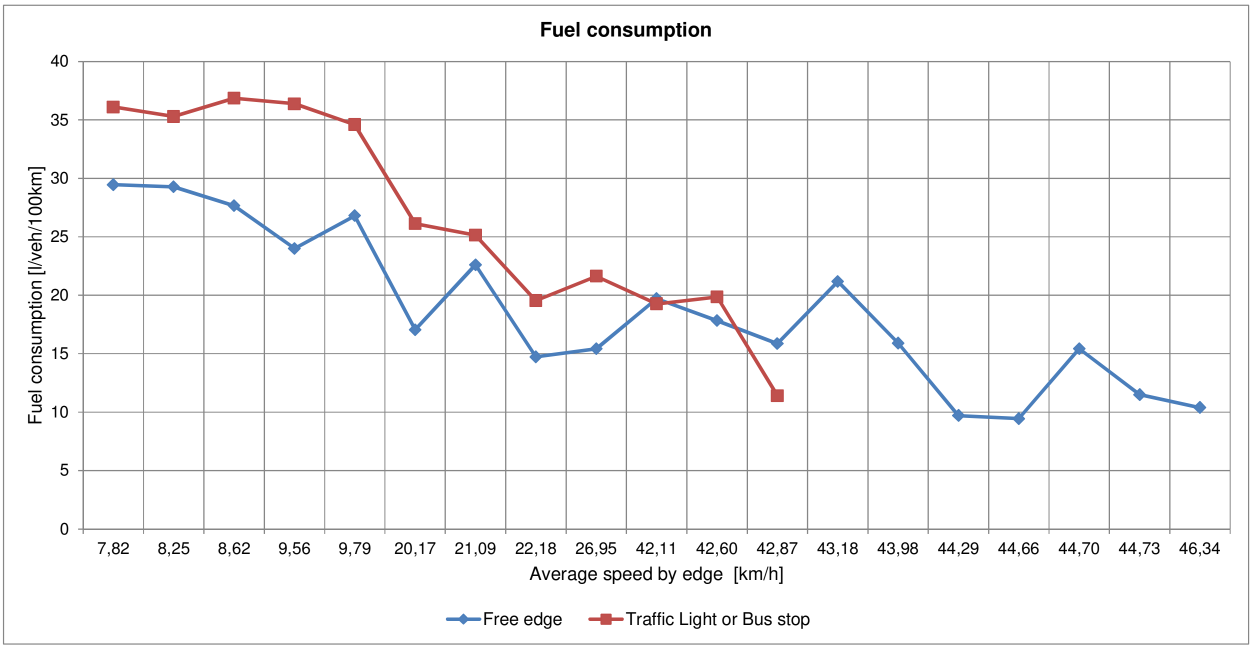

Figure 17 Fuel Consumption by edge – Base Line of evening results – HBEFA (Sumo) [Normalized scale]

Figure 17 represents same results than Figure 16 but changing the x-axis. This way the effect of acceleration and deceleration conditions, over fuel consumption per edge, has become independent from average edge speed. It is observed that acceleration conditions (traffic lights presence) increase fuel consumption by vehicles, even if vehicles are driving at same speed rate. Thus, red dots are in most cases represented above blue dots, mainly at slow edges. Same conclusions were obtained from Figure 15.

5.1.1.2.3 Night results:

Table of results included in Annex 1.

Figure 18 includes fuel consumption values (fuel consumed by vehicles driving along the particular edge per vehicle per 100km length of the edge), distinguishing fuel consumption by vehicles driving along different edges where traffic lights or bus stops are located and along those edges free of traffic lights or bus stops. . Fuel consumption at different edges is represented per average speed of vehicles driving along the edge, distinguishing free edges and edges where traffic lights or bus stops are located in.

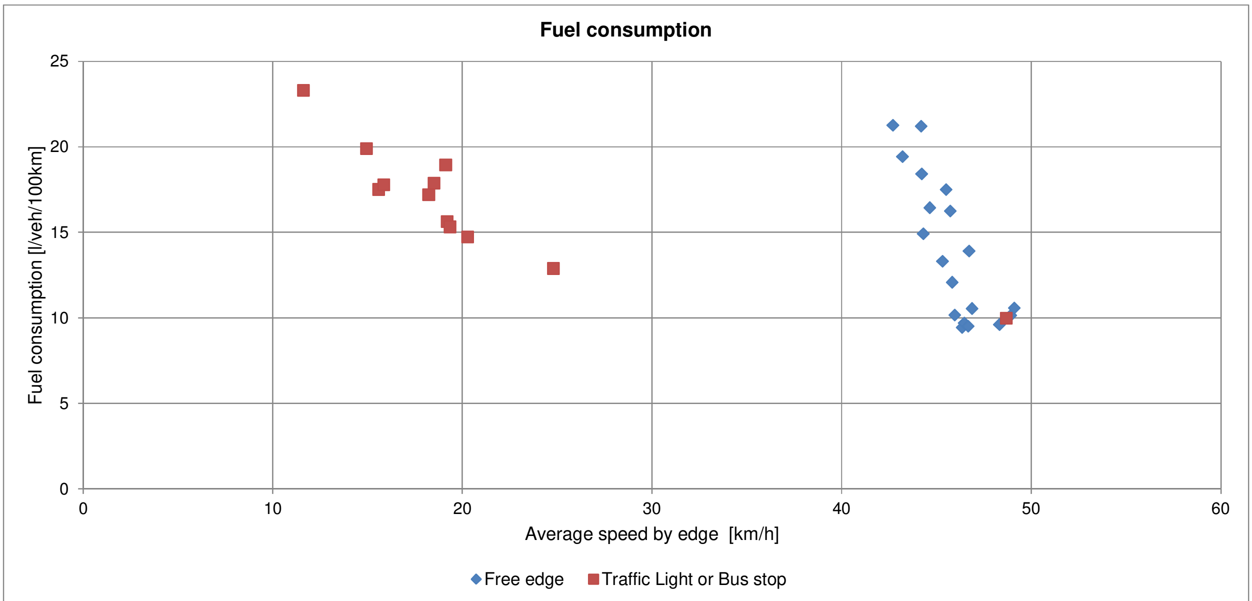

Figure 18 Fuel Consumption by edge – Base Line of night results – HBEFA (Sumo)

As happened at PHEMLight simulation, Figure 18 presents differences in comparison to day and evening graphs (Figure 14 and Figure 16). To start with, there exist two operating condition clouds of points: one associated to traffic lights edges (characteristics operating points of these edges) and the other one associated to free edges. It seems to be one operating point, associated to traffic light or bus stop edge, within the operating condition cloud associated to free edge. Actually, this edge is a free edge under night operating conditions because it is associated to a bus stop and in the analysis road there are no bus lines operating during night. This fact, the absence of buses during night, is also the reason for the existence of these two completely separate clouds of operating points.

Figure 19 has been included in order to represent fuel consumption evolution with speed, distinguishing between free edges and traffic light edges (acceleration conditions).

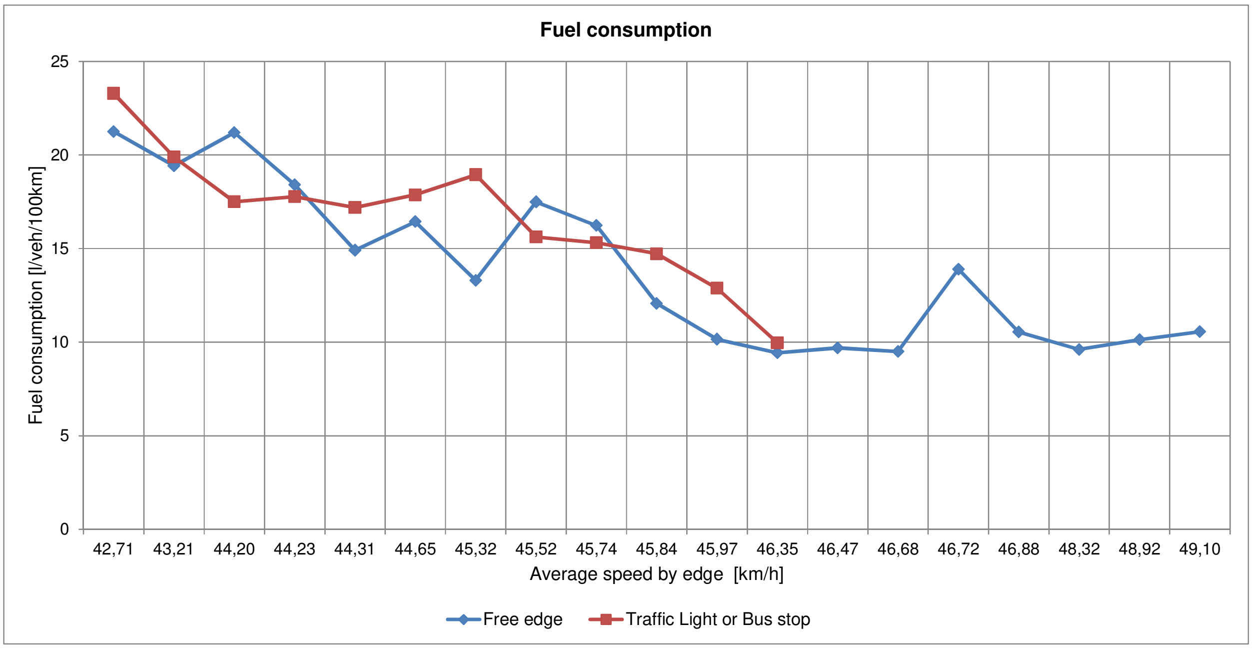

Figure 19 Fuel Consumption by edge – Base Line of night results – HBEFA (Sumo) [Normalized scale]

Speed influence over fuel consumption is represented in Figure 19. It has been observed, as at day and night periods, the concentration of traffic light and bus stops at low speed edges. However, as difference with previous analysed periods, the speed influence over fuel consumption is not so high. This is mainly because shown results are the totalized fuel consumption, including all types of vehicles and the overall hour of simulation; so, if there is no buses, the period of time in which vehicles are under deceleration and acceleration conditions is too low to have significantly effects over fuel consumption.

5.1.1.2.4 Day, evening and night results:

Conclusions are the same to those obtained for PHEMLight results.

Figure 20 and **Figure 21** represent the absolute fuel consumption per vehicles driving along the particular edge per average edge speed, in order to consider speed and acceleration and deceleration influence (related to traffic-light or bus stop presence) over fuel consumption.

Figure 20 represents the speed influence over fuel consumption (fuel consumed by vehicles driving along the particular edge per vehicle per 100km length of the edge) per period. Fuel consumption at different edges is represented per average speed of vehicles driving along the edge, distinguishing free edges and edges where traffic lights or bus stops are located in. The qualitative speed effect over fuel consumption is also observed from PHEMLight results.

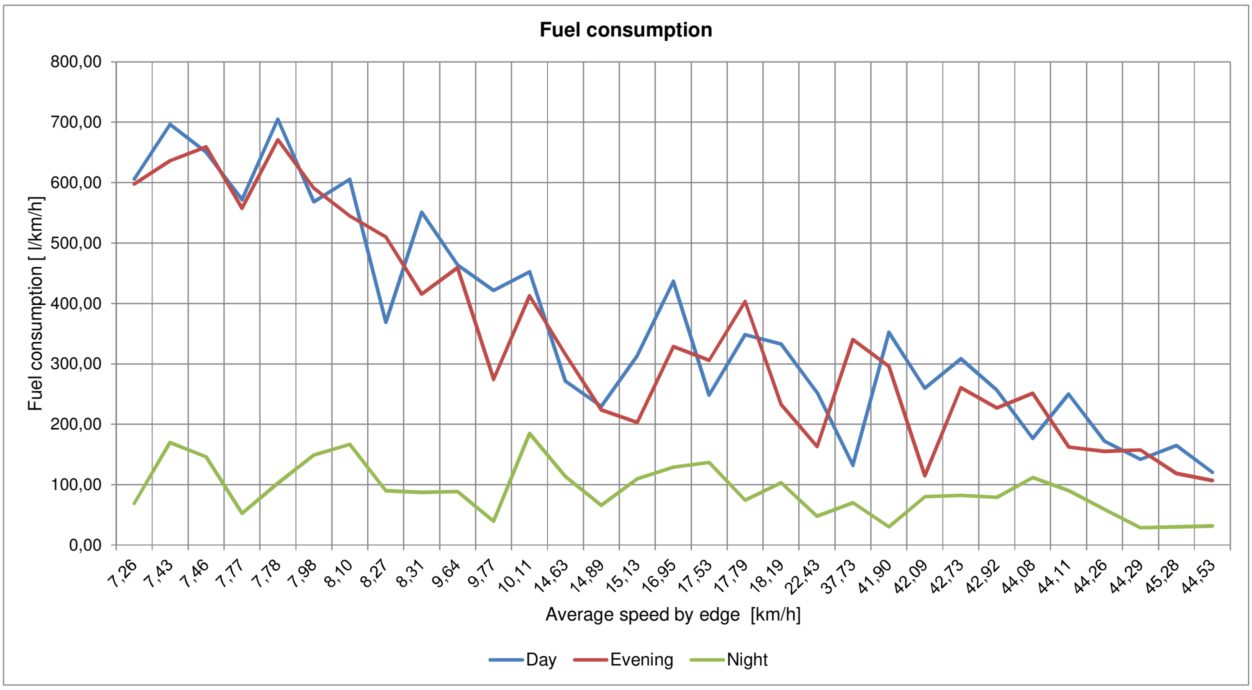

Figure 20– Fuel consumption base line under different periods – Results by edge (HBEFA (Sumo))

From Figure 20 it is observed that absolute fuel consumption values over day and evening periods are very similar each other, being considerably higher than night results. By other hand, speed influence over fuel consumption is clear at day and evening cases; however, under night conditions the speed effect is not so significant, mainly because of the no presence of buses, which have important influence over low speed edge, being one of the reasons of higher values at low speeds. In fact, another observation to be mentioned is the high fuel consumption values over low speed edges. It could be though that fuel consumption should be lower as speed decreases; however, operating points are not just conditioned by speed but also by other factors such as acceleration and deceleration or idle conditions. This is why at low speed edges fuel consumption is also high, because these edges are mainly associated to traffic lights and bus stops presence, associated to acceleration and deceleration conditions, which result in higher output engine power of vehicles and consequently higher fuel consumption.

Figure 21 represents same results than**Figure 20** but, instead of representing results per average edge speed, results are represented per edge. Edges, where traffic lights and bus stops are located, are represented through yellow lines. This way, Figure 21presents the influence of acceleration conditions over fuel consumption.

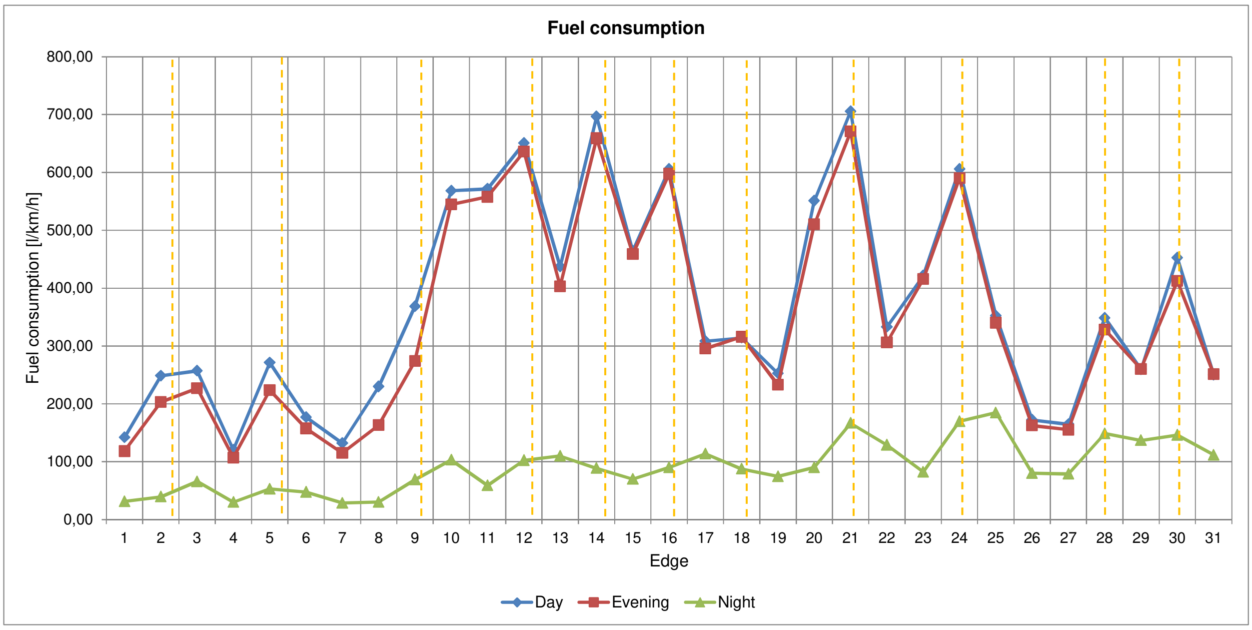

Figure 21– Fuel consumption base line under different periods and speed influence over results (HBEFA (Sumo))

5.1.1.3 PHEMLight-HBEFA comparison results

This section aims to compare simulations results analyzed at sections 5.1.1.1 and 5.1.1.2, associated to the implementation of both energy consumption and emission models (PHEMLight and HBEFA). Comparison has been performed by representing both models results at the same graph. Thus, following results are based on conclusions obtained from previous analyses.

Qualitative evolution of fuel consumption has already been tested and next graphs reflect that both models follow same evolution. However, quantitative results associated to fuel consumption are not so clear.

Despite results have been analyzed for the same scenario and traffic configuration, results obtained by each method are different each other. Detected reasons are the following:

1. HBEFA do not allow establishing the same fleet of vehicles than PHEMLight.
2. The definition of the fleet, strongly determine the proportion of vehicles which consume a particular fuel typology. Due to both models do not include the same fleet of vehicles, fuel consumption obtained values are the result of summing different fuels (in liters); so, results could never be the same.
3. PHEMLight results are higher than HBEFA because the vehicles fleet which has been implemented in PHEMLight simulation, following the real simulation of the scenario, includes a fleet of vehicles which consume natural gas as fuel. This fact makes the fuel consumption increase significantly due to including vehicles which consume a very low density fuel.

Previous explanation describes reasons why quantitative results obtained by both models, as it is shown in tables and figures below, are so different. It has also been concluded from this explanation that, in order to obtain the absolute daily value of the fuel consumption, the appropriate model to be used is the PHEMLight model.

5.1.1.3.1 Day results:

Figure 22 represents the evolution of fuel consumption (fuel consumed by vehicles driving along the particular edge) per average edge speed obtained through both models (PHEMLight and HBEFA) at day period.

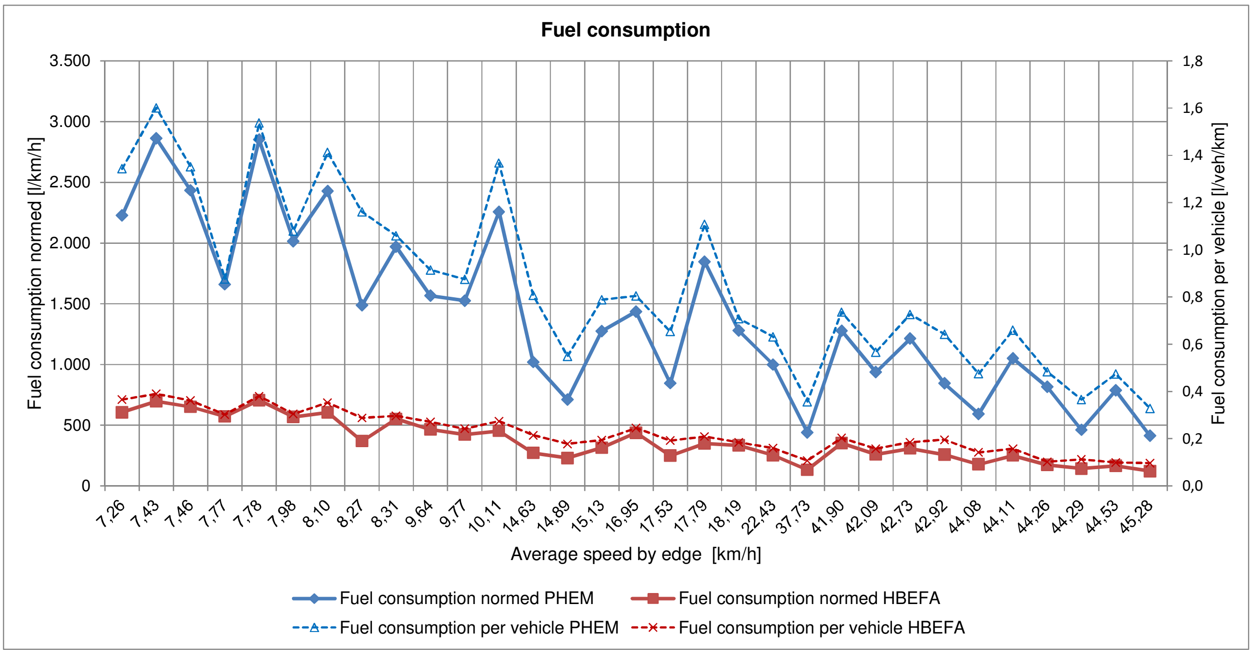

Figure 22 Speed influence over fuel consumption by edge – PHEMLight - HBEFA models comparison

From Figure 22 it is observed that fuel consumption results obtained through both models follow same evolution with average edge speed. It is also observed the difference between absolute values, result of the fleet characterization implemented at both simulations.

5.1.1.3.2 Evening results:

Figure 23 represents the evolution of fuel consumption (fuel consumed by vehicles driving along the particular edge) per average edge speed obtained through both models (PHEMLight and HBEFA) at evening period.

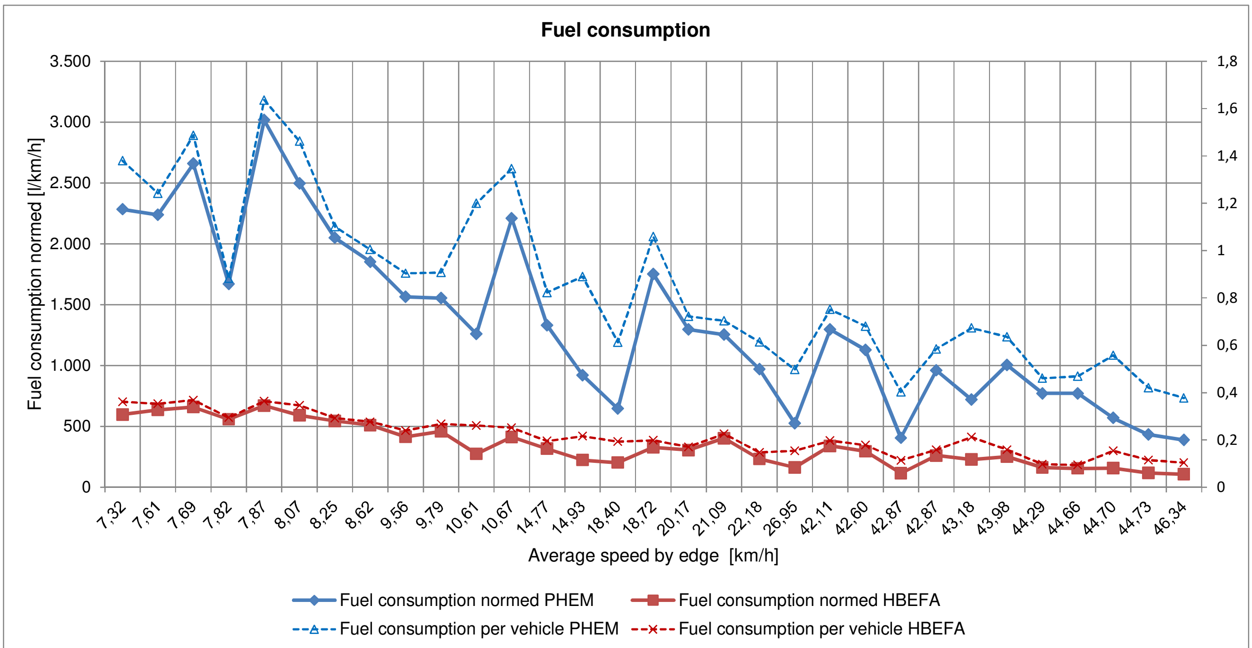

Figure 23 Speed influence over fuel consumption by edge – PHEMLight - HBEFA models comparison

Figure 23 follow same evolution than Figure 22, concluding same results for both periods.

5.1.1.3.3 Night results:

Figure 24 represents the evolution of fuel consumption (fuel consumed by vehicles driving along the particular edge) per average edge speed obtained through both models (PHEMLight and HBEFA) at night period.

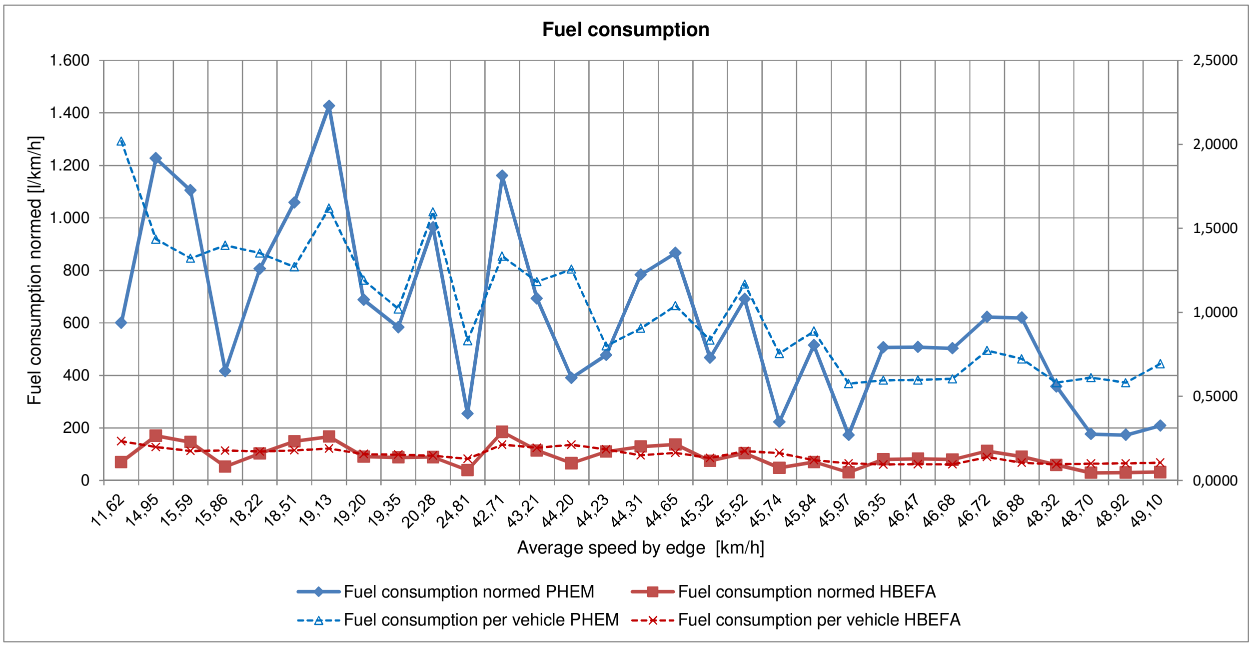

Figure 24 Speed influence over fuel consumption by edge – PHEMLight - HBEFA models comparison

From Figure 24 it is also observed (idem than conclusions obtained from Figure 23 and Figure 22) that fuel consumption results obtained through both models follow same evolution with average edge speed. It is also observed the difference between absolute values, result of the fleet characterization implemented at both simulations. However the evolution of fuel consumption presented at Figure 24 is different than presented at Figure 23 and Figure 22; the speed influence over fuel consumption is not so high. As it has been explained at previous sections, this is mainly because represented results are the totalized fuel consumption, including all types of vehicles and the overall hour of simulation; so, if there is no buses, the period of time in which vehicles are under deceleration and acceleration conditions is too low to have significantly effects over fuel consumption.

In order to observe differences among results obtained for different periods, different graphs have been included below comparing results.

5.1.1.3.4 Day, evening and night results:

Figure 25 represents fuel consumption by vehicles driving along the edges, per average edge speed, obtained through both models (PHEMLight and HBEFA) for three simulated periods.

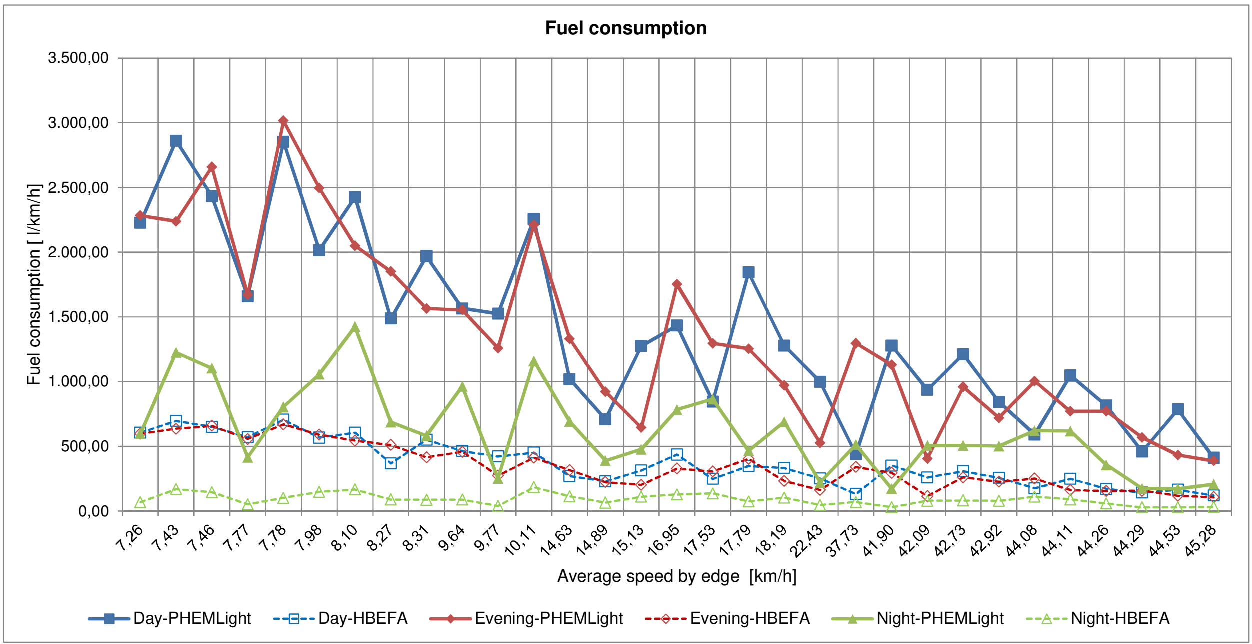

Figure 25 Speed influence over fuel consumption by edge (day, evening and night) – (PHEMLight - HBEFA models comparison)

Figure 26 represents same values than Figure 25 but including a secondary Y-axis for changing the scale of HBEFA fuel consumption values.

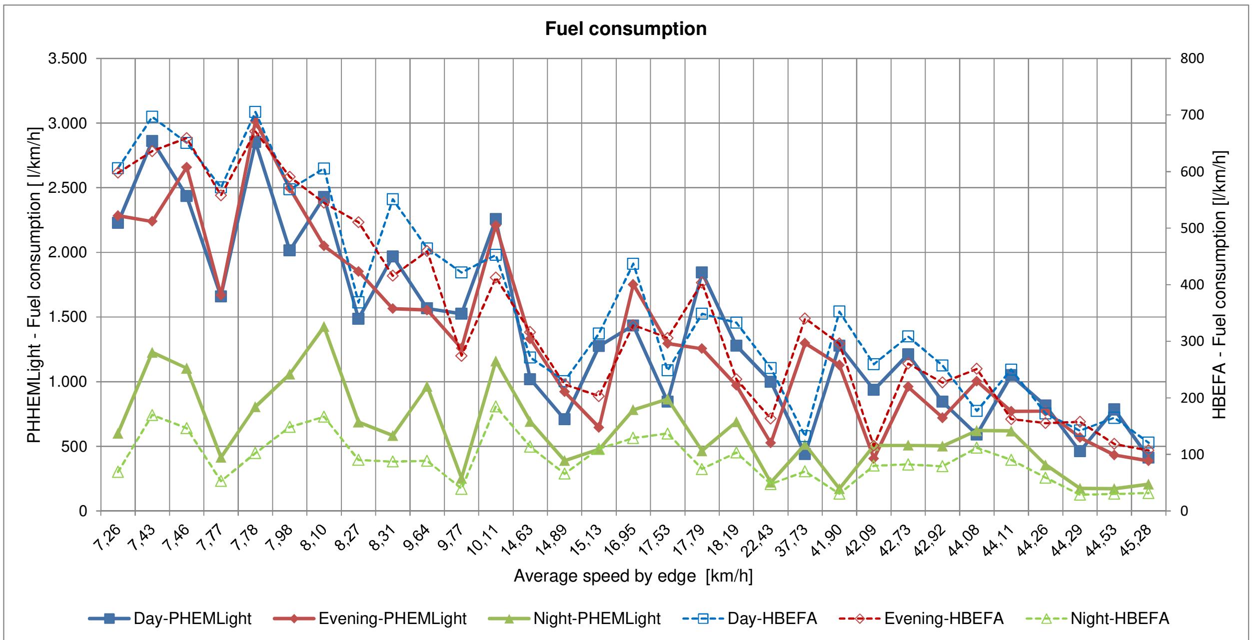

Figure 26 Speed influence over fuel consumption by edge (day, evening and night) – (PHEMLight - HBEFA models comparison)

From Figure 26 it results easier to compare speed influence over fuel consumption obtained through both models. As it was concluded from analyses performed for each model results, day and evening results follow same evolution since speed influence over fuel consumption at night is not so high.

From Figure 25 it is observed differences between results obtained through both models. One of explained reasons for this difference is the CNG (low density fuel) fleet of passenger cars which is characterized in PHEMLight model. Due this fuel is not possible to be defined within HBEFA simulation, obtained results are much lower (in terms of liters consumed by vehicles).

To verify that this reason could explain differences between results obtained from both models, it has resulted interesting to represent both model results but excluding CNG fleet of vehicles (**Figure 27**).

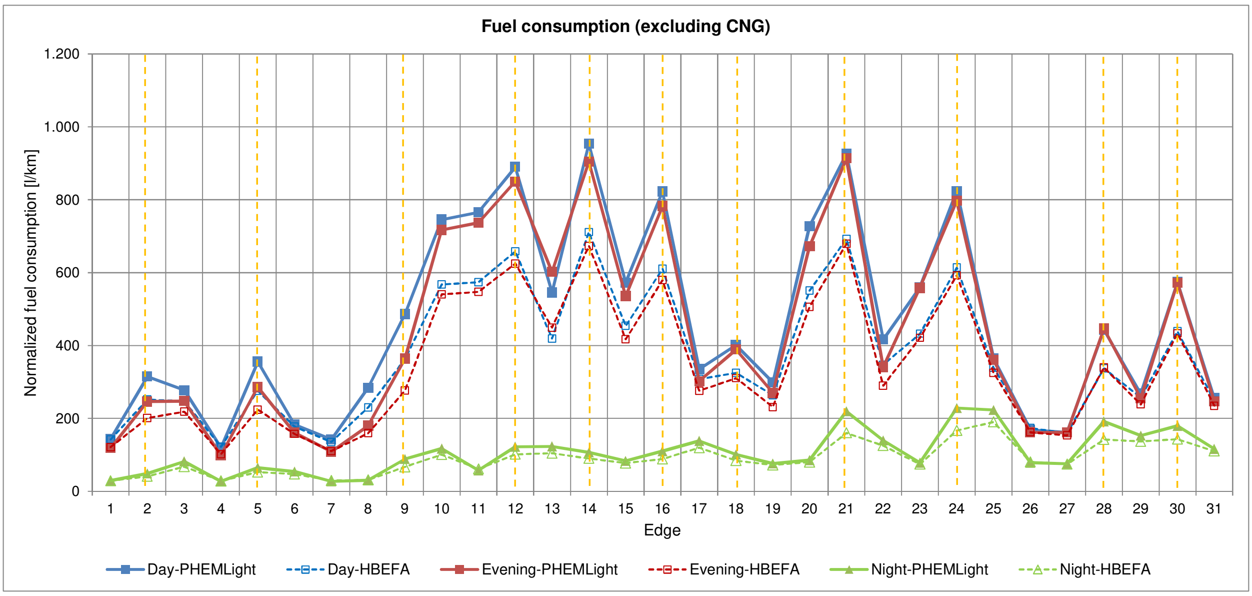

Figure 27 Fuel consumption by edge (day, evening and night) – (PHEMLight - HBEFA models comparison)

As it was expected, obtained results are very similar for both models once CNG fleet has been excluded from the simulation.

5.1.1.4 Daily fuel consumption

From previous fuel consumption analyses the following conclusions have been extracted:

1. Both models, PHEMLight and HBEFA, follow the expected behaviour along the road.
2. Both models are sensitive to operating points variations (speed and acceleration conditions).
3. PHEMLight model is sensitive to fleet composition (it takes into account fuel consumed by each category of vehicles composing the fleet) while HBEFA model just takes into account different typologies of vehicles.

From previous conclusions, it has been decided to obtain daily absolute fuel consumption values from PHEMLight simulations, due obtained results are more accurate to the traffic configuration and scenario definition.

Values, included within **Table 29**, have been obtained for the three analysis periods and accumulate daily values have been obtained considering the duration of each period.

Table 29 Daily fuel consumption – PHEMLight simulation

Fleet	Fuel	Day [l/h]	Evening [l/h]	Night [l/h]	Daily [l/day]
Passenger cars	Gasoline	977,03	729,79	200,25	**16.245,57**
	Diesel	41,62	33,70	12,85	**737,09**
	CNG	4.449,10	4.127,65	2.164,77	**87.217,92**
	Hybrid (G)	4,24	3,36	1,45	**75,85**
Motos	Gasoline	260,89	211,08	62,71	**4.476,65**
	Diesel	0	0	0	**0**
	CNG	0	0	0	**0**
	Hybrid (G)	0	0	0	**0**
Trucks	Gasoline	0	0	0	**0**
	Diesel	809,84	662,66	222,98	**14.152,59**
	CNG	0	0	0	**0**
	Hybrid (G)	0	0	0	**0**
Buses	Gasoline	0	0	0	**0**
	Diesel	150,54	150,54	0	**2.408,70**
	CNG	0	0	0	**0**
	Hybrid (G)	0	0	0	**0**
Total fleet	Gasoline	1.237,92	940,86	262,97	**20.722,22**
	Diesel	1.002,01	846,90	235,84	**17.298,38**
	CNG	4.449,10	4.127,65	2.164,77	**87.217,92**
	Hybrid (G)	4,24	3,36	1,45	**75,85**

From Table 29 it is observed that the highest fuel consumption is associated to compressed natural gas consumption (87.217,92 l/day). As has been explained before, this value is result of the low associated fuel density since values are given in litters (not mass flow). Apart from natural gas, next highest fuel consumption is associated to gasoline consumption (20.722,22 l/day) mainly due to passenger cars consumption (16.245,57 l/day).

In order to realize a deeper analysis of included results within Table 29, it result interesting to have into account the fleet of vehicles defined for the analysed scenario (**Table 30**) in order to determine the origin of these results.

Table 30 Fleet of vehicles driving along the road per period

Fleet	Fuel	Day [l/h/veh]	Evening [veh/h]	Night [veh/h]	Daily [veh/day]
Passenger cars	Gasoline	2290,881	1845,250	537,379	**39170,608**
	Diesel	128,957	103,872	30,250	**2204,968**
	CNG	13,214	10,643	3,100	**225,936**
	Hybrid (G)	13,948	11,235	4,840	**251,034**
Motos	Gasoline	648,000	522,000	152,000	**11080,000**
	Diesel				**0**
	CNG				**0**
	Hybrid (G)				**0**
Trucks	Gasoline				**0**
	Diesel	463,000	373,000	109,000	**7920,000**
	CNG				**0**
	Hybrid (G)				**0**
Buses	Gasoline				**0**
	Diesel	33,161	33,161		**530,571**
	CNG				**0**
	Hybrid (G)				**0**
Total fleet	Gasoline	2938,881	2367,250	689,379	**50250,608**
	Diesel	625,118	510,032	139,250	**10655,539**
	CNG	13,214	10,643	3,100	**225,936**
	Hybrid (G)	13,948	11,235	4,840	**251,034**

From Table 30 it is observed that cars which consume CNG represents a very low flow comparing with other vehicles categories. Gasoline cars represent the most of the vehicles fleet followed by diesel cars and hybrid cars which also represent a very low flow of the total vehicles flow driving along the road. Apart from CNG cars, from Table 29 and Table 30 can be concluded that gasoline fleet (most of the total vehicles fleet) is responsible for most of fuel consumption by the total fleet of vehicles.

From Table 29 and Table 30, it has been obtained the unitary fuel consumption per category of vehicle and per period. Obtained results have been included within **Table 31**.

Table 31Unitary fuel consumption per vehicle category and period

Fleet	Fuel	Day [l/veh/h]	Evening [l/veh/h]	Night [l/veh/h]	Daily [l/veh/day]
Passenger cars	Gasoline	0,426	0,395	0,373	**0,415**
	Diesel	0,323	0,324	0,425	**0,334**
	CNG	336,701	387,813	698,403	**386,029**
	Hybrid (G)	0,304	0,300	0,299	**0,302**
Motos	Gasoline	0,403	0,404	0,413	**0,404**
	Diesel	0	0	0	**0**
	CNG	0	0	0	**0**
	Hybrid (G)	0	0	0	**0**
Trucks	Gasoline	0	0	0	**0**
	Diesel	1,749	1,777	2,046	**1,787**
	CNG	0	0	0	**0**
	Hybrid (G)	0	0	0	**0**
Buses	Gasoline	0	0	0	**0**
	Diesel	4,540	4,540		**4,540**
	CNG	0	0	0	**0**
	Hybrid (G)	0	0	0	**0**
Total fleet	Gasoline	0,421	0,397	0,381	**0,412**
	Diesel	1,603	1,660	1,694	**1,623**
	CNG	336,701	387,813	698,403	**386,029**
	Hybrid (G)	0,304	0,300	0,299	**0,302**

Regarding CNG passenger cars, Table 31 reflects the huge unitary associated fuel consumption, mainly due to the low density of this fuel, since values are given in litters. Otherwise, next most intensity fuel consumer are buses, which unitary consumption exceeds 4,540 l/veh/h, which is far from other vehicles consumption. Oriented actions for reducing fuel consumption would have to be aligned with replacing the buses fleet by another more efficient. Unitary diesel consumptions by trucks (1,787 l/veh/h) and buses are significantly different. Both vehicles are considered as heavy cars at the simulation, however, the driving cycle of busses include more acceleration periods than trucks, mainly due to bus stops.

Regarding passenger cars, as it was expected, unitary consumption of diesel cars (0,334 l/veh/h) is lower than gasoline (0,415 l/veh/h). Nevertheless, regarding GHG emissions, it is not contemplated to replace gasoline cars by diesel because of the negative effects of associated diesel emissions, mainly NO_x.

Hybrid cars also consume gasoline but associated consumption (0,302 l/veh/h) is lower than pure gasoline cars (0,415 l/veh/h), resulting in the less intensive consumer of the fleet, as it is extracted from total fleet consumption cells.

Figure 28 shows fuel consumption values of a day simulation, distinguishing different fuels consumption by the fleet. Represented numeric results are all included within Table 29.

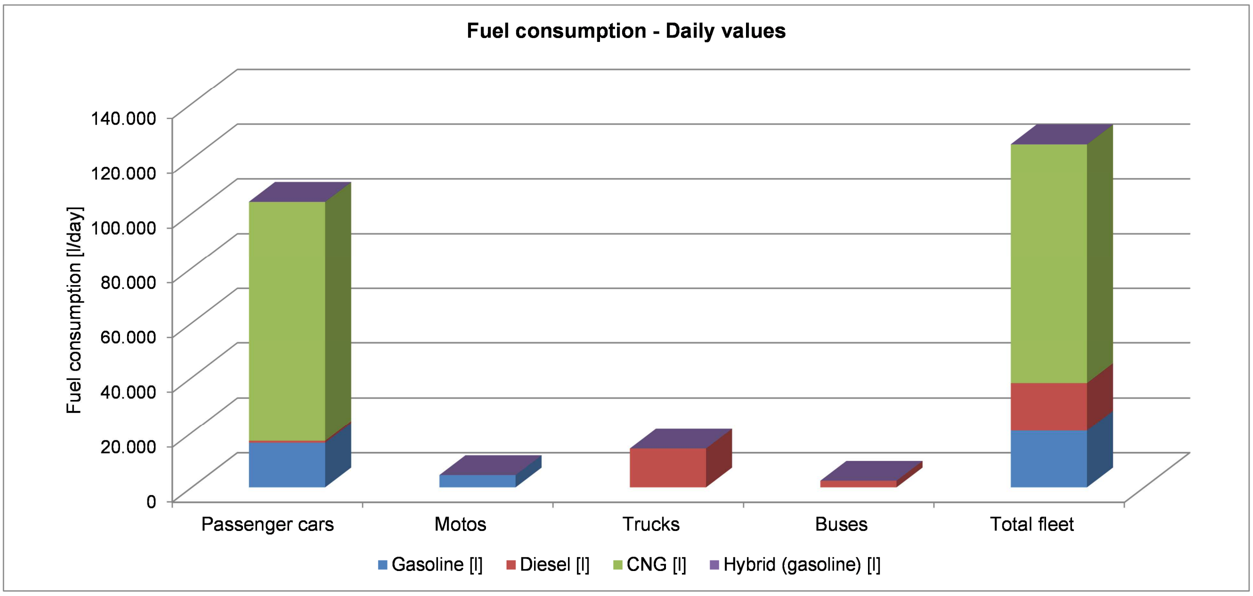

Figure 28 Daily fuel consumption by vehicle typology and type of fuel

Figure 28 shows the huge volumetric fuel consumption associated to passenger CNG passenger cars, followed by diesel cars. CNG values, as it was previously expressed are the result of the low fuel density. It is also shown that gasoline is the next most consumed fuel, followed by diesel and gasoline consumed by hybrid cars. This is due a bigger fleet of gasoline cars (Table 30) and a higher unitary fuel consumption (Table 31).

From Table 31 it was also extracted that buses unitary diesel consumption is higher than trucks, but not the fleet (Table 30), which is much bigger in the trucks case; so the highest absolute fuel consumption associated to trucks fleet.

Figure 29 shows same values that Figure 28 but excluding CNG consumption which hides the importance of other fuel consumptions.

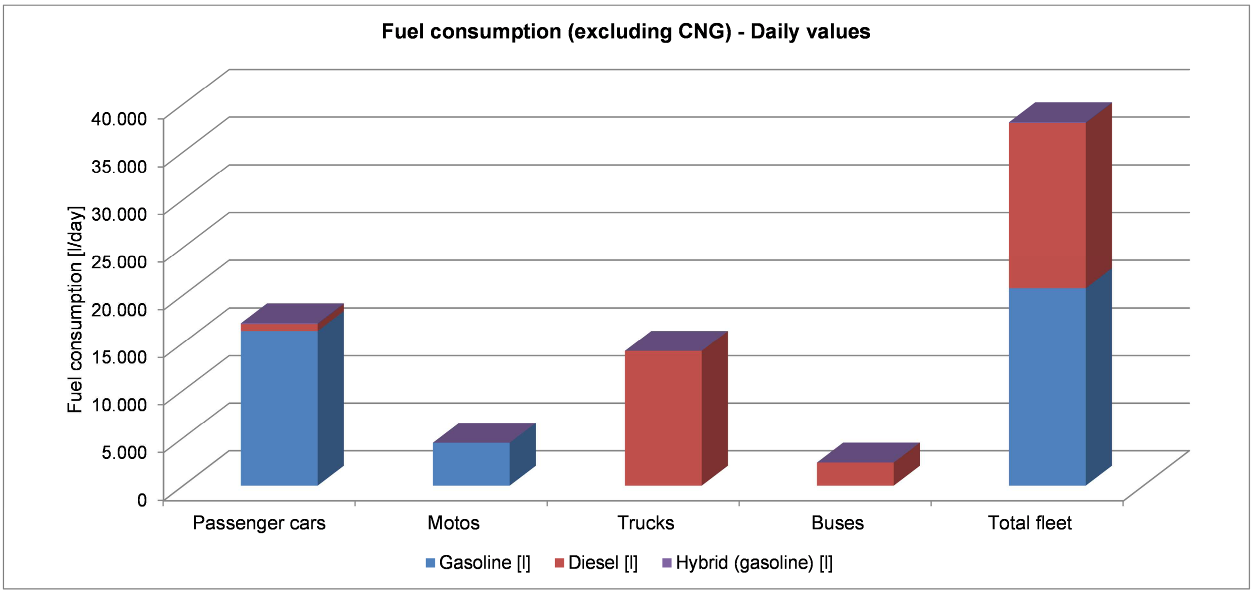

Figure 29 Daily fuel consumption by vehicle typology and type of fuel (excluding CNG)

From Figure 28 and Figure 29 it is possible to establish the following results:

1. Most fuel consumption is associated to passenger cars, which mainly consume gasoline. Unitary fuel consumption associated to gasoline cars (which is higher than diesel and hybrid) and the huge of gasoline cars fleet are the causes.
2. Fuel consumption associated to trucks (7.920 l/day) represents an important proportion of the total

diesel consumption (10.655 l/day); nevertheless, unitary diesel consumption of trucks is smaller than busses, but not the fleet.

3. Consumption associated to hybrid cars (75,85 l/day) represents a few part of the total consumption in the road (20.722,22 l/day), but also the fleet and the unitary consumption which is the lowest of the fleet.

From previous results, the following conclusions are drawn:

1. Due to the high diesel consumption, concluded from graphs (10.655 l/day), and detecting the main consumer, trucks (7920 l/day); it would be interesting to limit the number of trucks driving along this road (which is located in an urban area) or establish politic strategies in order to dismiss the fleet of trucks which consume diesel and replace it by other category of vehicles, since diesel combustion is source of high air pollutants emissions, including NO_x, one of the most critical emissions which is strongly limited by legislation. These emissions have seriously consequences over environment and population health [10].
2. Gasoline consumption associated to passenger cars (16.245,57 l/day) represents a high proportion of the total daily consumption (20.722,22 l/day). This way, actions to impulse replacements of gasoline cars (unitary gasoline consumption 0,415 l/veh/h) by hybrid cars (unitary gasoline consumption 0,302 l/veh/h) would be an interesting strategy for this scenario in order to reduce fuel consumption and associated air pollution.

Actions plans:

From previous conclusions, two different actions plans have been proposed:

1. Limit the number of trucks driving along the road.
2. Replace the fleet of pure gasoline cars by hybrid cars.

The second action plan, which consists on replacing gasoline passenger cars fleet by hybrid fleet, results to be the most interesting since gasoline cars (39.170,608 veh/day) represent the most of the total fleet (61.383,12 veh/day) and its unitary gasoline consumption (0,415 l/veh/h) is higher than hybrids (0,302 l/veh/h). By other hand, this strategy it is aligned to actions plans which are currently been implemented in European countries. The increasing development of hybrid and electric passenger cars is also helping to increase the real fleet of passenger driving along city roads, so the interest in evaluating results associated to the increase of this passenger cars fleet.

The action plan (2) is implemented in the reference scenario in order to obtain results evolution.

Figure 30 compares fuel consumption associated to the reference scenario and to the improved scenario by implementing the action plan, which consists on replacing the gasoline passenger cars by hybrid passenger cars.

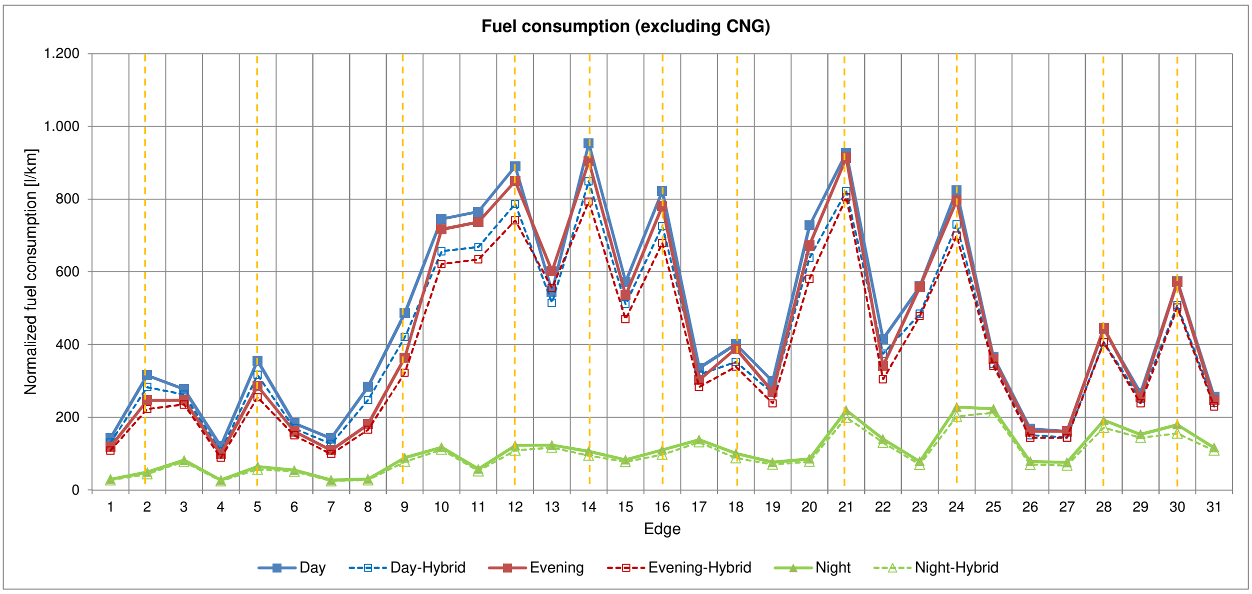

Figure 30 Fuel consumption by edge (day, evening and night) – (Gasoline passenger cars replacement by hybrid cars)

Expected results have been obtained from simulating the road traffic once the action plan has been implemented. Figure 30 shows how the fuel consumption is reduced (at the three periods) when implementing the named action. This reduction it is better observed at day and evening graphs than night due to less absolute values achieved for that periods. Figure 30 also reflects that at those edges where traffic lights are located (yellow vertical lines), differences between fuel consumptions, before and after implementing the action plan, are higher. This is mainly because vehicles are under acceleration conditions along these edges and under these conditions hybrid cars highly reduce their consumption (the battery starts working).

Table 32 shows absolute gasoline consumption by fleet of vehicles, associated to the real simulation and to the simulation once the action plan has been implemented.

Table 32 Gasoline consumption – Before and after action plan implementation

Fleet	Fuel	Day [l/h]	Evening [l/h]	Night [l/h]	Daily [l/day]
Passenger cars	Gasoline	977,03	729,79	200,25	**16.245,57**
Passenger cars*	Gasoline	689,76	530,68	151,67	**11.613,21**
Motos	Gasoline	260,89	211,08	62,71	**4.476,65**
Trucks	Gasoline	0	0	0	**0**
Buses	Gasoline	0	0	0	**0**
Total fleet	Gasoline	1.237,92	940,86	262,97	**20.722,22**
Total fleet*	Gasoline	950,65	741,75	214,38	**16.089,86**

The action plan results in fuel savings of 4.632 litters/day, which supposes a 22,4% of total gasoline consumption savings.

5.1.2 Emissions

CO_2 emissions are one of most significant emissions associated directly to traffic. These traffic emissions, classified as greenhouse gases, are progressively increasing in levels of concentration in the earth atmosphere, which has been proved to leads into health problems as well as environmental problems. So, it is fundamental to realize an accurate prediction of these emissions in order to establish politics strategies destined to decrease the level of these critical emissions.

Sumo is presented as useful tool for the prediction of CO_2 emissions thanks to it accurate simulation of traffic, characterized by an established fleet of vehicles and characteristics of the road traffic, such as bus lines, traffic lights, etc. After simulation, the user obtains emissions results characterized by edge in which the traffic line is divided in the scenarios generation.

CO2 emissions are directly related to fuel consumption and it depends strongly on vehicles fleet and particular characteristics of each fuel. This way, as it was explained in the fuel consumption analysis, PHEMLight offers the user the possibility to establish the complete fleet (broken down by vehicle typology and European emission class) already defined in 4.3.2, while HBEFA just distinguish by vehicle typology (motorbike, car, truck, bus).

Sumo results have been obtained for day, evening and night period and have been analyzed along this section as tables and graphs.

Tables below show fuel consumption by edge in which the road is divided, identifying the length of the edge, average speed over the edge, number of vehicles along the edge and average speed of vehicles driving along the edge. By other hand, fuel consumption values are given as absolute values, as normed values per km and as liters per vehicle per km. Since edges lengths are different, in order to compare results under different operating points, resuming in different edges conditions, it seems to be more representative to compare fuel consumption in liters per vehicle and per km length of the edge. So, fuel consumption in liters per vehicle km is included within graphs.

Black rows in tables are associated to edges where traffic lights and bus stops are located.

5.1.2.1 PHEMLight results

PHEMLight results are obtained for day, evening and night period and are included in this section within tables and graphs.

Tables below show CO_2 emissions by edge in which the road is divided, identifying the length of the edge, average speed over the edge, number of vehicles along the edge and average speed of vehicles driving along the edge. By other hand, CO_2 emission values are given as absolute values, as normed values per km and as grams per vehicle per km. Since edge lengths are different, in order to compare results under different operating points, resuming in different edges conditions, it seems to be more representative to compare CO_2 emissions in grams per vehicle and per km length of the edge. So, these values per vehicle and per km are included within represented graphs.

Black rows in tables are associated to edges where traffic lights and bus stops are located.

5.1.2.1.1 Day results:

Table 33 CO_2 emissions by edge – Base Line of day results – PHEMLight (Sumo)

Edge	Length	Speed		vehicles		CO2 abs	CO2 normed	CO2 per Veh		
	m	m/s	km/h	nº	veh/m	mg	g/km/h	mg/veh	g/h/veh	g/veh/km
1	721,97	12,3	44,29	1.261,37	1,75	254.416.226,53	352.391,69	201.712,07	12.374,08	279,37
2	**158,73**	**4,87**	**17,5**	**1.294,5**	**8,16**	**123.980.630,6**	**781.078,75**	**95.781,38**	**10.576,2**	**603,37**
3	98,83	11,9	42,9	1.313,4	13,29	70.561.991,36	713.973,40	53.695,42	23.329,5	543,59
4	280,86	12,5	45,2	1.254,3	4,47	83.835.502,12	298.495,70	66.828,40	10.775,4	237,98
5	**156,57**	**4,06**	**14,6**	**1.262,3**	**8,06**	**135.885.824,9**	**867.891,84**	**107.637,5**	**10.057,9**	**687,54**
6	256,88	12,2	44,08	1.245,28	4,85	117.424.981,82	457.119,99	94.315,02	16.180,43	367,08
7	**253,63**	**10,4**	**37,7**	**1.230,9**	**4,85**	**88.318.265,43**	**348.216,95**	**71.752,06**	**10.673,5**	**282,89**
8	70,75	4,14	14,89	1.290,3	18,24	50.170.898,18	709.129,30	38.877,33	8.180,90	549,57
9	**79,90**	**2,30**	**8,27**	**1.280,4**	**16,03**	**97.390.833,04**	**1.218.909,0**	**76.052,31**	**7.875,31**	**951,97**
10	135,54	2,22	7,98	1.865,4	13,76	249.661.102,0	1.841.973,6	133.845,0	7.875,27	987,43
11	84,43	2,16	7,77	1.891,0	22,40	159.827.409,2	1.893.016,8	84.521,14	7.775,83	1.001,05
12	**183,31**	**2,07**	**7,46**	**1.800,9**	**9,82**	**399.298.686,6**	**2.178.270,0**	**221.719,2**	**9.023,87**	**1.209,49**
13	141,53	4,71	16,9	1.782,1	12,59	204.233.596,3	1.443.041,0	114.590,5	13.724,5	809,72
14	**98,60**	**2,06**	**7,43**	**1.786,6**	**18,12**	**227.957.109,5**	**2.311.938,2**	**127.579,2**	**9.615,17**	**1.294,00**
15	185,89	2,68	9,64	1.711,6	9,21	273.226.850,1	1.469.830,8	159.630,2	8.281,39	858,70
16	**192,76**	**2,02**	**7,26**	**1.658,2**	**8,60**	**390.092.370,6**	**2.023.720,5**	**235.232,5**	**8.865,02**	**1.220,39**
17	117,04	11,8	42,7	1.668,3	14,25	96.262.340,91	822.473,86	57.718,65	21.066,6	492,99
18	**224,94**	**4,20**	**15,1**	**1.617,4**	**7,19**	**215.879.328,6**	**959.719,61**	**133.471,1**	**8.977,95**	**593,37**
19	305,31	6,23	22,4	1.580,3	5,18	211.899.598,5	694.047,36	134.078,9	9.851,36	439,19
20	281,01	2,31	8,31	1.857,7	6,61	509.351.488,7	1.812.574,2	274.182,0	8.108,91	975,66
21	**119,86**	**2,16**	**7,78**	**1.855,7**	**15,48**	**280.428.523,1**	**2.339.633,9**	**151.119,0**	**9.810,90**	**1.260,76**
22	191,13	5,05	18,1	1.805,8	9,45	188.987.955,9	988.792,74	104.662,3	9.961,49	547,54
23	239,56	2,71	9,77	1.741,4	7,27	325.991.438,8	1.360.792,4	187.200,6	7.634,43	781,40
24	**143,26**	**2,25**	**8,10**	**1.717,9**	**11,99**	**290.122.850,6**	**2.025.149,0**	**168.882,3**	**9.547,23**	**1.178,83**
25	91,82	11,6	41,9	1.736,3	18,91	88.179.060,22	960.346,99	50.774,20	23.172,0	553,10
26	160,18	12,2	44,2	1.684,9	10,52	66.191.503,96	413.232,01	39.297,26	10.853,9	245,26
27	214,99	12,3	44,5	1.657,1	7,71	87.983.547,55	409.244,84	53.084,64	10.997,3	246,96
28	**168,42**	**4,94**	**17,7**	**1.664,3**	**9,88**	**189.008.953,3**	**1.122.247,6**	**113.578,3**	**11.992,5**	**674,28**
29	166,96	11,6	42,0	1.651,1	9,89	113.255.296,7	678.337,91	68.603,12	17.291,6	410,82
30	**122,56**	**2,81**	**10,1**	**1.650,1**	**13,46**	**180.178.657,7**	**1.470.126,1**	**109.194,1**	**9.003,21**	**890,90**
31	256,32	12,2	44,1	1.589,3	6,20	164.278.862,4	640.913,16	103.355,7	17.786,7	403,25

Included values within Table 33 (CO_2 emissions by vehicles driving along the particular edge per vehicle per km length of the edge) are represented at **Figure 31** , distinguishing CO_2 emissions by vehicles driving along different edges where traffic lights or bus stops are located and along those edges free of traffic lights or bus stops.

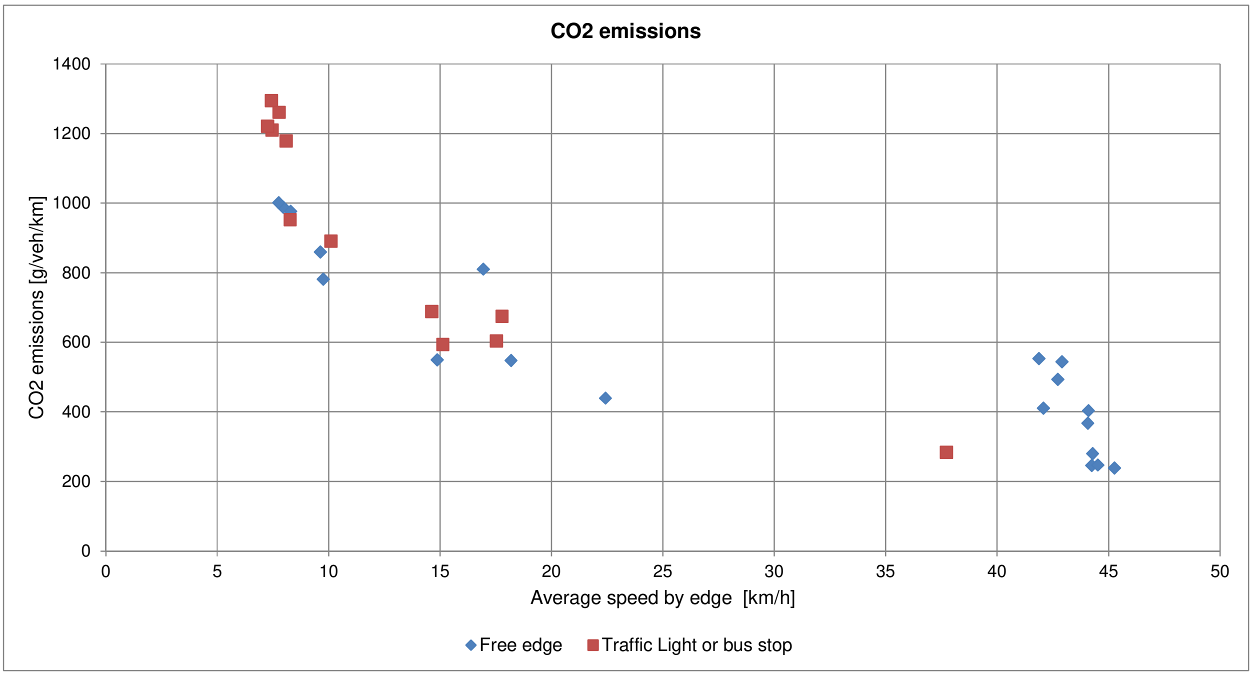

Figure 31 CO_2 emissions by edge – Base Line of day results – PHEMLight (Sumo)

The CO_2 emissions of vehicles driving along edges, where traffic lights or bus stops are located (represented by red dots within Figure 31), are in most cases associated to edges where the average speed of vehicles driving along is low. However, despite the average speed is lower, the unitary CO_2 emissions of vehicles driving along these edges is, in most cases, higher than in free edges (edges free of traffic lights and bus stops (green dots)). This is explained as vehicles are under acceleration and deceleration conditions along these edges, this results in an increase of the output engine power of vehicles and consequently on higher fuel consumption and CO_2 emissions.

5.1.2.1.2 Evening results:

Table of results included in Annex 1.

Figure 32 includes CO_2 emissions (CO_2 emissions of vehicles driving along the particular edge per vehicle per km length of the edge) results obtained for evening simulation. CO_2 emissions at different edges is represented per average speed of vehicles driving along the edge, distinguishing free edges and edges where traffic lights or bus stops are located in.

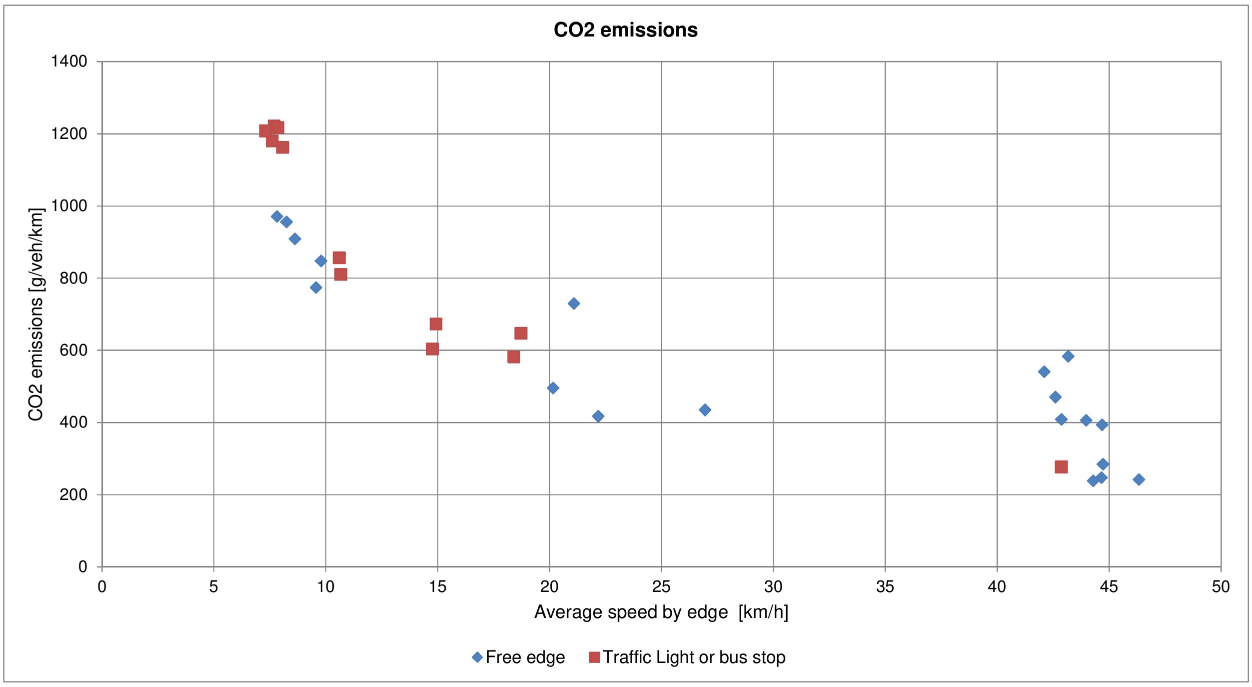

Figure 32 CO_2 emissions by edge – Base Line of evening results – PHEMLight (Sumo)

As it is concluded from Figure 32, evening results are closed to day results, quantitatively and qualitatively. Same observations have been realized for both simulations; most traffic-light edges are associated to a lower average speed and higher CO_2 emissions, which is again result of deceleration and acceleration conditions within the edge.

5.1.2.1.3 Night results:

Table of results included in Annex 1.

Figure 33 includes CO_2 emissions (CO_2 emissions of vehicles driving along the particular edge per vehicle per km length of the edge) results obtained from night simulation. CO_2 emissions at different edges is represented per average speed of vehicles driving along the edge, distinguishing free edges and edges where traffic lights or bus stops are located in.

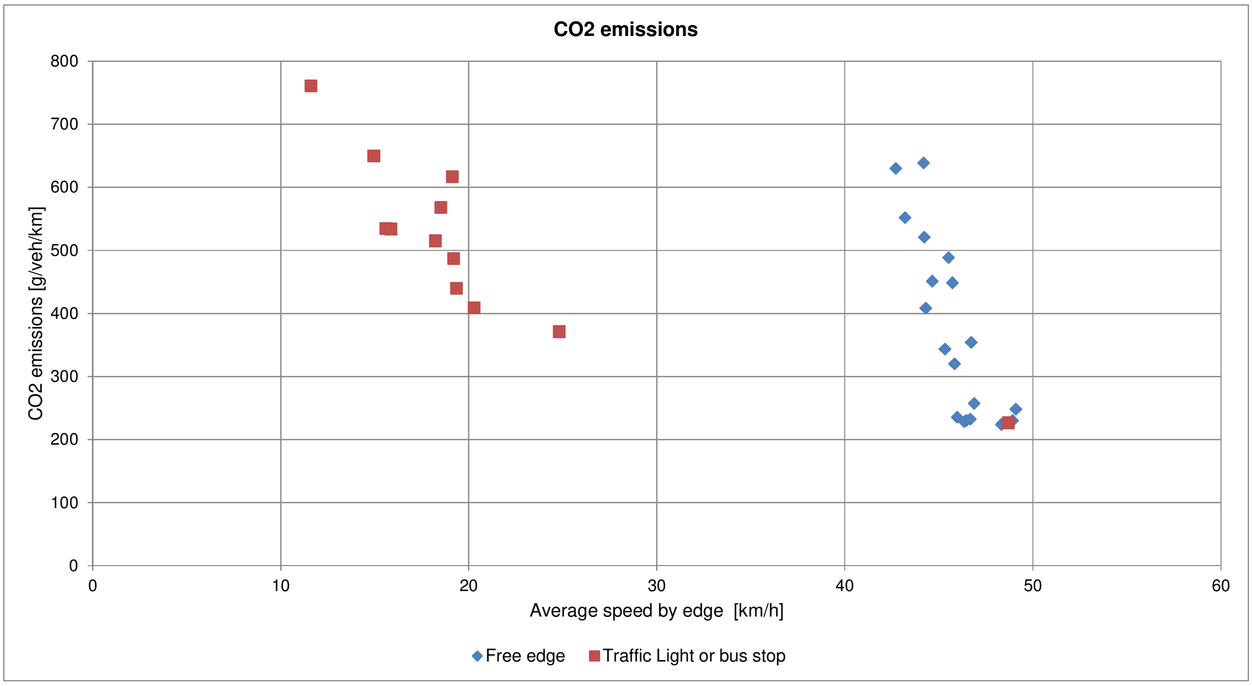

Figure 33 CO_2 emissions by edge – Base Line of night results – PHEMLight (Sumo)

Figure 33 presents differences in comparison to day and evening graphs (Figure 31 and Figure 32). To start with, there exist two operating condition clouds of points: one associated to traffic lights edges (characteristics operating points of these edges) and the other one associated to free edges. It seems to be one operating point, associated to traffic light or bus stop edge, within the operating condition cloud associated to free edge. Actually, this edge is a free edge under night operating conditions because it is associated to a bus stop and in the analysis road there are no bus lines operating during night. This fact, the absence of buses during night, is also the reason for the existence of these two completely separate clouds of operating points.

5.1.2.1.4 Day, evening and night results:

Once CO_2 emissions results have been briefly analyzed for different periods, it results interesting to realize a comparison of these three results. For these purpose, **Figure 34** and **Figure 35** represent CO_2 emissions (normed per km length) per vehicles driving along the particular edge per average edge speed, in order to consider speed and acceleration and deceleration influence (related to traffic-light or bus stop presence) over CO_2 emissions.

Figure 34 represents the speed influence over CO_2 emissions (CO_2 emissions of vehicles driving along the particular edge per vehicle per km length of the edge) per period. CO_2 emissions at different edges is represented per average speed of vehicles driving along the edge, distinguishing free edges and edges where traffic lights or bus stops are located in.

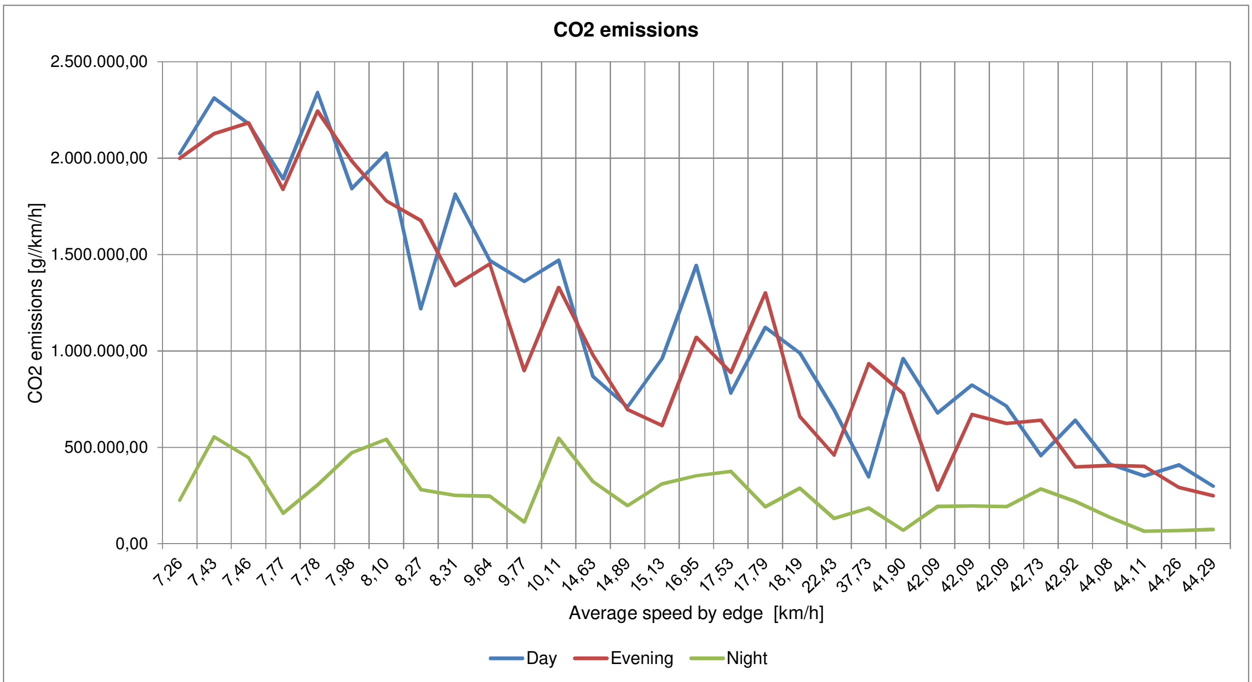

Figure 34– CO_2 emissions base line under different periods and speed influence over results (PHEMLight (Sumo))

From Figure 34 it is observed that absolute normed CO_2 emission values over day and evening periods are very similar each other, being considerably higher than night results. By other hand, speed influence over emissions is clear at day and evening cases; however, under night conditions the speed effect is not so significant, mainly because of the no presence of buses, which have important influence over low speed edge, being one of the reasons of higher values at low speeds. In fact, another observation to be mentioned is the high CO_2 emission values over low speed edges. It could be though that CO_2 emission should be lower as speed decreases; however, operating points are not just conditioned by speed but also by other factors such as acceleration and deceleration or idle conditions. This is why at low speed edges emission is also high, because these edges are mainly associated to traffic lights and bus stops presence, associated to acceleration and deceleration conditions, which result in higher output engine power of vehicles and consequently higher CO_2 emission.

Figure 35 represents same results than Figure 34 but, instead of representing results per average edge speed, results are represented per edge. Drawn yellow lines in graph below represent traffic lights or bus stops edges.

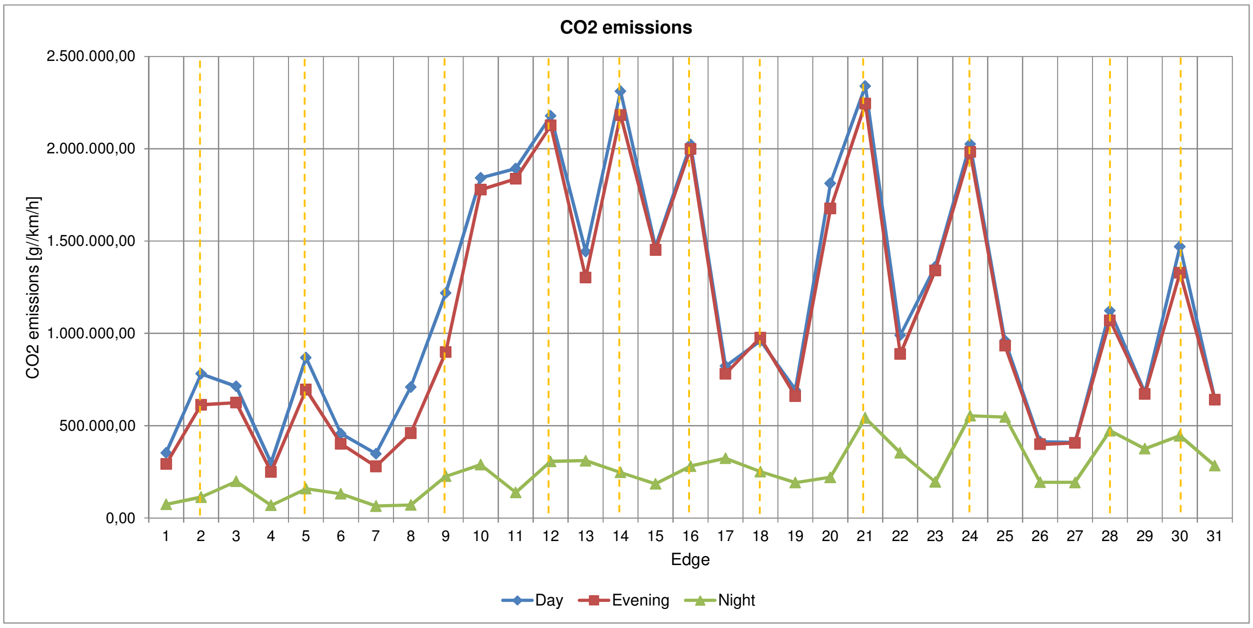

Figure 35– CO_2 emissions base line under different periods – Results by edge (PHEMLight (Sumo))

From Figure 35 same conclusions than obtained from Figure 34 have been concluded.

5.1.2.2 HBEFA results

HBEFA results are obtained for day, evening and night period and are included in this section within tables and graphs.

Tables below show CO_2 emissions by edge in which the road is divided, identifying the length of the edge, average speed over the edge, number of vehicles along the edge and average speed of vehicles driving along the edge. CO_2 values are given as absolute values, as normed values per km and as unitary values per vehicle and per kilometers.

Black rows within tables are associated to edges where traffic lights and bus stops are located.

5.1.2.2.1 Day results:

Table 34 CO_2 emissions by edge – Base Line of day results – HBEFA (Sumo)

Edge	Length	Speed		Vehicles		CO2 abs	CO2 normed		CO2perVeh	
	m	m/s	km/h	nº	veh/m	mg	g/km/h	mg/veh	g/h/veh	g/veh/km
1	721,97	12,3	44,2	1.261,3	1,75	255.841.730,3	354.366,15	202.842,2	12.443,4	280,94
2	**158,73**	**4,87**	**17,53**	**1.294,52**	**8,16**	**98.521.313,86**	**620.684,90**	**76.112,75**	**8.404,40**	**479,47**
3	98,83	11,9	42,9	1.313,4	13,29	63.341.003,14	640.908,66	48.200,48	20.942,1	487,96
4	280,86	12,58	45,28	1.254,31	4,47	84.575.721,64	301.131,25	67.418,45	10.870,64	240,08
5	**156,57**	**4,06**	**14,63**	**1.262,32**	**8,06**	**106.030.659,00**	**677.209,29**	**83.988,76**	**7.848,15**	**536,48**
6	256,88	12,24	44,08	1.245,28	4,85	113.244.711,65	440.846,74	90.957,45	15.604,42	354,01
7	**253,63**	**10,48**	**37,73**	**1.230,91**	**4,85**	**83.546.654,11**	**329.403,68**	**67.875,48**	**10.096,93**	**267,61**
8	70,75	4,14	14,89	1.290,34	18,24	40.666.633,37	574.793,40	31.512,50	6.631,13	445,46
9	**79,90**	**2,30**	**8,27**	**1.280,41**	**16,03**	**73.454.318,46**	**919.328,14**	**57.360,33**	**5.939,73**	**718,00**
10	135,54	2,22	7,98	1.865,43	13,76	191.690.850,74	1.414.275,13	102.766,80	6.046,66	758,15
11	84,43	2,16	7,77	1.891,02	22,40	120.160.664,35	1.423.198,68	63.544,27	5.845,99	752,61
12	**183,31**	**2,07**	**7,46**	**1.800,98**	**9,82**	**297.156.715,14**	**1.621.061,13**	**165.002,73**	**6.715,53**	**900,10**
13	141,53	4,71	16,95	1.782,15	12,59	154.045.212,25	1.088.427,98	86.431,06	10.351,87	610,74
14	**98,60**	**2,06**	**7,43**	**1.786,67**	**18,12**	**171.172.275,91**	**1.736.027,14**	**95.798,82**	**7.220,00**	**971,66**
15	185,89	2,68	9,64	1.711,69	9,21	214.729.554,06	1.155.143,12	125.453,73	6.508,36	674,85
16	**192,76**	**2,02**	**7,26**	**1.658,25**	**8,60**	**291.110.640,98**	**1.510.223,29**	**175.544,81**	**6.615,62**	**910,73**
17	117,04	11,87	42,73	1.668,35	14,25	89.957.566,99	768.605,32	53.938,33	19.686,88	460,70
18	**224,94**	**4,20**	**15,13**	**1.617,41**	**7,19**	**176.150.332,78**	**783.099,19**	**108.908,03**	**7.325,70**	**484,17**
19	305,31	6,23	22,43	1.580,30	5,18	192.325.152,43	629.934,01	121.693,24	8.941,33	398,62
20	281,01	2,31	8,31	1.857,78	6,61	385.695.643,86	1.372.533,52	207.618,54	6.140,30	738,80
21	**119,86**	**2,16**	**7,78**	**1.855,73**	**15,48**	**210.636.496,88**	**1.757.354,39**	**113.509,06**	**7.369,20**	**946,99**
22	191,13	5,05	18,19	1.805,89	9,45	158.443.965,99	828.985,33	87.746,97	8.351,53	459,05
23	239,56	2,71	9,77	1.741,48	7,27	251.419.720,03	1.049.506,26	144.377,82	5.888,03	602,65
24	**143,26**	**2,25**	**8,10**	**1.717,92**	**11,99**	**216.368.680,02**	**1.510.321,65**	**125.949,55**	**7.120,16**	**879,16**
25	91,82	11,64	41,90	1.736,30	18,91	80.688.538,99	878.768,67	46.461,10	21.203,69	506,11
26	160,18	12,29	44,26	1.684,90	10,52	68.900.885,71	430.146,62	40.905,80	11.298,22	255,30
27	214,99	12,37	44,53	1.657,16	7,71	88.409.427,55	411.225,77	53.341,60	11.050,61	248,15
28	**168,42**	**4,94**	**17,79**	**1.664,36**	**9,88**	**146.347.778,85**	**868.945,37**	**87.942,57**	**9.285,70**	**522,09**
29	166,96	11,69	42,09	1.651,19	9,89	108.055.279,78	647.192,62	65.453,27	16.497,72	391,96
30	**122,56**	**2,81**	**10,11**	**1.650,15**	**13,46**	**138.308.779,10**	**1.128.498,52**	**83.819,61**	**6.911,05**	**683,87**
31	256,32	12,25	44,11	1.615,60	6,30	159.724.496,18	623.144,88	100.490,42	17.293,62	392,07

Included values within Table 34 (CO_2 emission of vehicles driving along the particular edge per vehicle per km length of the edge) are represented at **Figure 36**, distinguishing CO_2 emission of vehicles driving along different edges where traffic lights or bus stops are located and along those edges free of traffic lights or bus stops.

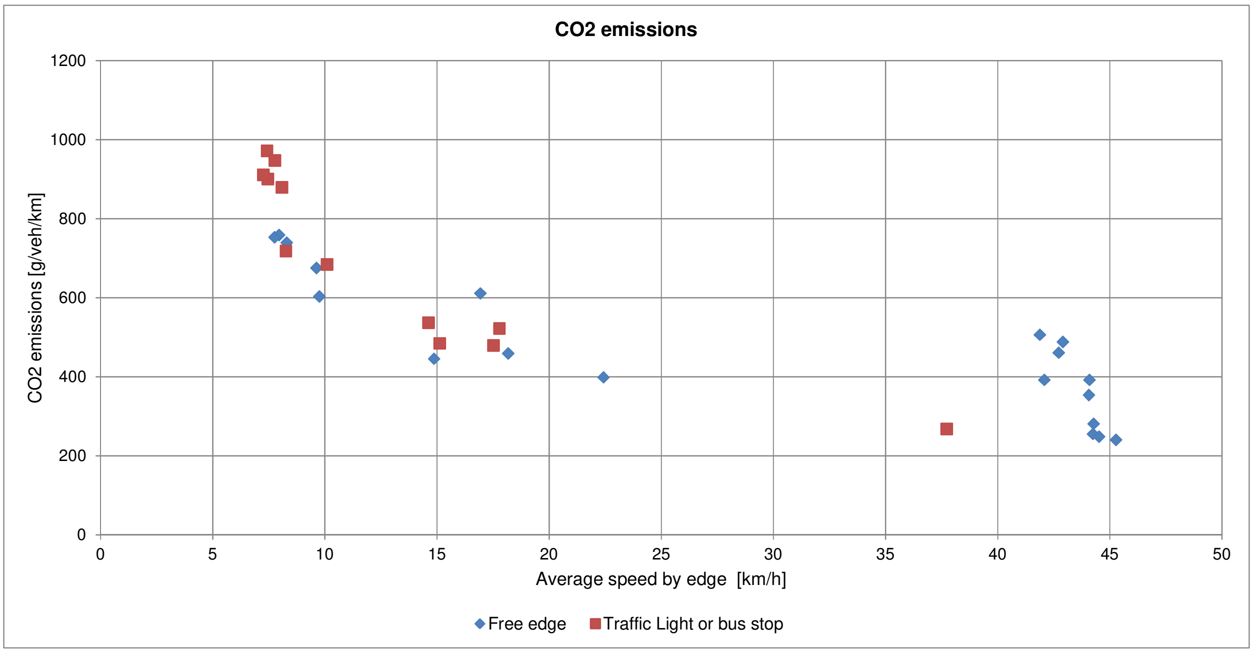

Figure 36 CO_2 emissions by edge – Base Line of day results – HBEFA (Sumo)

From Figure 36 same conclusions than in the PHEMLight simulation have been obtained; CO_2 emissions of vehicles driving along edges, where traffic lights or bus stops are located (represented by red dots), are in most cases associated to edges where the average speed of vehicles driving along is low. However, despite the average speed is lower, the unitary vehicles CO_2 emissions along these edges is, in most cases, higher than in free edges (edges free of traffic lights and bus stops (green dots)). This is explained as vehicles are under acceleration and deceleration conditions along these edges, this results in an increase of the output engine power of vehicles and consequently on higher fuel consumption and CO_2 emissions.

Once detected the speed influence over emissions, **Figure 37** has been included in order to represent fuel consumption evolution with speed, distinguishing between free edges and traffic light edges.

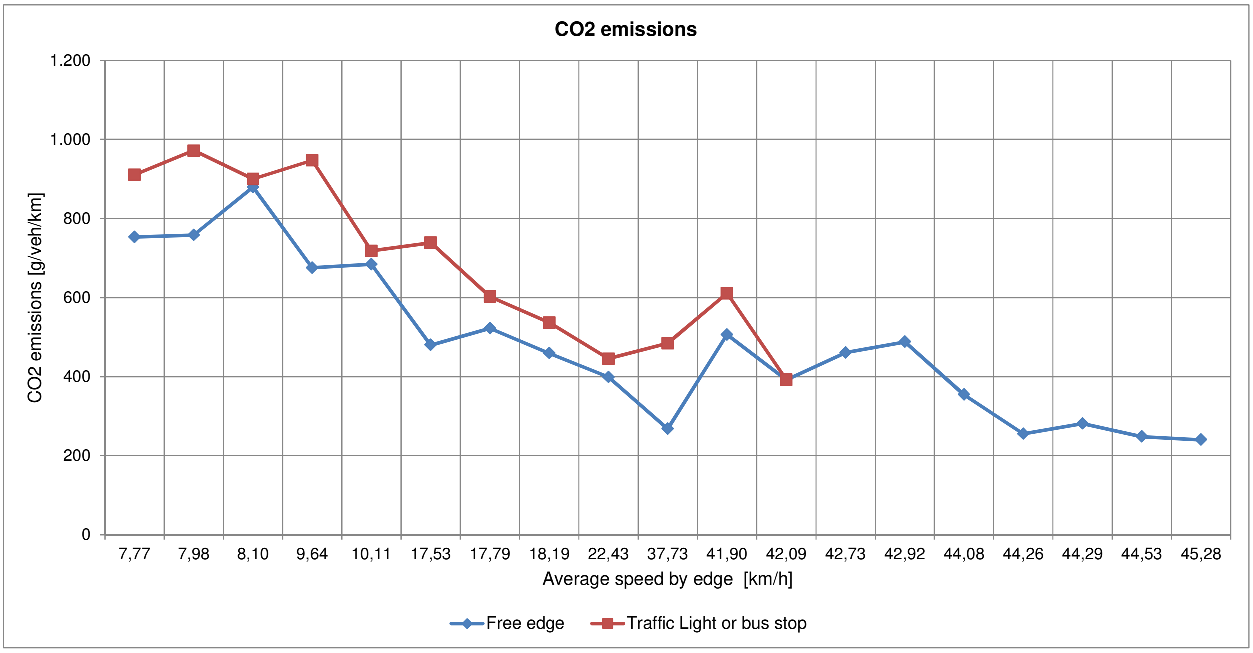

Figure 37 CO_2 emissions by edge – Base Line of day results – HBEFA (Sumo) [Normalized scale]

Figure 37 represents same results than Figure 36 but changing the x-axis. This way the effect of acceleration and deceleration conditions, over CO_2 emissions per edge, has become independent from average edge speed. It is observed that acceleration conditions (traffic lights presence) increase CO_2 emitted by vehicles, even if vehicles are driving at same speed rate. Thus, red dots are in most cases represented above blue dots, mainly at slow edges.

5.1.2.2.2 Evening results:

Table of results included in Annex 1.

Figure 38 includes CO_2 emissions values (CO_2 emissions of vehicles driving along the particular edge per vehicle per km length of the edge), distinguishing CO_2 emissions of vehicles driving along different edges where traffic lights or bus stops are located and along those edges free of traffic lights or bus stops. CO_2 emissions at different edges is represented per average speed of vehicles driving along the edge, distinguishing free edges and edges where traffic lights or bus stops are located in.

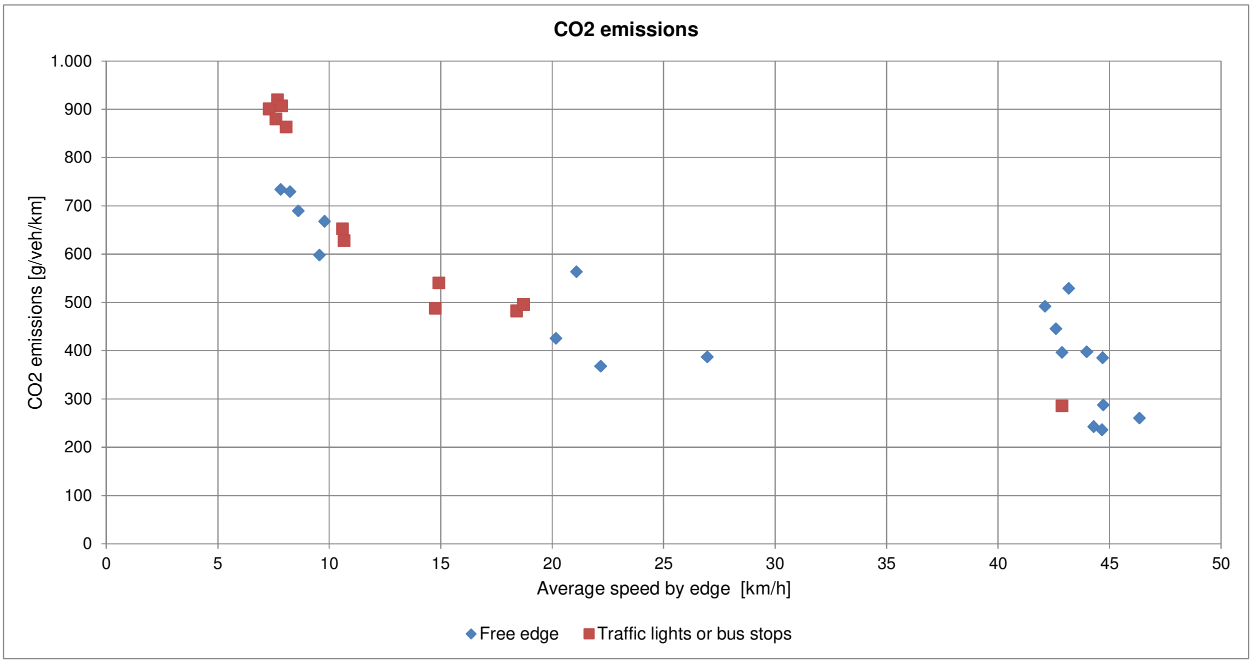

Figure 38 CO_2 emissions by edge – Base Line of evening results – HBEFA (Sumo)

From Figure 38Figure 14 same conclusions than in the PHEMLight simulation have been obtained; the CO_2 emissions of vehicles driving along edges, where traffic lights or bus stops are located (represented by red dots), are in most cases associated to edges where the average speed of vehicles driving along is low. However, despite the average speed is lower, the unitary CO_2 emitted per vehicle along these edges is, in most cases, higher than in free edges (edges free of traffic lights and bus stops (green dots)). This is explained as vehicles are under acceleration and deceleration conditions along these edges, this results in an increase of the output engine power of vehicles and consequently on higher fuel consumption and CO_2 emissions.

Once detected the speed influence over the fuel consumption, **Figure 39** has been included in order to represent CO_2 emissions evolution with speed, distinguishing between free edges and traffic light edges.

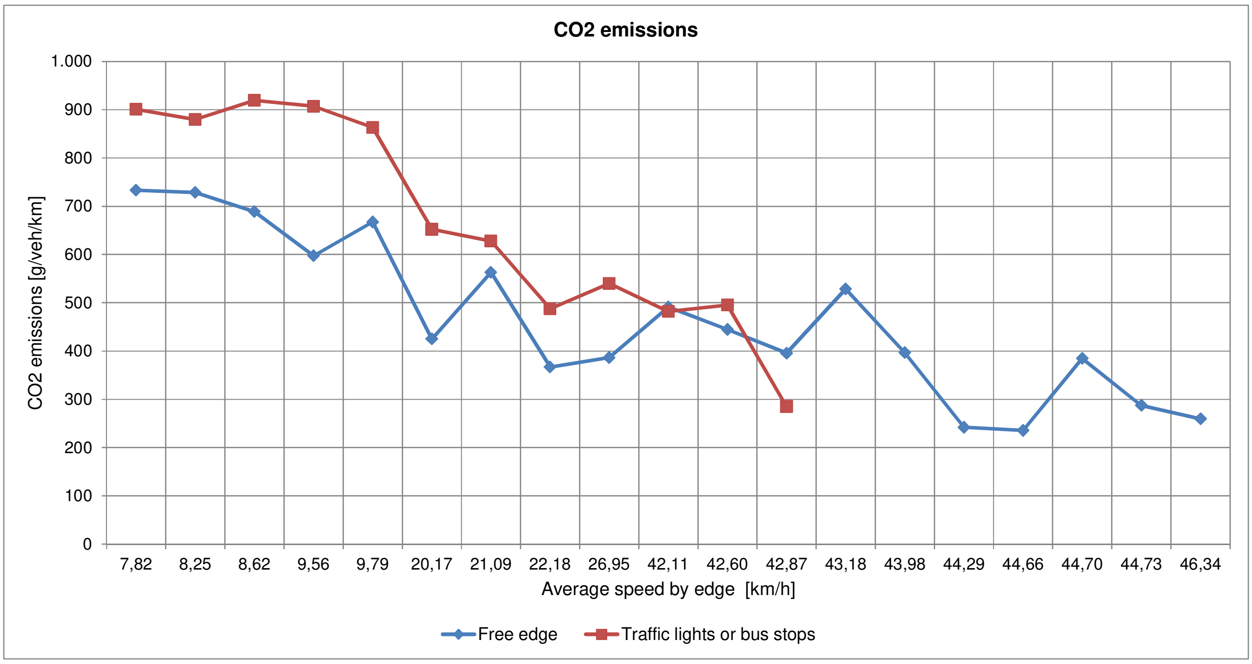

Figure 39 CO_2 emissions by edge – Base Line of evening results – HBEFA (Sumo) [Normalized scale]

Figure 39 represents same results than Figure 38 but changing the x-axis. This way the effect of acceleration and deceleration conditions, over CO_2 emissions per edge, has become independent from average edge speed. It is observed that acceleration conditions (traffic lights presence) increase CO_2 emissions by vehicles, even if vehicles are driving at same speed rate. Thus, red dots are in most cases represented above blue dots, mainly at slow edges. Same conclusions were obtained from Figure 38.

5.1.2.2.3 Night results:

Table of results included in Annex 1.

Figure 40 includes CO_2 emissions values (fuel consumed by vehicles driving along the particular edge per vehicle per km length of the edge), distinguishing CO_2 emissions of vehicles driving along different edges where traffic lights or bus stops are located and along those edges free of traffic lights or bus stops. CO_2 emissions at different edges is represented per average speed of vehicles driving along the edge, distinguishing free edges and edges where traffic lights or bus stops are located in.

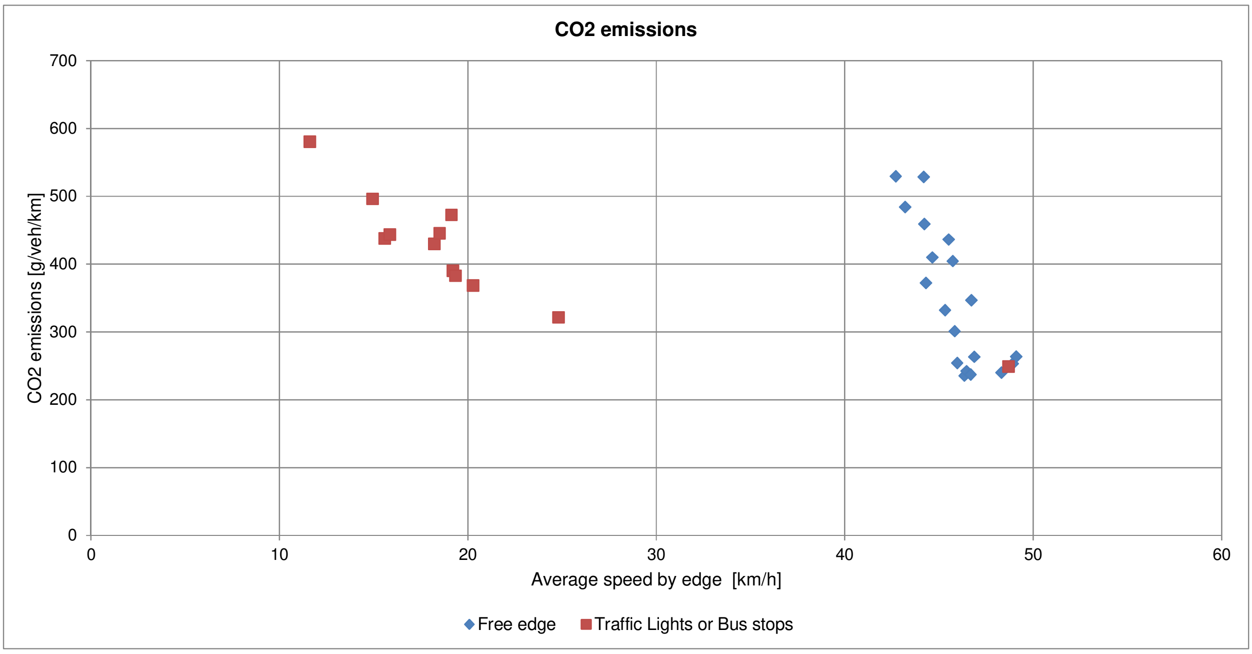

Figure 40 CO_2 emissions by edge – Base Line of night results – HBEFA (Sumo)

As happened at PHEMLight simulation, Figure 40 presents differences in comparison to day and evening graphs (Figure 36 and Figure 38). To start with, there exist two operating condition clouds of points: one associated to traffic lights edges (characteristics operating points of these edges) and the other one associated to free edges. It seems to be one operating point, associated to traffic light or bus stop edge, within the operating condition cloud associated to free edge. Actually, this edge is a free edge under night operating conditions because it is associated to a bus stop and in the analysis road there are no bus lines operating during night. This fact, the absence of buses during night, is also the reason for the existence of these two completely separate clouds of operating points.

Figure 41 has been included in order to represent emissions evolution with speed, distinguishing between free edges and traffic light edges (acceleration conditions).

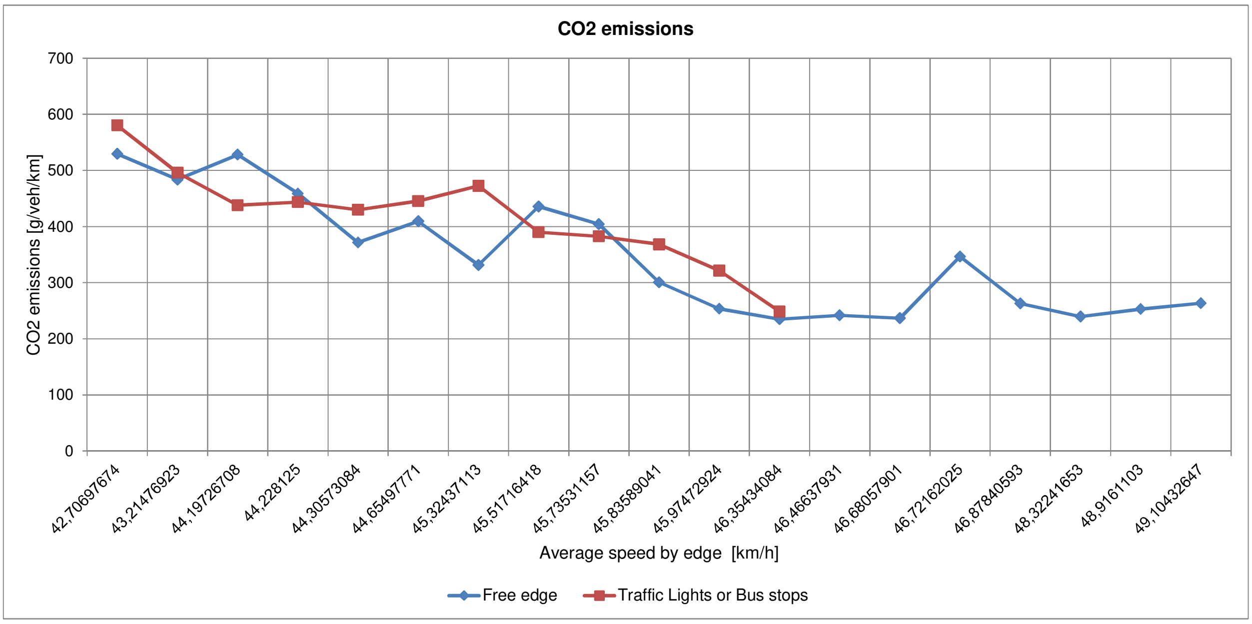

Figure 41 CO_2 emissions by edge – Base Line of night results – HBEFA (Sumo) [Normalized scale]

Speed influence over emissions is represented in Figure 41. It has been observed, as at day and night periods, the concentration of traffic light and bus stops at low speed edges. However, as difference with previous analysed periods, the speed influence over emissions is not so high. This is mainly because shown results are totalized emission values, including all types of vehicles and the overall hour of simulation; so, if there are no buses, the period of time in which vehicles are under deceleration and acceleration conditions is too low to have significantly effects over fuel consumption and, consequently, over emissions. Nevertheless, this effect when there are buses accelerating and decelerating at bus stops is higher.

5.1.2.2.4 Day, evening and night results:

Figure 42 and **Figure 43** represent normed CO_2 emissions per vehicles driving along the particular edge per average edge speed, in order to consider speed and acceleration and deceleration influence (related to traffic-light or bus stop presence) over emissions.

Figure 42 represents the speed influence over CO_2 emissions (CO_2 emissions of vehicles driving along the particular edge per vehicle per km length of the edge) per period. CO_2 emitted at different edges is represented per average speed of vehicles driving along the edge, distinguishing free edges and edges where traffic lights or bus stops are located in. The qualitative speed effect over emissions is also observed from PHEMLight results.

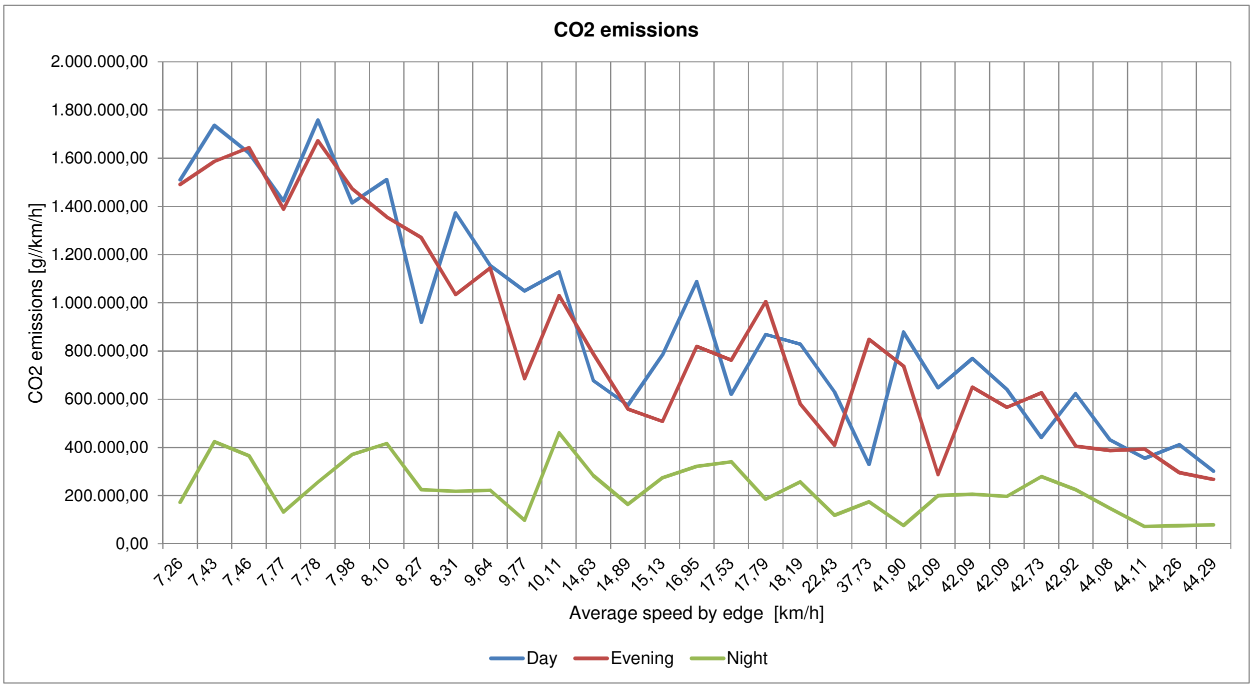

Figure 42– CO_2 emissions base line under different periods and speed influence over results (HBEFA (Sumo))

From Figure 42 it is observed that normed CO_2 emissions values over day and evening periods are very similar each other, being considerably higher than night results. By other hand, speed influence over fuel consumption (and consequently over CO_2 emissions) is clear at day and evening cases; however, under night conditions the speed effect is not so significant, mainly because of the no presence of buses, which have important influence over low speed edge, being one of the reasons of higher values at low speeds. In fact, another observation to be mentioned is the high CO_2 emissions values over low speed edges. It could be though that CO_2 emissions should be lower as speed decreases; however, operating points are not just conditioned by speed but also by other factors such as acceleration and deceleration or idle conditions. This is why at low speed edges normed CO_2 emissions are also high, because these edges are mainly associated to traffic lights and bus stops presence, associated to acceleration and deceleration conditions, which result in higher output engine power of vehicles and consequently higher fuel consumption and CO_2 emissions.

Figure 43 represents same results than Figure 42 but, instead of representing results per average edge speed, results are represented per edge. Edges, where traffic lights and bus stops are located, are represented through yellow lines. This way, Figure 43 presents the influence of acceleration conditions over fuel consumption.

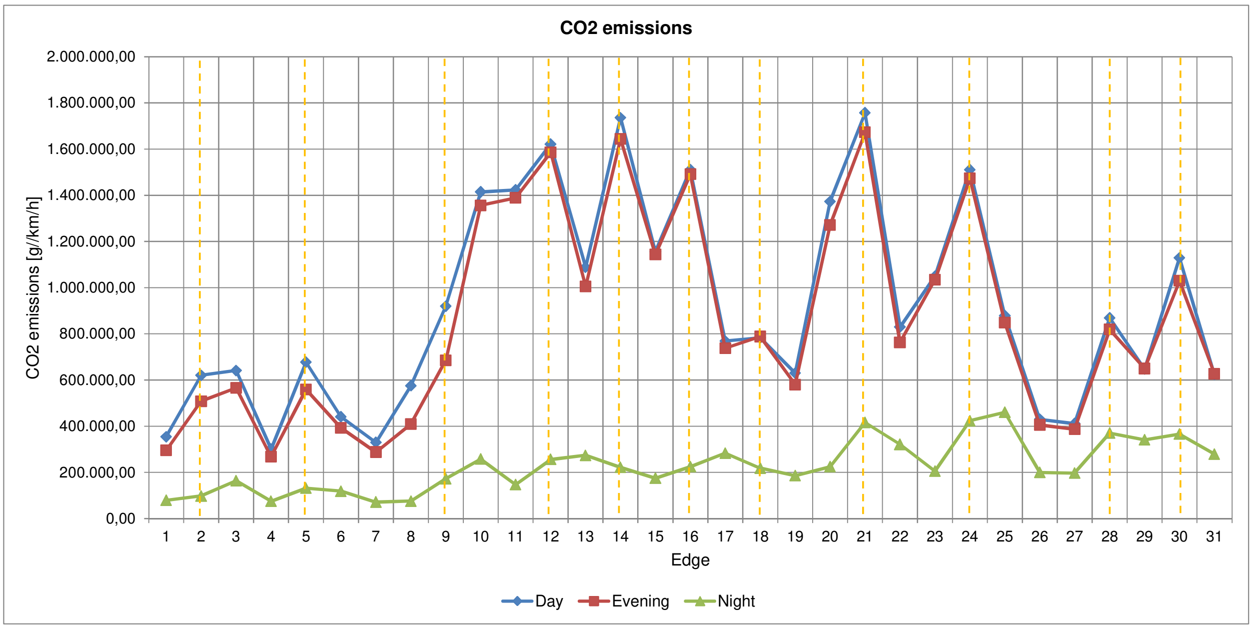

Figure 43– CO_2 emissions base line under different periods – Results by edge (HBEFA (Sumo))

5.1.2.3 PHEMLight-HBEFA comparison results

This section aims to compare simulations results analyzed at sections 5.1.1.1 and 5.1.1.2, associated to the implementation of both energy consumption and emission models (PHEMLight and HBEFA). Comparison has been performed by representing both models results at the same graph. Thus, following results are based on conclusions obtained from previous analyses.

Qualitative evolution of CO_2 emissions has already been tested and next graphs reflect that both models follow same evolution. However, quantitative results associated to CO_2 emissions are not so clear.

Despite results are analyzed for the same scenario and the same traffic configuration, results obtained by each methods are different each other. Detected reasons are the following:

1. HBEFA do not allow establishing the same fleet of vehicles than PHEMLight.
2. The definition of the fleet, strongly determine the proportion of vehicles which consume a particular fuel typology. Due to both models do not include the same fleet, emissions obtained values are the result of summing different emissions associated to different engines, which consume different fuels; so, results could never be the same.

Previous explanation describes reasons why quantitative results obtained by both models, as it is shown in tables and figures below, are so different. It has also been concluded from this explanation that, in order to obtain the absolute daily value of CO_2 emissions associated to vehicles driving along the road, the appropriate model to be used is the PHEMLight model.

5.1.2.3.1 Day results:

Figure 44 represents the evolution of CO_2 emissions (CO_2 emissions of vehicles driving along the particular edge) per average edge speed obtained through both models (PHEMLight and HBEFA) at day period.

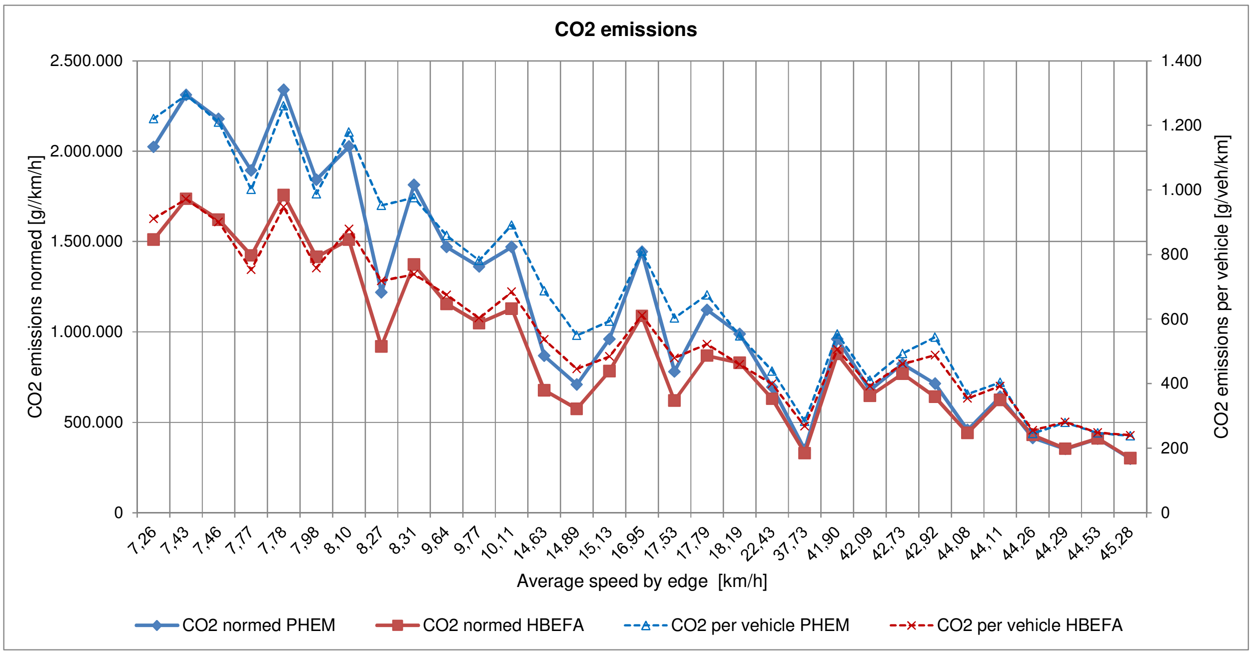

Figure 44 Speed influence over CO_2 emissions by edge (Day) – PHEMLight - HBEFA models comparison

From Figure 44 it is observed that CO_2 emissions results obtained through both models follow same evolution with average edge speed. It is also observed the difference between absolute values, result of the fleet characterization implemented at both simulations.

5.1.2.3.2 Evening results:

Figure 45 represents the evolution of CO_2 emissions (CO_2 emissions by vehicles driving along the particular edge) per average edge speed obtained through both models (PHEMLight and HBEFA) at evening period.

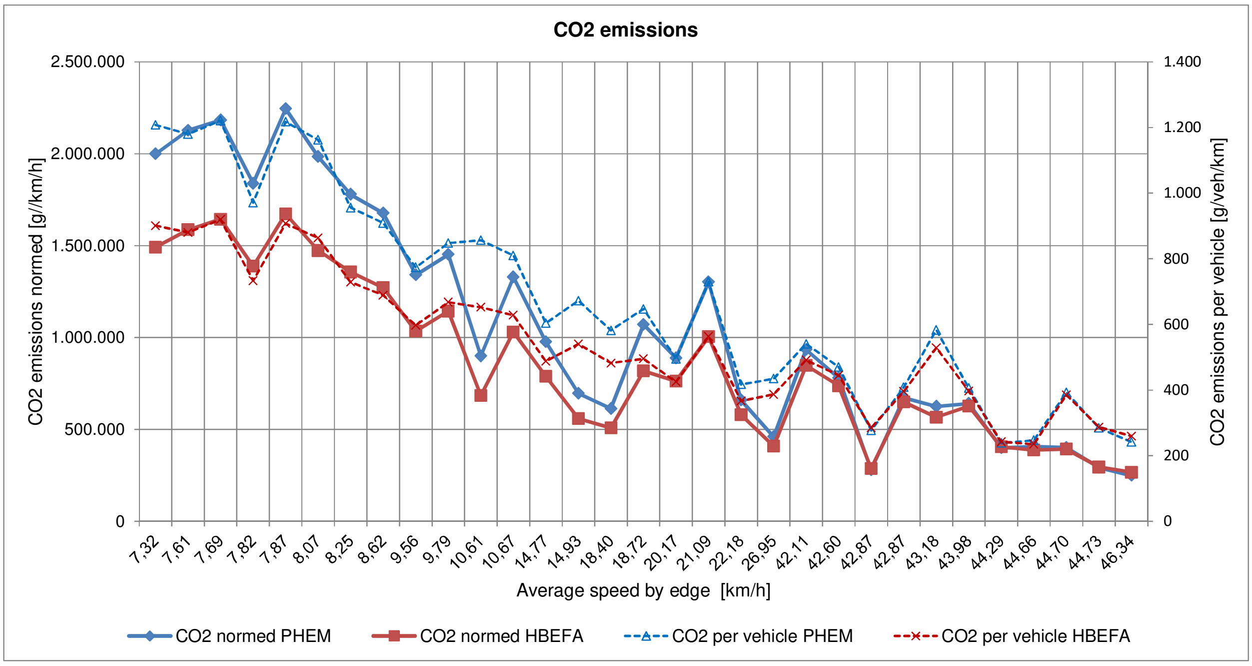

Figure 45 Speed influence over CO_2 emissions by edge (Evening) – PHEMLight - HBEFA models comparison

Figure 45 follow same evolution than Figure 44, concluding same results for both periods.

5.1.2.3.3 Night results:

Figure 46 represents the evolution of CO_2 emissions (CO_2 emissions of vehicles driving along the particular edge) per average edge speed obtained through both models (PHEMLight and HBEFA) at night period.

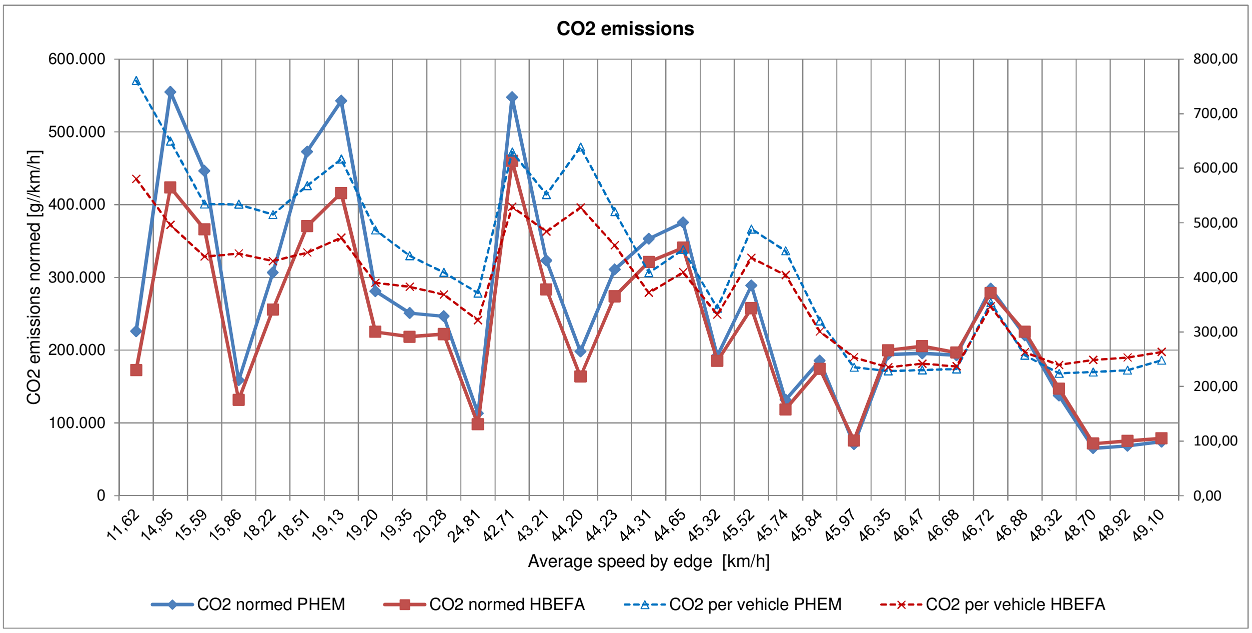

Figure 46 Speed influence over CO_2 emissions by edge (Night) – PHEMLight - HBEFA models comparison

From Figure 24 it is also observed (idem than conclusions obtained from Figure 45 and Figure 44) that CO_2 emissions results obtained through both models follow same evolution with average edge speed. It is also observed the difference between absolute values, result of the fleet characterization implemented at both simulations. However the evolution of CO_2 emissions presented at Figure 24 is different than presented at Figure 45 and Figure 44; the speed influence over emissions is not so high. As it has been explained at previous sections, this is mainly because represented results are the totalized CO_2 emissions, including all types of vehicles and the overall hour of simulation; so, if there are no buses, the period of time in which vehicles are under deceleration and acceleration conditions is too low to have significantly effects over fuel consumption and CO_2 emissions.

In order to observe differences among results obtained for different periods, different graphs have been included below comparing results.

5.1.2.3.4 Day, evening and night results:

Figure 47 represents CO_2 emissions by vehicles driving along the edges, per average edge speed, obtained through both models (PHEMLight and HBEFA) for three simulated periods.

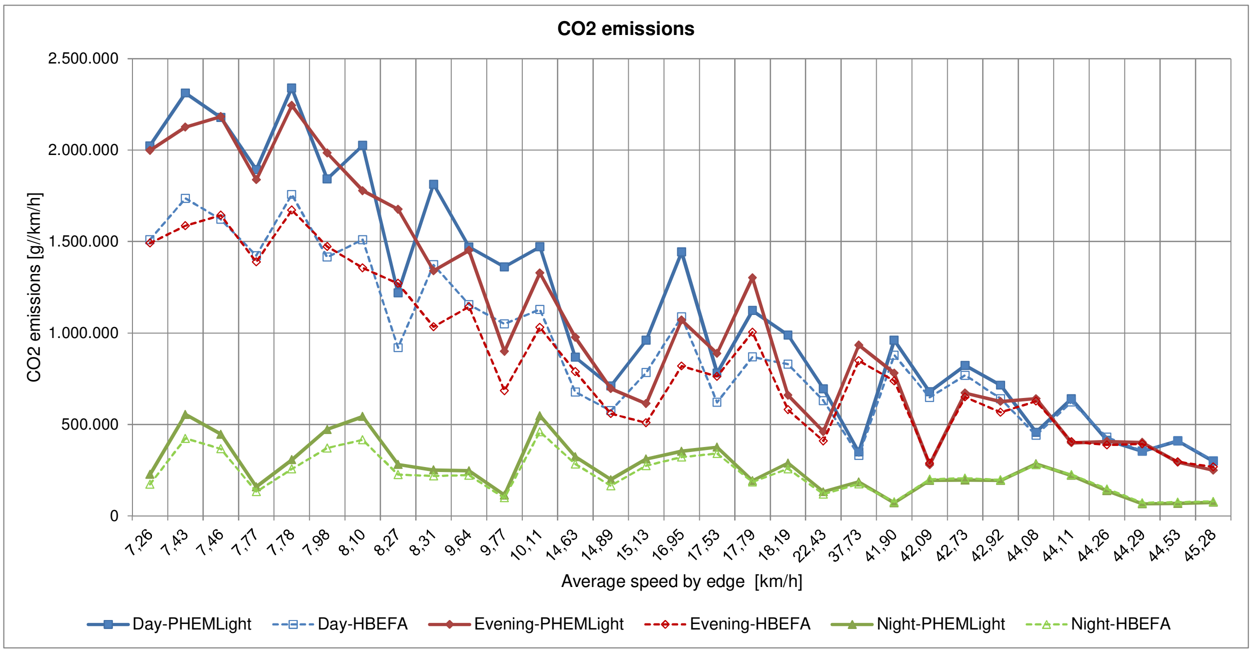

Figure 47 Speed influence over CO_2 emissions by edge (day, evening and night) – PHEMLight - HBEFA models comparison

Figure 48 represents CO_2 emissions by vehicles driving along the edges, per edge where vehicles are driving along (PHEMLight and HBEFA) for three simulated periods

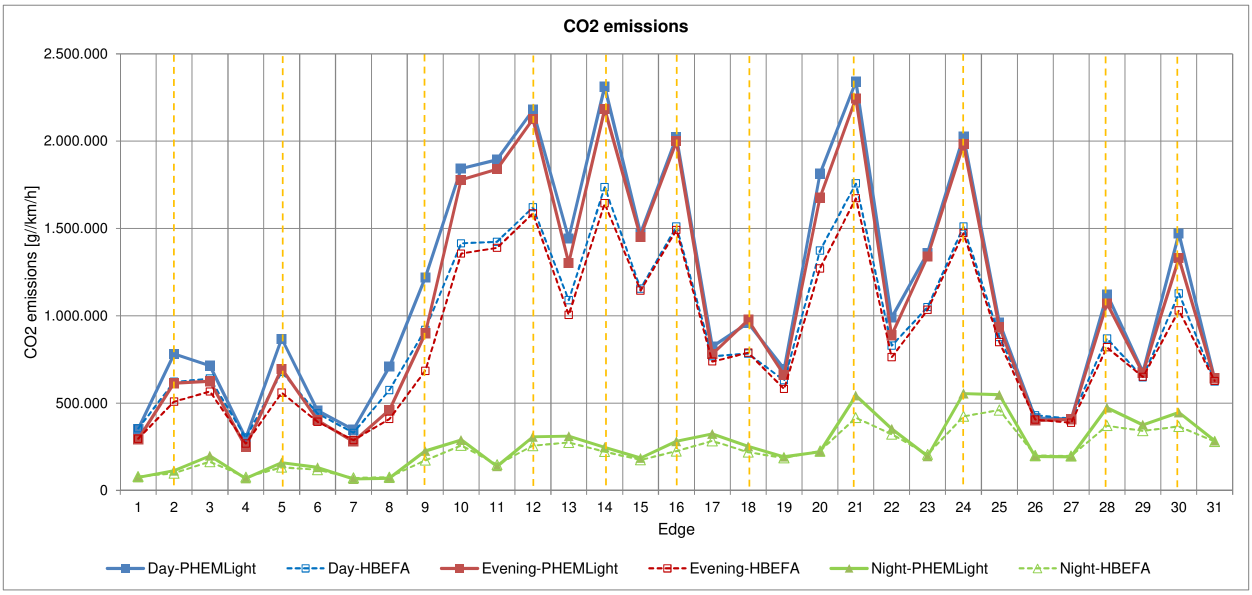

Figure 48– CO_2 emissions base line under different periods – Results by edge (PHEMLight - HBEFA models comparison)

5.1.2.4 Daily emissions

From previous CO_2 emissions analyses the following conclusions have been extracted:

1. Both models, PHEMLight and HBEFA, follow the expected behaviour along the road.
2. Both models are sensitive to operating points variations (speed and acceleration conditions).
3. PHEMLight model is sensitive to fleet composition (it takes into account fuel consumed by each category of vehicles composing the fleet) while HBEFA model just takes into account different typologies of vehicles.

From previous conclusions, it has been decided to obtain daily absolute CO_2 emissions values from PHEMLight simulations, due obtained results are more accurate to the traffic configuration and scenario definition.

Values, included within **Table 35**, have been obtained for the three analysis periods and accumulate daily values have been obtained considering the duration of each period.

Table 35 Daily CO_2 emissions – PHEMLight simulation

Fleet	Fuel	Day [g/h]	Evening [g/h]	Night [g/h]	Daily [g/day]
Passenger cars	Gasoline	619,87	463,70	127,20	**10.310,85**
	Diesel	30,52	24,71	9,42	**540,53**
	CNG	3,11	2,89	1,52	**61,08**
	Hybrid (G)	2,74	2,17	0,93	**49,00**
Motos	Gasoline	168,57	136,39	40,52	**2.892,58**
	Diesel	0	0	0	**0**
	CNG	0	0	0	**0**
	Hybrid (G)	0	0	0	**0**
Trucks	Gasoline	0	0	0	**0**
	Diesel	591,20	483,78	162,83	**10.332,19**
	CNG	0	0	0	**0**
	Hybrid (G)	0	0	0	**0**
Buses	Gasoline	0	0	0	**0**
	Diesel	109,97	109,97	0	**1.759,47**
	CNG	0	0	0	**0**
	Hybrid (G)	0	0	0	**0**
Total fleet	Gasoline	788,45	600,09	167,72	**13.203,43**
	Diesel	731,70	618,46	172,25	**12.632,19**
	CNG	3,11	2,89	1,52	**61,08**
	Hybrid (G)	2,74	2,17	0,93	**49,00**

From Table 35 it is observed that the highest CO_2 emission levels are associated to trucks (10.332,19 g/day) followed by gasoline cars (10.310,85 g/day).

In order to realize a deeper analysis of included results in Table 29, it result interesting to have into account the fleet of vehicles defined for the analysed scenario (Table 30) in order to determine the origin of these results.

From Table 35 and Table 30, it has been obtained the unitary emissions per vehicle considering different categories of vehicles and evaluation periods. Obtained results have been included within **Table 36**.

Table 36 Unitary CO_2 emissions per vehicle category and period

Fleet	Fuel	Day [g/vehicle/h]	Evening [g/vehicle/h]	Night [g g/vehicle/h	Daily [g/vehicle/h]
Passenger cars	Gasoline	0,271	0,251	0,237	**0,263**
	Diesel	0,237	0,238	0,312	**0,245**
	CNG	0,236	0,272	0,489	**0,270**
	Hybrid (G)	0,196	0,194	0,193	**0,195**
Motos	Gasoline	0,260	0,261	0,267	**0,261**
	Diesel				
	CNG				
	Hybrid (G)				
Trucks	Gasoline				
	Diesel	1,277	1,297	1,494	**1,305**
	CNG				
	Hybrid (G)				
Buses	Gasoline				
	Diesel	3,316	3,316		**3,316**
	CNG				
	Hybrid (G)				
Total fleet	Gasoline	0,268	0,253	0,243	**0,263**
	Diesel	1,170	1,213	1,237	**1,186**
	CNG	0,236	0,272	0,489	**0,270**
	Hybrid (G)	0,196	0,194	0,193	**0,195**

Regarding CNG passenger cars, Table 31 reflects the huge unitary associated fuel consumption, mainly due to the low density of this fuel, since values are given in litters; nevertheless, from Table 36 it is extracted that associated emissions (0,270 g/veh/h) are higher than gasoline (0,263 g/veh/h) and diesel (0,245 g/veh/h). Otherwise, hybrid passenger cars emissions are the lowest (0,195 g/veh/h). Unitary CO_2 emissions associated to motorbikes (0,261 g/veh/h), which consume gasoline, are near to gasoline cars.

Otherwise, the most intensive fuel consumers are buses, which unitary consumption exceeds 4,540 l/veh/h and is also the fleet which emissions per vehicle are highest (3,316 g/veh/h), followed by trucks, which associated emissions are (1,305 g/veh/h) which is far from other vehicles unitary emissions (motorbikes and cars).

Regarding passenger cars, as it was expected, unitary emissions of hybrid cars (0,195 g/veh/h) are the lowest of the fleet. Thus, oriented action plan proposed once fuel consumption was analysed, which consisted on replacing pure gasoline cars by hybrid cars is also an action justified by the emissions analysis.

Figure 49 Table 49Figure 28 shows the fleet CO_2 emissions values of a day simulation. Represented numeric results are all included within Table 35.

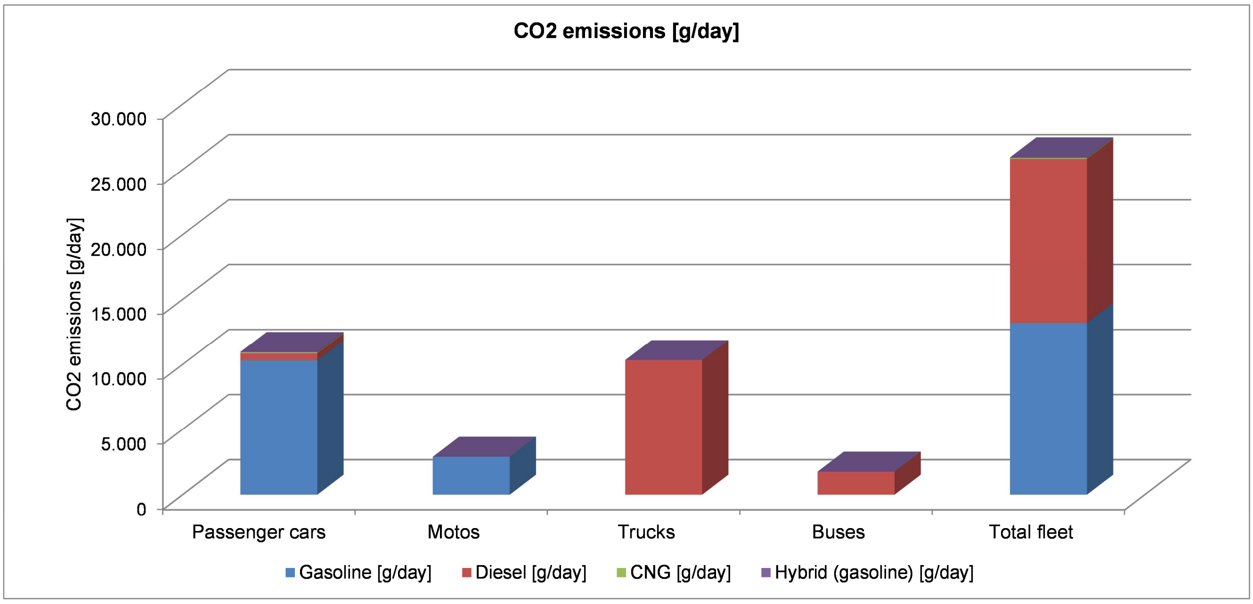

Figure 49 Daily CO_2 emissions by vehicle typology and type of fuel

Figure 49 represents emissions associated to the consumption of different fuels. As it is observed, almost the half of emissions are due to gasoline consumption, being the other half mainly the result of diesel consumption. It is also concluded that most of emissions are associated to the flows of pure gasoline cars and diesel trucks along the road.

From Figure 49 it is possible to establish the following results:

1. Most CO_2 emissions are due to diesel consumed by trucks (10.332 g/day), which associated unitary vehicle emissions are also very high (1,204 g/veh/day) just below buses. Trucks emissions are followed by emissions associated to cars gasoline consumption, which obtained value for a simulated day is 10.310 g/day. Unitary emissions of pure gasoline cars (0,263 g/veh/day) are not as high as trucks but represent the biggest fleet.
2. CO_2 emitted by hybrid cars (49 g/day) represents a few part of the total fleet emissions. Both, unitary emissions (0,195 g/veh/day), which are the lowest of the total fleet, and the small hybrid fleet driving along the road, are the causes of these emission levels.

Actions plans:

As it is been explained within section 51, chosen action plan to be implemented within this project, is the replacement of gasoline passenger cars fleet by hybrid cars.

The action plan is implemented in the reference scenario in order to obtain results evolution. Thus, **Figure 50** compares CO_2 emissions associated to the reference scenario and to the improved scenario by implementing the action plan, which consists on replacing the gasoline passenger cars by hybrid passenger cars.

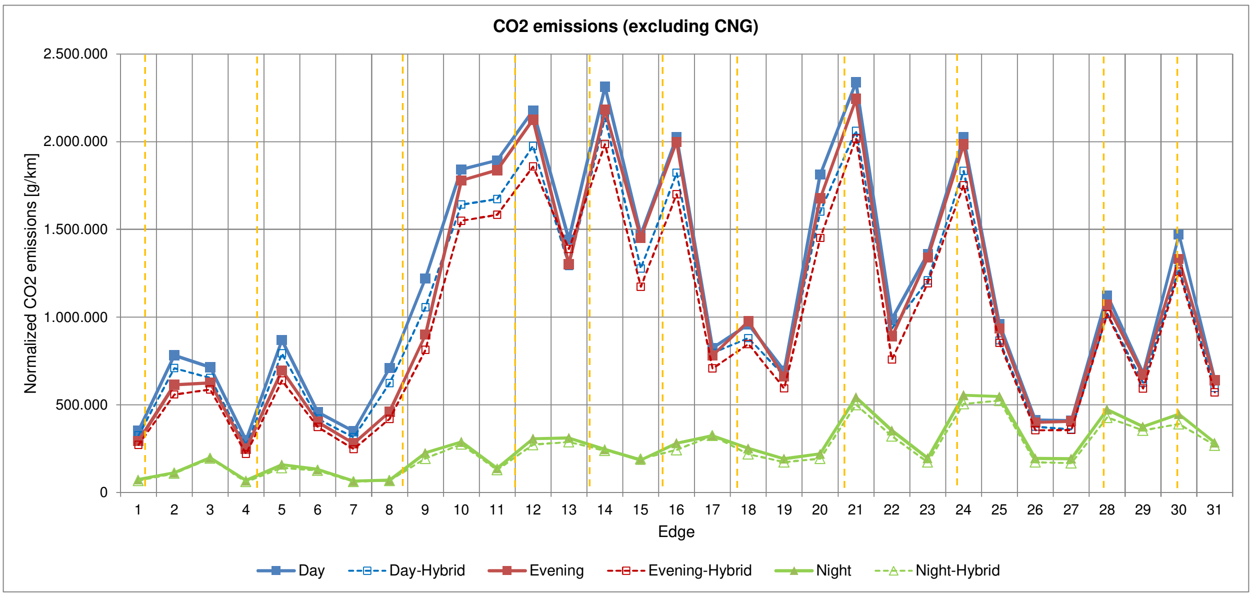

Figure 50 CO_2 emissions by edge (day, evening and night) – (Gasoline passenger cars replacement by hybrid cars)

Expected results have been obtained from simulating the road traffic once the action plan has been implemented. Figure 50 shows how CO_2 emissions have been reduced (at the three periods) when implementing the named action. This reduction it is better observed at day and evening graphs than night due to less absolute values achieved for that periods. Figure 50 also reflects that at those edges where traffic lights are located (yellow vertical lines), differences between CO_2 emissions, before and after implementing the action plan, are higher. This is mainly because vehicles are under acceleration conditions along these edges and under these conditions hybrid cars highly reduce their gasoline consumption (the battery starts working) and associated emissions.

Table 37 shows CO2 emissions by fleet of vehicles, associated to the reference simulation and to the simulation once the action plan has been implemented.

Table 37 CO_2 emissions – Before and after action plan implementation

Fleet	Day [g/h]	Evening [g/h]	Night [g/h]	Daily [g/day]
Passenger cars	0,00	0,00	0,00	8.140,68
Motos	168,57	136,39	40,52	**2.892,58**
Trucks	591,20	483,78	162,83	**10.332,19**
Buses	109,97	109,97	0	**1.759,47**
Total fleet	1.350,88	1.102,39	313,10	**23.124,92**

The action plan results in CO_2 savings of 2.820 g/day, which supposes 11% of total CO_2 emission savings, directly associated to the implementation of the action plan.

5.1.3 Noise

Noise is one of most significant issues which affect population health and comfort, and which is directly related to road traffic, mostly in urban areas (where the most of world population lives). Due to this strongly relation the interest in characterizing the noise associated to road traffic is deduced. Sumo allows the user to calculate the noise associated to a road traffic line.

Sumo tool includes noise models to characterize the noise of the road, which is treated as a noise source line. There is no different between HBEFA results and PHEM-lights results in terms of noise due to implemented noise models in the tools are based on the Harmonoise method, which do not take into account different classification that both models (HBFA and PHEM) implement for each type of vehicles. The noise model, as it is explained in the theoretical noise model, just take into account the fleet definition in terms of type of vehicles: passenger cars, heavy cars.

Noise results obtained through Sumo, are based on the *Harmonoise model* implemented for the characterization of traffic source lines. This model was developed within *IMAGINE* project (*European Commission project*) which is a previous step to *CNOSSOS*, which resulted in the definition of a complete methodology for characterizing noise associated to traffic flows. This *CNOSSOS* model is detailed in the explanation of the noise theoretical model.

The traffic noise is characterized as the noise pressure level (dB) calculated by edge of the traffic line.

Simulation results have been obtained for day, evening and night period and have been included in this section in tables and graphs.

Tables below show noise pressure levels in dB, associated to the traffic fleet driving along the road, by edge; identifying the length of the edge, average speed over the edge, number of vehicles along the edge and average speed of vehicles driving along the edge. By other hand, noise values are given as absolute values and as normed values per 100meters length of edge. Since edge lengths are different, in order to compare results under different operating points, resuming in different edges conditions, it seems to be more representative to compare normalized noise. So, these values have been represented within graphs.

Black rows in tables are associated to edges where traffic lights and bus stops are located.

5.1.3.1.1 Day results

Table 38 Noise by edge – Base Line of day results – PHEMLight

Edge	Length	Speed		Vehicles		Noise (abs)	Noise (normed 100m)
	m	m/s	km/h	nº veh	nº veh/m	dB	dB
1	721,97	12,30	44,29	1.261,37	1,75	82,54	73,95
2	**158,73**	**4,87**	**17,53**	**1.294,52**	**8,16**	**79,38**	**78,06**
3	98,83	11,92	42,92	1.313,45	13,29	77,38	78,12
4	280,86	12,58	45,28	1.254,31	4,47	81,82	79,19
5	**156,57**	**4,06**	**14,63**	**1.262,32**	**8,06**	**79,80**	**78,29**
6	256,88	12,24	44,08	1.245,28	4,85	79,74	79,80
7	**253,63**	**10,48**	**37,73**	**1.230,91**	**4,85**	**80,67**	**77,98**
8	70,75	4,14	14,89	1.290,34	18,24	81,64	78,79
9	**79,90**	**2,30**	**8,27**	**1.280,41**	**16,03**	**78,15**	**77,47**
10	135,54	2,22	7,98	1.865,43	13,76	80,50	76,98
11	84,43	2,16	7,77	1.891,02	22,40	80,97	76,12
12	**183,31**	**2,07**	**7,46**	**1.800,98**	**9,82**	**78,26**	**76,25**
13	141,53	4,71	16,95	1.782,15	12,59	82,41	77,92
14	**98,60**	**2,06**	**7,43**	**1.786,67**	**18,12**	**80,58**	**79,79**
15	185,89	2,68	9,64	1.711,69	9,21	79,95	77,14
16	**192,76**	**2,02**	**7,26**	**1.658,25**	**8,60**	**80,76**	**76,97**
17	117,04	11,87	42,73	1.668,35	14,25	80,63	79,07
18	**224,94**	**4,20**	**15,13**	**1.617,41**	**7,19**	**77,66**	**78,03**
19	305,31	6,23	22,43	1.580,30	5,18	77,07	75,02
20	281,01	2,31	8,31	1.857,78	6,61	78,23	74,91
21	**119,86**	**2,16**	**7,78**	**1.855,73**	**15,48**	**79,70**	**77,44**
22	191,13	5,05	18,19	1.805,89	9,45	78,87	76,64
23	239,56	2,71	9,77	1.741,48	7,27	76,88	76,93
24	**143,26**	**2,25**	**8,10**	**1.717,92**	**11,99**	**79,17**	**78,29**
25	91,82	11,64	41,90	1.736,30	18,91	80,49	76,40
26	160,18	12,29	44,26	1.684,90	10,52	78,03	73,55
27	214,99	12,37	44,53	1.657,16	7,71	78,39	76,44
28	**168,42**	**4,94**	**17,79**	**1.664,36**	**9,88**	**79,12**	**75,02**
29	166,96	11,69	42,09	1.651,19	9,89	77,92	73,88
30	**122,56**	**2,81**	**10,11**	**1.650,15**	**13,46**	**74,44**	**75,94**
31	256,32	12,25	44,11	1.589,38	6,20	76,01	76,98

Included values within Table 38 are represented at **Figure 51** and **Figure 52** , distinguishing CO_2 emissions by vehicles driving along different edges where traffic lights or bus stops are located and along those edges free of traffic lights or bus stops.

Figure 51 represents the effect of traffic lights (yellow spots) over source line normalized noise (blue graph). The figure also shows difference beetwen absolute noise and normalized; which depends on the length of edges and associated number of vehicles which driving along.

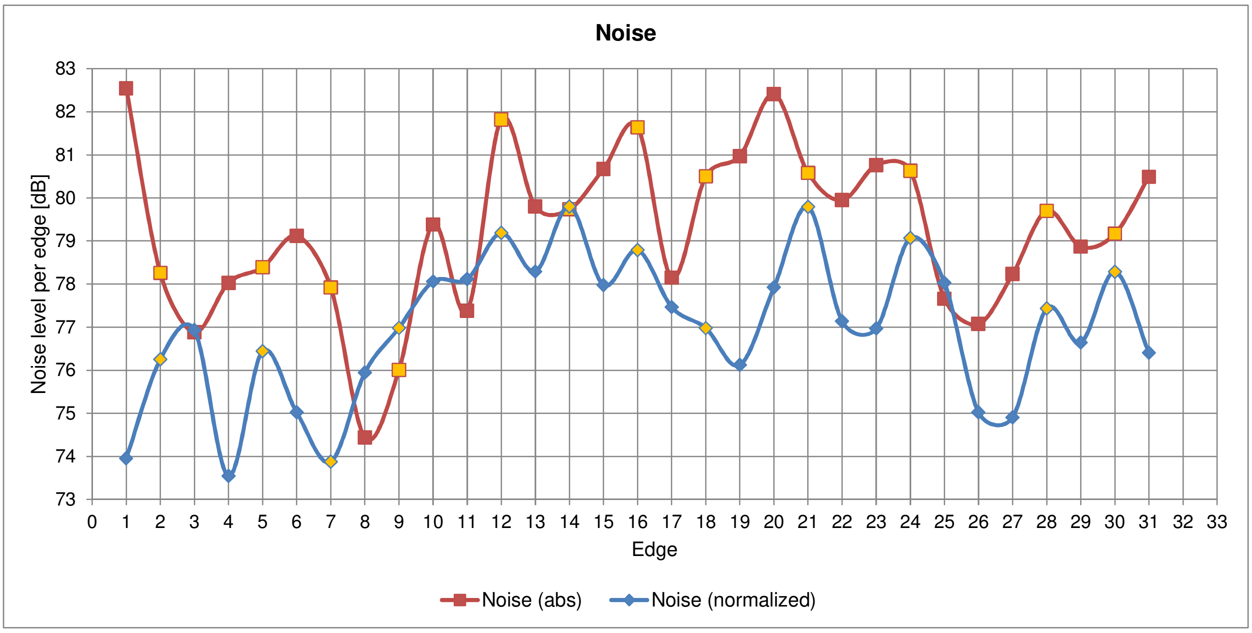

Figure 51 Noise by edge – Base Line of day results – PHEMLight (Sumo)

As it was expected, from Figure 51 it is extracted that the noise associated to acceleration and deceleration conditions (higher engine output power) increases significantly, which can be observe on graphs peaks.

Figure 52 represents the normalized source line noise evolution by speed variation.

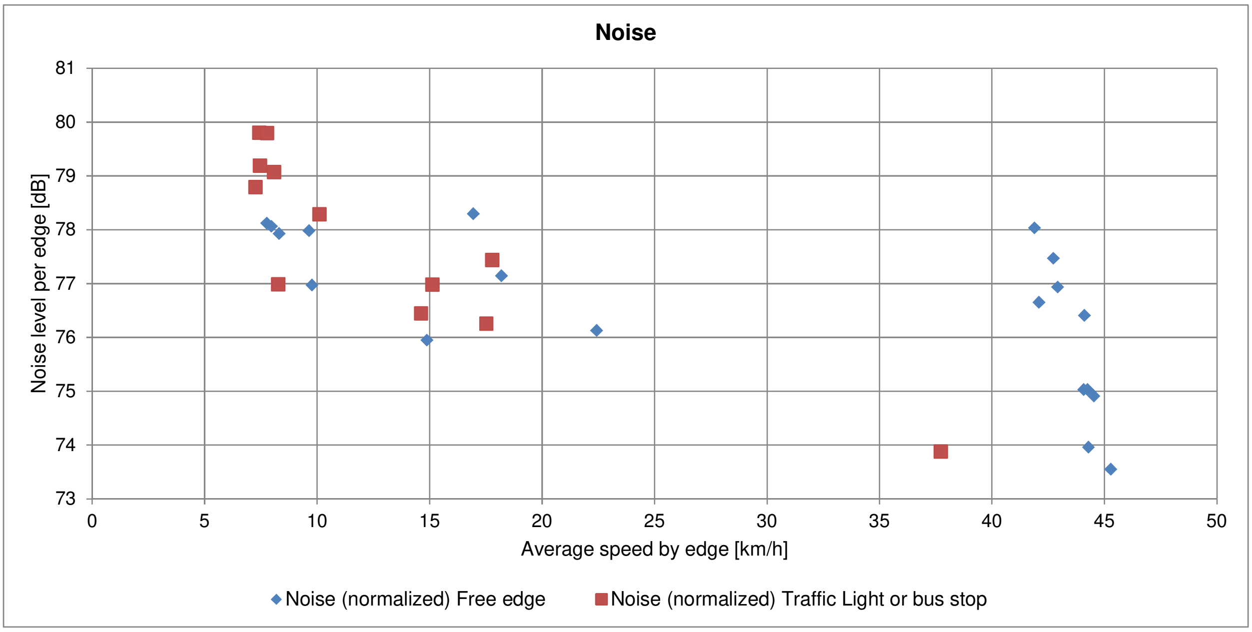

Figure 52 Normalized noise by edge – Base Line of day results – PHEMLight (Sumo)

As it is shown in Figure 52, most traffic-light edges are associated to a lower average speed and higher noise source line, which is again result of higher engine output power (higher propulsion noise) and higher rolling friction (higher rolling noise).

Figure 53 represents same results than Figure 52 but changing the x-axis.

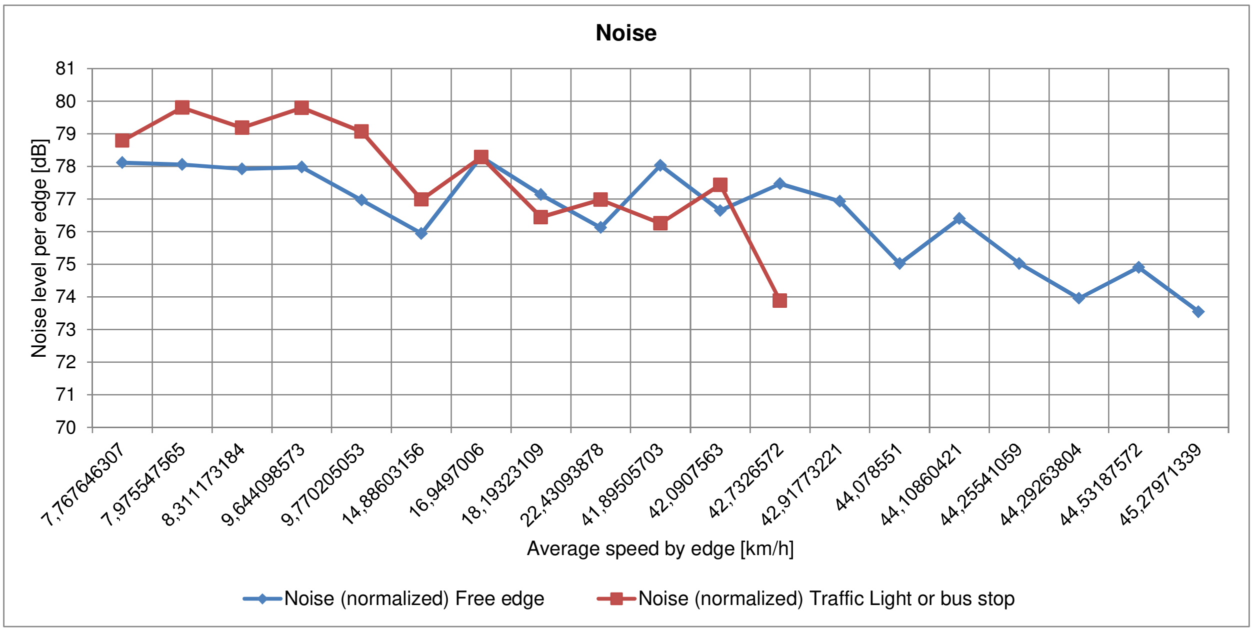

Figure 53 Normalized noise by edge – Base Line of day results – PHEMLight (Sumo) [Normalized scale]

Figure 53 shows the effect of acceleration and deceleration conditions, over noise emissions per edge, has become independent from average edge speed. It is observed that acceleration conditions (traffic lights presence) increase noise emitted by vehicles in most cases.

5.1.3.1.2 Evening results:

Table of results included in Annex 1.

Figure 54 represents the effect of traffic lights (yellow spots) over source line normalized noise (blue graph) obtained from evening simulation The figure also shows difference beetwen absolute noise and normalized; which depends on the length of edges and associated number of vehicles which driving along.

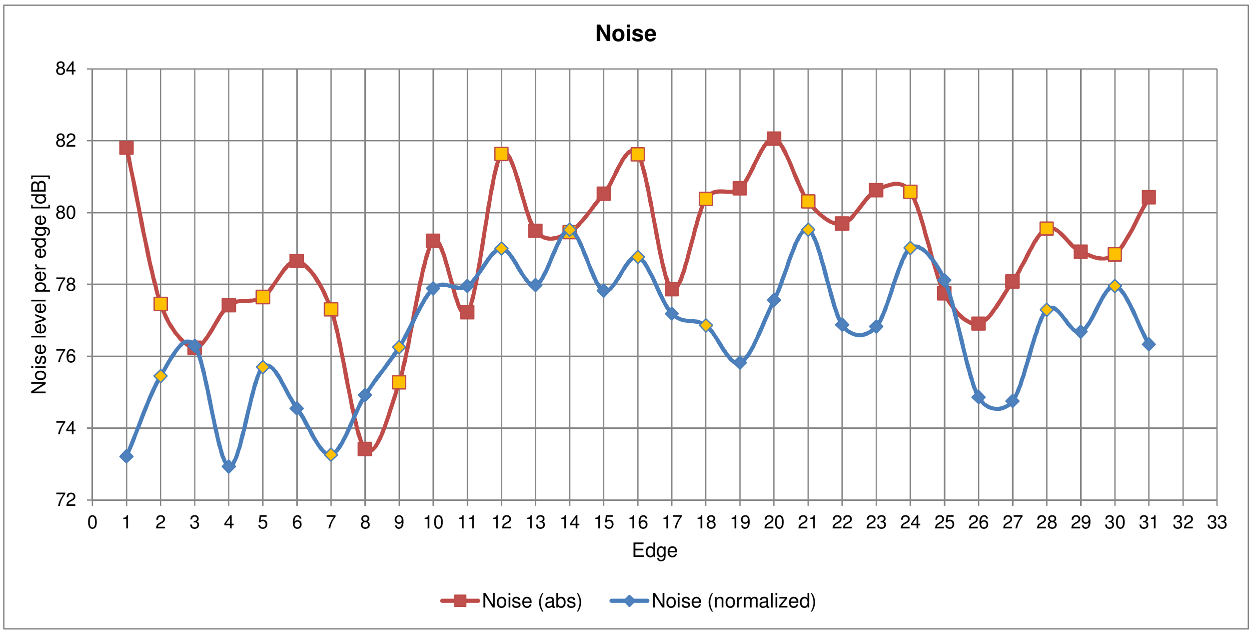

Figure 54 Noise by edge – Base Line of evening results – PHEMLight (Sumo)

As it was expected, from Figure 54 it is extracted that the noise associated to acceleration and deceleration conditions (higher engine output power) increases significantly, which can be observe on graphs peaks. Same conclusions were obtained from day simulation.

Figure 55 represents the normalized source line noise evolution by speed variation.

As is been shown in figures below, evening results are closed to day results, quantitatively and qualitatively. Same observations are realized within day case; most traffic-light edges are associated to a lower average speed and higher noise source line, which is again result of higher engine output power (higher propulsion noise) and higher rolling friction (higher rolling noise).

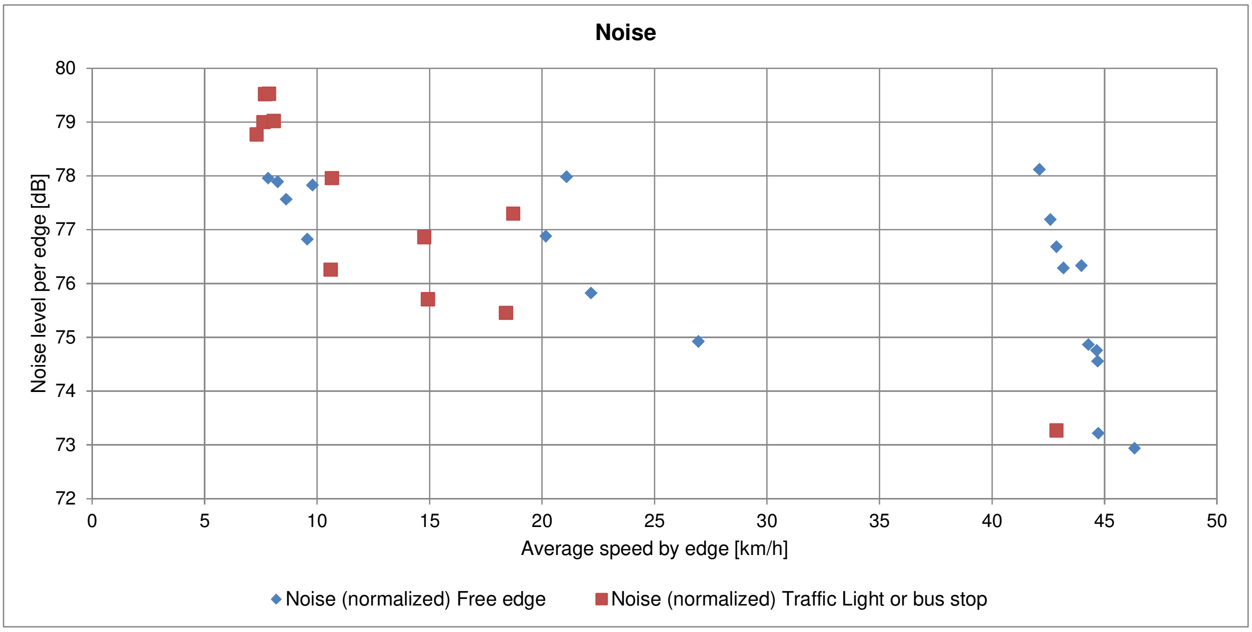

Figure 55 Normalized noise by edge – Base Line of evening results – PHEMLight (Sumo)

As it is shown in Figure 55, evening results are closed to day results, quantitatively and qualitatively. Same observations are realized within day case; most traffic-light edges are associated to a lower average speed and higher noise source line, which is again result of higher engine output power (higher propulsion noise) and higher rolling friction (higher rolling noise).

5.1.3.1.3 Night results:

Table of results included in Annex 1.

Figure 56 represents the effect of traffic lights (yellow spots) over source line normalized noise (blue graph) obtained from night simulation The figure also shows difference beetwen absolute noise and normalized; which depends on the length of edges and associated number of vehicles which driving along.

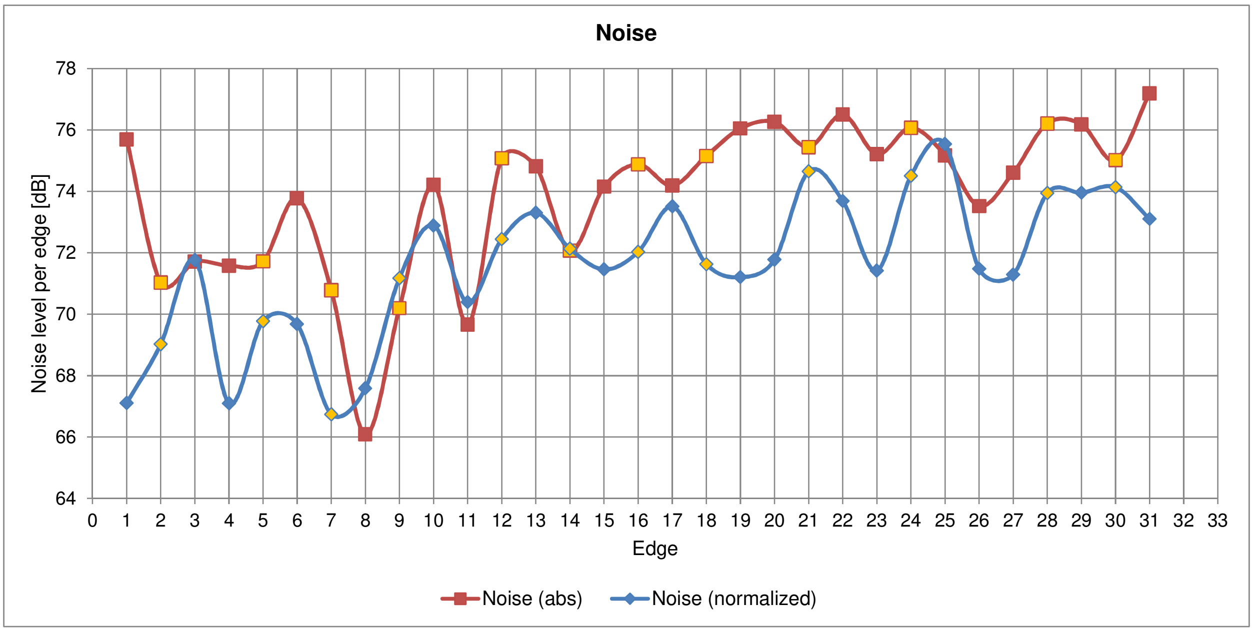

Figure 56 Noise by edge – Base Line of night results – PHEMLight (Sumo)

From Figure 56 it is observed that the effect of acceleration and deceleration conditions is not so clear in the night simulation comparing results with day and evening.

This way, **Figure 57** presents differences in comparison to day and evening graphs. To start with, there exist two operating condition clouds of points: one associated to traffic lights edges (characteristics operating points of these edges) and the other one associated to free edges. It seems to be one operating point, associated to traffic light or bus stop edge, within the operating condition cloud associated to free edge. Actually, this edge is a free edge under night operating conditions because it is associated to a bus stop and in the analysis road there are no bus lines operating during night. This fact, the absence of buses during night, is also the reason for the existence of these two completely separate clouds of operating points.

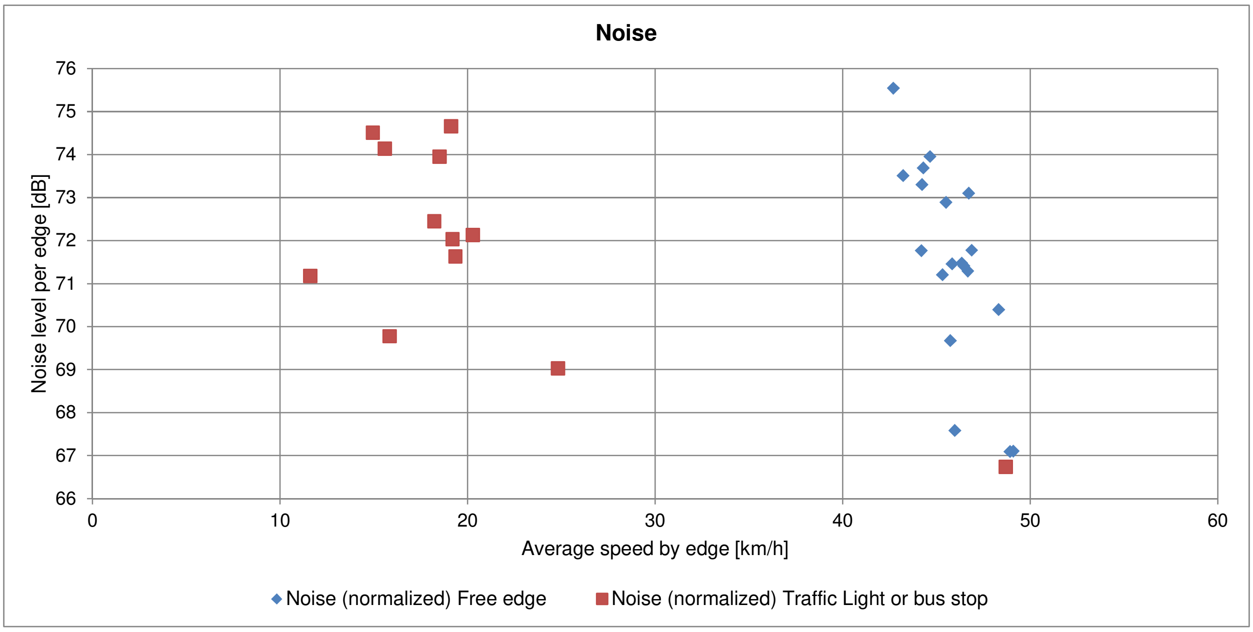

Figure 57 Normalized noise by edge – Base Line of night results – PHEMLight (Sumo)

5.1.3.1.4 Day, evening and night results:

Once briefly analyzed noise results for different periods, it seems to be interesting realizing a comparison of these three results. For these purpose, **Figure 58** and **Figure 59** represent the source line noise associated to the traffic flow along the road by average edge speed and by edge, for considering speed and acceleration and deceleration influence (related to traffic-light or bus stop presence) over noise.

Figure 58 represents the speed influence over noise source line levels by period.

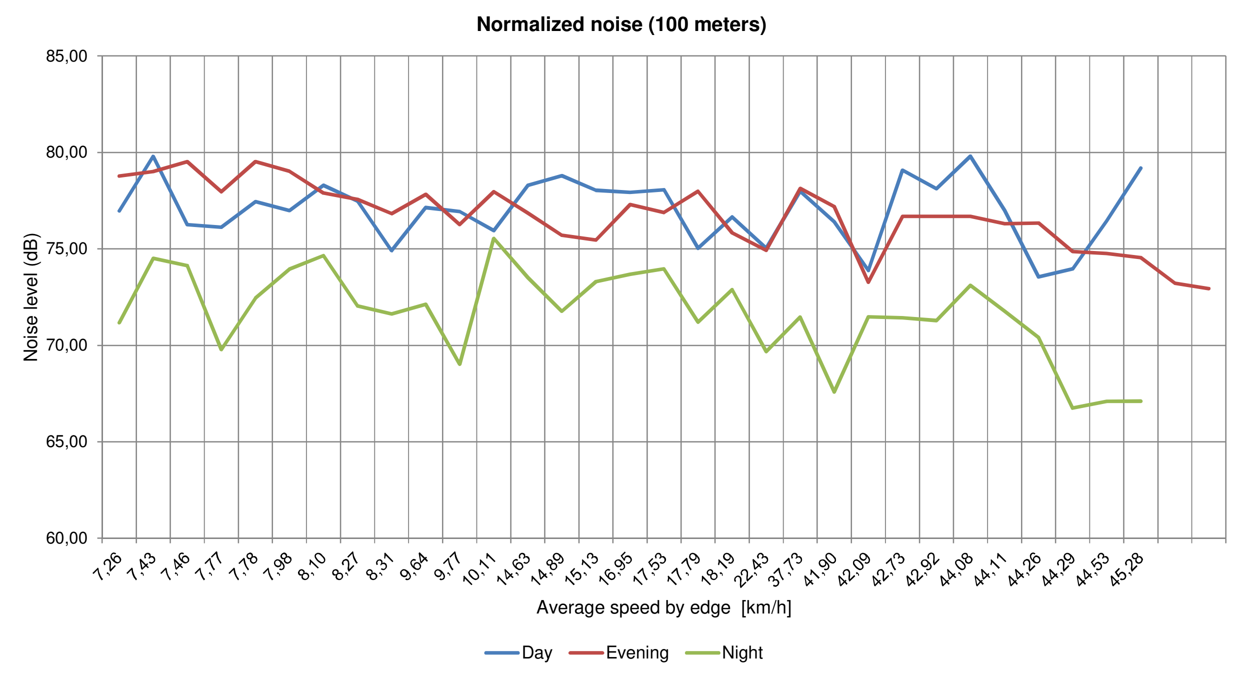

Figure 58– Noise base line under different periods and speed influence over results (Sumo)

Graphs show that for noise source line emission level, the flow density along the road results being the most influence parameter, thus difference obtained between night period results and the rest.

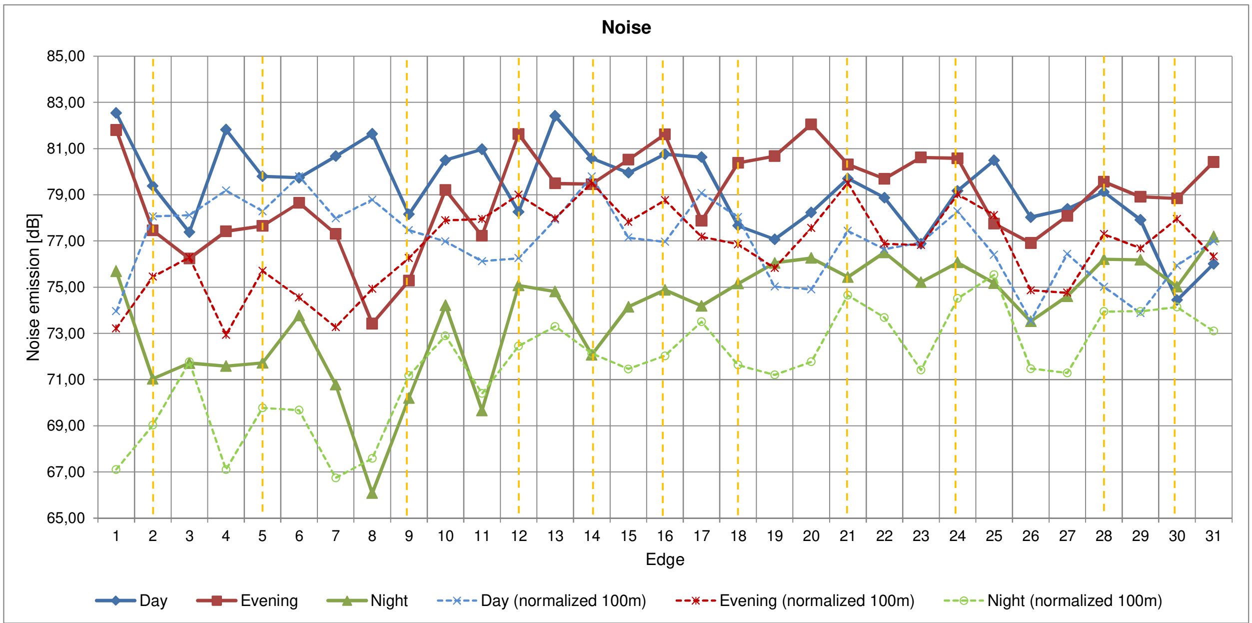

Figure 59– Noise base line under different periods – Results by edge ((Sumo)

5.2 Comparison models

5.2.1 Fuel Consumption and emissions - PHEMLIGHT

The PHEMLight model is a simplification of the model PHEM (Passenger Car and Heavy Duty Emission Model) to be integrated into traffic models [19].

PHEMLight calculates fuel consumption and pollutant emissions of vehicles on the basis of vehicle data to be entered for various driving cycles[8] on basis of characteristic emission curves and vehicle longitudinal dynamics. Since the vehicle longitudinal dynamics model calculates the engine power output and speed from physical interrelationships, any imaginable driving condition can be illustrated by this approach. The simulation of different payloads of vehicles in combination with road longitudinal gradients and variable speeds and accelerations can thus be illustrated by the model.

PHEMLight offers a very extensive database of previously measured vehicles and engines for the calculation of traffic emissions in road networks. This data is compiled as average vehicles, which illustrates the vehicle categories of passenger, light duty and heavy duty vehicles with Otto and diesel engines from EURO 0 to EURO 6c for each engine. Also provided are data for hybrid and battery electric vehicles. The user needs to enter either only the speed curves.

The database for the average vehicles in PHEMLight is identically to PHEM. The emission curves were generated by PHEM.

5.2.1.1 Theoretical models

The PHEMLight model calculates the necessary **engine power output** for the actual second for a driving cycle from the driving resistances and drivetrain losses. The emissions are then interpolated from **emission curves** in the normalised format according to the current engine power output.

Apart from **emission curves**, all of the vehicle data required for calculating the **engine power output** has to be predefined for the model. This database is currently available for the vehicle categories shown *Table 20* and was parameterised by the PHEM vehicle database. As in PHEM case happens, the difference vehicle size classes are currently only enabled for light duty and freight vehicles. For all the other vehicle categories, there is only an "average size".

5.2.1.1.1 Calculation of power output

For the most accurate calculation of power output, the most important parts of power output under real operating. In detail, these are rolling and air **resistance**, **acceleration** and road **gradient**, **transmission losses** as well as **power demand of auxiliaries**. Equations needed for the approach shown below.

<u>Driving power in the cycle:</u>

$$P_e = \frac{P_{roll} + P_{air} + P_a + P_{grd}}{\eta} + P_{aux} \qquad (5\text{–}1)$$

Where

η Efficiency due to transmission losses. This parameters takes the value of 0,9 for all vehicles classes excluded "heavy duty vehicle – city bus" which have an efficiency from 0,8.

[8] *Speed curve and road longitudinal gradient over time.*

P_{roll}, P_{air}, P_a, P_{grd} Individual parts of power output.

Power to overcome rolling resistance in [W]

$$P_{roll} = (m_{vehicle} + m_{load}) \cdot g \cdot (Fr_0 + Fr_1 \cdot v + Fr_4 \cdot v^4) \cdot v \quad (5\text{–}2)$$

Where,

$m_{vehicle}$	Vehicle mass [kg]
m_{load}	Vehicle loading [kg]
v	Vehicle speed [m/s]

Power to overcome air resistance in [W]

$$P_{air} = C_w \cdot A_{cross} \cdot \frac{\rho}{2} \cdot v^3 \quad (5\text{–}3)$$

Where

C_w	Aerodynamic coefficient
A_{cross}	Cross section area [m^2]
ρ	Air density [kg/m^3]

Acceleration power in [W]

$$P_a = (m_{vehicle} \cdot \Lambda_v + m_{rot,wheels} + m_{load}) \cdot a \cdot v \quad (5\text{–}4)$$

Where

a	Vehicle acceleration [m/s^2]
Λ_v	Rotating mass factor [-]

Power to overcome the road gradient [W]

$$P_{grd} = (m_{vehicle} + m_{load}) \cdot gradient \cdot 0{,}01 \cdot v \quad (5\text{–}5)$$

Power consumption of auxiliaries [W]

$$P_{aux} = P_0 \cdot P_{rated} \quad (5\text{–}6)$$

Where

P_0	Ratio of power consumption of auxiliaries to the rated power of the internal combustion engine [-]
P_{rated}	Rated power of the internal combustion engine

5.2.1.2 Implementation in scenario0 and Sumo comparison

In order to compare the theoretical model described above with Sumo simulations. Equations have been particularized for a vehicle typology PC_G_EU4 (*Table 18*) which represent a significant part of the total fleet which drives along the road. Also, the procedure to determine emissions and fuel consumption through this theoretical model is explained:

1. Available data for each vehicle emission model are included in PHEMLight database. This data base particularized for PC_G_EU4 is presented below in excel format because the theoretical model has been implemented also in an excel file (one excel file by vehicle typology included in PHEMLight).

Vehicle				*Engine*			
Vehicle category		PC		Engine rotational inertia		0,5	kg*m2
Fueltype		G		Wheels equivalent rotational inertia		40	kg
Emission standard*3		EU4		Gearbox rotational inertia		0,06	kg*m2
Vehicle mass	m_vehicle	1235	kg	Auxiliaries base power demand	P_0	0,015	normalized
Vehicle loading	m_load	50	kg	Engine rated power	P_rated	72	kW
		0,3113		Engine rated speed		5565	rpm
Cross section área	Cd	2,11756	m^2	Engine idling speed		798	rpm
Drive train efficiency	η	0,9					
Air density	ρ	1,2	kg/m3				
Acceleration of gravity	g	9,8	m/s2				

Figure 60– PHEMLight theoretical model. Input data (Vehicle and engine)

Rolling resistence coefficients		*Transmission*			*Power nominal values*	
Fr0	0,009	Loss factor	0,3		P_n_max_v0	5
Fr1	0,00005	Wheel effective diameter	0,6064		P_n_max_p0	0,15
Fr2	0	Axle ratio	4,0826	m	P_n_max_v1	40
Fr3	0	*Transmission gears*			P_n_max_p1	0,8
Fr4	1,6E-09	1	3,6298			
		2	2,0523			
		3	1,3801			
		4	1,0477			
		5	0,8423			
		6	0			
		c Gearshift model (Version fast driver)				
		c shift up at ratio rpm/rated rpm in actual gear greater than	0,768717			
		c shift down when rpm/rated rpm in lower gear is higher than	0,5802642			
		c Gearshift model (Version economic driver)				
		c shift up at ratio rpm/rated rpm in higher gear greater than	0,5288679			
		c Shift down when ratio rpm/rated rpm in actual gear is lower than	0,4860377			

Figure 61– PHEMLight theoretical model. Input data (Rolling resistance coefficients, transmission and power nominal values)

Operative conditions

Vehicle speed (km/k)	gear ratio [-]	rotational mass factor [-]
0	3,6298	2,008095
12,31168	3,6298	2,008095
29,96561	2,0523	1,316293
44,09933	1,3801	1,145397
69,54142	1,0477	1,077003
103,4718	0,08423	1,053688

n_norm	pe_drag_norm
0	-0,015
0,002	-0,015
0,05	-0,017
0,1	-0,02
0,2	-0,028
0,3	-0,039
0,4	-0,05
0,5	-0,063
0,6	-0,078
0,7	-0,098
0,8	-0,121
0,9	-0,145
1	-0,169
1,1	-0,198
1,2	-0,232

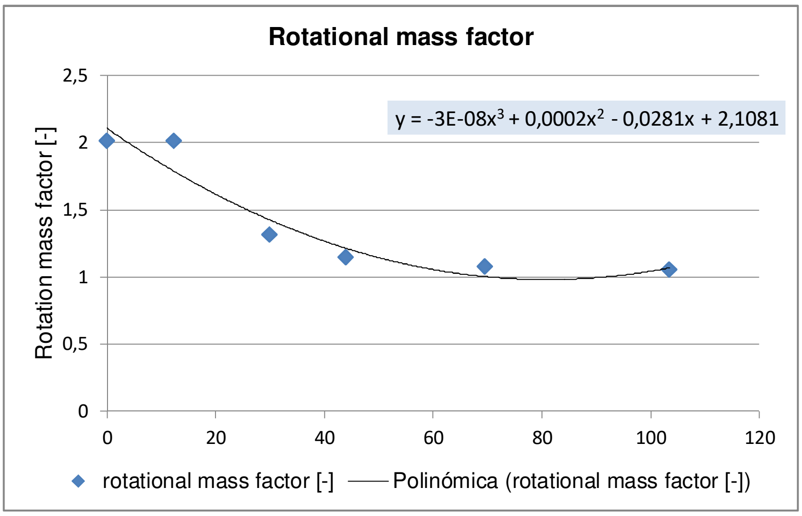

Figure 62– PHEMLight theoretical model. Input data (Operative conditions)

These exposed data, in addition to the driving cycle (speed-time) obtained through the simulation of the vehicle driving along the road in Sumo, are the input data needed to calculate the power output, through equation (5-1).

Figure 63 shows driving cycle obtained for a PC_G_EU4 driving along the simulated road. The vehicle is 10 minutes driving until arriving to the final node.

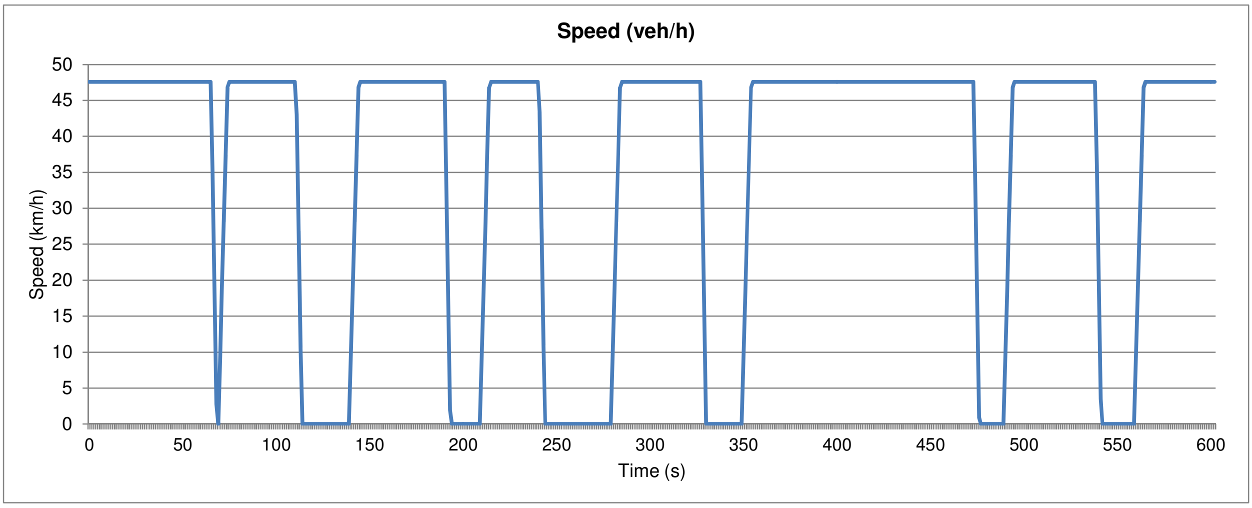

Figure 63– PC_G_EU4 driving along the road. Driving cycle

Figure 63 represents a very constant speed profile along time, just disturbed due to traffic lights presence[9]. This is consequence of the driving model chosen in Sumo for the simulation. In this case, the chosen model was Krauß model.

2. Output power calculated though implementing theoretical model equations (*5-1,5-2,5-3,5-4, 5-5, 5-6*)

[9] *If a public transport vehicle would be represented, then the speed profile would be disturbed not just due to traffic lights, but also due to bus stops.*

including base data associated to the analysed vehicle (*Figure 60, Figure 61, Figure 62*). A set data corresponding to the first traffic light located in the road, which is been represented in **Figure 64**, in order to observe acceleration and deceleration effects over the output power.

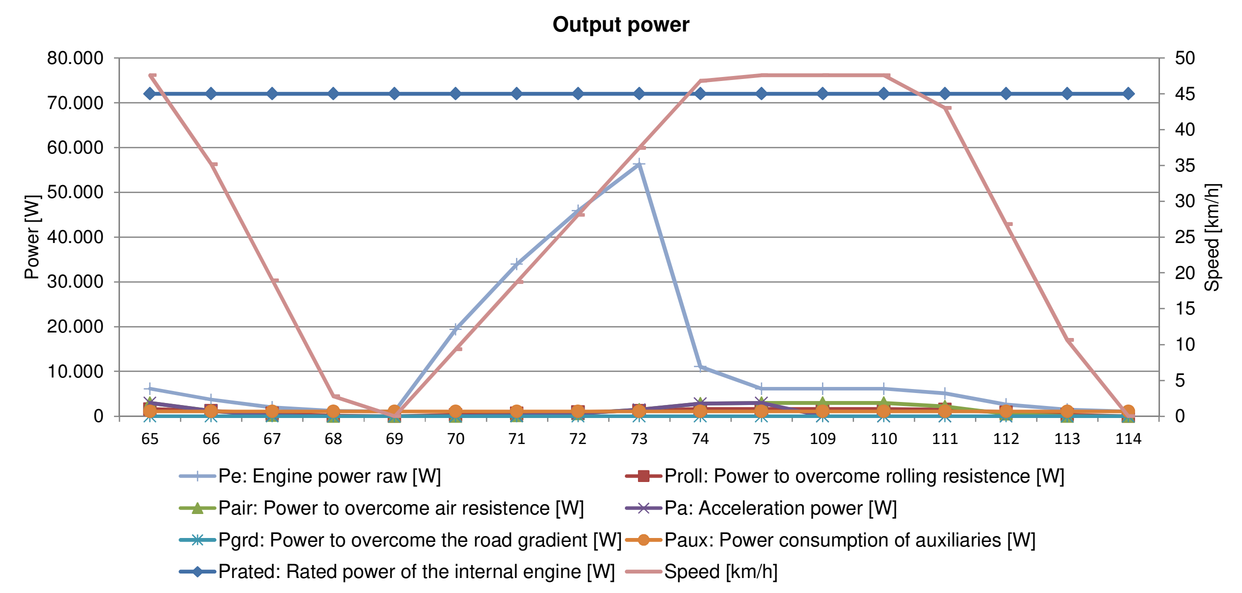

Figure 64– PC_G_EU4 Output power associated to a deceleration and acceleration period (first traffic light)

Table 39 includes represented values within Figure 64.

Table 39 Output power associated to a deceleration and acceleration period (first traffic light)

t [s]	v [m/s]	grd [%]	a [m/s^2]	v [km/h]	P_{roll} [W]	P_{air} [W]	P_a [W]	P_{grd} [W]	P_{aux} [W]	P_e [W]	Pr_{ated} [W]
65	13,22	0	0	47,59	1.616,49	2.935,49	0	0	1.080	6.137,77	72.000
66	9,77	0	0	35,17	1.169,20	1.184,87	0	0	1.080	3.695,63	72.000
67	5,27	0	0	18,97	614,86	185,96	0	0	1.080	1.969,79	72.000
68	0,77	0	0	2,77	87,64	0,58	0	0	1.080	1.178,03	72.000
69	0	0	2,6	0	0	0	0	0	1.080	1.080,00	72.000
70	2,6	0	2,6	9,36	298,94	22,33	16.158	0	1.080	19.390,68	72.000
71	5,2	0	2,6	18,72	606,45	178,65	28.800	0	1.080	33.952,21	72.000
72	7,8	0	2,6	28,08	922,92	602,94	38.795	0	1.080	45.880,87	72.000
73	10,4	0	2,6	37,44	1.249,26	1.429,18	47.009	0	1.080	56.288,10	72.000
74	13	0	0,22	46,80	1.587,27	2.791,37	4.595	0	1.080	11.050,48	72.000
75	13,22	0	0	47,59	1.616,49	2.935,49	0	0	1.080	6.137,77	72.000
76	13,22	0	0	47,59	1.616,49	2.935,49	0	0	1.080	6.137,77	72.000
77	13,22	0	0	47,59	1.616,49	2.935,49	0	0	1.080	6.137,77	72.000
78	13,22	0	0	47,59	1.616,49	2.935,49	0	0	1.080	6.137,77	72.000
79	13,22	0	0	47,59	1.616,49	2.935,49	0	0	1.080	6.137,77	72.000
109	13,22	0	0	47,59	1.616,49	2.935,49	0	0	1.080	6.137,77	72.000
110	13,22	0	0	47,59	1.616,49	2.935,49	0	0	1.080	6.137,77	72.000
111	11,95	0	0	43,02	1.449,20	2.168,16	0	0	1.080	5.099,29	72.000
112	7,45	0	0	26,82	879,77	525,36	0	0	1.080	2.641,25	72.000
113	2,95	0	0	10,62	339,83	32,62	0	0	1.080	1.493,83	72.000
114	0	0	0	0	0	0	0	0	1.080	1.080,00	72.000

3. Once the output power has been calculated for the simulated driving cycle of the vehicle, next step consists on obtaining emissions and fuel consumption associated to each operating point. Fuel

consumption and emission curves are available in PHEMLight database for this purpose.

Fuel consumption

a. The fuel consumption is stored over the normalised engine power output. **Figure 65** shows the fuel consumption curve for the analysed PC_G_EU4 vehicle:

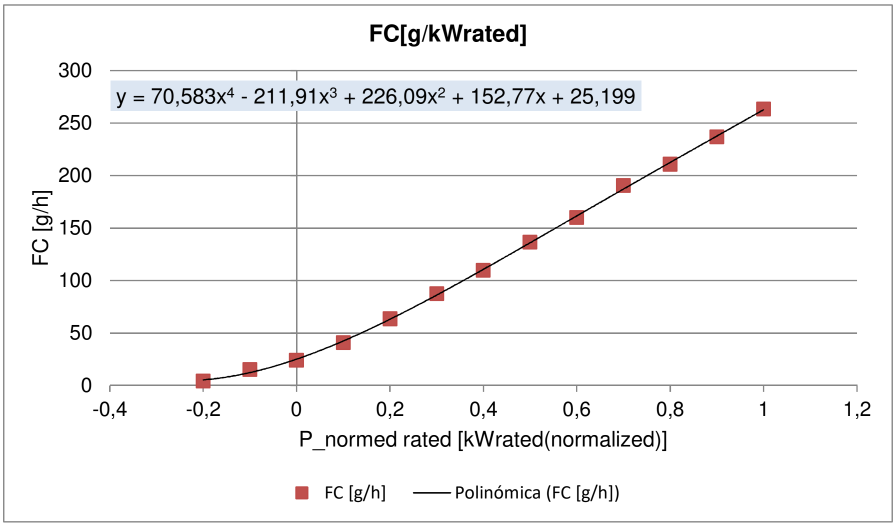

Figure 65– PC_G_EU4 Fuel consumption curve

The normalized engine power output has been calculated following this equation below:

$$P_{rated_{normed}} = \frac{(P_e - P_{aux})}{\eta \cdot P_{rated}} \tag{5–7}$$

a. By replacing normalised engine power output associated to each operating point within obtaining regression equation, it is possible to calculate the fuel consumption associated to each operating point of the driving cycle.

Fuel consumption is also an output obtained through Sumo simulation, so the next step consists on comparing results obtained by implementing the theoretical PHEMlight model or obtaining values from Sumo simulation.

Values obtained from fuel consumption curve are in [g/h], while values obtained in Sumo simulation are in [ml/s], so the decision to standardize results into [ml/s]. The following equation will be apply for this purpose:

$$FC\ [ml/s] = \frac{FC\ [g/h]}{3600 \cdot \rho_F}, \qquad (5–8),$$

where is the density of the fuel, in this case, gasoline (0,680g/c.c).

Figure 66 shows the comparison between fuel consumption over the driving cycle obtained through Sumo simulation and through the implementation of regression equation over driving cycle operating points.

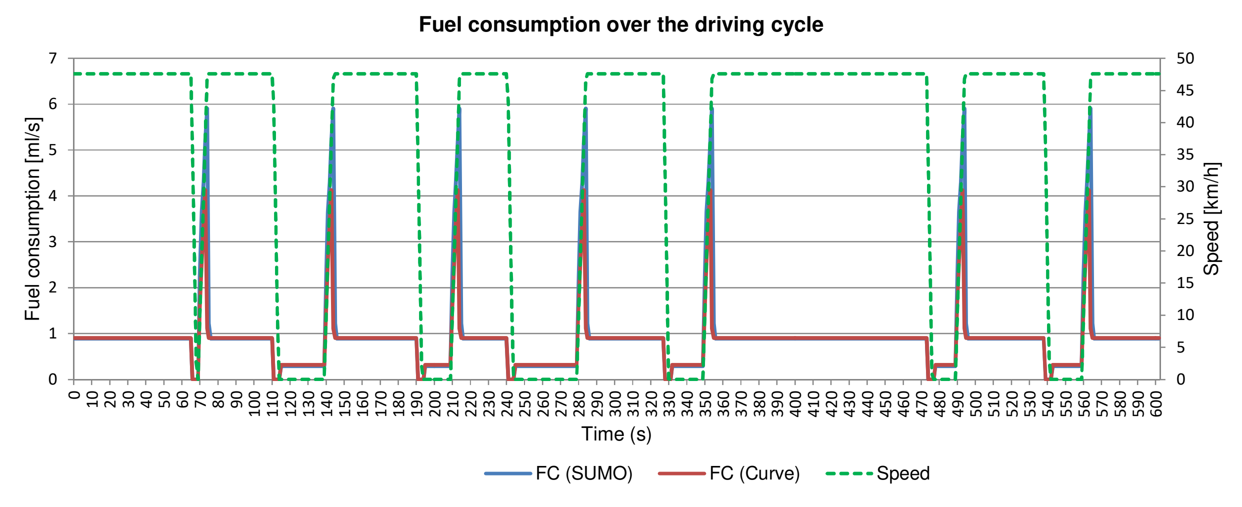

Figure 66– PC_G_EU4 Fuel consumption over driving cycle. Sumo and theoretical model results comparison

As it can be observed from Figure 66, both results are very similar following perfectly different driving cycle operating points: deceleration, acceleration, idle and constant speed operation points.

Figure 67 shows the fuel consumption over a particular period of the overall driving cycle represented in Figure 66 for a better comprehension of the fuel consumption along different operating points.

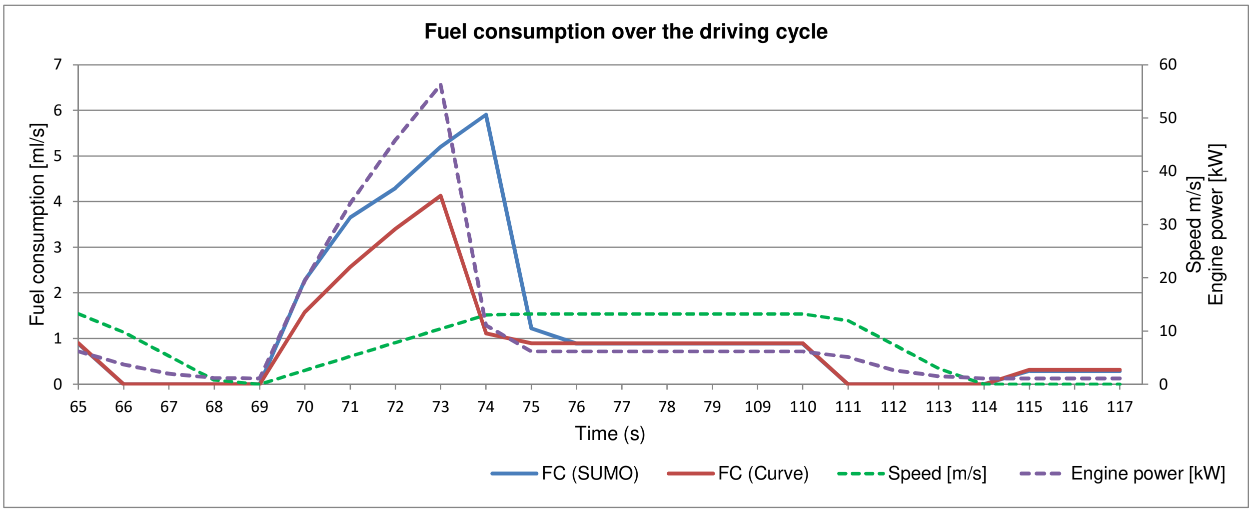

Figure 67– PC_G_EU4 Fuel consumption over first deceleration and acceleration period . Sumo and theoretical model results comparison

Figure 67 also shows that the theoretical model implemented do not accurately follow simulation results during acceleration periods. However, these acceleration periods do not represent the most periods of the driving cycle.

- Accumulate fuel consumption values over the driving cycle are the following:

	Sumo	Theoretical model
Fuel consumption [ml]	504,60	559,09

- Accumulate fuel consumption values over the acceleration and deceleration period, represented in *Figure 79,* are the following

	Sumo	Theoretical model
Fuel consumption [ml]	20,95	29,66

Emissions

Emission calculations follow same procedure than fuel consumption:

b. The emissions for NOx, HC, CO, PM, PN and NO are stored over the normalised engine power normalised over the driving engine power at 70 km/h speed and 0.45 m/s^2. CO2 is been calculated as a correction factor over fuel consumption [g/h]. **Figure 68** shows emission curves for the analysed PC_G_EU4 vehicle:

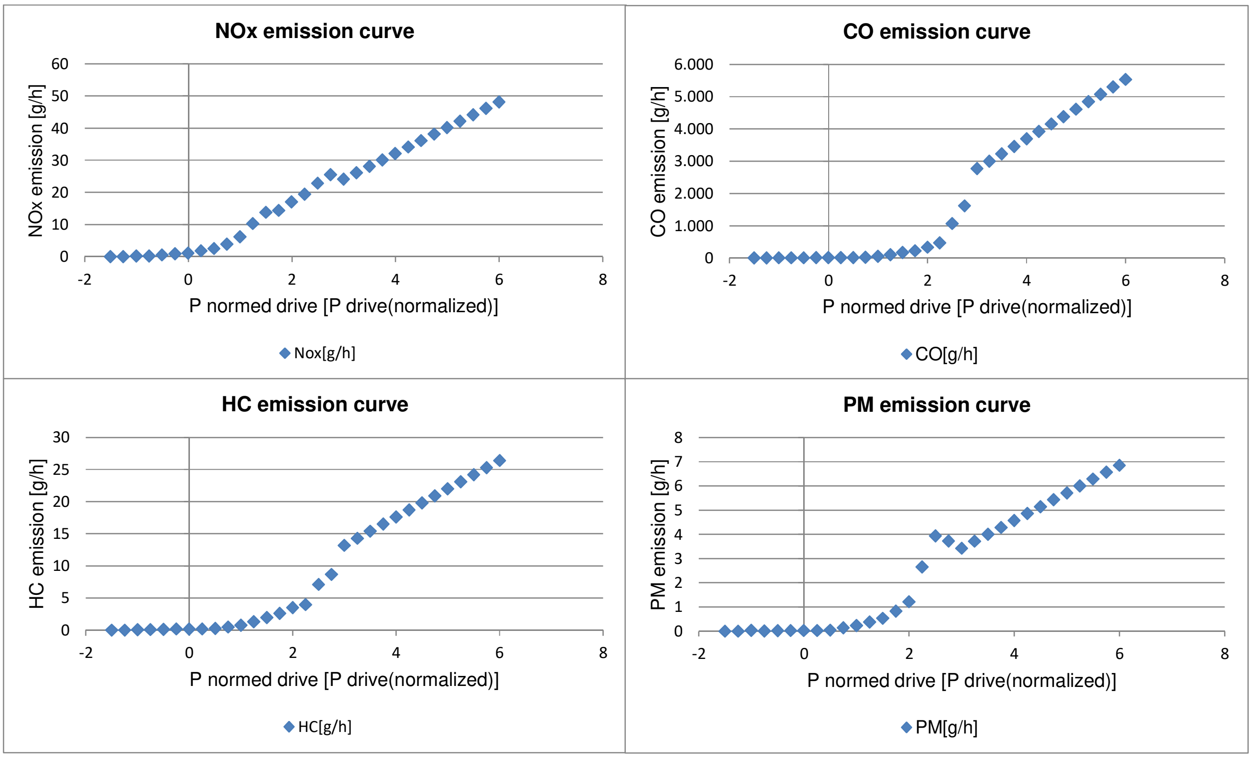

Figure 68– PC_G_EU4 NOx, CO, HC and PM emission curve

The output engine power normalised over the driving engine power at 70 km/h speed and 0.45 m/s^2 (P_{drive}) is been calculated following this equation below:

$$P_{drive_{normed}} = \frac{(P_e - P_{aux})}{\eta \cdot P_{drive}} \qquad (5–9)$$

b. By replacing each operating point ($P_{drive(normed)}$) within the emission curve, it is possible to calculate the emissions associated to each operating point of the driving cycle.

Figure 69 shows the comparison between fuel consumption over the driving cycle obtained through Sumo simulation and through the implementation of regression equation over driving cycle operating points.

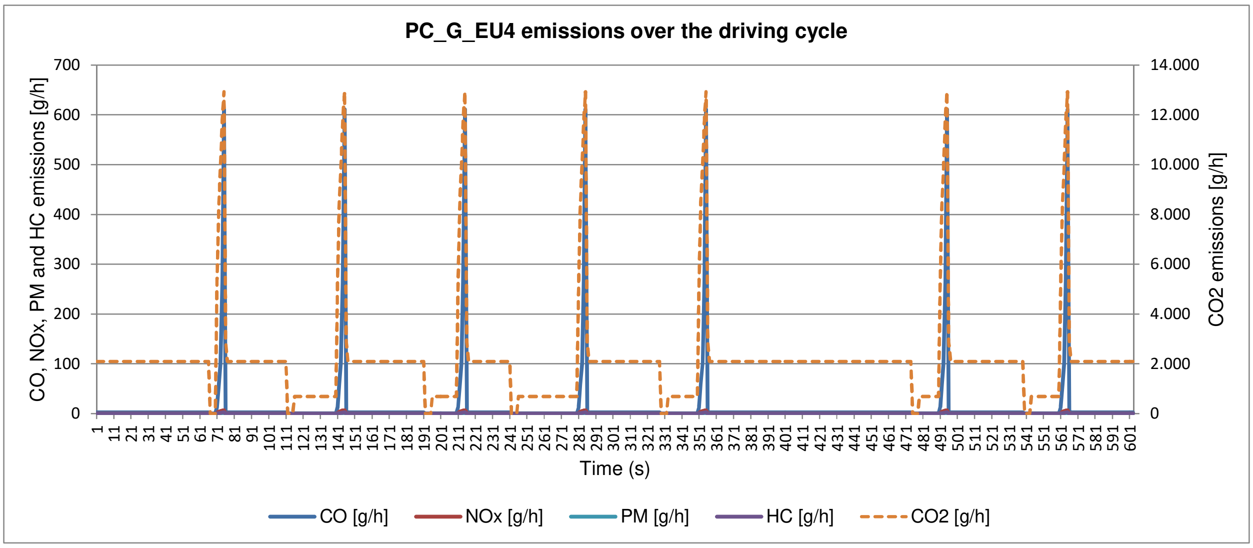

Figure 69– PC_G_EU4 Emissions over driving cycle

As it can be observed from Figure 69, both results are very similar following perfectly different driving cycle operating points: deceleration, acceleration, idle and constant speed operation points.

Figure 70 shows the vehicle emission over a particular period of the overall driving cycle represented in Figure 81 for a better comprehension of the fuel consumption along different operating points.

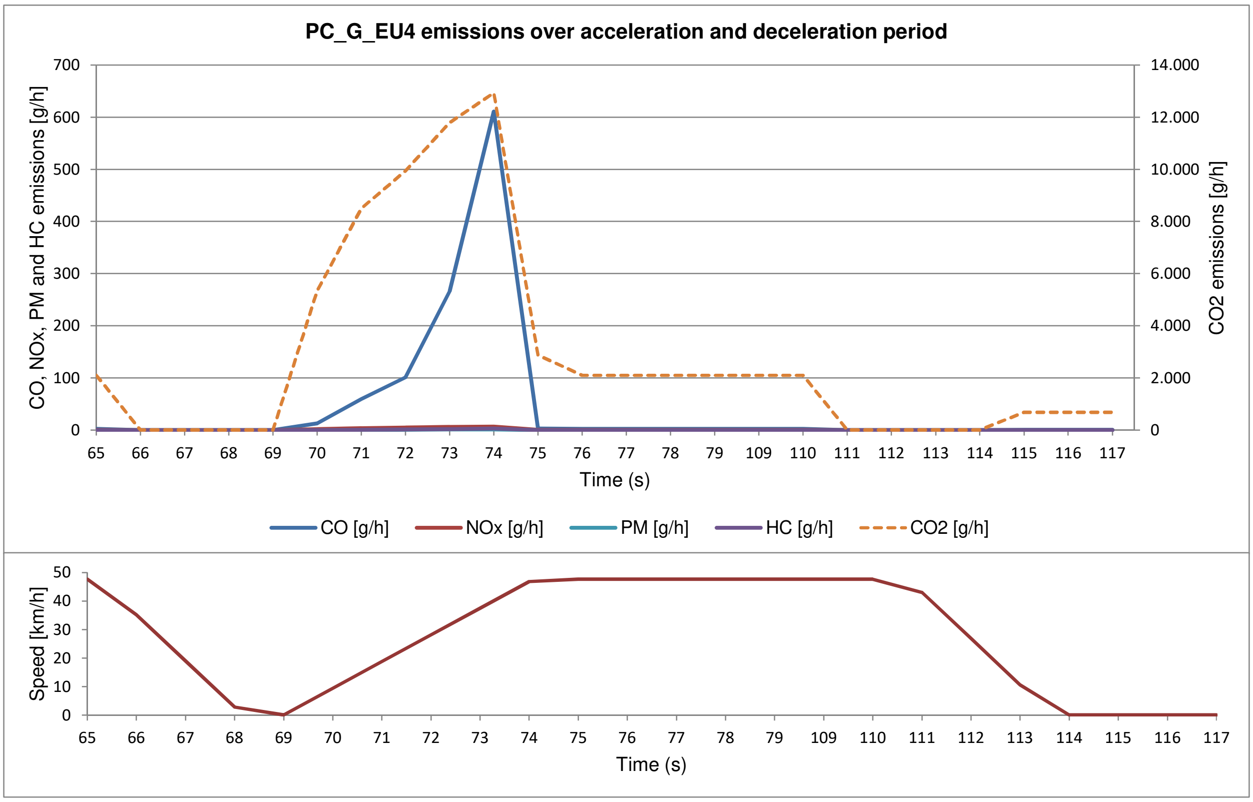

Figure 70– PC_G_EU4 Vehicle emissions over first deceleration and acceleration period and speed profile.

As it is been observed from Figure 70, the most significant emissions are CO_2, so the evaluation of the emissions associated to different simulations (0) has been realized attending to CO_2 emissions. Otherwise, it is observed that the second most relevant emissions associated are CO emissions, which increase, significantly, when the vehicle is under acceleration conditions.

Due Figure 69 and Figure 70 do not show NOx, PM and HC emissions over the driving cycle, **Figure 71** shows how they vary along the specified speed profile

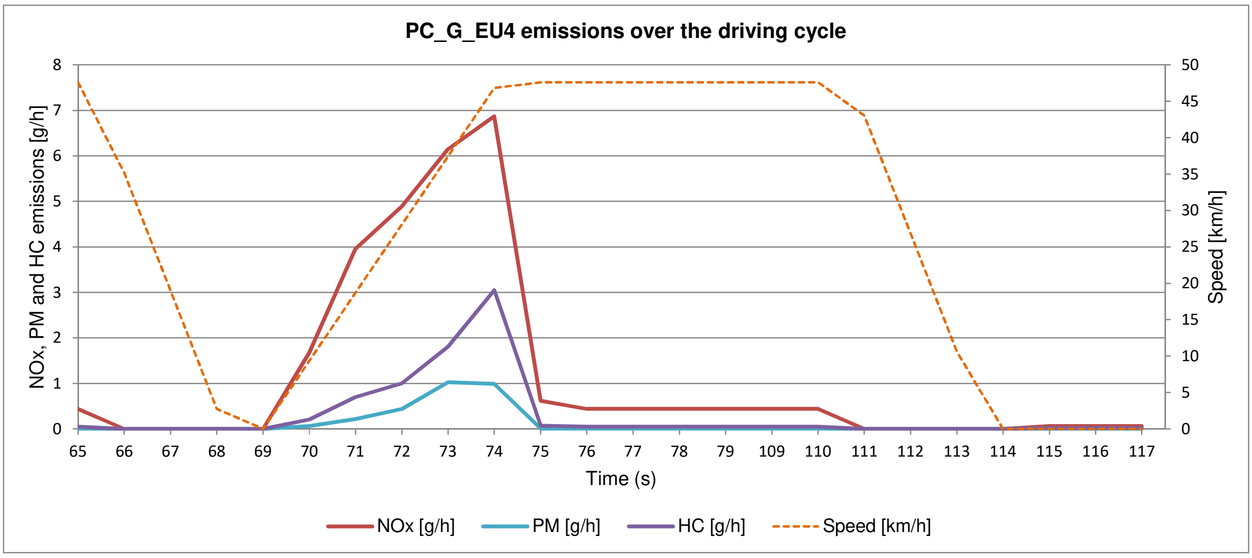

Figure 71– PC_G_EU4 NOx, PM and HC over first deceleration and acceleration period and speed profile.

As it is observed from Figure 71 the behavior of all analyzed emissions is very similar; all of them increase significantly under acceleration conditions and the decrease for a constant velocity, being almost zero under deceleration and idle conditions.

Accumulate values of emissions over the driving cycle are been shown below:

- Accumulate emissions values over the driving cycle are the following:

	CO_2	CO	HC	NO_X	PM_X
Emissions [mg]	362.518,88	2.364,30	19,69	99,26	6,49

- Accumulate emission values over the acceleration and deceleration period are the following:

	CO_2	CO	HC	NO_X	PM_X
Emissions [mg]	18.918,04	298,21	2,01	7,62	0,78

5.2.2 Noise – Cnossos

A theoretical model has been developed based on CE projects: HARMONOISE and IMAGINE, both them based on the combination of:

- Source models
- Propagation paths
- Noise propagation

The first followed step has been the generation of the source module. Due to have used the software SUMO for the definition of traffic flow and the generation of the energy module, a deep study has been done to explore possibilities of this software in the acoustics field. The conclusion is that SUMO uses the "Harmonoise Engineering Model"[20] developed in the context of CE IMAGINE [21] project, to determine the noise level of the edges[10], these edges are divisions of the completed analysed road, this way SUMO characterises the acoustics of a traffic flow, based on the directional source sound power levels of single moving equivalent vehicles. No more information can be extracted from SUMO tutorial [22] . So, to be able for controlling variables of influence in the noise models, the interest in implementing an acoustical theoretical model based on CNOSSOS[11] [10].

5.2.2.1 Theoretical models

The noise theoretical model consists on the progressive implementation of the CNOSSOS theoretical model[23], firstly solving source models followed by propagation paths definition and attenuation models.

However, within this project just source models are analyzed and implemented due its relation to road traffic. Propagation paths definition and attenuation models need to stablish several considerations as well as realizing a more exhaustive definition of the road geometry (facades, surfaces materials, green areas, meteorological conditions…), which is out of the project scope.

Source models are based on the calculation of the directional sound power per meter per frequency band[12] of the traffic noise determined by the **source line.** It is also possible to determine frequency band results at the corresponding frequency interval.

The following table summed up the variables of influence in the theoretical CNOSSOS Model.

---

[10] *In the Harmonoise Engineering module, the road line is treated as a source line which characterises the the particular traffic flow of the road.*

[11] *An harmonized method developed in the framework of CE projects HARMONOISE and IMAGINE.*

[12] *CNOSSOS is valid for determining Noise in frequency range from 125 Hz to A kHz for road traffic noise. Calculations are made in octave bands.*

Table 40 Variables of influence in the acoustical source model

ID	VI	Definition	Availability
1	m	Category of vehicle	Introduced by user
2	Ai	A-weighting correction for 1/3 octave band results.	Tabulated and implemented in tool IEC-61672-1
3	$\text{length}_{\text{line}}$	Legth of the evaluated source line	Calculated by the tool from nodes previously introduced by user.
4	Q_m	Traffic flow (vehicles per hour)	Introduced by user
5	V_m	Average speed per category of vehicle (km/h)	Calculated by the tool from the interaction with SUM.
6	V_{ref}	Reference speed per category of vehicle (km/h)	Fixed value, 70 km/h.
7	x	Distance in meters from the end of line to the nearest intersection (traffic light or roundabout).	Calculated by the tool from net data

Calculation procedure is shown below:

The directional sound power of the traffic noise:

$$L_{w',\text{line}} = 10 \cdot \log\left(\sum_m 10^{\frac{L_{w',\text{line},m}}{10}}\right) \tag{5–10}$$

Where

m Category of the vehicle and bus line[13] indicator.

$L_{w',\text{line},m}$ The directional sound power per metre per category of vehicle of the traffic noise.

The directional sound power per category of vehicle of the traffic noise:

$$L_{w',\text{line},m} = 10 \cdot \log\left(\frac{\text{length}_{\text{line}}}{1000} \cdot 10^{\frac{L_{w',m}}{10}}\right) \tag{5–11}$$

Where

$L_{w',m}$ The directional sound power per line per category of vehicle of the traffic noise.

$\text{length}_{\text{line}}$ Legth of the evaluated source line.

[13] It is not possible the evaluation of buses in conjunction, due to particular traffic characteristics of each bus-line.

<u>The directional sound power per metre per category of vehicle of the traffic noise:</u>

$$L_{w',m} = 10 \cdot \log\left(\sum_i 10^{\frac{L_{w',m,i+Ai}}{10}}\right) \quad (5\text{–}12)$$

Where

$L_{w',m,i}$ The directional sound power per metre per category of vehicle per frequency band of the traffic noise. The CNOSSOS-EU method is valid for frequency range from 125 Hz to 4kHz.

Ai A-weighting correction according to **IEC-61672-1**.

Table 41 A-weighting correction according to IEC-61672-1

Frequency (Hz)	31,5	63	125	250	500	1kHz	2kHz	4kHz	8kHz	16kHz
Ai (dB)	-39,4	-26,2	-16,1	-8,6	-3,2	0	1,2	2	-1,1	-6,6

Calculations are performed in octave bands. Based on these 1/3 octave band results, the A-weighted sound pressure level $L_{w',line,m}$ is computed by summation over all frequencies.

<u>The directional sound power per meter per category of vehicle per frequency band of the traffic noise:</u>

$$L_{w',m,i} = L_{w,m,i} + 10 \cdot \log\left(\frac{Q_m}{1000 \cdot V_m}\right) \quad (5\text{–}13)$$

Where

$L_{w,m,i}$ Instantaneous directional sound power per category of vehicle per frequency band of a single vehicle.

Q_m Traffic flow (vehicles per hour).

V_m Average speed per category of vehicle (km/h).

<u>Instantaneous directional sound power per category of vehicle per frequency band of a single vehicle</u>

$$L_{w,m,i} = 10 \cdot \log\left(10^{\frac{L_{w,m,i,R}}{10}} + 10^{\frac{L_{w,m,i,P}}{10}}\right) \quad (5\text{–}14)$$

Where

$L_{w,m,iR}$ Instantaneous directional sound power per category of vehicle per frequency band of a single vehicle.

$L_{w,m,i,P}$ Instantaneous directional propulsion noise produced by the driveline (engine, exhaust) of the vehicle, per a category of vehicle per frequency band of a single vehicle.

Instantaneous directional rolling Noise:

$$L_{w,m,i,R} = A_{m,i,R} + B_{m,i,R} \cdot \log\left(\frac{V_m}{V_{ref}}\right) + \Delta L_{W,R,i,m} \tag{5–15}$$

Where

$A_{m,i,R}$, $B_{m,i,R}$ Rolling noise coefficients per category of vehicle per octave band center frequency.

$\Delta L_{W,R,i,m}$ Correction on rolling due to specific road or vehicle conditions deviating from the reference conditions.

4. Rolling noise coefficients per category of vehicle per octave band center frequency:

Table 42 Rolling noise coefficients per category of vehicle

Frequency (Hz)	$A_{m,i,R}$					$B_{m,i,R}$				
	1	2	3	4a	4b	1	2	3	4a	4b
125	85,7	88,7	91,7	0	0	41,5	35,8	33,5	0	0
250	84,5	91,5	94,1	0	0	38,9	32,6	31,3	0	0
500	90,2	96,7	100,7	0	0	25,7	23,8	25,4	0	0
1000	97,3	97,4	100,8	0	0	32,5	30,1	31,8	0	0
2000	93,9	90,9	94,3	0	0	37,2	36,2	37,1	0	0
4000	84,1	83,8	87,1	0	0	39	38,3	38,6	0	0

5. Correction on rolling due to specific road or vehicle conditions deviating from the reference conditions:

$$\Delta L_{W,R,i,m} = \Delta L_{W,R,road,i,m} + \Delta L_{W,R,acc,i,m} + \Delta L_{W,R,temp,i,m} \tag{5–16}$$

Instantaneous directional propulsion Noise:

$$L_{w,m,i,P} = A_{m,i,P} + B_{m,i,P} \cdot \frac{V_m - V_{ref}}{V_{ref}} + \Delta L_{W,P,i,m} \tag{5–17}$$

Where

$A_{m,i,P}$,$B_{m,i,P}$ Propulsion noise coefficients per category of vehicle per octave band center frequency.

$\Delta L_{W,P,i,m}$ Correction on propulsion noise due to specific road or vehicle conditions deviating from the reference conditions.

1. Propulsion noise coefficients per category of vehicle per octave band center frequency:

Table 43 Propulsion noise coefficients per category

Frequency (Hz)	$A_{m,i,P}$	$B_{m,i,P}$

	1	2	3	4a	4b	1	2	3	4a	4b
125	89,2	96,5	100,6	87,5	97,2	7,2	4,7	3	7,4	5,9
250	88	98,8	101,7	89,5	92,7	7,7	6,4	4,6	9,8	11,9
500	85,9	96,8	101	93,7	92,9	8	6,5	5	11,6	11,6
1000	84,2	98,6	100,1	96,6	94,7	8	6,5	5	15,7	11,5
2000	86,9	95,2	95,9	98,8	93,2	8	6,5	5	18,9	12,6
4000	83,3	88,8	91,3	93,9	90,1	8	6,5	5	20,3	11,1

2. Correction on propulsion due to specific road or vehicle conditions deviating from the reference conditions:

$$\Delta L_{W,P,i,m} = \Delta L_{W,P,road,i,m} + \Delta L_{W,P,acc,i,m} + \Delta L_{W,P,temp,i,m} \quad (5\text{–}18)$$

5.2.2.2 Tool developed in Excel

Developed theoretical noise model, which inputs are Sumo defined parameters, is implemented in *Excel* as a module *("computer tool")* which allows the user to obtain the noise level of a traffic line under different scenarios (different configurations of traffic, fleet, geometrical conditions, meteorological conditions…) without having to simulate the traffic flow in SUMO. Accuracy of obtained results is verified as is explained in section *5.2.2.3*.

The noise module tool developed is divided in four different excel files: L_{day}, $L_{evening}$, L_{night} and L_{den}.

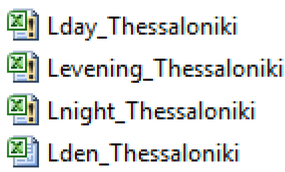

Figure 72– Noise module tool – Excel files

- L_{day}, $L_{evening}$, L_{night}: These files calculate the directional sound power of the traffic noise under day, evening and night conditions based on methodology purposed within CNOSSOS-EU (Kephalopoulos et al., 2012) *f*or the calculation of $L_{Aeq,LT}$ under different scenarios, marking out the relevance of traffic characteristics and road geometrical distribution in obtained results.
- L_{den}: This file calculates the indicator for the combination of day, evening and night conditions. The END [9] requires Member States to limit values for L_{den} and L_{night} and, when it is appropriate, for L_{day} and $L_{evening}$. These indicators are stablished the same way as $L_{Aeq,LT}$ but particularizing conditions for each periods, so if exposed scenarios follows same traffic distribution, meteorological conditions and road geometrical distribution, exposed values could be compared to threshold values in order to stablishes or not mitigation measures or purpose other design specifications for the road in the urban planning stage. If we do not consider attenuation effects due to propagation, the equivalent noise level due to a traffic source at a receiver point is the same than the noise level of the traffic flow. This means that $L_{Aeq,LT}$ is equal than $L_{w',line}$ for day, evening and night periods.

L_{day}, $L_{evening}$ and L_{night} calculation:

The Excel tool follows the procedure explained within the theoretical model described in 5.2.2.1.

Inputs data:

- Per period, edge and category of vehicle the following inputs are required for the calculation of the equivalent noise level:

Edge	9	
Input data:		
Vref (km/h)	70	70km/h CNOSSOS
Vm (km/h)	50,0243478	Vehicle speed = 3,6*lenght/traveltime
m	1	vehicle class
T (ºC)	20	Anual average temperature
k	1	(=1(crossing); =2(roundabout))
Slope (%)	0	The slope of the road gradient (should not vary more than 2% within a segment)
Qm (veh/h)	633	Traffic flow: Vehicles per category m per hour en el tramo
Lain legth (m)	79,9	Se toma del archivo NET
Road surface (*Insert number "1" to select the road surface*)		
Transversely brushed concrete	0	
Concrete with surface dressing 2/4	0	
Exposed agregated	0	
Drain asphalt 6/16	0	
2-layer drain asphalt 4/8-11/16	0	
SMA 0/6	0	
Surface dressing 4/8	0	
x	0	Associated to traffic light and roundaboutDistance from the end of the edge to the nearest traffic light or roundabout.
y	0	Associated to bus stops. If a bus line is analyzed, this variable takes the value of 10 in the next edge to that where a bus stop is placed. Otherwise the value is 1000

Figure 73– Input data per period, per vehicle and per edge of the road – Excel files

- Values recovered in Figure 73 are includes in tables per edge, for all vehicles categories. These tables are used by a Excel macro in order to realize a loop that takes values per row and copy them into the cells shown in Figure 72. Calculations are realized per iteration in the loop, obtaining $L_{w',line,m}$ *(The directional sound power per category of vehicle of the traffic flow).*

RUN MACRO m_4b									Inputs								Output
									Road surface								
edge	Vref (km/h)	Vm (km/h)	m	T (ºC)	k	Slope (%)	Qm (veh/h)	Lain legth (m)	Transversely brushed concrete	Concrete with surface dressing 2/4	Exposed agregated	Drain asphalt 6/16	2-layer drain asphalt 4/8-11/1	SMA 0/6	Surface dressing 4/8	x	Noise (dB)
1	70,00	50,04	4,00	20,00	1,00	0,00	216,00	721,97	0	0	0	0	0	0	0	568,51	70,80
10	70,00	50,05	4,00	20,00	1,00	0,00	216,00	135,54	0	0	0	0	0	0	0	201,64	63,53
11	70,00	50,07	4,00	20,00	1,00	0,00	216,00	84,43	0	0	0	0	0	0	0	201,64	61,48
12	70,00	50,03	4,00	20,00	1,00	0,00	216,00	183,31	0	0	0	0	0	0	0	0,00	64,84
13	70,00	50,05	4,00	20,00	1,00	0,00	216,00	141,53	0	0	0	0	0	0	0	98,60	63,72
14	70,00	50,06	4,00	20,00	1,00	0,00	216,00	98,60	0	0	0	0	0	0	0	0,00	62,15
15	70,00	50,05	4,00	20,00	1,00	0,00	216,00	185,89	0	0	0	0	0	0	0	189,33	64,90
16	70,00	50,03	4,00	20,00	1,00	0,00	216,00	192,76	0	0	0	0	0	0	0	0,00	65,06
17	70,00	50,04	4,00	20,00	1,00	0,00	216,00	117,04	0	0	0	0	0	0	0	170,99	62,89
18	70,00	50,05	4,00	20,00	1,00	0,00	216,00	224,94	0	0	0	0	0	0	0	0,00	65,73
19	70,00	50,05	4,00	20,00	1,00	0,00	216,00	305,31	0	0	0	0	0	0	0	353,09	67,06
2	70,00	50,04	4,00	20,00	1,00	0,00	216,00	158,73	0	0	0	0	0	0	0	0,00	64,22
20	70,00	50,03	4,00	20,00	1,00	0,00	216,00	281,01	0	0	0	0	0	0	0	200,44	66,70
21	70,00	50,06	4,00	20,00	1,00	0,00	216,00	119,86	0	0	0	0	0	0	0	0,00	63,00
22	70,00	50,04	4,00	20,00	1,00	0,00	216,00	191,13	0	0	0	0	0	0	0	286,98	65,02
23	70,00	50,05	4,00	20,00	1,00	0,00	216,00	239,56	0	0	0	0	0	0	0	286,98	66,01
24	70,00	50,02	4,00	20,00	1,00	0,00	216,00	143,26	0	0	0	0	0	0	0	0,00	63,77
25	70,00	50,01	4,00	20,00	1,00	0,00	216,00	91,82	0	0	0	0	0	0	0	91,82	61,84
…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…

Figure 74– Input data per day, per truck – Example of data base (Excel file) and results obtained per edge.

Intermediate calculations:

The directional sound power per category of vehicle per frequency band of the traffic noise is calculated taken into account rolling and propulsion noise coefficients as well as correction factor associated to rolling and propulsion conditions. An average value is calculated considering A-weighting factors associated to considered frequency bands and the time spent by vehicles in the road section considered by taken into account velocity and flow of vehicles of the specific category of vehicles.

m	1	Noise emission of a vehicle flow		Rolling noise					Propulsion noise				
Frecuency Hz	A-weighting Ai	LA'eq,line,i,m	Lw,i,m	LwR,i,m	Ar	Br	f(v)	ΔLwR,i,m	Lwp,i,m	Ap	Bp	f(v)	ΔLwP,i,m
125	-16,1	80,329	98,204	**79,636**	85,7	41,5	-0,146128	0	**98,143**	89,2	7,2	-0,2857	11
250	-8,6	78,994	96,869	**78,816**	84,5	38,9	-0,146128	0	**96,800**	88	7,7	-0,2857	11
500	-3,2	77,356	95,230	**86,445**	90,2	25,7	-0,146128	0	**94,614**	85,9	8	-0,2857	11
1000	0	77,872	95,747	**92,551**	97,3	32,5	-0,146128	0	**92,914**	84,2	8	-0,2857	11
2000	1,2	78,505	96,380	**88,464**	93,9	37,2	-0,146128	0	**95,614**	86,9	8	-0,2857	11
4000	1	74,325	92,199	**78,401**	84,1	39	-0,146128	0	**92,014**	83,3	8	-0,2857	11
	LA'eq,line,m	83,5872069											

Noise emission of a traffic flow

Lw'line,m=1 **72,612675** Db

This value corresponds to the sum of the sound emission of the individual vehicles in the traffic flow, taking into account the time spent by the vehicles in the road section considered.

Figure 75– Methodology for calculating the directional sound power per category of vehicle per edge – Excel file (example)

Correction coefficients, associated to rolling and propulsion conditions, are calculated in the excel tool, implementing equations considering road gradients, acceleration and deceleration due to traffic lights and road surfaces:

No correction for category Category 4: Powered two-wheleers

Input data			Speed correction	m
Vm	**50**	km/h		
Vref	**70**	km/h	-0,14612804	**1**
T	**20**	ºC		

CORRECTION

Hz	ΔLwr
125	1,607
250	1,607
500	1,607
1000	0,507
2000	-2,893
4000	-3,693

category 1: Light motor vehicles

	Hz	Transversely brushed concrete	Concrete with surface dressing 2/4	Exposed agregate	Drain asph alt 6/1	2-layer drain asphalt 4/8-11/16	SMA 0/	Surface dressing 4/
α	125	0	0	0	0	0	0	0
	250	2,6	2,1	1	0	-1,6	0	5,1
	500	2,4	3	1,2	0	-3,3	0	5,6
	1000	1,2	3,5	1,9	-1,1	-4,3	-2	4,6
	2000	2,4	0,1	0,8	-4,5	-6,9	-2,9	-1,5
	4000	0	-0,8	0	-5,3	-6,7	-2,2	-2,5
	β	6	-5	0	-11	-6	-5	-4
	A-weighted ε	1,4	2,7	1,3	-1,4	-4,6	-1,7	3,4
	Select	**0**	**0**	**0**	**1**	**0**	**0**	**0**

Coefficients selection

	Coefficients selection	Hz	ΔLwr
α	0	125	1,61
	0	250	1,61
	0	500	1,61
	-1,1	1000	0,51
	-4,5	2000	-2,89
	-5,3	4000	-3,69
β	-11		
A	-1,4		

category 2 y 3:Medium heavy and heavy vehicles

	Octave band frecuency Hz	Transversely brushed concrete	Concrete with surface dressing 2/4	Exposed agregate	Drain asph alt 6/1	2-layer drain asphalt 4/8-11/16	SMA 0/	Surface dressing 4/
α	125	0	0	0	0	0	0	0
	250	2,2	1,1	0	1	-0,3	0	2,5
	500	1,7	0,8	-0,2	-4,2	-5,7	-0,6	0,4
	1000	1,3	-0,9	-0,8	-4,5	-6,9	-1,6	-1
	2000	0,2	-2	-1,5	-3,3	-5,5	-1,2	-1,8
	4000	-1,3	-2	-1,9	-2,6	-4,4	-1,1	-2,1
	β	12	5	15	-6	-8	0	13
	A-weighted ε	1,1	-0,6	-0,8	-3,8	-5,8	-1,1	-0,7
	Select	**0**	**0**	**0**	**1**	**0**	**0**	**0**

Coefficients selection

	Coefficients selection	Hz	ΔLwr
α	0	125	0,88
	1	250	1,88
	-4,2	500	-3,32
	-4,5	1000	-3,62
	-3,3	2000	-2,42
	-2,6	4000	-1,72
β	-6		
A	-3,8		

Figure 76– Road surface – Rolling correction coefficients - Example

No correction for category Category 4: Powered two-wheleers

Input data

x	**96,1**	m	*m*	**1**
k	**1**	1 ó 2		

	k	k
	1	2
	Crossing	Roundabout
Coefficients for acceleration and deceleration — Category m	CR	CR2
1	-4,5	-4,4
2	-4	-2,3
3	-4	-2,3
4	0	0

Coefficient selection -4,5

CORRECTION Hz	ΔLwr,cc,i,m
125	-0,1755
250	-0,1755
500	-0,1755
1000	-0,1755
2000	-0,1755
4000	-0,1755

The correction term is attributed to all octave band

Figure 77– Traffic light and roundabouts - Rolling correction coefficients – Example

No correction for category Category 4: Powered two-wheleers

Input data

Vm	**50**	km/h
Slope	**7**	%
m	**1**	*vehicle category*

ΔLwp,grad,i,m — m			
1	s<-6%	-6%<=s<=2%	s>2%
1	0	0	1,666666667
2	s<-4%	-4%<=s<=0%	s>0%
0	0	0	3,5
3	s<-4%	-4%<=s<=0%	s>0%
0	0	0	4,375

Coefficient selection 1,667

CORRECTION Hz	ΔLwp,grad,i,m
125	1,7
250	1,7
500	1,7
1000	1,7
2000	1,7
4000	1,7

The correction term is attributed to all octave band

Figure 78– Road gradient - Propulsion correction coefficients – Example

No correction for category Category 4: Powered two-wheleers

Input data

x	**20**	m	*m*	**1**
k	**1**	1 ó 2		

	k	k
	1	2
	Crossing	Roundabout
Coefficients for acceleration and deceleration — Category m	CP1	CP2
1	5,5	3,1
2	9	6,7
3	9	6,7
4	0	0

Coefficient selection 5,5

CORRECTION Hz	ΔLwp,cc,i,m
125	4,4
250	4,4
500	4,4
1000	4,4
2000	4,4
4000	4,4

The correction term is attributed to all octave band equally

Figure 79– Traffic light and roundabouts - Propulsion correction coefficients – Example

Once corrections factors have been calculated for different rolling and noise conditions, two global corrections factor are calculated per frequency band: a rolling correction factor and a propulsion correction factor. Both factor are implemented in the calculation of the directional sound power of the traffic line, as it is shown in

Figure 75. The following table shows values of rolling and propulsion correction factors, taken into account correction factor associated to different sound and propulsion conditions defined in figures above.

Hz	Rolling ΔLwR,i,m	Propulsion ΔLwP,i,m
125	**1,43190839**	**11,5666667**
250	**1,43190839**	**13,2333333**
500	**1,43190839**	**13,2333333**
1000	**0,33190839**	**13,2333333**
2000	**-3,06809161**	**13,2333333**
4000	**-3,86809161**	**13,2333333**

Figure 80– Rolling and propulsion correction factors

Results

- $L_{w',line,m}$ (dB) calculated for each segment of the road. In Figure 74, the cell named "noise" contains the directional sound power calculated per edge for trucks and day conditions. Same values are obtained for the other categories of vehicle in order to obtain the directional sound power of the traffic flow, taking into account the specific fleet of the traffic flow.
- $L_{w',line}$ (dB) associated to the traffic flow. This is equal to L_{day}, $L_{evening}$ or L_{night} (depending on the considered period of the day).

Day results

	Noise (dB)												
	CAR	TRUCK		MOTO		BUS							Lday
Edge	m1	m2	m3	m4a	m4b	m3line3	m3line5	m3line6	m3line8	m3line33	m3line39	m3line78	Combinación
1	78,58	0,00	77,66	0,00	70,80	64,54	63,48	62,02	61,43	61,43	63,48	58,41	81,90
10	71,32	0,00	70,40	0,00	63,53	57,19	56,22	54,74	54,16	54,16	56,22	51,15	74,64
11	69,26	0,00	68,35	0,00	61,48	55,13	54,16	52,68	52,10	52,10	54,16	49,09	72,58
12	76,22	0,00	79,39	0,00	64,84	66,27	65,30	63,85	63,27	63,27	65,30	60,26	81,78
13	71,54	0,00	70,68	0,00	63,72	57,46	56,49	55,02	54,44	54,44	56,49	51,43	74,88
14	73,53	0,00	76,70	0,00	62,15	63,58	62,61	61,16	60,58	60,58	62,61	57,56	79,09
15	72,69	0,00	71,77	0,00	64,90	58,56	57,59	56,11	55,53	55,53	57,59	52,52	76,01
16	76,44	0,00	79,61	0,00	65,06	69,22	68,24	66,79	63,49	63,49	65,52	63,21	82,27
17	70,68	0,00	69,76	0,00	62,89	64,79	63,82	62,36	53,52	53,52	55,58	58,77	75,03
18	77,11	0,00	80,28	0,00	65,73	67,16	66,19	64,74	64,16	64,16	66,19	61,15	82,67
19	74,84	0,00	73,93	0,00	67,06	60,71	59,74	58,26	57,68	57,68	59,74	54,67	78,16
2	75,59	0,00	78,77	0,00	64,22	65,65	64,68	63,22	62,64	62,64	64,68	59,63	81,15
20	74,48	0,00	73,54	0,00	66,70	60,35	59,38	57,90	57,32	57,32	59,38	54,31	77,79
21	74,37	0,00	77,55	0,00	63,00	64,43	63,46	62,00	61,42	61,42	63,46	58,41	79,93
22	72,81	0,00	71,89	0,00	65,02	58,68	57,71	56,23	55,65	55,65	57,71	52,64	76,13
23	73,79	0,00	72,87	0,00	66,01	59,66	58,69	57,21	56,63	56,63	58,69	53,62	77,11
24	75,15	0,00	78,32	0,00	63,77	68,63	64,23	62,78	65,62	62,20	64,23	62,62	80,96
25	69,86	0,00	69,24	0,00	61,84	64,68	55,07	53,59	61,67	53,01	55,07	58,66	74,12
26	72,04	0,00	71,13	0,00	64,26	57,91	56,92	55,46	54,88	54,88	56,94	51,87	75,36
27	73,32	0,00	72,40	0,00	65,53	59,19	58,20	56,74	56,16	56,16	58,21	53,15	76,64
28	75,85	0,00	79,02	0,00	64,47	65,91	64,94	63,48	62,90	62,90	64,94	59,89	81,41
29	72,22	0,00	71,31	0,00	64,44	58,08	57,11	55,64	55,06	55,06	57,11	52,05	75,54
3	69,98	0,00	69,10	0,00	62,16	55,89	54,92	53,46	52,86	52,86	54,92	49,85	73,31
30	74,47	0,00	77,64	0,00	63,09	64,53	63,56	62,10	61,52	61,52	63,56	58,51	80,03
31	74,09	0,00	73,17	0,00	66,30	59,94	58,97	57,51	56,93	56,93	58,97	53,92	77,40
4	74,48	0,00	73,56	0,00	66,69	60,35	59,38	57,92	57,32	57,32	59,38	54,31	77,80
5	75,53	0,00	78,71	0,00	64,16	65,59	64,62	63,16	62,58	62,58	64,62	59,57	81,09
6	74,09	0,00	73,18	0,00	66,31	59,96	58,99	57,53	56,93	56,93	58,99	53,92	77,41
7	74,04	0,00	73,12	0,00	66,25	59,91	58,94	57,48	56,88	56,88	58,94	53,87	77,36
8	69,09	0,00	68,92	0,00	60,71	60,26	54,77	53,30	57,26	52,71	54,77	54,25	73,00
9	72,61	0,00	75,79	0,00	61,23	72,41	61,70	60,24	69,40	59,66	61,70	66,39	79,68

Figure 81– The directional sound power per category of vehicle and per fleet of the traffic flow under day conditions – Excel results

Evening results

	Noise (dB)												
	CAR	TRUCK		MOTO		BUS							Levening
Edge	m1	m2	m3	m4a	m4b	m3line3	m3line5	m3line6	m3line8	m3line33	m3line39	m3line78	Combinación
1	75,70	0,00	76,73	0,00	69,86	64,54	63,48	62,02	61,43	61,43	63,48	58,41	80,26
10	68,36	0,00	69,46	0,00	62,59	57,19	56,22	54,74	54,16	54,16	56,22	51,15	72,97
11	66,38	0,00	67,41	0,00	60,54	55,13	54,16	52,68	52,10	52,10	54,16	49,09	70,94
12	71,69	0,00	78,45	0,00	63,90	66,27	65,30	63,85	63,27	63,27	65,30	60,26	80,25
13	68,64	0,00	69,74	0,00	62,78	57,46	56,49	55,02	54,44	54,44	56,49	51,43	73,24
14	69,00	0,00	75,76	0,00	61,21	63,58	62,61	61,16	60,58	60,58	62,61	57,56	77,56
15	69,81	0,00	70,83	0,00	63,96	58,56	57,59	56,11	55,53	55,53	57,59	52,52	74,37
16	71,91	0,00	78,67	0,00	64,12	69,22	68,24	66,79	63,49	63,49	65,52	63,21	80,85
17	67,79	0,00	68,82	0,00	61,95	64,79	63,82	62,36	53,52	53,52	55,58	58,77	73,79
18	72,58	0,00	79,34	0,00	64,79	67,16	66,19	64,74	64,16	64,16	66,19	61,15	81,14
19	71,96	0,00	72,99	0,00	66,12	60,71	59,74	58,26	57,68	57,68	59,74	54,67	76,52
2	71,07	0,00	77,83	0,00	63,28	65,65	64,68	63,22	62,64	62,64	64,68	59,63	79,63
20	71,58	0,00	72,61	0,00	65,76	60,35	59,38	57,90	57,32	57,32	59,38	54,31	76,14
21	69,85	0,00	76,61	0,00	62,06	64,43	63,46	62,00	61,42	61,42	63,46	58,41	78,41
22	69,92	0,00	70,95	0,00	64,08	58,68	57,71	56,23	55,65	55,65	57,71	52,64	74,49
23	70,91	0,00	71,94	0,00	65,07	59,66	58,69	57,21	56,63	56,63	58,69	53,62	75,47
24	70,62	0,00	77,38	0,00	62,83	68,63	64,23	62,78	65,62	62,20	64,23	62,62	79,53
25	66,84	0,00	68,30	0,00	60,90	64,68	55,07	53,59	61,67	53,01	55,07	58,66	72,79
26	69,16	0,00	70,19	0,00	63,32	57,91	56,92	55,46	54,88	54,88	56,94	51,87	73,72
27	70,43	0,00	71,46	0,00	64,59	59,19	58,20	56,74	56,16	56,16	58,21	53,15	75,00
28	71,32	0,00	78,08	0,00	63,53	65,91	64,94	63,48	62,90	62,90	64,94	59,89	79,89
29	69,34	0,00	70,37	0,00	63,50	58,08	57,11	55,64	55,06	55,06	57,11	52,05	73,90
3	67,07	0,00	68,16	0,00	61,22	55,89	54,92	53,46	52,86	52,86	54,92	49,85	71,67
30	69,94	0,00	76,70	0,00	62,15	64,53	63,56	62,10	61,52	61,52	63,56	58,51	78,51
31	71,20	0,00	72,23	0,00	65,36	59,94	58,97	57,51	56,93	56,93	58,97	53,92	75,76
4	71,59	0,00	72,63	0,00	65,76	60,35	59,38	57,92	57,32	57,32	59,38	54,31	76,16
5	71,01	0,00	77,77	0,00	63,22	65,59	64,62	63,16	62,58	62,58	64,62	59,57	79,57
6	71,21	0,00	72,24	0,00	65,37	59,96	58,99	57,53	56,93	56,93	58,99	53,92	75,77
7	71,15	0,00	72,18	0,00	65,31	59,91	58,94	57,48	56,88	56,88	58,94	53,87	75,72
8	65,88	0,00	67,98	0,00	59,77	60,26	54,77	53,30	57,26	52,71	54,77	54,25	71,45
9	68,09	0,00	74,85	0,00	60,30	72,41	61,70	60,24	69,40	59,66	61,70	66,39	78,66

Figure 82– The directional sound power per category of vehicle and per fleet of the traffic flow under evening conditions – Excel results

Night results

	Noise (dB)												
	CAR	TRUCK		MOTO		Buslines							
Edge	m1	m2	m3	m4a	m4b	L3	L5	L6	L8	L33	L39	L178	Combinación
1	70,34	0	71,38	0,00	64,50	0	0	0	0	0	0	0	74,37
10	63,00	0	64,12	0,00	57,23	0	0	0	0	0	0	0	67,08
11	61,02	0	62,06	0,00	55,18	0	0	0	0	0	0	0	65,06
12	66,34	0	73,11	0,00	58,54	0	0	0	0	0	0	0	74,06
13	63,28	0	64,40	0,00	57,42	0	0	0	0	0	0	0	67,35
14	63,65	0	70,42	0,00	55,85	0	0	0	0	0	0	0	71,37
15	64,45	0	65,49	0,00	58,61	0	0	0	0	0	0	0	68,48
16	66,55	0	73,33	0,00	58,76	0	0	0	0	0	0	0	74,28
17	62,44	0	63,48	0,00	56,60	0	0	0	0	0	0	0	66,47
18	67,23	0	74,00	0,00	59,43	0	0	0	0	0	0	0	74,95
19	66,60	0	67,65	0,00	60,76	0	0	0	0	0	0	0	70,64
2	65,71	0	72,48	0,00	57,92	0	0	0	0	0	0	0	73,44
20	66,22	0	67,26	0,00	60,40	0	0	0	0	0	0	0	70,26
21	64,49	0	71,26	0,00	56,70	0	0	0	0	0	0	0	72,22
22	64,57	0	65,61	0,00	58,73	0	0	0	0	0	0	0	68,60
23	65,55	0	66,59	0,00	59,71	0	0	0	0	0	0	0	69,58
24	65,26	0	72,04	0,00	57,47	0	0	0	0	0	0	0	72,99
25	61,48	0	62,95	0,00	55,54	0	0	0	0	0	0	0	65,73
26	63,80	0	64,84	0,00	57,96	0	0	0	0	0	0	0	67,84
27	65,08	0	66,12	0,00	59,24	0	0	0	0	0	0	0	69,11
28	65,97	0	72,74	0,00	58,18	0	0	0	0	0	0	0	73,69
29	63,98	0	65,02	0,00	58,14	0	0	0	0	0	0	0	68,02
3	61,72	0	62,82	0,00	55,86	0	0	0	0	0	0	0	65,78
30	64,59	0	71,36	0,00	56,80	0	0	0	0	0	0	0	72,31
31	65,84	0	66,89	0,00	60,00	0	0	0	0	0	0	0	69,88
4	66,24	0	67,28	0,00	60,40	0	0	0	0	0	0	0	70,27
5	65,65	0	72,43	0,00	57,86	0	0	0	0	0	0	0	73,38
6	65,85	0	66,90	0,00	60,01	0	0	0	0	0	0	0	69,89
7	65,79	0	66,84	0,00	59,95	0	0	0	0	0	0	0	69,83
8	60,52	0	62,64	0,00	54,41	0	0	0	0	0	0	0	65,10
9	62,73	0	69,50	0,00	54,94	0	0	0	0	0	0	0	70,46

Figure 83– The directional sound power per category of vehicle and per fleet of the traffic flow under night conditions – Excel results

L_{den} calculation:

Inputs data:

- Results of ***Lday***, ***Levening*** and ***Lnight*** (dB) for each segment (edge of the traffic line) in which the road is divided.
- Duration of periods (day, evening and night) in hours.

Results:

- L_{den} (dB) calculated for each segment of the road.

Input data					Output data			
Period	Day	Evening	Night			Min	Average	Max
Hours	12	4	8		Lden (Db)	74,20	79,37	84,24
Edge	Lday (dB)	Levening (dB)	Lnight (dB)		Edge	Lden (dB)		
1	81,90	80,26	74,37		1	83,52		
10	74,64	72,97	67,08		10	76,23		
11	72,58	70,94	65,06		11	74,20		
12	81,78	80,25	74,06		12	83,35		
13	74,88	73,24	67,35		13	76,49		
14	79,09	77,56	71,37		14	80,65		
15	76,01	74,37	68,48		15	77,62		
16	82,27	80,85	74,28		16	83,76		
17	75,03	73,79	66,47		17	76,37		
18	82,67	81,14	74,95		18	84,24		
19	78,16	76,52	70,64		19	79,78		
2	81,15	79,63	73,44		2	82,72		
20	77,79	76,14	70,26		20	79,40		
21	79,93	78,41	72,22		21	81,50		
22	76,13	74,49	68,60		22	77,74		
23	77,11	75,47	69,58		23	78,72		
24	80,96	79,53	72,99		24	82,46		
25	74,12	72,79	65,73		25	75,49		
26	75,36	73,72	67,84		26	76,98		
27	76,64	75,00	69,11		27	78,25		
28	81,41	79,89	73,69		28	82,98		
29	75,54	73,90	68,02		29	77,16		
3	73,31	71,67	65,78		3	74,92		
30	80,03	78,51	72,31		30	81,60		
31	77,40	75,76	69,88		31	79,02		
4	77,80	76,16	70,27		4	79,41		
5	81,09	79,57	73,38		5	82,66		
6	77,41	75,77	69,89		6	79,03		
7	77,36	75,72	69,83		7	78,97		
8	73,00	71,45	65,10		8	74,49		
9	79,68	78,66	70,46		9	80,87		

Figure 84– The directional sound power per category of vehicle and per fleet of the traffic under day, evening and night conditions – Excel results

5.2.2.3 Source noise level. Sumo comparison

The source line noise level is one of SUMO results and is the reference for comparison of our models. Followed procedure consists on determine the noise level per edge following the theoretical methodology and stablish how to include geometrical and traffic parameters, defined in SUMO in the theoretical model in order to obtain accurate results, compared to SUMO results.

5.2.2.3.1 Testing

Several tests have been done in order to test the theoretical described model for source noise. Tests consist on the comparison between SUMO and theoretical model results for simple traffic models. The objective is the achievement of similar results due that both methods are based on the same model.

TESTING 1:

Objective: Verify the correct implementation of edges intersection (traffic lights and roundabouts) in the theoretical traffic model

Table 44 Testing 1. Inputs.

Net	Thessaloniki road
Number of edges	31 (traffic lights: 2,5,9, 12, 14, 16, 18)
Category of vehicle and flow	m=1 (Q=633 vehicles/h)
Vm	Calculated from edge lengths and travel time of the vehicle in the edge (SUMO output)
Other variables of influence	Default values

Table 45 Testing 1. Results

Noise (dB)		Error (%)	
SUMO	Theoretical Model	Average	Max
71,2348	69,9036	2,72%	5,81%

Conclusions:

- Medium speed reduction is not taken into account in the correction due to a traffic light or a roundabout.
- Just the noise correction factor due to acceleration and deceleration is taken into account in the correction.
- No correction in rolling conditions is realized in SUMO
- The end of the edge is taken as reference for the calculation of the x distance.

TESTING 2:

Objective: Verify the correct implementation of trucks.

Table 46 Testing 2. Inputs

Net	Thessaloniki road
Number of edges	31
Category of vehicle and flow	m=2,3 (Q=120 vehicles/h)
Vm	Calculated from edge lengths and travel time of the vehicle in the edge (SUMO output)
Other variables of influence	Default values

Table 47 Testing 2. Results m2

Noise (dB)		Error (%)	
SUMO (trucks)	Theoretical Model m2	Average	Max
74,2103	67,5435	8,95%	11,69%

Table 48 Testing 2. Results m3

Noise (dB)		Error (%)	
SUMO (trucks)	Theoretical Model m3	Average	Max
74,2103	70,2377	5,31%	8,09%

Conclusions:

- The vehicle category "truck" in SUMO corresponds with category m3 in the theoretical model.
- Correction factors implemented in the theoretical models delivers in lower noise level than the level obtained by SUMO model.

TESTING 3:

Objective: Verify the correct implementation of motorcycles.

Table 49 Testing 3. Inputs

Net	Thessaloniki road
Number of edges	31
Category of vehicle and flow	m=4a,4b (Q=168 vehicles/h)
Vm	Calculated from edge lengths and travel time of the vehicle in the edge (SUMO output)
Other variables of influence	Default values

Table 50 Testing 3. Results m4a

Noise (dB)		Error (%)	
SUMO (motorcycle)	Theoretical Model m4a	Average	Max
64,4661	63,4810	1,41%	11,39%

Table 51 Testing 3. Results m4b

Noise (dB)		Error (%)	
SUMO (motorcycle)	Theoretical Model m4b	Average	Max
64,4661	63,3689	1,64%	4,67%

Conclusions:

- The vehicle category "motorcycle" in SUMO corresponds with category m4b in the theoretical model.
- Correction factors implemented in the theoretical models delivers in lower noise level than the level obtained by SUMO model. *Idem trucks*.

TESTING 4:

Objective: Verify the correct implementation of buses.

Table 52 Testing 4. Inputs

Net	Thessaloniki road
Number of edges	31 (No bus stop)
Category of vehicle and flow	m=2,3 (Q=168 vehicles/h)
Vm	Calculated from edge lengths and travel time of the vehicle in the edge (SUMO output)
Other variables of influence	Default values

Table 53 Testing 4. Results m4a

Noise (dB)		Error (%)		
SUMO (bus)	Theoretical Model m2	Average	Max	Min
75,8545	68,9850	9,02%	11,86%	5,23%

Table 54 Testing 4. Results m4b

Noise (dB)		Error (%)		
SUMO (bus)	Theoretical Model m3	Average	Max	Min
75,8545	71,6815	5,46%	8,31%	1,74%

Conclusions: *Idem trucks*

TESTING 5:

Objective: Verify the correct implementation of a combination of different categories of vehicles

Table 55 Testing 5. Inputs

Net	Pilot zone Thessaloniki
Number of edges	31
Category of vehicles and flow	Passenger cars, m=1 (Q=633 vehicles/h) Trucks, m=3 (Q=120 vehicles/h) Motorcycles, m=4b (Q=168 vehicles/h)
Vm	Calculated from edge lengths and travel time of the vehicle in the edge (SUMO output)
Other variables of influence	Default values

Table 56 Testing 5. Results

Noise (dB)		Error (%)		
SUMO	Theoretical Model m3	Average	Max	Min
71,3245	73,2297	3,64%	6,28%	-0,18%

TESTING 6:

Objective: Verify the correct implementation of bus stops

Table 57 Testing 6. Inputs

Net	Pilot zone Thessaloniki (Lane3)
Number of edges	31 (Bus stops: edges 8, 16 and 24)
Category of vehicles and flow	Buses, m=3 Period: 480s (Q=7,5 vehicles/h)
Vm	Calculated from edge lengths and travel time of the vehicle in the edge (SUMO output)
Other variables of influence	Default values

Table 58 Testing 6. Results

Noise (dB)		Error (%)		
SUMO	Theoretical Model m3	Average	Max	MIn
60,2006	59,1883	1,68%	4,33%	-4,66%

Conclusions:

- Considering bus stop as a traffic light in terms of noise influence. *K=1*.
- Considering congestion issues in the bus stop next edge.

5.2.2.3.2 Implementation in scenario_0

The model exposed above, is been implemented within this project in order to obtain the noise level associated to the traffic flowing along the studied road. Then, results are been compared to those obtained through the microsimulation of the traffic flow in Sumo tool (5.1.2.4).

Figure 85 represents noise values emitted by the source line along different edges in which the road is divided:

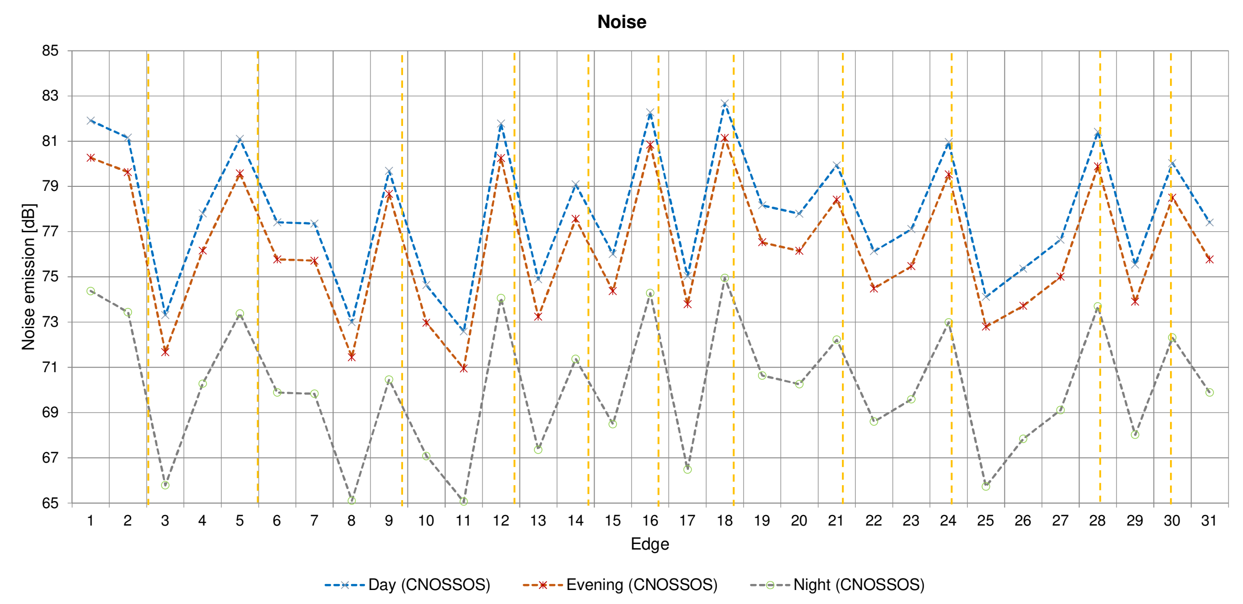

Figure 85 Noise by edge – CNOSSOS results for day, evening and night period

As it is represented within Figure 85, the noise emission level decreases when the traffic flow is reduced, as it is the case of the night period. Otherwise, Figure 85 shows how the noise level is increased in edges represented through yellow lines. These edges are those where a traffic light or a bus stop is located. Traffic lights and stops result in periods of acceleration and deceleration, which are corrected though propulsion and rolling correction factors in the CNOSSOS model implemented.

Table 59 shows the noise level differences obtained through the microsimulation in Sumo and through the implementation of CNOSSOS models in the analysed road.

Table 59 Noise results-Scenario 0. Cnossos-Sumo comparison

Period	Noise (dB) *Average values*		Cnossos-Sumo results *Difference*		
	SUMO	CNOSSOS model	Average	Max	Min
Day	79,26	77,81	-1,45	5,59	-8,64
Evening	78,94	76,26	-2,26	3,38	-6,27
Night	73,88	70,08	-3,80	2,41	-9,44

One consideration to be taken into account, is different edges length. Edges length influence in noise results calculated within both methods. So, is important to obtain normalized results considering the same length for all simulated edges. In this case the length considered is 100meters length. Normalized noise results are obtained for day, evening and night periods.

The following graphs (Figure 86, Figure 87 and Figure 88) show these results, as well as the difference obtained by edge between CNOSSOS and Sumo results. As expected, the difference between noise levels obtained by both methods, is equal that obtained for not normalized results.

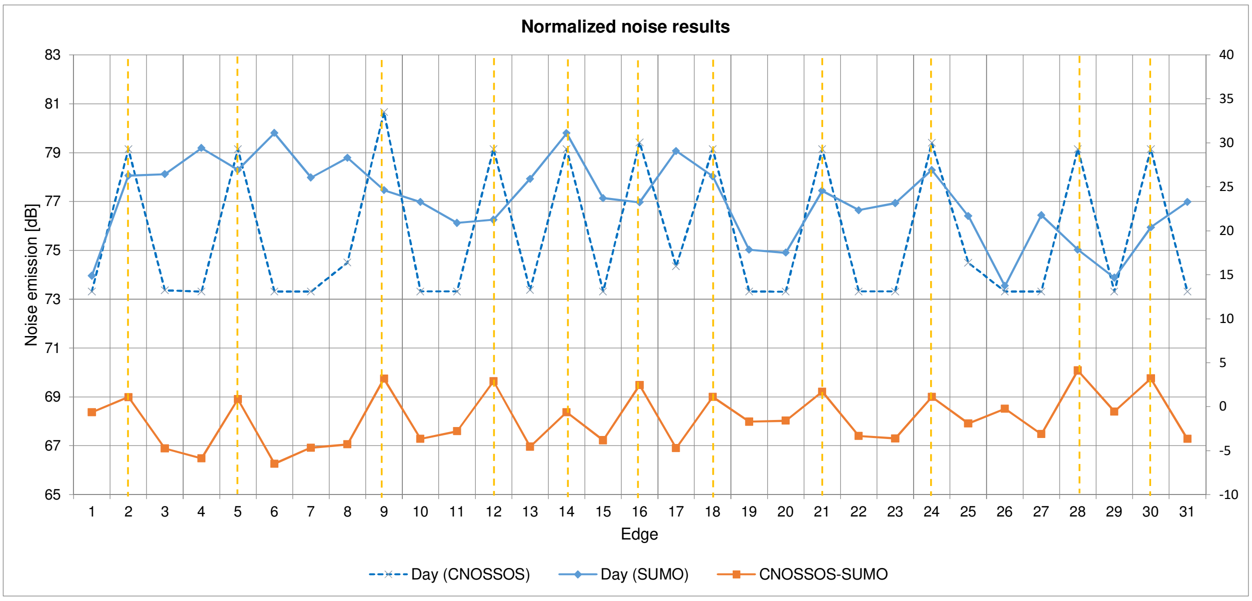

Figure 86 Normalized noise results by edge. Cnossos-Sumo results. Day period.

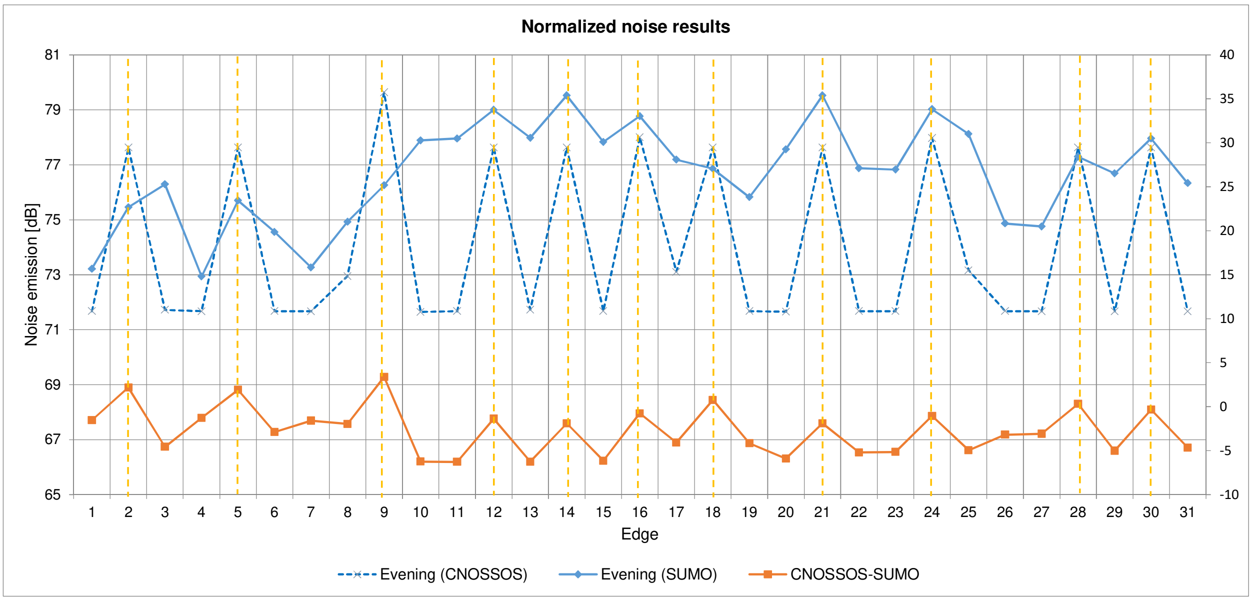

Figure 87 Normalized noise results by edge. Cnossos-Sumo results. Evening period.

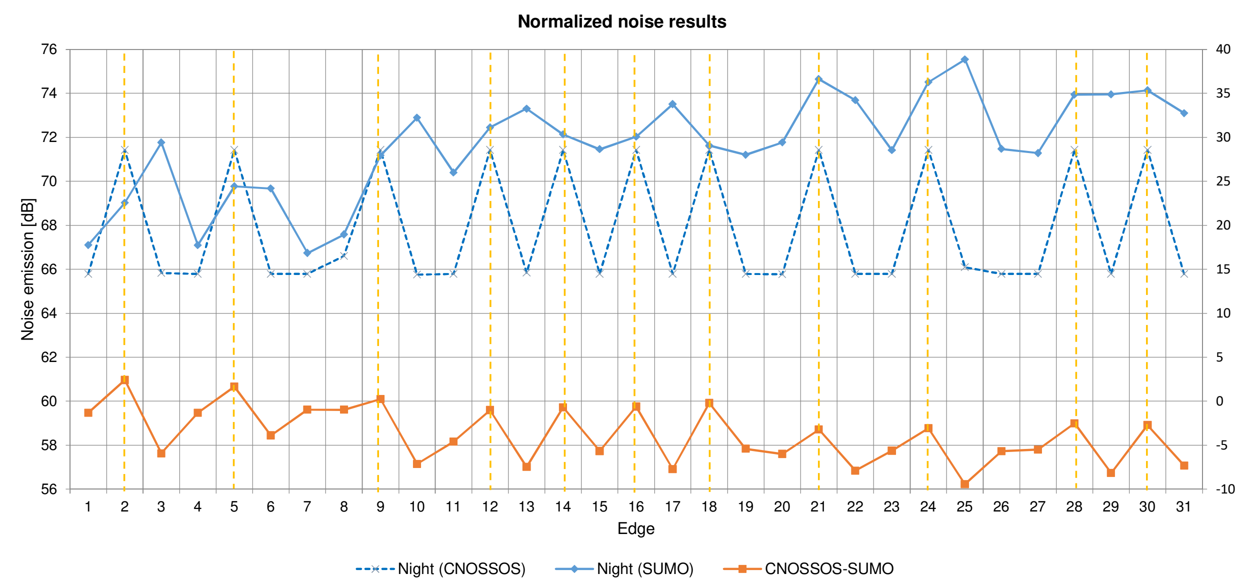

Figure 88 Normalized noise results by edge. Cnossos-Sumo results. Night period.

5.2.2.4 Source noise level. Paper comparison

Another important step within the validation process stablished for the considered noise model, consists on the comparison between the implemented model and the *CNOSSOS* applied by [24] for known operating conditions and simple traffic configuration.

Three different comparison analysis are realized in order to compare the sensitivity of both models to speed variation, slope variation and distance to traffic lights evolutions.

5.2.2.4.1 Acoustical source level-Speed

This sensitivity analysis is realized for cars and heavy vehicles:

Passenger cars:

- **Reference model**: (Bartolomaeus, 2017)[24]
- **Theoretical model:**
  Table below includes the configuration of the scenario to perform the simulation, in order to obtain result associated to the implemented model. The scenario is equal to paper description for same sensitivity analysis.

Table 60 Noise-Speed analysis for passenger cars. Constant parameters

Vehicle category	m1
Vehicle flow	1 veh/hour
Source line length	1 km
Slope	0%
Traffic lights	-
Road surface	Reference road surface

Once the simulation is performed, a sensitivity analysis is been realized by applying the theoretical model in order to obtain noise variation, associated to the source line (road), by varying the speed of cars driving along the road (**Figure 89**).

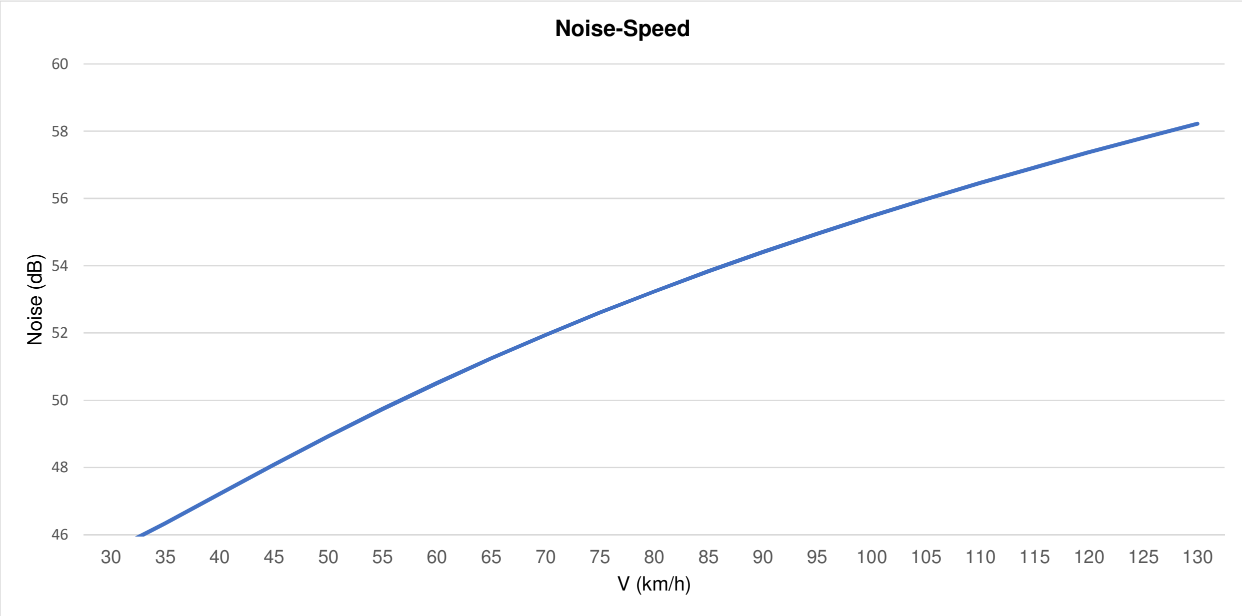

Figure 89: Noise-Speed analysis for passenger cars. Parametric analysis

- **Comparison *CNOSSOS* (paper)-Theoretical model**:
  Obtained results from previous sensitivity analysis have been compared to same analysis reflected in the reference paper. **Figure 90** shows this comparison.

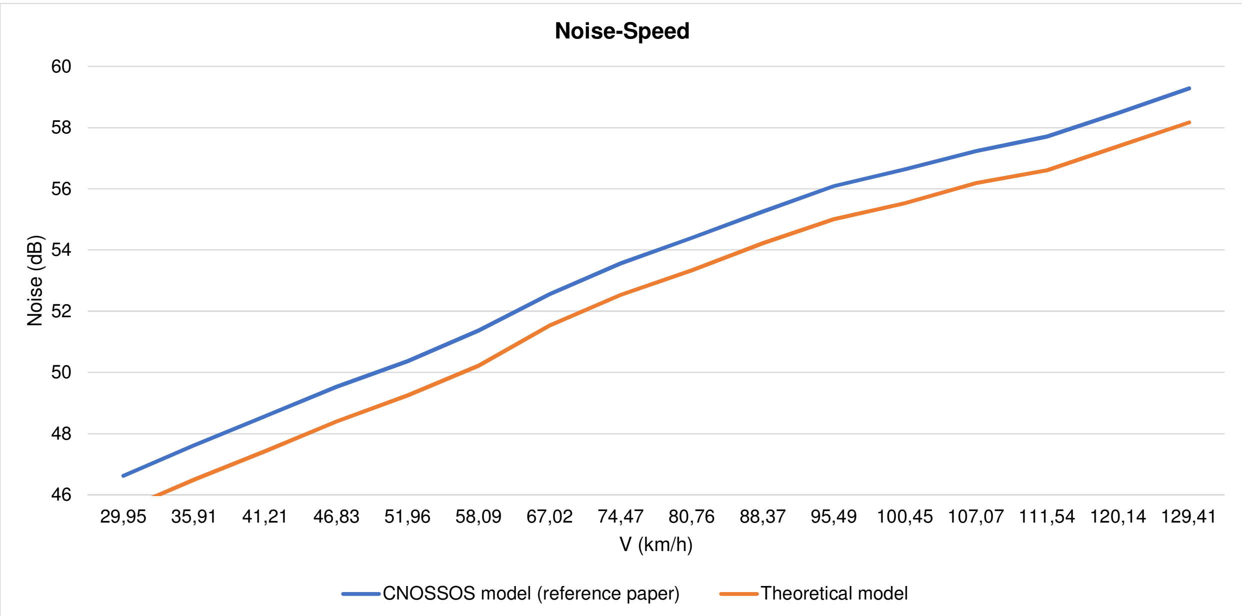

Figure 90: Noise-Speed analysis for passenger cars. Comparison CNOSSOS-Theoretical model

As it is shown in Figure 90, the sensitivity of both models to speed is similar.

Results obtained from the comparison are shown in Table 61.

Table 61. Noise-Speed analysis for passenger cars. Comparison results

Absolute Deviation (Cnossos-Theoretical model) [dB]	
Average	1,0933
Max	1,1515
Min	1,0232

Heavy vehicles:

- **Reference model**: (Bartolomaeus, 2017)[24]
- **Theoretical model:**
  Table 62 includes the configuration of simulated scenarios. The configuration is equal to cars analysis but changing vehicle typology. Two simulations are realized and two associated sensitivity analysis are obtained: one associated to medium heavy vehicles (m3) and the other associated to heavy vehicles.

Table 62 Noise-Speed analysis for heavy vehicles. Constant parameters

Vehicle category	m2,3
Vehicle flow	1 veh/hour
Source line length	1 km
Slope	0%
Traffic lights	-
Road surface	Reference road surface

Once scenarios have been simulated, two speed sensitivy analysis are realized, one per simulation. Obtained results are included in graphs below. As it was expected, the heavier of the vehicle, the higher engine output power and corresponding propulsion and rolling associated noise.

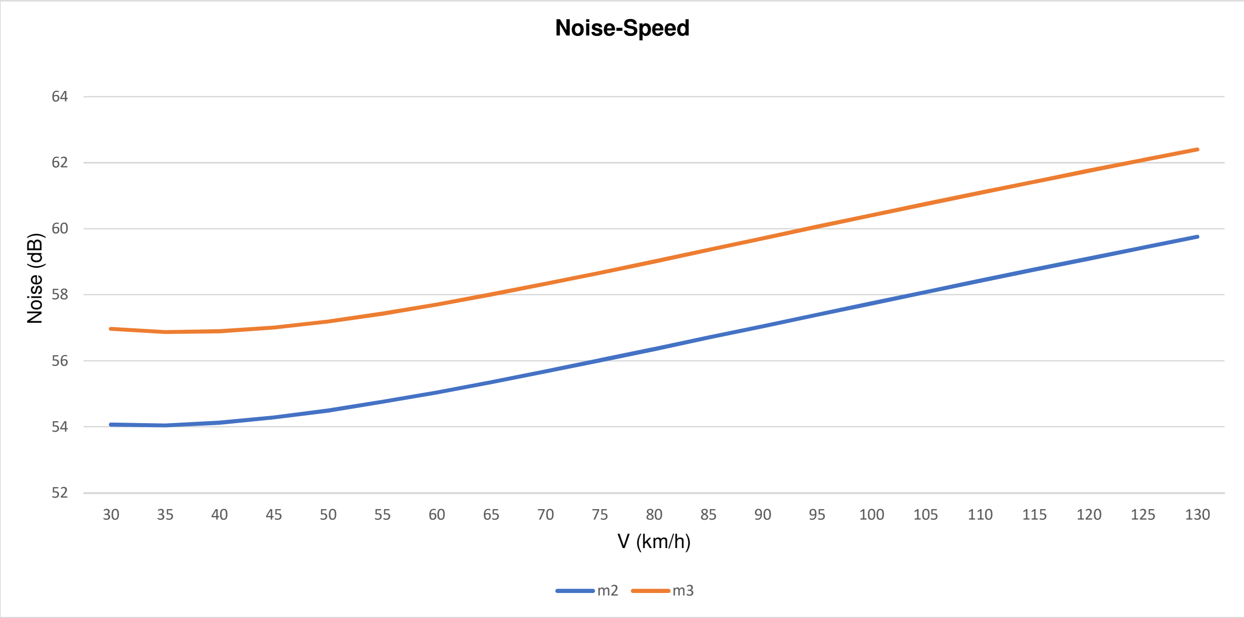

Figure 91: Noise-Speed analysis for heavy vehicles. Parametric analysis

Previous analysed is not included in the reference paper, so it is not possible to realize the comparison for these car typologies.

5.2.2.4.2 Acoustical source level-Slope

This sensitivity analysis is realized for cars and heavy vehicles:

Passenger cars:

- **Reference model**: (Bartolomaeus, 2017)[24]
- **Theoretical model:**
  Table 63 includes the configuration of the scenario to perform the simulation, in order to obtain result associated to the implemented model. The scenario is equal to paper description for same sensitivity analysis. In this case the speed of vehicles is fixed and the slope vary from -5% to +5%.

Table 63 Noise-Slope analysis for passenger cars. Constant parameters

Vehicle category	m1
Vehicle flow	1 veh/hour
Source line length	1 km
Speed	70km/h
Traffic lights	-
Road surface	Reference road surface

Once the simulation is performed, a sensitivity analysis is been realized by applying the theoretical model in order to obtain noise variation, associated to the source line (road), by varying the slope of the road where vehicles are driving along**. Figure 92** includes obtained results. As it was expected, deceleration and acceleration conditions are associated to higher source line noise. In case of negative slopes, vehicles are under deceleration condition in order to keep constant speed. Otherwise, positive slopes, under constant speed conditions, result in acceleration conditions.

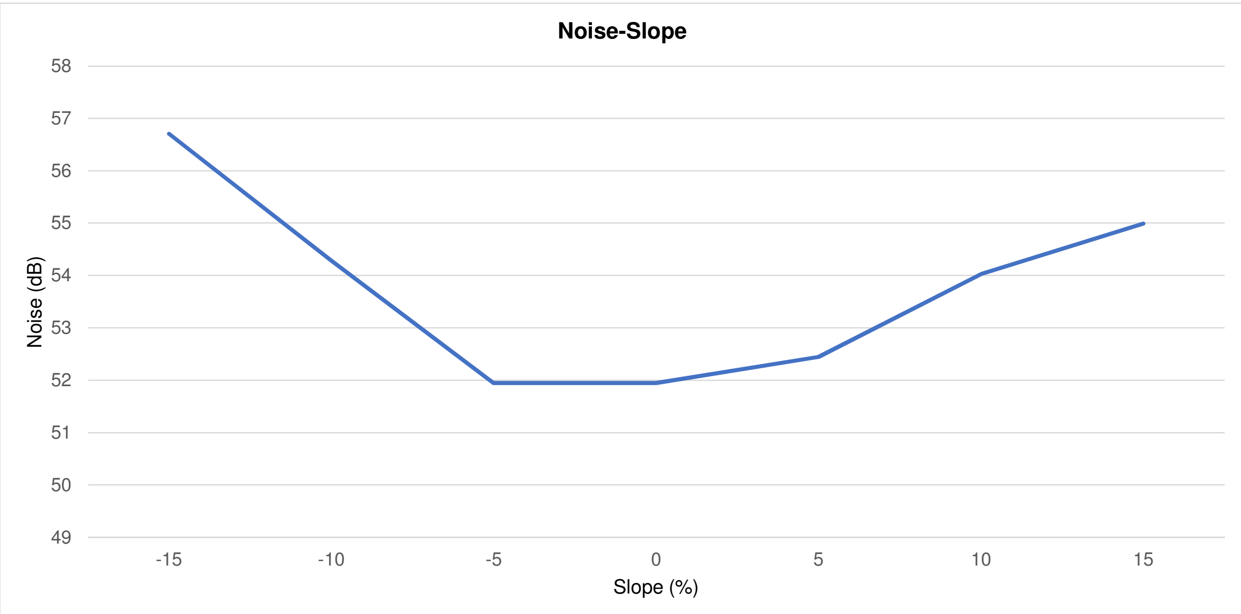

Figure 92: Noise-Slope analysis for passenger cars. Parametric analysis

- **Comparison *CNOSSOS* (paper)-Theoretical model**:
  Obtained results from previous sensitivity analysis have been compared to same analysis reflected in the reference paper. **Figure 93** shows this comparison.

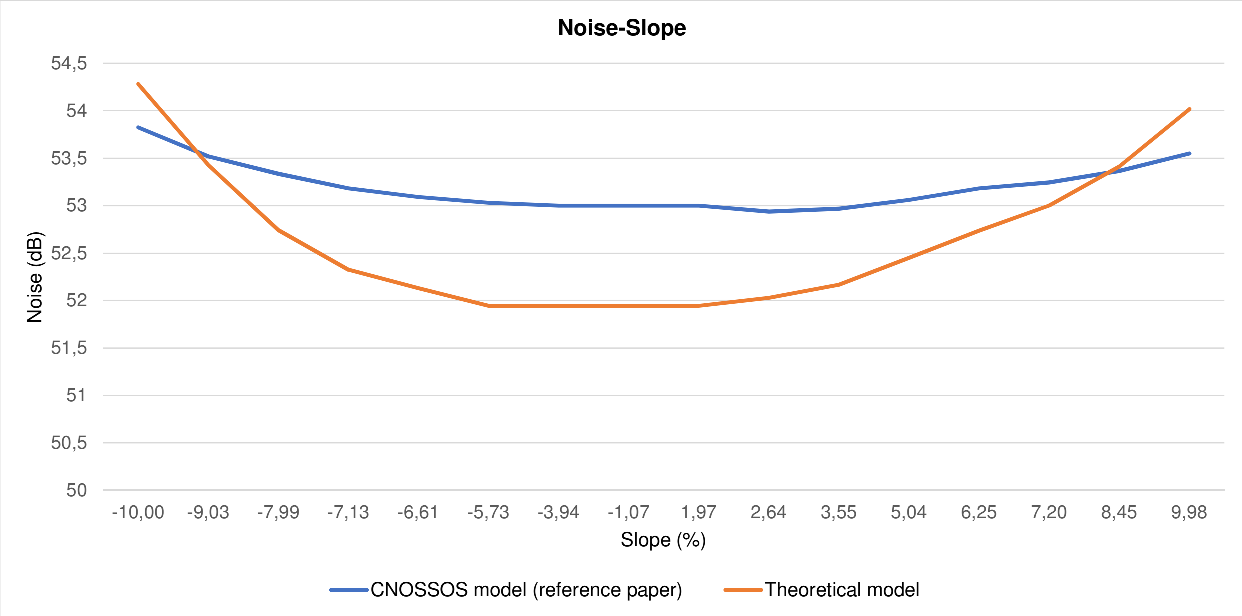

Figure 93: Noise-Slope analysis for passenger cars. Comparison CNOSSOS-Theoretical model

Figure 94 shows higher noise levels under acceleration and deceleration conditions. Nevertheless, it is also reflected the higher sensitivity of theoretical model to slope variation, face to the sensitivity of the paper model. Despite it, the scale of the graph shows the small difference between results, which is also reflected in Table 64.

Table 64 Noise-Slope analysis for passenger cars. Comparison results

Absolute Deviation (Cnossos-Theoretical model)	
Average	0,6714
Max	1,0875
Min	0,0471

<u>Heavy vehicles:</u>

- **Reference model**: (Bartolomaeus, 2017)[24]
- **Theoretical model:**
  Table 65 includes the configuration of simulated scenarios. The configuration is equal to cars analysis but changing vehicles typology. Two simulations are realized and two associated sensitivity analysis are obtained: one associated to medium heavy vehicles (m3) and the other associated to heavy vehicles.

Table 65 Noise-Slope analysis for heavy vehicles. Constant parameters

Vehicle category	m2,3
Vehicle flow	1 veh/hour
Source line length	1 km
Speed	70km/h
Traffic lights	-
Road Surface	Reference road surface

Once simulations are performed, both sensitivity analyses have been realized by applying the theoretical model to both simulations in order to obtain noise variation, associated to the source line (road), by varying the slope of the road where vehicles are driving along. **Figure 94** includes obtained results. As it was expected, deceleration and acceleration conditions are associated to higher source line noise. Also heavy cars are more sensible to slope than medium heavy vehicles due to stronger variations in engine output power.

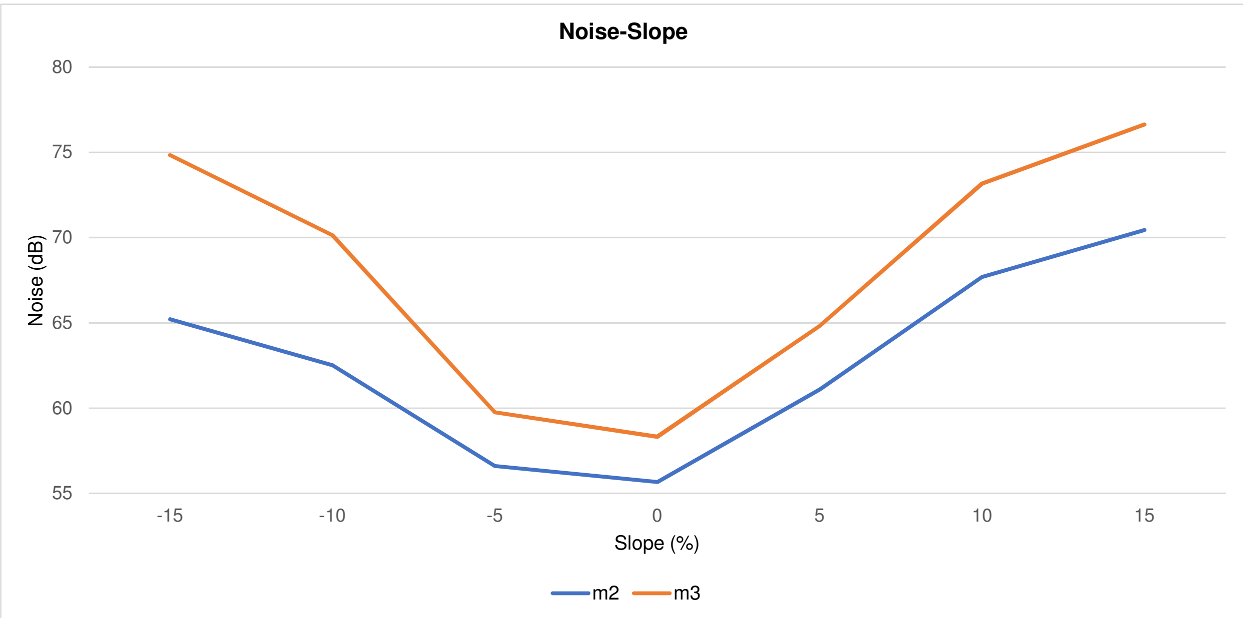

Figure 94: Noise-Slope analysis for heavy vehicles. Parametric analysis

- **Comparison *CNOSSOS* (paper)-Theoretical model**:
  Obtained results from previous sensitivity analysis have been compared to same analysis reflected in the reference paper. **Figure 95** shows this comparison. The reference paper just takes into account one typology of truck.

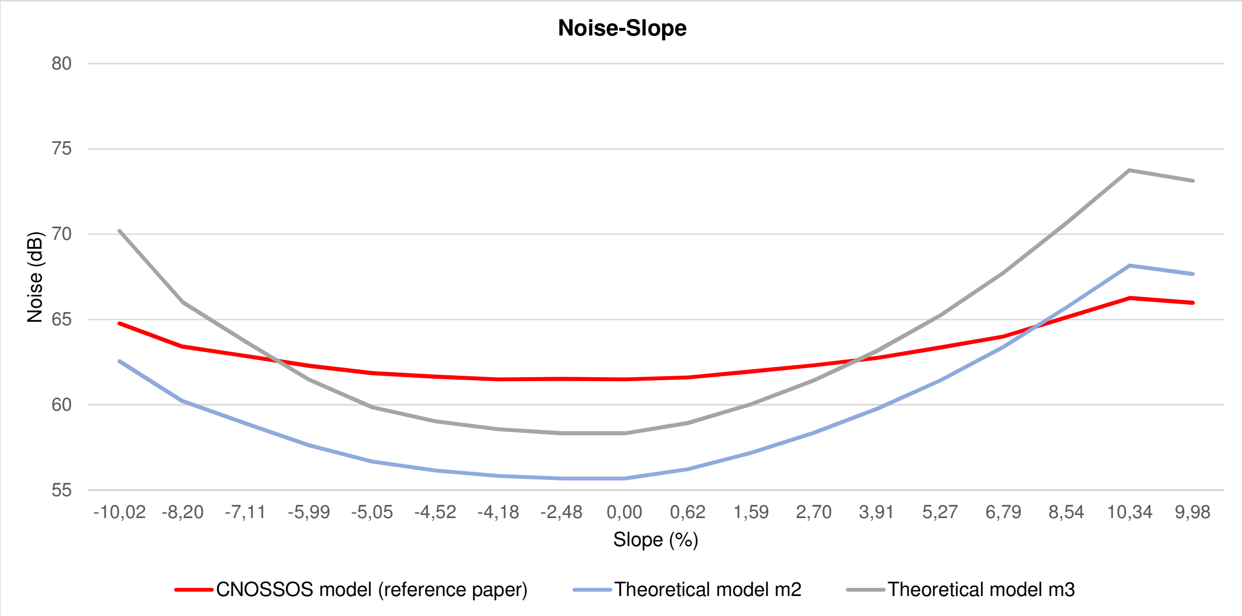

Figure 95: Noise-Slope analysis for heavy vehicles. Comparison CNOSSOS-Theoretical model

Figure 94 and Figure 95 show higher noise levels under acceleration and deceleration conditions. Nevertheless, it is also reflected the higher sensitivity of theoretical model to slope variation, face to the sensitivity of the paper model. Despite it, the scale of the graphs shows the small difference between results, which is also reflected in Table 66.

Table 66 Noise-Slope analysis for heavy vehicles. Comparison results

Absolute Desviation (Cnossos-Theoretical model)		
Category	m2	m3
Average	3,6533	3,0664
Max	5,8407	7,4874
Min	0,5771	0,4145

5.2.2.4.3 Acoustical source level-x (distance from the edge to the next crossing)

Passenger cars:

- **Reference model**: (Bartolomaeus, 2017)[24]
- **Theoretical model:**
  Table 67 includes the configuration of the scenario to performed the simulation, in order to obtain result associated to the implemented model. In this case the speed of vehicles and slope of the road is fixed and distance to closer crossing varies from 0 to 100 meters. In the end, this results in a sensitivity analysis of noise by acceleration and deceleration conditions variation.

Table 67 ΔNoise-x analysis for passenger cars. Constant parameters

Vehicle category	m1
Vehicle flow	1 veh/hour
Source line length	1 km
Speed	30km/h
Slope	0%
Crossing	K=2
Road surface	Reference road surface

Once simulations have been performed, sensitivity analyses have been realized by applying the theoretical model to the simulation in order to obtaine noise variation, by varying acceleration and deceleration conditions. As it was expected, deceleration and acceleration conditions are associated to higher source line noise.

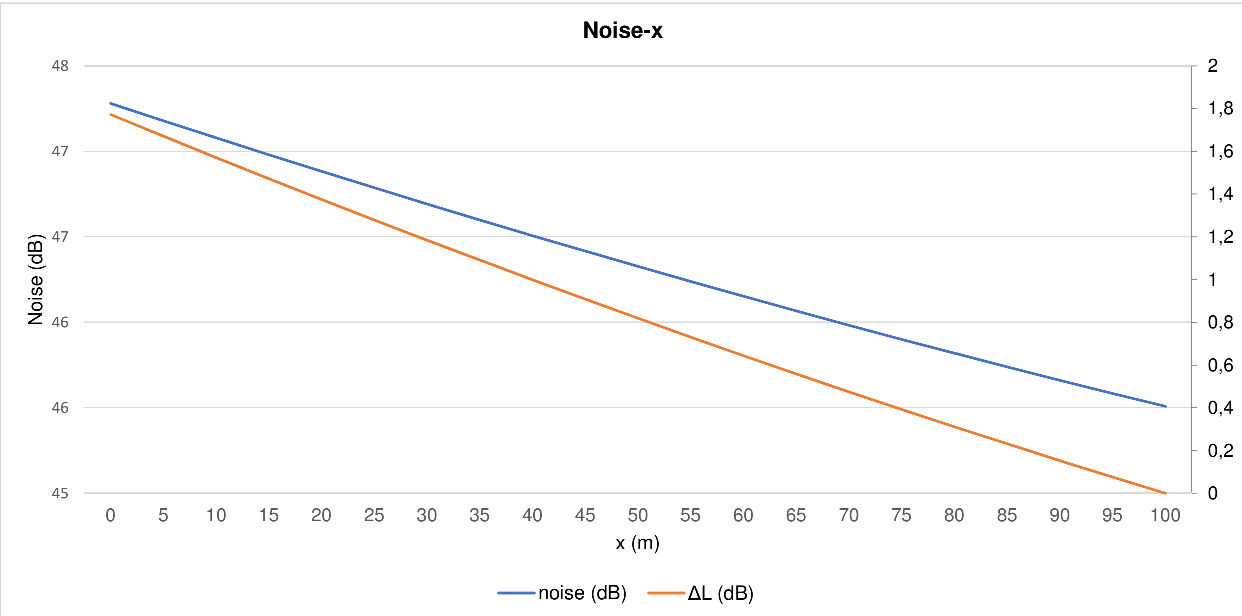

Figure 96: ΔNoise-x analysis for passenger cars. Parametric analysis

- **Comparison *CNOSSOS* (paper)-Theoretical model**:
  Obtained results from previous sensitivity analyses have been compared to same analysis reflected in the reference paper.

  Figure 97 shows noise variation by varying the distance to the closest crossing. For realizing the comparison, it is fundamental to use same distance reference coordinate. Within Figure 97, the paper noise variation is represented face to x (in de paper reference system). The red line, drawn in the graph, represents the reference system used by the implemented theoretical method.

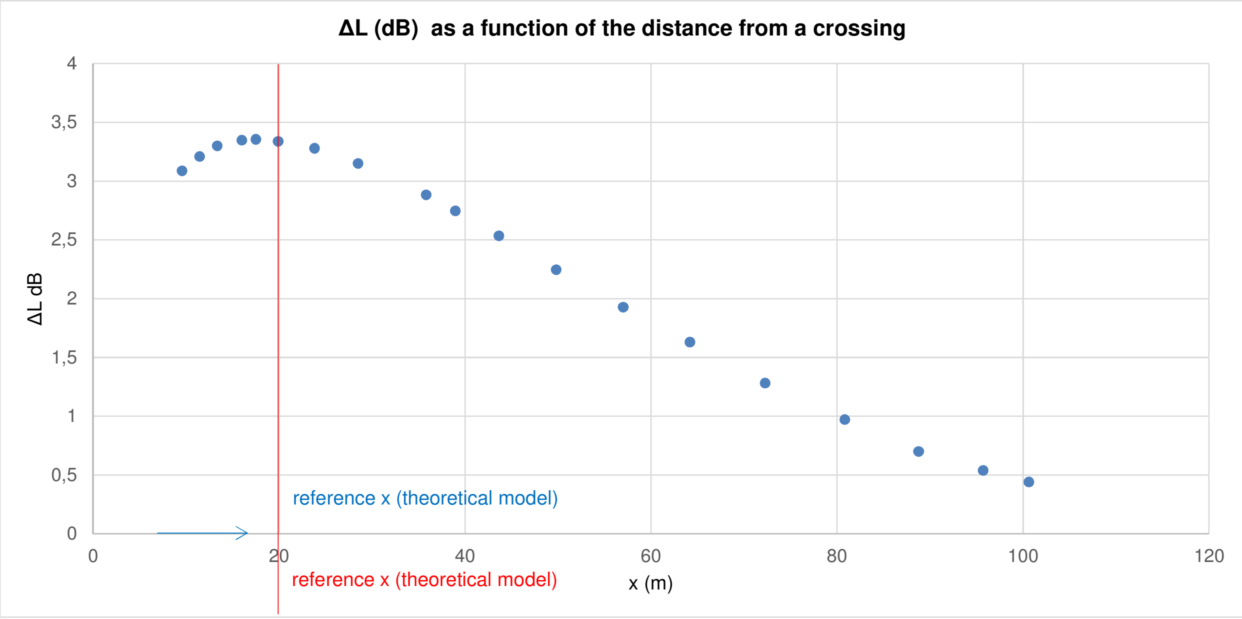

Figure 97: ΔNoise-x analysis for passenger cars. X references for both models.

Sensitivity analysis realized through both models under same reference system are been compared within **Figure 98**. The compared variable is not the noise, but the noise variation with crossing distance (purple and grey lines). Thus, it is verified the equivalence between both results.

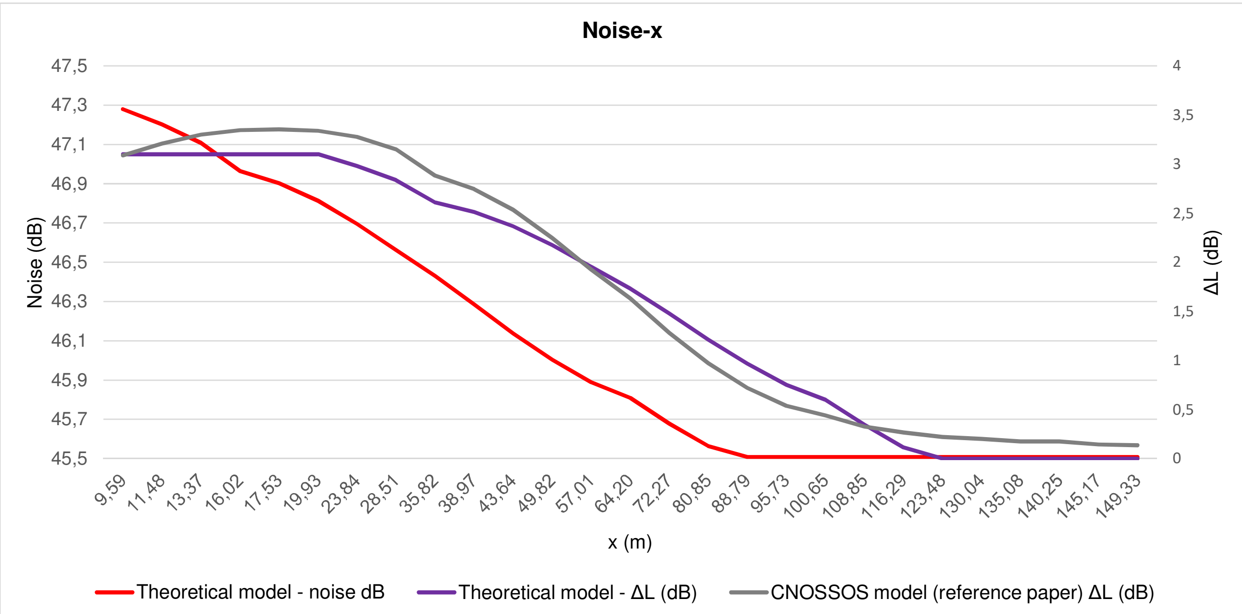

Figure 98: ΔNoise-x analysis for passenger cars. Comparison CNOSSOS-Theoretical model

Comparison results are shown in Table 69.

Table 68 Noise-Slope analysis for passenger cars. Comparison results

Absolute Desviation (Cnossos-Theoretical model)	
Average	0,178547074
Max	0,312655
Min	0,019743

Heavy vehicles:

- **Reference model**: (Bartolomaeus, 2017)
- **Theoretical model:**
  Same passenger cars configuration scenario, but replacing this typology of vehicles by medium and heavy vehicles. Configuration parameters are shown below:

Table 69 ΔNoise-x analysis for heavy vehicles. Constant parameters

Vehicle category	m2,3
Vehicle flow	1 veh/hour
Source line length	1 km
Speed	50km/h
Slope	0%
Crossing	K=2
Road surface	Reference road surface

Figure 99 represents noise evolution per distance to crossing, as well as Noise attenuation (grey and yellow lines) evolution. It has been observed that noise attenuation is the same for both typologies of vehicles, while absolute noise values vary due to different engine nominal output power.

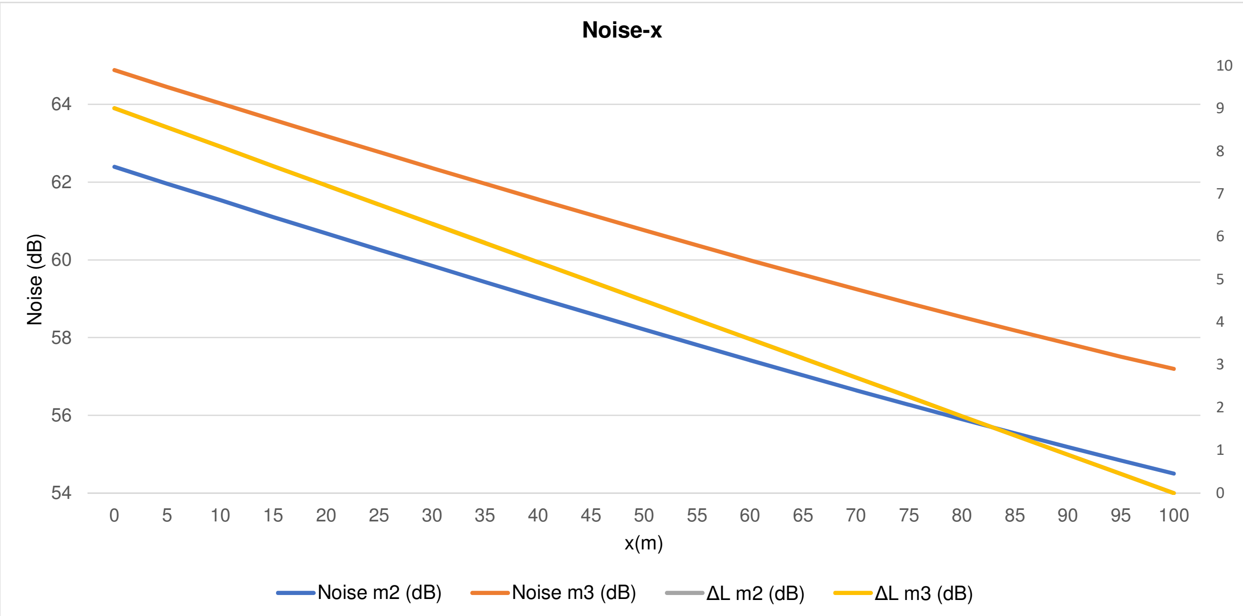

Figure 99: ΔNoise-x analysis for heavy vehicles. Parametric analysis

- **Comparison *CNOSSOS* (paper)-Theoretical model**:

  Significant variation in the comparative analysis exposed above, considering correcting factors for categories of vehicles m2 and m3. However, it is observed that both CNOSSOS graphs are the same in the case of passenger cars and heavy vehicles.

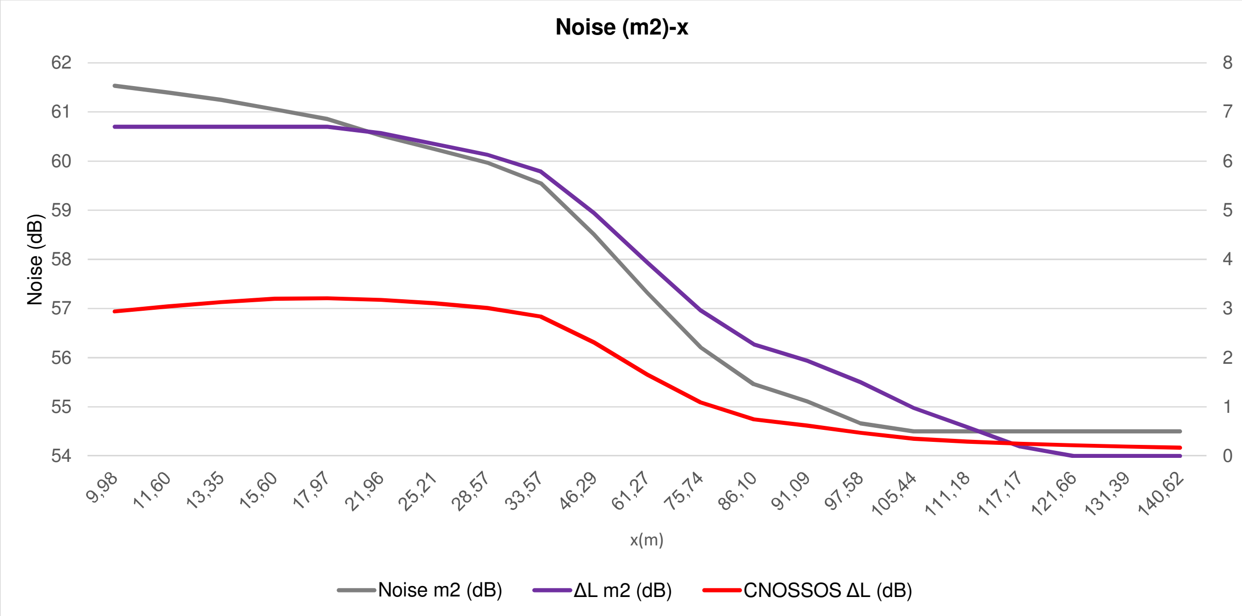

Figure 100: ΔNoise-x analysis for trucks (m2). Comparison CNOSSOS-Theoretical model

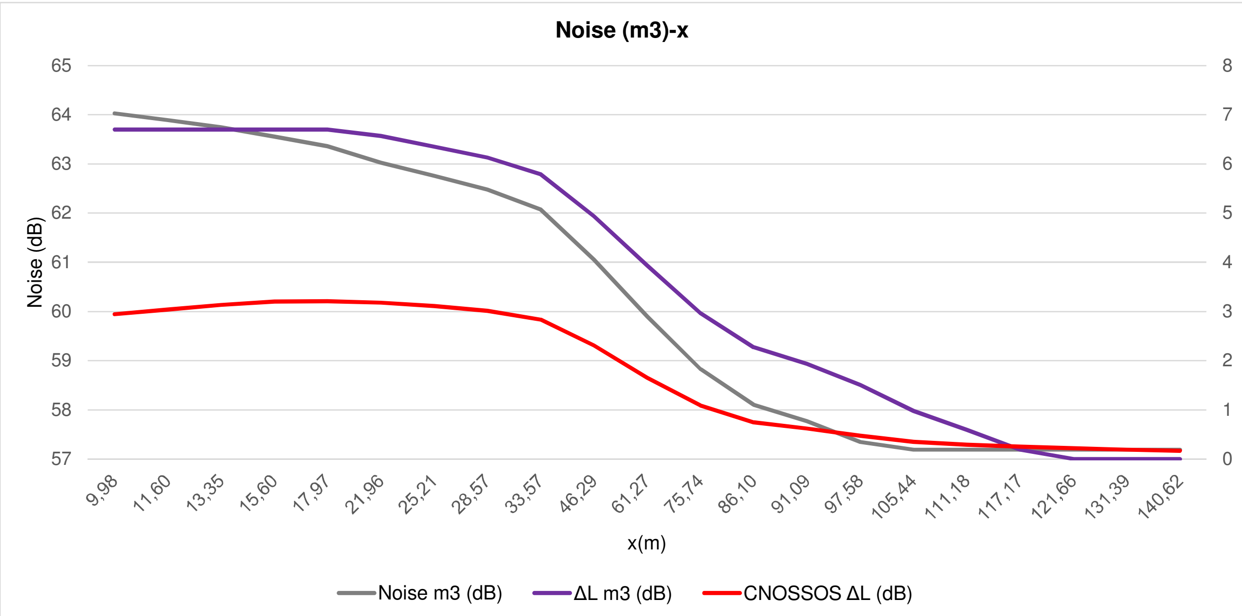

Figure 101: ΔNoise-x analysis for trucks (m3). Comparison CNOSSOS-Theoretical model

The follow figure shows a comparison between both CNOSSOS graphics (passenger cars and heavy vehicles)

	car		h.veh	
	x (m)	ΔL (dB)	x (m)	ΔL (dB)
9,586	9,586	3,088		
9,982			9,982	2,942
11,477	11,477	3,209		
11,604			11,604	3,041
13,351			13,351	3,133
13,369	13,369	3,3		
15,597			15,597	3,201
16,018	16,018	3,346		
17,532	17,532	3,354		
17,968			17,968	3,209
19,928	19,928	3,338		
21,961			21,961	3,178
23,838	23,838	3,278		
25,205			25,205	3,11
28,505	28,505	3,149		

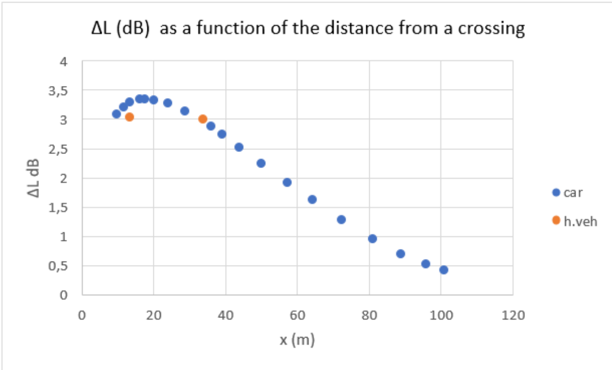

Figure 102: ΔNoise-x analysis for passenger cars and heavy cars

5.2.2.4.4 Conclusions

Specific conclusions associated to each sensitivity analysis are been realized when corresponded. Nevertheless, once realizing the comparison of the theoretical model with results obtained from the reference paper, it can be concluded the accuracy between both results, thus, representing another step in the validation of the noise tool and overall methodology.

6 CONCLUSIONS

Road transport within urban areas and environmental and health issues are strongly related each other. This relation is, mostly caused by road transportation outcomes, such as energy consumption, air pollutant emissions and noise.

It is been conclude that exposed methodology allows generating road transportation scenarios, including traffic configuration, in a very simple way. The simplified methodology includes the simulation of the traffic by Sumo tool, which allows the user obtaining noise emission values, based on Harmonoise method, and fuel consumption and emissions values; based on two different models PHEMLight and HBEFA models.

Both methods allow the user realizing qualitative analysis on simulation outcomes. This way it is been detected the high influence of engine operating points over those outcomes.

PHEMLight is been concluded to be the most accurate method to characterize the simulated scenario quantitatively. Exhaustive fleet characterization stablished within this model, allows the user to determine the absolute fuel consumption and emissions associated to the analysed scenario per category of vehicle and period. Thus, allowing the user to stablish accurate politics to reduce emissions and fuel consumption. This is been tested in the reference scenario.

Several results have been concluded once applying the methodology to the reference scenario:

1. Most fuel consumption is associated to passenger cars, which mainly consume gasoline. Unitary fuel consumption associated to gasoline cars (which is higher than diesel and hybrid) and the huge of gasoline cars fleet are the causes. Gasoline consumption associated to passenger cars (39.170,608 l/day) represents a high proportion of the total daily consumption (50.250,608 l/day). This way, actions to impulse replacements of gasoline cars (unitary gasoline consumption 0,415 l/veh/h) by hybrid cars (unitary gasoline consumption 0,302 l/veh/h) would be an interesting strategy for this scenario in order to reduce fuel consumption and associated air pollution. Consumption associated to hybrid cars (75,85 l/day) represents a few part of the total consumption in the road (20.722,22 l/day), but also the fleet and the unitary consumption which is the lowest of the fleet.
2. Fuel consumption associated to trucks (7.920 l/day) represents an important proportion of the total diesel consumption (10.655 l/day); nevertheless, unitary diesel consumption of trucks is smaller than busses, but not the fleet. This way, it would be interesting to limit the number of trucks driving along this road (the reference scenario) or applying actions in order to dismiss the fleet of trucks or replace it by other category of vehicles. Since diesel combustion is source of high air pollutants emissions, including NO_x, one of the most critical emissions, which is strongly limited by legislation (these emissions have seriously consequences over environment and population health [10])
3. Most CO_2 emissions are due to diesel consumed by trucks (10.332 g/day), which associated unitary vehicle emissions are also very high (1,204 g/veh/day) just below buses. Trucks emissions are followed by emissions associated to cars gasoline consumption, which obtained value for a simulated day is 10.310 g/day. Unitary emissions of pure gasoline cars (0,263 g/veh/day) are not as high as trucks but represent the biggest fleet. The highest CO_2 emission levels associated to trucks are followed by gasoline cars (10.310,85 g/day). Otherwise, the most intensive fuel consumers are buses, which unitary consumption exceeds 4,540 l/veh/h and is also the fleet which emissions per vehicle are highest (3,316 g/veh/h), followed by trucks, which associated emissions are (1,305 g/veh/h) which is far from other vehicles unitary emissions (motorbikes and cars).
4. CNG passenger cars associated unitary emissions (0,270 g/veh/h) are lower than gasoline (0,263

g/veh/h) and diesel (0,245 g/veh/h). Otherwise, hybrid passenger cars emissions are the lowest (0,195 g/veh/h). Unitary CO_2 emissions associated to motorbikes (0,261 g/veh/h), which consume gasoline, are near to gasoline cars.

5. CO_2 emitted by hybrid cars (49 g/day) represents a few part of the total fleet emissions. Both, unitary emissions (0,195 g/veh/day), which are the lowest of the total fleet, and the small hybrid fleet driving along the road, are the causes of these emission levels.

To sum up, implemented methodology is resulted to be useful for traffic evaluation, which allows the user to **promote strategic politics** in order to reduce fuel consumption, emissions and noise for improving population life conditions (comfort and health), preserving the environment and trying to mitigate climate change evidences. This way, replacing the pure gasoline fleet of vehicles, within the reference scenario by hybrid cars, resulted in fuel **savings** of 4.632 litters/day, which supposes a **22,4% of total gasoline consumption** savings and savings of 2.820 litters/day, which supposes a **11% of total CO_2 emission** savings, directly associated to the implementation of the action plan.

Harmonoise noise model implemented in Sumo is also sensible to different operating points associated to vehicles driving along the road. As it was expected, noise pressure levels increase due to high output engines power mostly to acceleration conditions and its effect over propulsion and rolling noise.

PHEMLight energy and emission models as well as noise models, are been compared to theoretical model by its implementation over the same reference scenarios. The accurate of both models with the theoretical ones is been also tested achieving favourable results.

7 OUTLOOK

The natural evolution of this project should be the progressive generation of bigger scenarios, which include different roads intersections. Thus, allowing the generation of scenarios database which could be used by public institutions in order to promote politic strategies which mitigate the effect of transportation activities outcomes, aiming to improve health conditions of urban areas inhabitants and reducing associated negative effects over environment.

It would be also interesting generating a tool, which includes Sumo toll, generated scenarios and indicators associated to transportation outcomes effects over air qualities. This would also include the possibility to simulate proposed strategies in order to decide between different options and promote the most efficient one.

ANNEXES

1. Energy Consumption – PHEMLIGHT results

1.1. Evening results

Table 70 Fuel consumption by edge – Base Line of evening results – PHEMLight (Sumo)

Edge	Length	Speed		Vehicles		Fuel abs	Fuel normed	FuelperVeh		
	m	m/s	km/h	nº veh	nº veh/m	ml	l/km/h	ml/veh	l/h/veh	l/veh/km
1	721,97	12,42	44,73	1.030,16	1,43	312.563,35	432,93	303,44	18,80	0,42
2	**158,73**	**5,11**	**18,40**	**1.054,27**	**6,64**	**102.518,49**	**645,87**	**97,24**	**11,27**	**0,61**
3	98,83	11,99	43,18	1.071,16	10,84	71.225,54	720,69	66,46	29,05	0,67
4	280,86	12,87	46,34	1.029,32	3,66	109.085,10	388,40	106,00	17,48	0,38
5	**156,57**	**4,15**	**14,93**	**1.034,71**	**6,61**	**144.253,70**	**921,34**	**139,43**	**13,29**	**0,89**
6	256,88	12,42	44,70	1.021,05	3,97	146.221,03	569,22	143,23	24,92	0,56
7	**253,63**	**11,91**	**42,87**	**1.008,82**	**3,98**	**103.098,23**	**406,49**	**102,22**	**17,27**	**0,40**
8	70,75	7,49	26,95	1.058,23	14,96	37.255,97	526,59	35,22	13,41	0,50
9	**79,90**	**2,95**	**10,61**	**1.049,50**	**13,14**	**100.606,60**	**1.259,16**	**95,85**	**12,72**	**1,20**
10	135,54	2,29	8,25	1.860,84	13,73	277.835,78	2.049,84	149,31	9,09	1,10
11	84,43	2,17	7,82	1.893,34	22,42	141.052,65	1.670,65	74,50	6,90	0,88
12	**183,31**	**2,11**	**7,61**	**1.802,52**	**9,83**	**410.374,02**	**2.238,69**	**227,66**	**9,46**	**1,24**
13	141,53	5,86	21,09	1.783,94	12,60	177.593,41	1.254,81	99,56	14,83	0,70
14	**98,60**	**2,14**	**7,69**	**1.787,92**	**18,13**	**262.139,85**	**2.658,62**	**146,61**	**11,43**	**1,49**
15	185,89	2,72	9,79	1.713,02	9,22	288.910,48	1.554,20	168,67	8,88	0,91
16	**192,76**	**2,03**	**7,32**	**1.655,15**	**8,59**	**440.165,63**	**2.283,49**	**265,93**	**10,09**	**1,38**
17	117,04	11,83	42,60	1.658,73	14,17	132.128,23	1.128,92	79,68	29,00	0,68
18	**224,94**	**4,10**	**14,77**	**1.617,27**	**7,19**	**299.249,55**	**1.330,35**	**185,03**	**12,15**	**0,82**
19	305,31	6,16	22,18	1.581,07	5,18	296.477,38	971,07	187,50	13,62	0,61
20	281,01	2,40	8,62	1.844,77	6,56	520.619,39	1.852,67	282,22	8,66	1,00
21	**119,86**	**2,19**	**7,87**	**1.843,67**	**15,38**	**361.527,48**	**3.016,25**	**196,09**	**12,87**	**1,64**
22	191,13	5,60	20,17	1.794,55	9,39	247.595,22	1.295,43	137,97	14,56	0,72
23	239,56	2,66	9,56	1.731,24	7,23	374.889,10	1.564,91	216,54	8,64	0,90
24	**143,26**	**2,24**	**8,07**	**1.706,77**	**11,91**	**357.628,89**	**2.496,36**	**209,54**	**11,81**	**1,46**
25	91,82	11,70	42,11	1.726,79	18,81	119.111,53	1.297,23	69,00	31,63	0,75
26	160,18	12,30	44,29	1.673,86	10,45	123.549,19	771,31	73,82	20,41	0,46
27	214,99	12,41	44,66	1.645,38	7,65	165.984,67	772,06	100,86	20,96	0,47
28	**168,42**	**5,20**	**18,72**	**1.653,55**	**9,82**	**295.066,19**	**1.751,97**	**178,44**	**19,83**	**1,06**
29	166,96	11,91	42,87	1.642,27	9,84	160.359,10	960,46	97,66	25,07	0,58
30	**122,56**	**2,96**	**10,67**	**1.640,90**	**13,39**	**270.730,69**	**2.208,96**	**164,99**	**14,36**	**1,35**
31	256,32	12,22	43,98	1.578,85	6,16	257.257,32	1.003,66	162,92	27,96	0,64

1.2. Night results

Table 71 Fuel consumption by edge – Base Line of night results – PHEMLight (Sumo)

Edge	Length	Speed		Vehicles		Fuel abs	Fuel normed	FuelperVeh		
	m	m/s	km/h	nº veh	nº veh/m	ml	l/km/h	ml/veh	l/h/veh	l/veh/km
1	721,97	13,64	49,10	299,44	0,41	150.103,10	207,91	501,24	34,09	0,69
2	**158,73**	**6,89**	**24,81**	**305,05**	**1,92**	**40.289,24**	**253,82**	**132,06**	**20,65**	**0,83**
3	98,83	12,28	44,20	310,18	3,14	38.520,86	389,77	124,19	55,54	1,26
4	280,86	13,59	48,92	297,44	1,06	48.568,85	172,93	163,30	28,44	0,58
5	**156,57**	**4,40**	**15,86**	**296,92**	**1,90**	**65.030,20**	**415,34**	**219,03**	**22,18**	**1,40**
6	256,88	12,70	45,74	293,45	1,14	56.945,80	221,68	194,08	34,55	0,76
7	**253,63**	**13,53**	**48,70**	**287,93**	**1,14**	**44.645,50**	**176,03**	**155,10**	**29,77**	**0,61**
8	70,75	12,77	45,97	299,36	4,23	12.207,73	172,55	40,81	26,50	0,58
9	**79,90**	**3,23**	**11,62**	**297,00**	**3,72**	**47.908,44**	**599,61**	**161,34**	**23,45**	**2,02**
10	135,54	12,64	45,52	590,95	4,36	93.539,99	690,13	158,34	53,16	1,17
11	84,43	13,42	48,32	614,10	7,27	30.150,07	357,10	49,08	28,10	0,58
12	**183,31**	**5,06**	**18,22**	**595,28**	**3,25**	**147.604,14**	**805,22**	**247,92**	**24,65**	**1,35**
13	141,53	12,29	44,23	596,75	4,22	67.569,06	477,42	113,22	35,38	0,80
14	**98,60**	**5,63**	**20,28**	**602,87**	**6,11**	**95.008,86**	**963,58**	**157,60**	**32,42**	**1,60**
15	185,89	12,73	45,84	579,51	3,12	95.661,62	514,61	165,05	40,70	0,89
16	**192,76**	**5,33**	**19,20**	**577,11**	**2,99**	**132.534,10**	**687,56**	**229,66**	**22,88**	**1,19**
17	117,04	12,00	43,21	585,71	5,00	81.050,61	692,50	138,37	51,09	1,18
18	**224,94**	**5,37**	**19,35**	**570,79**	**2,54**	**131.102,90**	**582,83**	**229,67**	**19,76**	**1,02**
19	305,31	12,59	45,32	559,01	1,83	142.457,79	466,60	254,86	37,83	0,83
20	281,01	13,02	46,88	856,20	3,05	173.938,01	618,97	203,13	33,89	0,72
21	**119,86**	**5,31**	**19,13**	**879,90**	**7,34**	**170.906,68**	**1.425,89**	**194,28**	**30,99**	**1,62**
22	191,13	12,31	44,31	864,67	4,52	149.665,15	783,05	173,06	40,12	0,91
23	239,56	12,91	46,47	849,26	3,55	121.611,22	507,64	143,20	27,78	0,60
24	**143,26**	**4,15**	**14,95**	**853,76**	**5,96**	**175.623,96**	**1.225,91**	**205,68**	**21,47**	**1,44**
25	91,82	11,86	42,71	869,36	9,47	106.521,54	1.160,11	122,51	56,99	1,33
26	160,18	12,88	46,35	849,25	5,30	81.084,97	506,21	95,51	27,63	0,60
27	214,99	12,97	46,68	830,88	3,86	108.001,81	502,36	130,00	28,22	0,60
28	**168,42**	**5,14**	**18,51**	**832,23**	**4,94**	**178.127,15**	**1.057,64**	**214,04**	**23,52**	**1,27**
29	166,96	12,40	44,65	832,47	4,99	144.546,27	865,75	173,64	46,44	1,04
30	**122,56**	**4,33**	**15,59**	**835,31**	**6,82**	**135.312,89**	**1.104,05**	**162,00**	**20,61**	**1,32**
31	256,32	12,98	46,72	804,18	3,14	159.364,50	621,74	198,22	36,12	0,77

2. Energy Consumption – HBEFA results

2.1. Evening results

Table 72 Fuel consumption by edge – Base Line of evening results – HBEFA (Sumo)

Edge	Length	Speed		Vehicles		Fuel abs	Fuel normed	Fuel per Veh		
	m	m/s	km/h	nº veh	nº veh/m	ml	l/km/h	ml/veh	l/h/veh	l/veh/km
1	721,97	12,42	44,73	1.030,16	1,43	85.509,21	118,44	83,01	5,14	0,11
2	**158,73**	**5,11**	**18,40**	**1.054,27**	**6,64**	**32.235,60**	**203,08**	**30,58**	**3,55**	**0,19**
3	98,83	11,99	43,18	1.071,16	10,84	22.428,05	226,94	20,93	9,15	0,21
4	280,86	12,87	46,34	1.029,32	3,66	30.052,46	107,00	29,20	4,82	0,10
5	**156,57**	**4,15**	**14,93**	**1.034,71**	**6,61**	**35.029,57**	**223,73**	**33,86**	**3,23**	**0,22**
6	256,88	12,42	44,70	1.021,05	3,97	40.452,20	157,48	39,63	6,89	0,15
7	**253,63**	**11,91**	**42,87**	**1.008,82**	**3,98**	**29.170,67**	**115,01**	**28,92**	**4,89**	**0,11**
8	70,75	7,49	26,95	1.058,23	14,96	11.541,63	163,13	10,91	4,15	0,15
9	**79,90**	**2,95**	**10,61**	**1.049,50**	**13,14**	**21.911,55**	**274,24**	**20,88**	**2,77**	**0,26**
10	135,54	2,29	8,25	1.860,84	13,73	73.826,38	544,68	39,67	2,41	0,29
11	84,43	2,17	7,82	1.893,34	22,42	47.099,88	557,86	24,88	2,31	0,29
12	**183,31**	**2,11**	**7,61**	**1.802,52**	**9,83**	**116.597,02**	**636,06**	**64,68**	**2,69**	**0,35**
13	141,53	5,86	21,09	1.783,94	12,60	57.080,81	403,31	32,00	4,77	0,23
14	**98,60**	**2,14**	**7,69**	**1.787,92**	**18,13**	**64.983,56**	**659,06**	**36,34**	**2,83**	**0,37**
15	185,89	2,72	9,79	1.713,02	9,22	85.348,19	459,13	49,83	2,62	0,27
16	**192,76**	**2,03**	**7,32**	**1.655,15**	**8,59**	**115.201,49**	**597,64**	**69,60**	**2,64**	**0,36**
17	117,04	11,83	42,60	1.658,73	14,17	34.608,93	295,70	20,87	7,59	0,18
18	**224,94**	**4,10**	**14,77**	**1.617,27**	**7,19**	**71.083,18**	**316,01**	**43,95**	**2,89**	**0,20**
19	305,31	6,16	22,18	1.581,07	5,18	71.069,61	232,78	44,95	3,27	0,15
20	281,01	2,40	8,62	1.844,77	6,56	143.360,90	510,16	77,71	2,38	0,28
21	**119,86**	**2,19**	**7,87**	**1.843,67**	**15,38**	**80.403,64**	**670,81**	**43,61**	**2,86**	**0,36**
22	191,13	5,60	20,17	1.794,55	9,39	58.484,44	305,99	32,59	3,44	0,17
23	239,56	2,66	9,56	1.731,24	7,23	99.549,57	415,55	57,50	2,30	0,24
24	**143,26**	**2,24**	**8,07**	**1.706,77**	**11,91**	**84.599,98**	**590,53**	**49,57**	**2,79**	**0,35**
25	91,82	11,70	42,11	1.726,79	18,81	31.242,07	340,25	18,10	8,30	0,20
26	160,18	12,30	44,29	1.673,86	10,45	26.030,78	162,51	15,55	4,30	0,10
27	214,99	12,41	44,66	1.645,38	7,65	33.398,39	155,35	20,29	4,22	0,09
28	**168,42**	**5,20**	**18,72**	**1.653,55**	**9,82**	**55.325,47**	**328,50**	**33,46**	**3,72**	**0,20**
29	166,96	11,91	42,87	1.642,27	9,84	43.494,88	260,51	26,49	6,80	0,16
30	**122,56**	**2,96**	**10,67**	**1.640,90**	**13,39**	**50.569,82**	**412,61**	**30,82**	**2,68**	**0,25**
31	256,32	12,22	43,98	1.578,85	6,16	64.381,62	251,18	40,77	7,00	0,16

2.2. Night results

Table 73 Fuel consumption by edge – Base Line of night results – HBEFA (Sumo)

Edge	Length	Speed		Vehicles		Fuel abs	Fuel normed	FuelperVeh		
	m	m/s	km/h	nº veh	nº veh/m	ml	l/km/h	ml/veh	l/h/veh	l/veh/km
1	721,97	13,64	49,10	299,44	0,41	22.830,42	31,62	76,24	5,19	0,11
2	**158,73**	**6,89**	**24,81**	**305,05**	**1,92**	**6.234,95**	**39,28**	**20,44**	**3,20**	**0,13**
3	98,83	12,28	44,20	310,18	3,14	6.499,80	65,77	20,95	9,37	0,21
4	280,86	13,59	48,92	297,44	1,06	8.465,62	30,14	28,46	4,96	0,10
5	**156,57**	**4,40**	**15,86**	**296,92**	**1,90**	**8.264,18**	**52,78**	**27,84**	**2,82**	**0,18**
6	256,88	12,70	45,74	293,45	1,14	12.237,48	47,64	41,71	7,42	0,16
7	**253,63**	**13,53**	**48,70**	**287,93**	**1,14**	**7.277,05**	**28,69**	**25,28**	**4,85**	**0,10**
8	70,75	12,77	45,97	299,36	4,23	2.150,50	30,40	7,19	4,67	0,10
9	**79,90**	**3,23**	**11,62**	**297,00**	**3,72**	**5.527,47**	**69,18**	**18,61**	**2,71**	**0,23**
10	135,54	12,64	45,52	590,95	4,36	14.011,50	103,38	23,72	7,96	0,17
11	84,43	13,42	48,32	614,10	7,27	4.979,32	58,98	8,11	4,64	0,10
12	**183,31**	**5,06**	**18,22**	**595,28**	**3,25**	**18.761,40**	**102,35**	**31,51**	**3,13**	**0,17**
13	141,53	12,29	44,23	596,75	4,22	15.550,72	109,88	26,06	8,14	0,18
14	**98,60**	**5,63**	**20,28**	**602,87**	**6,11**	**8.749,37**	**88,74**	**14,51**	**2,99**	**0,15**
15	185,89	12,73	45,84	579,51	3,12	13.004,19	69,96	22,44	5,53	0,12
16	**192,76**	**5,33**	**19,20**	**577,11**	**2,99**	**17.373,42**	**90,13**	**30,10**	**3,00**	**0,16**
17	117,04	12,00	43,21	585,71	5,00	13.313,14	113,75	22,73	8,39	0,19
18	**224,94**	**5,37**	**19,35**	**570,79**	**2,54**	**19.663,25**	**87,42**	**34,45**	**2,96**	**0,15**
19	305,31	12,59	45,32	559,01	1,83	22.696,79	74,34	40,60	6,03	0,13
20	281,01	13,02	46,88	856,20	3,05	25.355,14	90,23	29,61	4,94	0,11
21	**119,86**	**5,31**	**19,13**	**879,90**	**7,34**	**19.981,91**	**166,71**	**22,71**	**3,62**	**0,19**
22	191,13	12,31	44,31	864,67	4,52	24.645,39	128,95	28,50	6,61	0,15
23	239,56	12,91	46,47	849,26	3,55	19.716,91	82,30	23,22	4,50	0,10
24	**143,26**	**4,15**	**14,95**	**853,76**	**5,96**	**24.330,78**	**169,84**	**28,49**	**2,97**	**0,20**
25	91,82	11,86	42,71	869,36	9,47	16.967,46	184,79	19,51	9,08	0,21
26	160,18	12,88	46,35	849,25	5,30	12.827,30	80,08	15,11	4,37	0,09
27	214,99	12,97	46,68	830,88	3,86	16.960,29	78,89	20,41	4,43	0,09
28	**168,42**	**5,14**	**18,51**	**832,23**	**4,94**	**25.048,38**	**148,73**	**30,10**	**3,31**	**0,18**
29	166,96	12,40	44,65	832,47	4,99	22.841,74	136,81	27,44	7,34	0,16
30	**122,56**	**4,33**	**15,59**	**835,31**	**6,82**	**17.919,20**	**146,21**	**21,45**	**2,73**	**0,18**
31	256,32	12,98	46,72	804,18	3,14	28.652,65	111,78	35,64	6,49	0,14

3. Emissions – PHEMLIGHT results

3.1. Evening results

Table 74 CO_2 emissions by edge – Base Line of evening results – PHEMLight (Sumo)

Edge	Length	Speed		Vehicles		CO2 abs	CO2 normed	CO2perVeh		
	m	m/s	km/h	nº	veh/m	mg	g/km/h	mg/veh	g/h/veh	g/veh/km
1	721,97	12,42	44,73	1.030,16	1,43	211.459.172,25	292.891,91	205.267,38	12.716,62	284,32
2	**158,73**	**5,11**	**18,40**	**1.054,27**	**6,64**	**97.338.969,97**	**613.236,12**	**92.328,69**	**10.704,78**	**581,67**
3	98,83	11,99	43,18	1.071,16	10,84	61.726.896,59	624.576,51	57.626,40	25.176,58	583,09
4	280,86	12,87	46,34	1.029,32	3,66	69.932.552,88	248.994,35	67.940,76	11.209,29	241,90
5	**156,57**	**4,15**	**14,93**	**1.034,71**	**6,61**	**108.912.610,60**	**695.616,09**	**105.258,61**	**10.035,25**	**672,28**
6	256,88	12,42	44,70	1.021,05	3,97	103.109.128,78	401.390,26	100.983,69	17.570,87	393,12
7	**253,63**	**11,91**	**42,87**	**1.008,82**	**3,98**	**70.893.735,92**	**279.516,37**	**70.273,71**	**11.877,25**	**277,07**
8	70,75	7,49	26,95	1.058,23	14,96	32.540.788,91	459.940,48	30.750,31	11.714,40	434,63
9	**79,90**	**2,95**	**10,61**	**1.049,50**	**13,14**	**71.829.219,51**	**898.988,98**	**68.441,08**	**9.085,10**	**856,58**
10	135,54	2,29	8,25	1.860,84	13,73	241.058.748,30	1.778.506,33	129.543,00	7.882,94	955,75
11	84,43	2,17	7,82	1.893,34	22,42	155.178.222,18	1.837.951,23	81.959,98	7.594,75	970,74
12	**183,31**	**2,11**	**7,61**	**1.802,52**	**9,83**	**389.725.243,27**	**2.126.044,64**	**216.211,65**	**8.979,72**	**1.179,49**
13	141,53	5,86	21,09	1.783,94	12,60	184.179.222,08	1.301.344,04	103.242,97	15.383,89	729,48
14	**98,60**	**2,14**	**7,69**	**1.787,92**	**18,13**	**215.227.934,51**	**2.182.839,09**	**120.378,92**	**9.384,24**	**1.220,88**
15	185,89	2,72	9,79	1.713,02	9,22	269.887.622,55	1.451.867,35	157.550,58	8.299,42	847,55
16	**192,76**	**2,03**	**7,32**	**1.655,15**	**8,59**	**385.298.297,29**	**1.998.849,85**	**232.787,12**	**8.836,29**	**1.207,65**
17	117,04	11,83	42,60	1.658,73	14,17	91.302.078,63	780.092,95	55.043,23	20.035,96	470,29
18	**224,94**	**4,10**	**14,77**	**1.617,27**	**7,19**	**219.610.980,83**	**976.309,15**	**135.790,86**	**8.914,06**	**603,68**
19	305,31	6,16	22,18	1.581,07	5,18	201.318.621,01	659.390,85	127.330,49	9.249,19	417,05
20	281,01	2,40	8,62	1.844,77	6,56	471.084.889,94	1.676.399,02	255.362,17	7.836,53	908,73
21	**119,86**	**2,19**	**7,87**	**1.843,67**	**15,38**	**268.989.764,64**	**2.244.199,60**	**145.899,08**	**9.575,87**	**1.217,25**
22	191,13	5,60	20,17	1.794,55	9,39	169.753.237,88	888.155,90	94.593,59	9.980,57	494,92
23	239,56	2,66	9,56	1.731,24	7,23	320.995.208,12	1.339.936,58	185.413,54	7.400,92	773,98
24	**143,26**	**2,24**	**8,07**	**1.706,77**	**11,91**	**284.176.483,49**	**1.983.641,52**	**166.499,44**	**9.383,19**	**1.162,22**
25	91,82	11,70	42,11	1.726,79	18,81	85.758.045,99	933.980,03	49.663,35	22.775,55	540,88
26	160,18	12,30	44,29	1.673,86	10,45	63.927.030,91	399.094,96	38.191,27	10.559,80	238,43
27	214,99	12,41	44,66	1.645,38	7,65	87.357.430,68	406.332,53	53.092,49	11.029,02	246,95
28	**168,42**	**5,20**	**18,72**	**1.653,55**	**9,82**	**180.233.910,19**	**1.070.145,53**	**108.997,99**	**12.114,63**	**647,18**
29	166,96	11,91	42,87	1.642,27	9,84	112.086.796,33	671.339,22	68.251,12	17.525,25	408,79
30	**122,56**	**2,96**	**10,67**	**1.640,90**	**13,39**	**162.838.308,66**	**1.328.641,55**	**99.237,43**	**8.639,78**	**809,70**
31	256,32	12,22	43,98	1.578,85	6,16	164.275.633,70	640.900,57	104.047,47	17.853,71	405,93

3.2. Night results

Table 75 CO_2 emissions by edge – Base Line of night results – PHEMLight (Sumo)

Edge	Length	Speed		Vehicles		CO2 abs	CO2 normed	CO2perVeh		
	m	m/s	km/h	nº	veh/m	mg	g/km/h	mg/veh	g/h/veh	g/veh/km
1	721,97	13,64	49,10	299,44	0,41	53.659.597,69	74.323,86	179.197,45	12.188,00	248,21
2	**158,73**	**6,89**	**24,81**	**305,05**	**1,92**	**17.969.827,58**	**113.210,03**	**58.908,49**	**9.208,45**	**371,12**
3	98,83	12,28	44,20	310,18	3,14	19.578.218,54	198.099,95	63.118,62	28.226,96	638,66
4	280,86	13,59	48,92	297,44	1,06	19.206.811,92	68.385,72	64.574,73	11.246,69	229,92
5	**156,57**	**4,40**	**15,86**	**296,92**	**1,90**	**24.816.876,26**	**158.503,39**	**83.580,51**	**8.463,85**	**533,82**
6	256,88	12,70	45,74	293,45	1,14	33.806.174,77	131.602,98	115.203,26	20.510,97	448,47
7	**253,63**	**13,53**	**48,70**	**287,93**	**1,14**	**16.544.582,88**	**65.231,17**	**57.460,73**	**11.032,46**	**226,55**
8	70,75	12,77	45,97	299,36	4,23	4.984.766,72	70.456,07	16.651,36	10.820,38	235,35
9	**79,90**	**3,23**	**11,62**	**297,00**	**3,72**	**18.046.312,00**	**225.861,23**	**60.761,58**	**8.834,48**	**760,47**
10	135,54	12,64	45,52	590,95	4,36	39.131.508,41	288.708,19	66.218,01	22.237,39	488,55
11	84,43	13,42	48,32	614,10	7,27	11.623.514,33	137.670,43	18.927,57	10.832,95	224,18
12	**183,31**	**5,06**	**18,22**	**595,28**	**3,25**	**56.201.429,58**	**306.592,27**	**94.411,71**	**9.386,42**	**515,04**
13	141,53	12,29	44,23	596,75	4,22	43.974.163,97	310.705,60	73.689,21	23.027,88	520,66
14	**98,60**	**5,63**	**20,28**	**602,87**	**6,11**	**24.311.607,05**	**246.568,02**	**40.326,58**	**8.295,75**	**408,99**
15	185,89	12,73	45,84	579,51	3,12	34.485.213,34	185.514,09	59.507,86	14.673,17	320,12
16	**192,76**	**5,33**	**19,20**	**577,11**	**2,99**	**54.154.548,13**	**280.942,87**	**93.837,95**	**9.347,44**	**486,81**
17	117,04	12,00	43,21	585,71	5,00	37.821.177,60	323.147,45	64.573,70	23.842,60	551,72
18	**224,94**	**5,37**	**19,35**	**570,79**	**2,54**	**56.440.201,44**	**250.912,25**	**98.880,40**	**8.505,84**	**439,59**
19	305,31	12,59	45,32	559,01	1,83	58.625.181,80	192.018,54	104.873,63	15.568,87	343,50
20	281,01	13,02	46,88	856,20	3,05	61.921.619,50	220.353,79	72.321,70	12.064,79	257,36
21	**119,86**	**5,31**	**19,13**	**879,90**	**7,34**	**65.026.273,99**	**542.518,55**	**73.902,28**	**11.792,92**	**616,57**
22	191,13	12,31	44,31	864,67	4,52	67.482.425,99	353.070,82	78.043,88	18.091,30	408,33
23	239,56	12,91	46,47	849,26	3,55	46.854.651,23	195.586,29	55.171,17	10.701,30	230,30
24	**143,26**	**4,15**	**14,95**	**853,76**	**5,96**	**79.452.179,62**	**554.601,28**	**93.060,96**	**9.713,52**	**649,59**
25	91,82	11,86	42,71	869,36	9,47	50.258.394,04	547.357,81	57.810,85	26.888,77	629,61
26	160,18	12,88	46,35	849,25	5,30	31.091.606,80	194.104,18	36.610,87	10.594,79	228,56
27	214,99	12,97	46,68	830,88	3,86	41.477.426,68	192.927,24	49.919,91	10.839,06	232,20
28	**168,42**	**5,14**	**18,51**	**832,23**	**4,94**	**79.620.681,40**	**472.750,75**	**95.671,89**	**10.513,39**	**568,06**
29	166,96	12,40	44,65	832,47	4,99	62.693.727,62	375.501,48	75.310,40	20.142,46	451,07
30	**122,56**	**4,33**	**15,59**	**835,31**	**6,82**	**54.699.136,66**	**446.304,97**	**65.483,92**	**8.330,11**	**534,30**
31	256,32	12,98	46,72	804,18	3,14	72.915.484,34	284.470,52	90.670,40	16.527,26	353,74

4. Emissions – HBEFA results

4.1. Evening results

Table 76 CO_2 emissions by edge – Base Line of night results –HBEFA (Sumo)

Edge	Length	Speed		Vehicles		CO2 abs	CO2 normed	CO2perVeh		
	m	m/s	km/h	nº	veh/m	mg	g/km/h	mg/veh	g/h/veh	g/veh/km
1	721,97	12,42	44,73	1.030,16	1,43	213.481.504,95	295.693,04	207.247,61	12.838,23	287,03
2	**158,73**	**5,11**	**18,40**	**1.054,27**	**6,64**	**80.648.688,19**	**508.087,24**	**76.497,54**	**8.869,28**	**481,93**
3	98,83	11,99	43,18	1.071,16	10,84	55.939.455,51	566.016,95	52.194,17	22.816,06	528,42
4	280,86	12,87	46,34	1.029,32	3,66	75.071.619,64	267.291,96	72.947,23	12.033,02	259,68
5	**156,57**	**4,15**	**14,93**	**1.034,71**	**6,61**	**87.512.370,23**	**558.934,47**	**84.587,10**	**8.063,42**	**540,18**
6	256,88	12,42	44,70	1.021,05	3,97	100.931.407,40	392.912,67	98.869,98	17.199,76	384,81
7	**253,63**	**11,91**	**42,87**	**1.008,82**	**3,98**	**72.938.465,74**	**287.578,23**	**72.314,67**	**12.219,81**	**285,06**
8	70,75	7,49	26,95	1.058,23	14,96	28.946.942,21	409.144,06	27.364,23	10.420,65	386,63
9	**79,90**	**2,95**	**10,61**	**1.049,50**	**13,14**	**54.699.044,78**	**684.593,80**	**52.111,53**	**6.918,44**	**652,30**
10	135,54	2,29	8,25	1.860,84	13,73	183.781.706,99	1.355.922,29	98.761,73	6.009,91	728,66
11	84,43	2,17	7,82	1.893,34	22,42	117.230.456,68	1.388.492,91	61.920,82	5.737,50	733,36
12	**183,31**	**2,11**	**7,61**	**1.802,52**	**9,83**	**290.730.953,81**	**1.586.007,06**	**161.287,20**	**6.698,78**	**879,88**
13	141,53	5,86	21,09	1.783,94	12,60	142.190.093,20	1.004.663,98	79.711,42	11.876,67	563,17
14	**98,60**	**2,14**	**7,69**	**1.787,92**	**18,13**	**162.062.083,63**	**1.643.631,68**	**90.638,75**	**7.066,13**	**919,30**
15	185,89	2,72	9,79	1.713,02	9,22	212.574.856,43	1.143.551,87	124.101,69	6.536,97	667,56
16	**192,76**	**2,03**	**7,32**	**1.655,15**	**8,59**	**287.439.876,49**	**1.491.180,10**	**173.658,68**	**6.592,04**	**900,93**
17	117,04	11,83	42,60	1.658,73	14,17	86.322.743,12	737.549,07	52.058,68	18.943,26	444,65
18	**224,94**	**4,10**	**14,77**	**1.617,27**	**7,19**	**177.333.667,34**	**788.359,86**	**109.646,02**	**7.198,01**	**487,46**
19	305,31	6,16	22,18	1.581,07	5,18	177.142.867,83	580.206,57	112.029,75	8.138,48	366,97
20	281,01	2,40	8,62	1.844,77	6,56	357.066.093,38	1.270.652,62	193.558,61	5.939,82	688,79
21	**119,86**	**2,19**	**7,87**	**1.843,67**	**15,38**	**200.460.584,82**	**1.672.456,07**	**108.728,12**	**7.136,28**	**907,13**
22	191,13	5,60	20,17	1.794,55	9,39	145.749.679,56	762.568,30	81.219,63	8.569,29	424,93
23	239,56	2,66	9,56	1.731,24	7,23	247.742.329,98	1.034.155,66	143.098,76	5.711,99	597,35
24	**143,26**	**2,24**	**8,07**	**1.706,77**	**11,91**	**211.050.272,91**	**1.473.197,49**	**123.659,16**	**6.968,64**	**863,15**
25	91,82	11,70	42,11	1.726,79	18,81	77.899.412,19	848.392,64	45.125,36	20.688,46	491,31
26	160,18	12,30	44,29	1.673,86	10,45	64.957.978,33	405.531,14	38.812,17	10.730,10	242,27
27	214,99	12,41	44,66	1.645,38	7,65	83.304.101,96	387.478,96	50.619,39	10.517,28	235,49
28	**168,42**	**5,20**	**18,72**	**1.653,55**	**9,82**	**137.922.037,16**	**818.917,21**	**83.406,99**	**9.270,59**	**495,25**
29	166,96	11,91	42,87	1.642,27	9,84	108.496.463,62	649.835,07	66.074,27	16.963,89	395,69
30	**122,56**	**2,96**	**10,67**	**1.640,90**	**13,39**	**126.260.191,46**	**1.030.190,86**	**76.947,93**	**6.699,04**	**627,82**
31	256,32	12,22	43,98	1.578,85	6,16	160.592.920,17	626.532,93	101.703,38	17.453,47	396,83

4.2. Night results

Table 77 CO_2 emissions by edge – Base Line of night results – HBEFA (Sumo)

Edge	Length	Speed		Vehicles		CO2 abs	CO2 normed	CO 2per Veh		
	m	m/s	km/h	nº	veh/m	mg	g/km/h	mg/veh	g/h/veh	g/veh/km
1	721,97	13,64	49,10	299,44	0,41	56.960.476,25	78.895,90	190.208,34	12.937,75	263,47
2	**158,73**	**6,89**	**24,81**	**305,05**	**1,92**	**15.566.130,93**	**98.066,72**	**51.023,61**	**7.976,70**	**321,48**
3	98,83	12,28	44,20	310,18	3,14	16.187.149,53	163.787,81	52.185,66	23.337,87	528,04
4	280,86	13,59	48,92	297,44	1,06	21.128.253,66	75.226,99	71.038,73	12.371,80	252,92
5	**156,57**	**4,40**	**15,86**	**296,92**	**1,90**	**20.621.922,34**	**131.710,56**	**69.458,03**	**7.033,15**	**443,59**
6	256,88	12,70	45,74	293,45	1,14	30.473.290,80	118.628,51	103.855,03	18.488,83	404,26
7	**253,63**	**13,53**	**48,70**	**287,93**	**1,14**	**18.160.222,97**	**71.601,24**	**63.087,33**	**12.109,82**	**248,68**
8	70,75	12,77	45,97	299,36	4,23	5.372.177,89	75.931,84	17.959,04	11.661,32	253,65
9	**79,90**	**3,23**	**11,62**	**297,00**	**3,72**	**13.772.994,09**	**172.377,90**	**46.382,51**	**6.742,50**	**580,39**
10	135,54	12,64	45,52	590,95	4,36	34.907.098,38	257.540,94	59.087,85	19.836,77	435,81
11	84,43	13,42	48,32	614,10	7,27	12.420.145,96	147.105,84	20.219,14	11.575,40	239,55
12	**183,31**	**5,06**	**18,22**	**595,28**	**3,25**	**46.909.341,43**	**255.901,70**	**78.791,31**	**7.834,51**	**429,88**
13	141,53	12,29	44,23	596,75	4,22	38.758.923,41	273.856,59	64.947,00	20.296,82	458,91
14	**98,60**	**5,63**	**20,28**	**602,87**	**6,11**	**21.895.484,88**	**222.063,74**	**36.319,92**	**7.471,31**	**368,35**
15	185,89	12,73	45,84	579,51	3,12	32.392.062,84	174.253,93	55.886,91	13.782,55	300,69
16	**192,76**	**5,33**	**19,20**	**577,11**	**2,99**	**43.390.553,84**	**225.101,44**	**75.187,40**	**7.489,51**	**390,05**
17	117,04	12,00	43,21	585,71	5,00	33.160.854,82	283.329,24	56.610,82	20.904,71	483,74
18	**224,94**	**5,37**	**19,35**	**570,79**	**2,54**	**49.129.445,59**	**218.411,33**	**86.066,26**	**7.404,07**	**382,65**
19	305,31	12,59	45,32	559,01	1,83	56.576.159,52	185.307,26	101.215,59	15.024,72	331,49
20	281,01	13,02	46,88	856,20	3,05	63.276.808,70	225.176,36	73.894,94	12.328,83	263,00
21	**119,86**	**5,31**	**19,13**	**879,90**	**7,34**	**49.845.193,95**	**415.861,79**	**56.660,85**	**9.039,73**	**472,63**
22	191,13	12,31	44,31	864,67	4,52	61.415.492,12	321.328,37	71.016,13	16.464,83	371,62
23	239,56	12,91	46,47	849,26	3,55	49.209.980,96	205.418,19	57.945,61	11.239,25	241,88
24	**143,26**	**4,15**	**14,95**	**853,76**	**5,96**	**60.668.842,39**	**423.487,66**	**71.050,52**	**7.417,14**	**496,02**
25	91,82	11,86	42,71	869,36	9,47	42.253.640,12	460.179,05	48.594,62	22.606,14	529,33
26	160,18	12,88	46,35	849,25	5,30	31.997.342,27	199.758,66	37.689,13	10.903,42	235,22
27	214,99	12,97	46,68	830,88	3,86	42.300.052,50	196.753,58	50.914,73	11.054,04	236,80
28	**168,42**	**5,14**	**18,51**	**832,23**	**4,94**	**62.425.538,56**	**370.653,95**	**75.009,66**	**8.242,89**	**445,38**
29	166,96	12,40	44,65	832,47	4,99	56.902.018,61	340.812,28	68.355,95	18.281,68	409,40
30	**122,56**	**4,33**	**15,59**	**835,31**	**6,82**	**44.843.646,69**	**365.891,37**	**53.686,52**	**6.829,22**	**438,03**
31	256,32	12,98	46,72	804,18	3,14	71.426.603,06	278.661,84	88.840,28	16.189,79	346,52

5. Noise results (Sumo)

5.1. Evening results

Table 78 Noise by edge – Base Line of evening results – PHEMLight

Edge	Length	Speed		Vehicles		Noise (abs)	Noise (normalized 100m)
	m	m/s	km/h	nº veh	nº veh/m	dB	dB
1	721,97	12,42	44,73	1.030,16	1,43	81,80	73,21
2	**158,73**	**5,11**	**18,40**	**1.054,27**	**6,64**	**77,46**	**75,45**
3	98,83	11,99	43,18	1.071,16	10,84	76,24	76,29
4	280,86	12,87	46,34	1.029,32	3,66	77,42	72,94
5	**156,57**	**4,15**	**14,93**	**1.034,71**	**6,61**	**77,65**	**75,70**
6	256,88	12,42	44,70	1.021,05	3,97	78,65	74,55
7	**253,63**	**11,91**	**42,87**	**1.008,82**	**3,98**	**77,31**	**73,27**
8	70,75	7,49	26,95	1.058,23	14,96	73,42	74,92
9	**79,90**	**2,95**	**10,61**	**1.049,50**	**13,14**	**75,28**	**76,25**
10	135,54	2,29	8,25	1.860,84	13,73	79,21	77,89
11	84,43	2,17	7,82	1.893,34	22,42	77,22	77,96
12	**183,31**	**2,11**	**7,61**	**1.802,52**	**9,83**	**81,63**	**79,00**
13	141,53	5,86	21,09	1.783,94	12,60	79,49	77,98
14	**98,60**	**2,14**	**7,69**	**1.787,92**	**18,13**	**79,46**	**79,52**
15	185,89	2,72	9,79	1.713,02	9,22	80,52	77,83
16	**192,76**	**2,03**	**7,32**	**1.655,15**	**8,59**	**81,62**	**78,77**
17	117,04	11,83	42,60	1.658,73	14,17	77,87	77,19
18	**224,94**	**4,10**	**14,77**	**1.617,27**	**7,19**	**80,38**	**76,86**
19	305,31	6,16	22,18	1.581,07	5,18	80,67	75,82
20	281,01	2,40	8,62	1.844,77	6,56	82,05	77,56
21	**119,86**	**2,19**	**7,87**	**1.843,67**	**15,38**	**80,31**	**79,52**
22	191,13	5,60	20,17	1.794,55	9,39	79,69	76,88
23	239,56	2,66	9,56	1.731,24	7,23	80,62	76,83
24	**143,26**	**2,24**	**8,07**	**1.706,77**	**11,91**	**80,58**	**79,02**
25	91,82	11,70	42,11	1.726,79	18,81	77,75	78,12
26	160,18	12,30	44,29	1.673,86	10,45	76,91	74,86
27	214,99	12,41	44,66	1.645,38	7,65	78,08	74,76
28	**168,42**	**5,20**	**18,72**	**1.653,55**	**9,82**	**79,56**	**77,30**
29	166,96	11,91	42,87	1.642,27	9,84	78,91	76,68
30	**122,56**	**2,96**	**10,67**	**1.640,90**	**13,39**	**78,84**	**77,96**
31	256,32	12,22	43,98	1.578,85	6,16	80,42	76,33

5.2. Night results

Table 79 Noise by edge – Base Line of night results – PHEMLight

Edge	Length	Speed		Vehicles		Noise (abs)	Noise (normalized 100m)
	m	m/s	km/h	nº veh	nº veh/m	dB	dB
1	721,97	13,64	49,10	299,44	0,41	75,69	67,10
2	**158,73**	**6,89**	**24,81**	**305,05**	**1,92**	**71,03**	**69,02**
3	98,83	12,28	44,20	310,18	3,14	71,71	71,76
4	280,86	13,59	48,92	297,44	1,06	71,58	67,10
5	**156,57**	**4,40**	**15,86**	**296,92**	**1,90**	**71,72**	**69,77**
6	256,88	12,70	45,74	293,45	1,14	73,77	69,67
7	**253,63**	**13,53**	**48,70**	**287,93**	**1,14**	**70,78**	**66,74**
8	70,75	12,77	45,97	299,36	4,23	66,08	67,58
9	**79,90**	**3,23**	**11,62**	**297,00**	**3,72**	**70,20**	**71,17**
10	135,54	12,64	45,52	590,95	4,36	74,21	72,89
11	84,43	13,42	48,32	614,10	7,27	69,66	70,40
12	**183,31**	**5,06**	**18,22**	**595,28**	**3,25**	**75,08**	**72,45**
13	141,53	12,29	44,23	596,75	4,22	74,81	73,30
14	**98,60**	**5,63**	**20,28**	**602,87**	**6,11**	**72,07**	**72,13**
15	185,89	12,73	45,84	579,51	3,12	74,15	71,46
16	**192,76**	**5,33**	**19,20**	**577,11**	**2,99**	**74,88**	**72,03**
17	117,04	12,00	43,21	585,71	5,00	74,19	73,51
18	**224,94**	**5,37**	**19,35**	**570,79**	**2,54**	**75,15**	**71,63**
19	305,31	12,59	45,32	559,01	1,83	76,05	71,20
20	281,01	13,02	46,88	856,20	3,05	76,26	71,77
21	**119,86**	**5,31**	**19,13**	**879,90**	**7,34**	**75,44**	**74,65**
22	191,13	12,31	44,31	864,67	4,52	76,50	73,69
23	239,56	12,91	46,47	849,26	3,55	75,21	71,42
24	**143,26**	**4,15**	**14,95**	**853,76**	**5,96**	**76,07**	**74,51**
25	91,82	11,86	42,71	869,36	9,47	75,17	75,54
26	160,18	12,88	46,35	849,25	5,30	73,52	71,47
27	214,99	12,97	46,68	830,88	3,86	74,61	71,29
28	**168,42**	**5,14**	**18,51**	**832,23**	**4,94**	**76,21**	**73,95**
29	166,96	12,40	44,65	832,47	4,99	76,18	73,95
30	**122,56**	**4,33**	**15,59**	**835,31**	**6,82**	**75,02**	**74,14**
31	256,32	12,98	46,72	804,18	3,14	77,19	73,10

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