

PlastiCircle

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D 3.4

Driving Behaviour Guidance

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Abstract

Project document D3.4 – Driving behaviour guidance is part of Working Package 3 of PlastiCircle Project, which is addressing the optimization of the transport and packaging process of waste from the urban containers to the sorting plants. This include a software platform to gather all data, a truck traceability system, algorithms for route optimization, and guidelines for efficient driving. Finally, the definition of the compensation policies, based on a characterization protocol of unitary garbage bags, is also defined in this WP.

This WP is addressing an important phase of the waste management process in terms of productivity, economic and environmental costs. WP3 is related with WP2, in which a smart container is developed and WP6, in which developments will be tested during pilots in real life environment of different cities. WP3 includes 5 tasks:

- T3.1 - Development of a IoT (Internet of Things) cloud platform, able to integrate all information received from the different sources of data (like smart container and truck solution).
- T3.2 - Module for route optimization, based on algorithms for the design of a route optimization system and information collected from containers.
- T3.3 - Definition of the characterization protocol and compensation procedure, able to improve the implication/ rewarding of the citizens in the collection process.
- T3.4 - Truck traceability system and driving behaviour guidance.
- T3.5 - Post-pilot final design WP3, will analyse the results of the three pilots.

The objective of deliverable 3.4 is to present the Truck Traceability System developed in the Task T3.4 of the PlastiCircle project. The truck traceability system aims to reduce the economic and environmental costs, in terms of fuel consumptions and GHG emissions, as well as to improve the productivity and to have a complete control over the fleet. Vehicle emissions also depends on driving behaviour such as acceleration and speed, excessive idling, unnecessary accelerations and braking, and information can be used to significantly reduce the fuel consumption, based on an Android application for feedback on driver behaviour.

Abbreviations

CAN: Controller Area Network

DTC: Diagnostic Trouble Codes

ECU: Electronic Control Unit

GHG: Greenhouse Gas

GPS: Global Positioning System

HTTP: Hypertext Transfer Protocol

IC: Integrated Chip

ID: Identification

JSON: JavaScript Object Notation

OBD: On-board diagnostics MSW: Municipal solid waste

PID: Parameter Identifiers

PTO: Power take off

RPM: Revolutions per minute

SDK: Software Development Kit

HDV: Heavy Duty Vehicles

Partners short names

1. SAV: SOCIEDAD ANONIMA AGRICULTORES DE LAVEGA DE VALENCIA
2. ITENE: INSTITUTO TECNOLÓGICO DEL EMBALAJE, TRANSPORTE Y LOGÍSTICA
3. UTRECHT: GEMEENTE UTRECHT
4. ALBA: PRIMARIA MUNICIPIULUI ALBA IULIA
5. POLARIS: POLARIS M HOLDING
6. MOV: MESTNA OBCINA VELENJE

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1. Introduction

PlastiCircle project addresses all phases related to the management of the Municipal solid waste (MSW) with accent on plastics circular economy. Working Package 3 of PlastiCircle Project is addressing the optimization of the transport and packaging process of waste from the urban containers to the sorting plants. As already mentioned, waste management activities contribute to the generation of emissions to the atmosphere of GHG in each one of the stages: collection, treatment and elimination, due to the use of fossil fuels, the combustion of the waste or the formation of methane by the fermentation of organic matter in landfills and also implies major concerns on public safety.

Confronted daily with huge quantities of waste which must be processed, municipalities and waste management companies are obliged to find efficient answers, able to ensure quality of services and public safety with low costs and environmental impact. In order to collect these high volumes of waste, a specialized fleet of trucks, equipped with emptying containers and compressing devices must visit all full containers, based on pre-determined map, or described by the route optimization algorithms in our project. Waste truck fleet management requires high logistics and operational efforts, together with costs and concerns regarding emissions and environmental pollution, or health problems caused by exhaust emissions and related to high power Diesel engines, like particles¹ and compounds recognized as carcinogenic². Special particles filters (like high efficiency catalytic exhaust control devices that limit particles emission, NOx and hydrocarbons) and new engine concepts and standards like EURO6 are diminishing pollution, but special equipment and their weight, increase collection trucks cost and fuel consumption³. There is a strong relation between fuel consumption involved in collection of MSW, collection and operational cost to waste management companies and the associated pollution level.

¹ Niraj Kumar, Varun, Sant Ram Chauhan, Performance and emission characteristics of biodiesel from different origins: A review, Renewable and Sustainable Energy Reviews, Volume 21, May 2013, Pages 633-658, ISSN 1364-0321.

² Benbrahim-Tallaa, Lamia, et al. "Carcinogenicity of diesel-engine and gasoline- engine exhausts and some nitroarenes." The lancet oncology 13.7 (2012): 663-664.

³ REGULATION 2017/0111 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on the monitoring and reporting of CO₂ emissions from and fuel consumption of new heavy - duty vehicles

<https://ec.europa.eu/transport/sites/transport/files/com20170279-regulation-hdv.pdf>

Recently (2017), the EU Commission proposed a new regulation⁴ on the monitoring and reporting of CO₂ emissions from and fuel consumption of new heavy-duty vehicles, considering reindustrialising Europe based on new business models and cutting-edge technologies, aiming to achieve a circular low carbon economy.

The Commission's vision is to ensure that European citizens and business have access to fair, sustainable and competitive mobility in the context of transport using heavy duty vehicles (HDV – busses, coaches, lorries). Confronted recently with car producers' scandal regarding software manipulation on emissions, which is based on manufacturers tests and emissions standard test in authorized services, EU Commission discovers that CO₂ emissions and fuel consumption from new HDVs placed on the EU market have so far neither been certified, nor monitored and reported, generating three challenges regarding HDVs:

- Missed opportunities to design policies to reduce the fuel bill for transport operators; usually, transport operators experience about 25% of their operational cost required by fuel cost and consider fuel efficiency as their top purchase criterion. While the fuel efficiency of HDVs has improved over past decades, many companies do not yet have access to standardised information to evaluate fuel efficiency technologies and compare HDV's in their purchasing decisions. That increases EU dependency on fossil fuels, imports and raised pollution.
- Increasing competition between HDV manufacturers; with over 12 million jobs, the EU HDV manufacturers are facing global competition and a delay in certification and fuel efficiency measures in the form of fuel consumption and/or emission standards, in order to stimulate innovation and rapidly improve vehicle efficiency.
- There are some barriers to setting policies to reduce greenhouse gas (GHG) emissions from the heavy duty-vehicle sector, which is a significant source of GHG emissions, representing 5 % of total EU emissions, a fifth of all transport emissions and about a quarter of road transport. From 1990 to 2014, overall GHG transport emissions increased by 20 % and HDV emissions by 14 % and without further action, emissions are set to increase by up to 10 % by 2030.

EU Commission is proposing three main actions:

- 1) VECTO - Vehicle Energy Consumption Calculation Tool (VECTO) — a software able

⁴ Proposal for a REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on the monitoring and reporting of CO₂ emissions from and fuel consumption of new heavy-duty vehicles: <https://ec.europa.eu/transport/sites/transport/files/com20170279-regulation-hdv.pdf>

to calculate the fuel consumption and CO2 emissions of new HDVs in a comparable and cost-effective manner.

- 2) A new regulation on the determination of CO2 emissions and fuel consumption for new heavy-duty vehicles (so-called certification regulation) under existing type approval legislation.
- 3) Monitor and report CO2 emissions from new HDVs subject to the certification procedure, in order to close the knowledge gap and create full market transparency.

These new regulations will impact the entire sector of HDV manufacturers and vehicle transport, including important changes in waste management companies' operation, waste collection, operational management and costs.

Many technical aspects regarding HDV are complementary to those proposed in our PlastiCircle project, because GPS/ CAN bus/ OBD II tracking systems include further reductions of economic and environmental costs of waste collection (especially in terms of fuel consumption and GHG/ particles emissions), and important changes in driving behaviour (like speeding, excessive idling, sudden accelerations/ braking⁵) which produce unnecessary fuel consumption (estimated between 5 % to 20%⁶ pollution and affects road safety and accidents, based on mobile tablet application able to alert driver when parameters are exceeding a correct driving behaviour, and a complete control over the fleet, corrective actions to be considered and comprehensive reports.

⁵ S.M. Ashrafur Rahman, H.H. Masjuki, M.A. Kalam, M.J. Abedin, A. Sanjid, H. Sajjad, Impact of idling on fuel consumption and exhaust emissions and available idle- reduction technologies for diesel vehicles - A review, *Energy Conversion and Management*, Volume 74, October 2013, Pages 171-182, ISSN 0196-8904.

⁶ G. S. Larue, H. Malik, A. Rakotonirainy, and S. Demmel, "Fuel consumption and gas emissions of an automatic transmission vehicle following simple eco-driving instructions on urban roads," *Intelligent Transport Systems*, vol. 8, no. 7, pp. 590-597, 2014.

Yukimasa Matsumoto, Daisuke Tsurudome, Evaluation of Providing Recommended Speed for Reducing CO2 Emissions from Vehicles by Driving Simulator, *Transportation Research Procedia*, Volume 3, 2014, Pages 31-40, ISSN 2352-1465.

1.1 Objective

The objective of deliverable D3.4. - “Driving behaviour guidance” is that in close relation with D3.3.- Truck Traceability system, to identify supplementary factors and actions able to further reduce fuel consumption and environmental costs, especially GHG/ particles emissions and economic costs associated to waste collection phase, together with an improved productivity, fleet and personnel coordination.

Both deliverables, D3.3. and D3.4 are developed in task T3.4 - Truck traceability system and driving behaviour guidance of the PlastiCircle project.

If the objective of deliverable D3.3 is to present the Truck Traceability system (developed in the task 3.4 of the PlastiCircle project), the next deliverable, D3.4 “Driving behaviour guidance” (related to the same task) will analyse the efficient driving (sometimes called eco-driving) and the driving behaviour impact on fuel consumption and pollution.

Based on information (like speed, RPM, acceleration, sudden acceleration/ braking, fuel consumption, idling time, power take off, read by sensors, CAN –Bus and OBDII systems) stored in the on-board truck system and sent via radio mobile modem (GPRS/ 3G) to the digital cloud and PlastiCircle platform, the truck traceability system aims to optimize both the performance of the vehicles and the driver's driving behaviour.

Also, using existing documentation research, the deliverable will provide a list of different parameters which affect the fuel consumption of trucks in order to select the most important ones, able to influence the truck traceability system and the driving parameters to be tested in PlastiCircle pilot cities and to assess the performance from the economic and environmental point of view.

It is expected that based on pilot results, D3.4 and associated systems to be further developed for maximizing benefits associated to lower fuel consumption and pollution.

1.2 Scope

This deliverable is structured in different chapters and sections, covering:

- **The eco driving description:** This section aims to briefly describe the eco driving concept, various methods of eco-driving implementation, advantages/ benefits and possible draw backs
- **European Commission projects related to Eco driving:** this section describes the main identified projects related to eco driving, their conclusions being useful for development of PlastiCircle systems
- **Main factors affecting consumption:** this section describes the most important factors and their expected influence on consumption and when possible, refers to actual conditions in PlastiCircle pilot cities
- **Eco driving parameters selection:** in this section we will decide which driving behaviour parameters will be monitored in our project
- **Conclusions for implementation in pilot cities:** together with conclusions, this chapter brings recommendations for implementing truck traceability and eco driving systems in project pilot cities

2. Analysing Eco-driving

2.1 Definition of Eco-driving

For many years, it was observed that for some vehicles, using same route, there are significant differences in fuel consumption and maintenance, which can be explained considering the driving style adopted. Numerous studies are testing various factors (like speed and aggressive use of the accelerator, steering, transmission and brakes) and their influence on fuel consumption and pollution⁷.

On other hand, driving style is influenced by a complex mixture of social, psychological and cultural factors, combined with traffic conditions, that affect directly the driver behavior.⁸

If initially eco-driving was related mainly to the driving style, being defined as “The practice of driving in such a way to minimize fuel consumption and the emission of carbon dioxide”⁹, the more recent definition includes a larger range of related actions: “Eco-driving refers to using a vehicle while reducing fuel consumption, it relates to how the vehicle is driven, as well as how it is used”¹⁰.

This broader definition considers the vehicle technical maintenance, as well as usage conditions, considered also to affect together with the driving behavior the fuel consumption and pollution.

Beginning with 2005, many European or national authorities and private companies have developed numerous studies, projects or own eco-driving guidelines¹¹.

Also, there are institutions and communities dedicated to eco driving, like <http://www.ecodriver.org/>, who are presenting and promoting simple fuel-efficient driving methods. As an example, we present the “Eco-drivers Tips” flyer created by this organization, including:

⁷ Further details and information are available within the ECOWILL Project: https://ec.europa.eu/energy/intelligent/projects/sites/iee-projects/files/projects/documents/ecowill_guidelines_short_duration_trainings_en.pdf

⁸

⁹ Collins Dictionary: <https://www.collinsdictionary.com/submission/7105/Eco-driving>

¹⁰ Futura Sciences/ Dictionary: <http://www.futura-sciences.us/dico/d/sustainable-development-ecodriving-50000981/>

¹¹ Eco-driving uncovered. The benefits and challenges of eco-driving based on the first study using real journey data: http://www.futuremobilitynow.com/assets/ECO-DRIVING_UNCOVERED_summary_2010_EN.pdf/

“Simple ways to save on the road

With simple changes to driving habits, most drivers can save 10 to 15% on gas.

- **Slow Down and Save:**

For every 10 km/h you go over 100, fuel efficiency drops by 10%. Driving 120 on the highway instead of 100 is like paying 20% extra for gas.

- **Easy on the Pedal:**

Jackrabbit starts from one stoplight to the next save only 2.5 minutes per hour but increase fuel consumption by 37%.

- **Slow Down and Save:**

On the highway, keeping a steady speed uses less fuel. Accelerate smoothly and avoid hard braking by leaving room between your car and the one in front.

- **Be Idle Free:**

Just ten seconds of idling uses more fuel than restarting the engine. In ten minutes, the average car will burn through 300 ml of fuel - almost 1/3 of a litre.

- **Warm Up on the Go:**

Today's cars shouldn't be idled to warm up, and too much idling can cause damage. Driving gently for the first few minutes lets your transmission, steering, and engine all warm up at once.

- **Combine Trips:**

Trips under 5 km are the most polluting because the engine and the pollution control system never reach peak operating temperature. Combining several trips into one can cut fuel use and emissions by 20 to 50%.

- **Travel Light:**

Every extra hundred pounds reduces fuel efficiency by up to 2%, so keep your trunk clear of unnecessary items, and in the winter remove all snow and ice.

- **Make the Most of Your Transmission:**

Using overdrive at high speeds saves fuel and reduces engine wear. With a manual transmission, shifting up gently but quickly to higher gears allows the engine to work more efficiently.

- **Use a Fuel Consumption Display:**

If your car comes with a consumption computer, use it to get instant feedback on fuel use. Drivers who learn to adjust their habits have saved up to 10% this way. If your vehicle doesn't have one, they're easy to install. The ScanGuage II is one model you can order online.

Maintain and Save

Regardless of the age and type of vehicle you drive, keeping it in top condition makes a significant difference in its fuel-efficiency.

- **Tire Pressure:**

Just one tire under-inflated by 8 psi can increase fuel consumption by 4%, and reduce the life of the tire by 15,000km. Check the pressure once a month.

- **Motor Oil:**

Using worn-out oil, or the wrong grade of oil, can increase fuel use by 2%. Change it regularly with the grade listed in your owners' manual. "Energy Conserving" brands can reduce friction, improving efficiency even more.

- **Air Filter:**

Fuel use can increase up to 10% when the air filter is clogged, because not enough air makes it to the combustion chambers. Check it on the same schedule as you change the oil, or more often if you travel on dusty roads.

- **Tune Ups:**

Keeping your vehicle in tune can reduce fuel consumption by up to 15% and smog causing emissions by even more. Follow the schedule in your owners' manual.

More fuel-efficiency factors

For those who want to go all the way, here are other things you can do to save on gas.

- **Roof racks:**

A loaded roof rack can increase fuel use by as much as 5% because of drag, and even empty racks add to drag, so take them off when not in use.

- **Travel light:**

An extra 100 pounds can reduce fuel efficiency by up to 2%, so don't forget to take the golf clubs out of the trunk.

- **Air conditioning:**

Major electronics like TVs, seat warmers, and AC all add a drain on the battery and make the engine work harder. At city speeds you'll save fuel by rolling down the windows instead of using the AC (though on the highway open windows add enough drag to make the difference negligible.)

- **Cruise control:**

Using cruise control on flat terrain improves fuel efficiency, because it helps you maintain a steady speed, and also prevents you from accidentally speeding. On hills though, it's best to turn it off.

- **Use a block heater:**

In winter weather using a block heater to pre-heat your car can improve overall fuel efficiency by as much as 10%. But use a timer: it only takes two hours for the block heater to warm the engine up.”

- Use engine brake instead of using brake drums¹²

More than that, many producers¹³ are using the capacity of the car computer to adjust to an Eco Mode, which is providing a smooth response to acceleration, or suggesting changing the gears lowering consumption. Many modern cars are providing (based on sensors and local computer display) the instant car consumption, which can be a very good indication of the best economical usage. Recently, several fleet management software companies, are using GPS and on-board sensors for reporting and improving drivers' behavior with tangible results¹⁴.

Different European projects have analyzed the efficiency of eco-driving style.

In next chapters, we will identify main factors involved in fuel consumption, their importance, and based on that information, we will develop eco-driving recommendations and their possible applications in PlastiCircle project, in conjunction with vehicle tracking system. It is expected that based on tracking (GPS/ CAN Bus/ ODB) the fleet of waste collection trucks to obtain a significant reduction of economic and environmental cost (reflected by fuel consumption and GHG emissions) [6, 7] combined with control over the fleet, able to improve productivity. Based on specific eco driving recommendations and information gathered by the tracking system, we are going provide feedback and reports regarding driving behavior in order to further reduce fuel consumption and pollution.

¹² Manual for using an efficient driving style in state car fleets; Economy Minister, Spain; Engine brake instead of using brake drums

http://www.idae.es/uploads/documentos/documentos_manualPME_6bc54e20.pdf/

¹³ For instance, Renault: <https://www.renault.ie/discover-renault/innovation-and-technology/eco-driving.html>

¹⁴ Example: TrustTrack by Ruptela <https://www.ruptela.com/product/trusttrack/>

2.2 Benefits of eco-driving

The studies dedicated to eco-driving¹⁵ revealed multiple benefits associated with an improved driving style and vehicle usage. Eco-driving offers numerous benefits: It does not only save fuel and costs, but also improves road safety as well as the quality of the local and global environment.

Moreover, Eco-driving provides direct benefits to the drivers and the passengers: namely more comfort and a relaxed atmosphere. All those benefits can be realised at equal or less travel time.

Globally, Eco-driving means small changes for the driver and high impacts on improving fuel economy and reducing emissions.

- a) **Small changes in driving behaviour will produce tangible benefits at no cost.** Further improvements, may require small investments in training or equipment, are easily covered by the demonstrated results.
- b) **Eco-driving can be used in any vehicle**, because is addressing energy and behaviour, not vehicle type.
- c) **Eco-driving saves costs**, estimated at an average of 15% of fuel costs (Eco-driving Uncovered. The benefits and challenges of eco-driving. Source: Fiat, 2010). This means considerable energy savings and pollution reduction.
- d) **Eco-driving reduces not only fuel costs, but also costs for maintenance** and costs for repairing cars after accidents. Eco-drivers cause less wear and tear on car parts (tyres, brakes and engine) and are less prone to accidents.
- e) **Important economic savings for companies**
Fuel is the main item of expenditure generated by the activity of a commercial vehicle. Higher efficiency in fuel consumption combined with lower maintenance costs, will lead to important cost savings and therefore a greater economic benefit for the companies, especially for those managing large fleets.
- f) **Eco-driving suits to modern engines**
In the past decades, engine technology (multiple/ automatic gears, wide torque range, high power with low consumption, sensors and computers are controlling the parameters) and performance of cars have improved rapidly. The correct way of driving with modern cars differs considerably from the way of driving as taught in driving schools in past decades. However, most drivers who got their driving licence decades ago have not adapted their driving style, many shifting to a higher gear around 3,000

¹⁵ Example: a study sponsored by Intelligent Envergy Europe: Together on the move http://www.together-eu.org/docs/102/TOGETHER_Eco-driving_5_Handout_15.pdf

rpm. Today's transmissions offer five or six gears and allow reduced engine speeds. Modern engines are generally designed to run efficiently at low speeds, with an optimum efficiency point around 1,750 revolutions per minute (rpm).

Eco-driving represents a driving culture which suits to modern engines and makes the best use of advanced vehicle technologies. It is an energy efficient style of driving motorised vehicles at lower engine speeds.

g) Eco-driving protects vehicle facilities

Contrary to the belief of some drivers, Eco-driving is not bad for the engine. On the contrary, driving with high revolutions has negative consequences on maintenance. Following the Eco-driving tips leads to a longer life-span of the engine, brakes and tyres. An Australian study (Driving green saves fuel and environment. Source: Monash University, 2010) found out that eco-driving reduced the number of gear changes and brake applications by 29 % and 41% respectively. The safer driving behaviour comes from an anticipating driving style, meaning less accelerating and braking, less speeding and overtaking, and a general less stressful and aggressive driving style. Eco driving becomes a combination between a reduction of variable costs (fuel, repairs, tires, and maintenance system), an important increase of effectiveness (less down time due to repair works and maintenance, a decrease of the environmental pollution and a decrease of insurance costs, due to fewer accidents¹⁶.

h) Eco-driving reduces stress levels and leads to greater safety and comfort

Eco-driving means more relaxed driving and thus has benefits for drivers' health and improves driver satisfaction. A smooth use of the accelerator, steering, transmission and brakes means not only efficient driving, but is also more comfort for the driver and passengers. Erratic driving may cause stress levels to rise which can affect concentration and make drivers tired and/or aggressive. Furthermore, some passengers feel uncomfortable when the driver drives at high speeds or does a lot of overtaking – actions which an eco-driver will avoid in many circumstances. Hence, eco-driving results in happier, healthier and more responsible drivers. Avoiding sudden accelerations and braking, make the working hours of collection driver and workers more comfortable. Eco-driving is a driving style imbued with tranquillity and stability in starts, during the journey and in braking.

i) Eco-driving leads to greater road and traffic safety

Large fleet companies, can expect to a decrease of up to 40% of costs¹⁷ for accidents after their drivers followed eco-driving trainings. This is mostly due to driving techniques are based on foresight, anticipation and keeping a greater distance from the car ahead.

¹⁶ See the article dedicated to Eco-driving on Energypedia:

https://energypedia.info/wiki/Eco_Driving

¹⁷ *Drive and save with security. Drive safely, economically and environmentally friendly*, Vierboom, Carl/Härten, Ingo, 2003.

j) **Eco-driving causes no time loss**

All the benefits mentioned can be realised at equal or less travel time. Experience shows that eco-drivers do not take longer to reach their destination but are often even faster. This is mostly due to accelerating traffic flow and thus avoiding stops.

k) **Eco-driving is environmentally and climate friendly**

Global climate and environment are under threat by toxic emissions caused by man-made CO₂, exhaust gases from motorised vehicles being one of the biggest contributors to the problem. Despite significant progress in improving engine technology and performances, most drivers have not adapted their individual driving style. On average, for every litre of petrol used in a motor vehicle, 2.2 kilograms of Carbon Dioxide is released from the exhaust¹⁸. Improved car driving behaviour have the potential for considerable fuel savings and consequently reduced CO₂ emissions from traffic. The impact on the local environment – toxic exhaust gases and particulates – when using internal-combustion engines depends on the type and amount of fuel used. Eco-driving reduces local air pollution by reducing fuel consumption. Hence, if Eco-driving becomes the norm rather than the exception, it has the potential to significantly reduce emissions from road transport.

l) **Eco-driving reduces noise**

After pollution, noise is another great problem of car traffic in urban areas. Driving styles have a high impact on the noise that is generated. Using low engine speeds and avoiding unnecessary high acceleration and vehicle speed values achieve a significant reduction of the propulsion noise of a vehicle. A car travelling with 4,000 revolutions per minute (rpm) produces the same amount of noise as 32 vehicles travelling at the same speed with only 2,000 rpm¹⁹.

¹⁸ Guidelines for National Greenhouse Gas Inventories. Source: IPCC, 2006.

¹⁹ Further details and information are available within the ECOWILL Project: [ECOWILL/
www.ecodrive.org](http://ECOWILL/www.ecodrive.org)

2.3. Possible negative effects of eco-driving

During a field trial aiming to improve eco-driving style of bus drivers working on same line, different methods were used and applied on three groups (in side vehicle feedback system, personal training and some personal feedback and a control group). Based mainly on decreases on acceleration, speeding and brakes usage, important fuel savings were obtained (6.8%) without a perceived difference between the two groups who used an eco-driving style. Both groups perceived an improvement in driving techniques but found it to be quite difficult to use eco-driving in practice in a real traffic context and found applicability limitations in combining eco-driving with their schedule or other work tasks²⁰. I.C. MariAnneKarlsson

Another study²¹ considers that eco-driving has many positive effects, but also reveals that many eco-technologies have limitations and there are still many policy limitations which may result in increases in accident risk or raises CO₂ emissions at traffic network level in a busy city traffic.

Eco-driving has some certain limitations, especially on busy city environment, where main recommendations (like smooth acceleration/ deceleration, or maintaining a consistent speed) are difficult to use or can be considered a higher accident risk to other traffic participants. Practically eco-driving abilities of a driver are dependant of the behaviour of other drivers and only when bigger proportion of drivers will apply these methods the results will be much important. Even eco-driving has tangible individual results, there is little governmental or financial support for large scale implementations²².

An interesting study²³ finds that most of the studies revealing important benefits of eco-driving in terms of fuel consumption and emissions have serious limitations, limiting results just on a short time after trainings, without certainties on long term and is addressing eco-driving effects on individual drivers, but not on traffic flow of a busy city. The simulation included several variables like:

- Different participants driving styles (aggressive, sportive, normal, eco, active eco)
- Different traffic levels (up to 300 cars/ hour = low, 600 cars/hour = normal, over 1000 cars/ hour = high)

²⁰ Comparative effects of eco-driving initiatives aimed at urban bus drivers - Results from a field trial
Helena K.Strömberg, I.C. MariAnneKarlsson,
<https://www.sciencedirect.com/science/article/pii/S136192091300031X>

²¹ A critical review and assessment of Eco-Driving policy & technology: Benefits & limitations, Md. Saniul Alam Aonghus McNabola,
<https://www.sciencedirect.com/science/article/abs/pii/S0967070X14001152>

²² Fiat: Eco-Driving Uncovered http://www.futuremobilitynow.com/assets/ECO-DRIVING_UNCOVERED_full_report_2010_EN.pdf

²³ Evaluating effects of eco - driving at traffic intersections based on traffic micro-simulation,
Gongbin Qian, Edward Chung Smart Transport Research Centre, Queensland University of Technology,
http://atrf.info/papers/2011/2011_Qian_Chung.pdf

- Different percentages of eco drivers (0 – 25 – 75 – 100%)

in order to address traffic performance (travel time) and environmental performance (fuel consumption and CO2 emission) at traffic intersection level.

The simulation revealed a negative effect (in trip time and pollution) of eco driving in very busy intersections (1000 cars/ hour) and when eco-drivers percentage is low (< 25%), affecting other participants and raising congestion. In busy intersections, the procedure of the stop - and - go involves numerous acceleration operations which have a significant effect on consumption and emissions. Before stop lines, moderate acceleration will slow down the average speed of start - up after the green light onset, thereby reducing the discharge flow rate of queuing vehicles which tends to cause congestion and hence increase fuel consumption and emissions.

As a conclusion, the driving behaviour is determining the performance of an individual vehicle, but traffic flow is subject to many variables, including flow speed, traffic signal control and driving behaviour.

2.4. Conclusions for PlastiCircle

Considering the presented aspects, there are several conclusions to be used in PlastiCircle project:

- 1) Eco-driving style can have tangible benefits, but considering some limitations, is better to have realistic expectations (for example a reduction of 10% of fuel consumption)
- 2) Eco-driving implementation needs consistent training and feedback for drivers
- 3) The benefits of eco-driving are expected to be lower in high traffic/ congestion conditions
- 4) The benefits obtained during testing must be controlled over a longer period, to ensure that modifications of driving style stick on long term

3. EU projects dedicated to eco-driving

3.1 ECOWILL

ECOWILL Project: Eco-driving – Widespread Implementation for Learner Drivers and Licensed Drivers²⁴.

The ECOWILL project was launched in May 2010 and ended in April 2013. Its aim was to reduce carbon emissions by up to 8 Mt until 2015 by boosting the application of eco-driving all over Europe. To reach this ambitious target the project rolled out short duration eco-driving training programs for licensed drivers in 13 EU countries and at the same time promoted the education of learner drivers in eco-driving.

The main objectives of the project therefore were:

- Integration of eco-driving in driving school curricula and driving tests
- Establishment of minimum standards for contents and set up of eco-driving trainings and train-the-trainer seminars
- Establishment of an eco-driving infrastructure which will keep the approach alive after the end of the project
- Roll-out of (short-term) eco-driving trainings for licensed drivers

ECOWILL is the next step and will roll out eco-driving snack training courses to the mass by deploying the existing infrastructure of driving schools. ECOWILL will also further introduce and roll out e-learning methods. In addition, ECOWILL aims at harmonization of driving lessons and driving tests for learner drivers. In collaboration with EFA (driving school association) and CIECA (examination association) in those countries in which eco-driving is not part of learner education and driver test, ECOWILL engages administrations to develop legislation for incorporation of eco-driving in the driver test and driving schools to integrate eco-driving in their driving lessons. By aiming at the driving school curricula and the driver test ECOWILL guarantees a sustainable lasting effect even beyond the conclusion of the project.

Top 5 golden rules of eco driving:

²⁴ Relevant information about the project can be accessed here:
<https://ec.europa.eu/energy/intelligent/projects/en/projects/ecowill>
https://www.cieca.eu/sites/default/files/documents/projects_and_studies/ECOWILL_FINAL_REP_ORF.pdf

1. Greater Anticipation

Anticipate situations and other road users as far ahead as possible. Maintain a greater distance between vehicles in order to avoid unnecessary acceleration and braking and make maximum use of the vehicle's momentum

2. Maintain a steady speed at low RPM

Drive smoothly, using the highest possible gear at low RPM

3. Shift up early

Shift to higher gear by approximately 2,000 RPM

4. Check tire pressures frequently, at least once a month and before driving at high speed

5. Remember all ancillary loads add to fuel consumption

Electrical equipment and, air conditioning add significantly to fuel consumption, so use it sparingly. Avoid carrying dead weight and adding unnecessarily to aerodynamic drag e.g. by opening windows at high speed or carrying roof boxes when not in use.

Silver eco driving rules:

1. Fuel saving starts with choosing a low emission car

Choose a fuel-efficient model with reduced CO₂ emissions. Diesel vehicles should always be equipped with particulate filters. A fuel consumption display helps you to save fuel. Cruise control and an automatic gearbox can decrease fuel consumption.

2. Avoid short car trips

Avoid short car trips as cold engines need much more fuel per km than warm engines and cause equivalently more CO₂. On short trips the engine does not reach its optimum operating temperature, increasing wear and reducing durability.

3. Don't start the engine until there is an opportunity to start driving.

Drive off immediately after starting the engine; do not warm up the engine, idling wastes fuel and the engine warms up more quickly when you are moving

4. Turn off the engine at stops

Turn off the engine if stationary for a significant time. For most modern engines the 'break even' period at which the fuel saved by turning off exceeds the fuel used to restart the engine is around 20 seconds.

5. Use low friction oils and low energy tires

Make use of the EU labelling system.

6. Close windows when driving at higher speeds

Open windows increase dynamic drag and consume extra fuel.

7. Check your car regularly and have it serviced

Make sure your car is regularly serviced (according to the manufacturer's schedule) to maintain engine efficiency.

8. **Consider alternative means of transport** (cycling, walking, public transport, car sharing, carpooling, park & ride). Around 25% of all car trips are less than 2 kilometers and 50% of car trips are less than 5 kilometers length.

Choosing to cycle or walk does not only have positive effects on the environment but also on your health and budget. The use of public transport also helps you to save money and to avoid stress and exhaust gases. Consider setting up a car pool with friends/colleagues or try car sharing in order to save fuel and costs

The ECOWILL project provided also a valuable public manual for trainers in eco-driving²⁵.

3.2 TREATISE (EC – Intelligent Energy Europe)

TREATISE (Training program for local energy agencies and actors in transport and sustainable energy actions) began by developing reference manuals and training materials on three subjects: Cleaner fuels & vehicles; Eco-driving; and Mobility Management. The project also developed complimentary web-based training tools including an eco-driving simulator, a fleet management tool and a transport CO₂ calculator to encourage people to choose lower carbon modes of transport. These manuals and tools have proved extremely popular and can be downloaded²⁶.

3.3 ECODRIVEN

European Campaign On improving DRIVING behaviour, ENergy-efficiency and traffic safety (ECODRIVEN)²⁷

Eco-driving brings environmental, financial and safety benefits at zero or low cost. It is therefore no surprise that eco-driving is an increasingly popular concept that is well-received by a wide range of stakeholders: policy makers like ecodriving as it contributes to environmental and safety targets; companies like the cost savings as well as the PR opportunities; private individuals like the cost savings and the more relaxed and safer style of driving; and vehicle manufacturers appreciate the recognition that it's not just about technologies and that their vehicles can achieve the official fuel consumption results if driven well.

ECODRIVEN is a synchronized European-wide ecodriving campaign aiming at drivers of passenger cars, delivery vans, lorries and buses in 9 EU countries. During a one-year

²⁵ Source: <http://www.ecodrive.org/trainers>.

²⁶ www.treatise.eu.com; <https://ec.europa.eu/energy/intelligent/projects/en/projects/treatise>.

²⁷ <https://ec.europa.eu/energy/intelligent/projects/en/projects/ecodrive>

campaigning period end-users will be regularly presented with Ecodriving activities within their familiar social environment, which will stimulate them to reflect on and optimize their driving behavior in a safe and energy-efficient manner. The campaign is based on a bottom-up approach through European-wide local and regional collaborations of the ECODRIVEN consortium with relevant national and local stakeholders such as car dealers, fuel companies, touring clubs, drivers' associations, driving schools, municipalities, SMEs and haulers etc. who will support campaign activities and disseminate campaign material²⁸.

The golden rules of ecodriving are:

When accelerating, change up to a higher gear between 2000 and 2500 rpm.

Changing up the gears at these relatively low revs reduces fuel consumption because an engine's internal friction increases with engine speed.

- i. Maintain a steady speed using the highest gear possible and driving with low engine RPM
- ii. Anticipate the road and traffic flow as far ahead as possible to avoid unnecessary acceleration and braking
- iii. When decelerating, driving downhill or stopping, remain in gear but to step off the accelerator as early as possible, for example when approaching a red light or a roundabout.
- iv. Avoid high speeds since above 80 or 90 km/h fuel consumption increases greatly.
- v. Check tyre pressures regularly as underinflated tyres add to fuel consumption.
- vi. Use air conditioning sparingly as long as this does not necessitate opening a window at high speed.
- vii. Switch the engine off if you're going to be stationary for more than a minute or so.
- viii. Remove roof racks, bike racks etc when not in use
- ix. Avoid carrying unnecessary weight.

Measured Key Facts

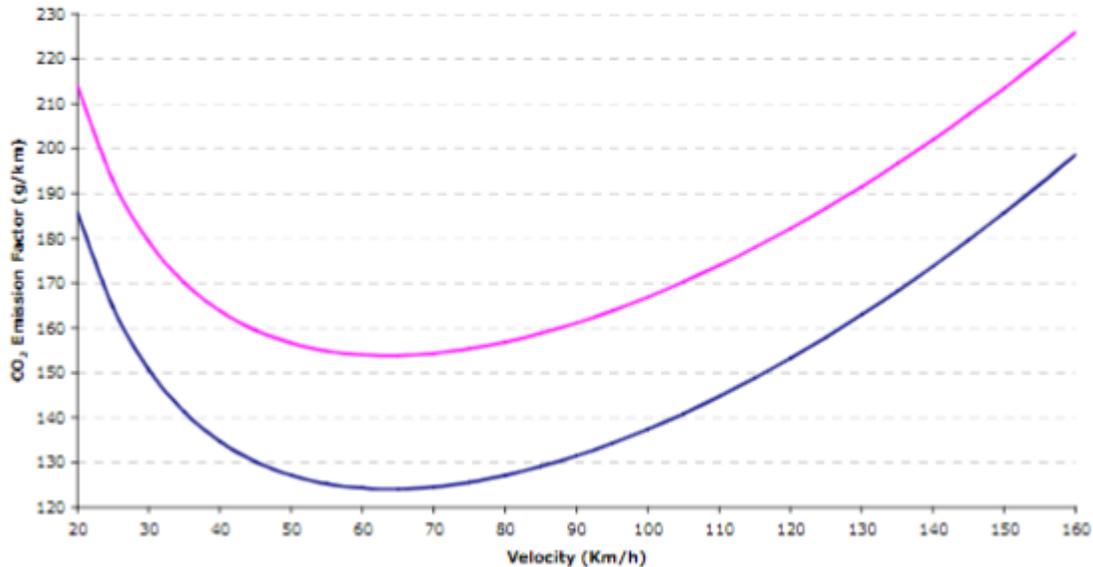
Change gear

Tests revealed that changing gears at 2000-2500 rpm has maximum efficiency.

Speed effect

In terms of emissions, CO₂ is proportional to fuel consumption, so the trends shown by these curves can also be read as the relationship between speed and fuel consumption. For high capacity Diesel engines, minimum emissions are at 60-70 km/h.

²⁸ ECODRIVEN Catalogue https://ec.europa.eu/energy/intelligent/projects/sites/iee-projects/files/projects/documents/ecodriven_catalogue_campaign_en.pdf



Maintaining Momentum

Newton's Second Law of Motion states that 'Force = Mass x Acceleration', which is the key to understanding why greater anticipation such a marked effect on can have reducing fuel consumption, particularly in urban driving. The increased consumption in low speed situations comes from both uneven speeds caused by congestion, and that the engines are less efficient at low power output.

In practice, of course a vehicle must also overcome air resistance and friction, so fuel is required to keep moving at constant speed, but nevertheless this principle explains why avoiding unnecessary acceleration and braking greatly reduces fuel consumption.

Decelerating

When decelerating or driving downhill with a gear engaged but no throttle applied, a modern engine is 'intelligent' enough to know that the engine is being driven by the car's momentum and that it can switch off fuel supply to the engine. Under these conditions an engine uses virtually no fuel, whereas if the car had been coasting in neutral as it decelerated more fuel would have had to have been burned to keep the engine running.

Tyre Pressures

Tyre underinflated by 25% increase rolling resistance by approximately 10% and fuel consumption by approximately 2%

Idling

There is very little fuel consumption (or CO2) penalty when restarting a modern engine if the accelerator pedal is not pressed. In fact, the 2006 TNO report concluded that even turning an engine off for just 10-20 seconds would lead to net benefits since the CO2 emissions avoided (& fuel saved) would be greater than the restart penalty. For reasons

of communication and comprehension it was decided to stick to the previously communicated 1-minute recommendation/tip concerning idling.

Air Conditioning

Research by ADEME6 in France found that for typical mixed use over a 1 2-month period (i.e. all 4 seasons) a car with air conditioning (a/c) would on average use around 5% more fuel than the same car without a/c.

Roof Racks

Manufacturers go to great lengths to make their vehicles aerodynamic, so it is no surprise that large items such as roof racks, roof boxes and bike carriers play havoc with the manufacturers' careful designs and greatly increase fuel consumption at medium to high speeds. A Dutch study in 2005⁸ found that at 100km/h a ski box added 21-23% to fuel consumption and a laden bike rack added 26-29%.

Extra weight

Referring again to the fundamental laws of physics we know the force required to accelerate or to lift an object is proportional to its mass. This explains why carrying unnecessary weight in a vehicle will add to its fuel consumption. The effect of extra weight would tend to be much greater around town, where a high proportion of the fuel is used to accelerate the vehicles than on the highway, where the majority of fuel is burn to overcome air resistance, which is unaffected by mass.

3.4 FLEAT

FLEAT (Fleet Environmental Action and Assessment) had the objective to increase energy efficiency for different types of fleets: fleets of public authorities, public transport fleets, private fleets with mainly company cars, private fleets with mainly utility vehicles. FLEAT offers existing tools and instruments to fleet operators to increase energy efficiency in 3 fields: improve energy efficiency and environmental performance of the vehicle fleet, encourage energy efficient use of vehicles and support energy efficient use of the fleet with mobility management actions²⁹.

When looking at costs, the next best option after changing fleet with more fuel-efficient

²⁹ More information and documents about FLEAT project can be found here: <https://ec.europa.eu/energy/intelligent/projects/en/projects/feat>; final report - https://ec.europa.eu/energy/intelligent/projects/sites/iee-projects/files/projects/documents/feat_final_result_oriented_report_en.pdf

vehicles, is to implement eco driving schemes for all drivers in a fleet. Based on our FLEAT pilot actions, we estimate the costs of this type of measure to be between € 300 and € 1.000 per driver. This is including the trainer and loss of man hours, and is independent from the type of vehicle. Because of the higher yearly mileage and the higher fuel consumption, the possible profits are higher for busses and trucks than for passenger cars and small vans. In addition, the largest effect in terms of relative reduction was seen with trucks (-9,4%), followed by busses (-7,2%) and then light duty vehicles (-6,4%). From these numbers we can conclude that the payback period is shortest for trucks (1,3 to 4,3 months), and longest for light duty vehicles (1,6 to 5,2 years).

The amount of CO₂ saved in the FLEAT pilot actions on eco driving amount up to 274 tons for passenger cars, 1680 tons for buses, and 1923 tons for trucks.

3.5 eCoMove

The eCoMove³⁰ (Cooperative Mobility Systems and Services for Energy Efficiency) project will create an integrated solution for road transport energy efficiency by developing systems and tools to help drivers sustainably eliminate unnecessary fuel consumption (and thus CO₂ emissions), and to help road operators manage traffic in the most energy-efficient way. By applying this combination of cooperative systems using vehicle-infrastructure communication, the project aims to reduce fuel consumption by 20% overall. This target can be achieved by:

- Saving unnecessary kilometers driven (optimizing routes)
- Helping driver to save fuel (optimizing driver behavior)
- Managing traffic more efficiently (optimizing network management)

The eCoMove concept rests on the idea that, for a given trip by a particular driver in a particular vehicle, there is some least possible fuel consumption that could be achieved by the "perfect eco-driver" travelling through the "perfectly eco-managed" road network. In reality, both drivers and traffic management systems fall short of this ideal, and much fuel is wasted, and CO₂ emitted unnecessarily. The eCoMove innovations will target the two sources of this avoidable fuel consumption: private trips and freight/logistics trips.

This integrated project (IP) will structure into six different sub-projects:

1. Coordination and Management.
2. Core Technology Integration both to develop common core technologies and to ensure strong technical coordination across the IP.

³⁰ More information about the project is available here:
https://cordis.europa.eu/project/rcn/94140_en.html

3. ecoSmartdriving to develop solutions for eco-driving support for car drivers,
 4. ecoFreight & Logistices, for both eco-driving support for trucks and eco-freight and logistics management.
 5. ecoTrafficManagement & Control to develop applications for cooperative eco-traffic network management.
 6. Validation & Evaluation, to validate the performance and effectiveness of all applications in a number of urban, non-urban and motorway environments.
- Key objectives of eCoMove innovation are to develop and validate the following applications:

- ecoSmartDriving to improve driver eco-performances, including: ecoTripPlanning, on trip dynamic green routing, ecoDriving support, ecoPostTrip and ecoMonitoring;
 - ecoDriver Coaching System and in-vehicle Truck eCoNavigation for good vehicle drivers
 - cooperative ecoFleet Planning and Routing for environmental sound ecoFreight & Logistics
 - ecoAdaptive Balancing & Control system as well as cooperative Fuel-efficient Motorway system as means for eco Traffic Management & Control.
- These important eCoMove innovations are enabled by the use of cooperative information exchange, such as vehicle fuel consumption data & route destination by the traffic system, the traffic lights phase data, speed and route recommendations by the vehicle.

3.6 EUROCATED

Innovative services and platform for sustainable transport based on eco- driving techniques³¹

Eurocated project main objective consists of taking advantage of the opportunity presented in the market by the necessity of saving costs and reduce emissions in terms of fuel combustion in the operation of all kind of road transport professional fleets. Based on the principle of efficient driving, the solutions, products and services, proposed by this project, will fit a market all around Europe of more than 200 million € per year.

Only Spanish market is ranged over 10 million € per year. Thousands of vehicles from public and private fleets will save billions € and tones of emissions, and fleet operators interest is growing as they become aware of the benefits of efficient driving technology supported systems over traditional training courses. Only a medium size city urban bus operator could save 375 thousand € per year and reduce emissions in 750 Tn per year. ADN Mobile Solutions distinguishes by its excellence in R&D activities that have permitted the firm to currently count with the most specialized, competitive and market-oriented tech-powered efficient driving solution.

³¹ More information about the project is available here:
https://cordis.europa.eu/project/rcn/194688_en.html

After 4 years of developments, and with the support of public and private investors, the product has already achieved a TRL of 7, with operation on course of real trials and pilots in a number of early-adopters of the product: It is worth mentioning bus urban fleets operating in Valencia (Spain) and Oslo (Norway) cities as well as the already shown interest of Istanbul (Turkey) city.

3.7 ecoDriver

ecoDriver addresses the need to consider the human element when encouraging "green" driving, since driver behavior is a critical element in energy efficiency. The focus of the project is on technology working with the driver.

The project aims to deliver the most effective feedback to drivers on green driving by optimizing the driver-powertrain-environment feedback loop. It will carry out a substantial programme of work to investigate how best to win the support of the driver to obtain the most energy-efficient driving style for best energy use. Feedback coverage will include preview of the upcoming situation, optimizing the current driving situation as well as post-drive feedback and learning. The project will address this across a wide range of vehicles -- e.g. cars, light trucks and vans, medium and heavy trucks and buses -- covering both individual and collective transport and will optimize feedback to drivers for both nomadic devices and built-in systems and compare the effectiveness of each.

The project will evaluate HMIs and feedback to drivers via both nomadic devices and built-in systems and compare the effectiveness of each. In each case a range of HMIs and feedback styles will be assessed. The project aims to examine driving not only with current and near-term powertrains but also with a full range of future vehicles, including various types of hybrid and plug-in electric vehicles. A comprehensive evaluation will be carried out both in the laboratory (a variety of driving simulators) and in real world driving in both the private and fleet contexts. Scenarios will be developed to assess the implications for the future effectiveness of green driving support.

The target of ecoDriver is to deliver a 20% improvement in energy efficiency by autonomous means alone, which opens up the possibility of greater than 20% savings in combination with cooperative systems³².

³² More information about the project is available here:
https://cordis.europa.eu/project/rcn/100771_en.html; project report -
<https://cordis.europa.eu/docs/projects/cnect/1/288611/080/deliverables/001-Part1Finalpublishablessummaryreport160612.pdf>

3.8 Conclusions on EU eco-driving projects

Presented EU projects have several tangible points with PlastiCircle project, can be adapted and very useful for most of activities related to management of waste collection fleet:

- Estimating various factors affecting fuel consumption
- Establishing an adapted configuration and system architecture for the sensors and tracking system
- Establishing main aspects/ parameters to be considered for monitoring eco-driving style, and integrate them with the tracking system and an application able to provide feedback for drivers and reports for fleet management
- Preparing eco-driving trainings for implicated drivers
- Measuring results in various conditions

4. Factors influencing fuel consumption

Fuel consumption and carbon dioxide (CO₂) emissions from road transport, passenger and freight transport, increased by 36 % between 1990 and 2010 in the EU-27 countries. The share of road transport in the European Union's (EU) total CO₂ emissions is around 17.5 % of which approximately 70 % originates from passenger cars (PCs) (EEA 2012).

The EU has implemented since 2009 (European Commission 2009b) a strategy for reducing CO₂ emissions and fuel consumption from passenger cars (Regulation EU No 397/2013, Regulation EU No 333/2014) and heavy-duty trucks (EU Regulation 595/2009, 582/2011, 133/2014). For the moment, emissions measurement and reporting is based on the New European Driving Cycle (NEDC) and the corresponding test protocol (Regulation (UN) No 83 2011) based on the sales weighted and mass-corrected average CO₂ emissions of each vehicle manufacturer (OEM) and are measured using the New European Driving Cycle (NEDC) and the corresponding test procedure.

The previous presented materials revealed the strong connection between fuel consumption and pollution, which are of major importance to waste management companies in their attempt to improve their operational efficiency and comply to environmental requirements. In this particular case, these aspects combine with other operational specific aspects, like high power required by useful load and by the waste compressing equipment, imposing traditionally high-power diesel engines, operation in busy centre of cities, as well as restrictions regarding noxes, noise and narrow access. That's why, identifying the most important factors affecting fuel consumption is of major importance in our attempt to define technical and eco-driving factors to be improved during PlastiCircle project.

More than that, in the introductory chapter, we presented the proposed new EU regulations regarding emission testing, based on recent studies that revealed an important gap between officially reported fuel consumption and emissions and the real one, experienced by drivers and companies. This difference can be explained on one hand by the actual certification test in Europe that is not considering the complexity of real world operating conditions, and on other hand, the so called flexibility of the testing procedure, resulting in lower measurements of fuel consumption and pollution. The certification test and imposed values evolved during years, compared values (Euro V and Euro VI) being presented in table below³³.

	Euro V Heavy-Duty		Euro VI Heavy-Duty	
	Euro V SS ^a	Euro V T ^b	Euro VI SS ^a	Euro VI T ^b
Emission limits (g/km)				
CO	1.5	4.0	1.5	4.0
HC	0.46	0.55	0.13	0.16 ^d
CH ₄ ^c		1.1		0.5
NO _x	2.0	2.0	0.4	0.46
PM	0.02	0.03	0.01	0.01
PN (#/km)			8.0 x 10 ¹¹	6.0 x 10 ¹¹
Smoke (1/m)	0.5			
Ammonia (ppm) ¹²			0.01	0.01
Fuel Sulfur Limit (ppm)	10	10	10	10
Test Cycle	ESC & ELR	ETC	WHSC	WHTC

Compared with Euro V, Euro VI imposed a major reduction of NOX emissions and particle mass limit, sets limit of ammonia (imposed by Selective Catalytic Reduction Aftertreatment used for NOx reduction), a methane emission limit (used by natural and liquefied petroleum gas engines). Euro VI standards require OBD systems to measure and control the performance of the emission system. As a result, heavy duty vehicles shift from vanadium to zeolite SCR catalysts and use a diesel particulate filter as a standard.

The certification test is currently the main instrument used to regulate the environmental performance and to provide information to consumers regarding the fuel economy of their vehicle. Yet, it should be noted that in reality vehicle fuel consumption is affected by a great number of factors, which are not necessarily uniform and equal for all drivers or all

³³ Source: The International Council on Clean Transportation- A summary of Euro VI vehicle emission standards: https://www.theicct.org/sites/default/files/publications/ICCT_Euro6-VI_briefing_jun2016.pdf

operating conditions. In fact, there is no single fuel consumption value, but the fuel consumption of a specific vehicle under very specific conditions.

Recently, the European Commission, based on studies revealing that 6% of emissions are generated by lorries, buses and coaches, proposed³⁴ a very ambitious mandatory target of 15% reduction of their emission in 2025 compared to 2019, and an “indicative” target of 30% in 2030. It is important to notice that focus will be on lorries (over 98% relying on diesel and responsible for 65-70% of total heavy-duty vehicles emissions), “vocational” vehicles like construction and garbage trucks being exempted, due to their limited potential for cost efficient CO2 reduction.

The real-world operation includes a multitude of factors (like temperature, slopes, usage of air conditioning, tyre pressure, driving style, etc.) which combined, can generate over 25% more fuel and pollution compared with those certificated. Some of these factors can't be influenced (like, truck technical specifications, road and climate conditions), but other can be controlled by the driving style. Based on an important European Commission study³⁵ we will identify the most important factors affecting fuel consumption and pollution, and whenever possible, we will use aspects related to PlastiCircle pilot cities.

4.1 Technical factors

a) Truck type

The waste collection trucks are specialized equipment, requiring a high-power truck and a specialized equipment for container lifting, emptying, waste compressing and transport. Usually, these trucks are combinations between truck manufacturers and waste equipment manufacturers, selected after decisions regarding container type, locations and access are already known, in which consumption and price are playing a major role. There are major differences between equipment used in PlastiCircle pilot cities.

³⁴ 03/07/2018 - COM/2018/284 - Proposal for a regulation setting CO2 emission performance standards for new heavy-duty vehicles

https://ec.europa.eu/clima/policies/transport/vehicles/heavy_en#tab-0-0

³⁵ Review of in use factors affecting fuel consumption and CO2 emissions

http://publications.jrc.ec.europa.eu/repository/bitstream/JRC100150/jrc100150_ldna27819enn.pdf

City	Truck	Engine	Consumption	Capacity	Equipment	Container	Loading	Year	Pollution
Valencia	Mercedes Acros 2532	320HP	47 - 60 l/100km	17t	Ros Roca/ Farid	2.4-3.2m3	Lateral right	2006	Euro IV
Utrecht						Underground 3.1m3	Crane		
Alba Iulia	Iveco 150E	180HP	40/53 l/100km	15t	Farid	1.1m3	Rear	2013	Euro V

There are big differences between pilot cities in terms of truck type, consumption, pollution.

b) Low friction tyres

Some tyres are special designed and produced to have low rolling resistance, reducing required rolling effort and improving fuel efficiency. Is usually known as RRC. Low RRC tyres have a 10-20% lower resistance compared with normal ones, conducting to a decrease of 2-3% of fuel consumption.

c) Lubrication

Low viscosity oil is reducing engine friction, lowering consumption with up to 2.4%.

d) Aerodynamics

Waste trucks have a “bulky” design, with a high aerodynamic resistance (usual over 0.8 coefficient). More than that, the waste storage compartments and supplementary equipment (on roof, boxes, loading / crane equipment) are raising consumption with 3.6-4.5%.

e) Vehicle mass

Full truck has higher consumption with over 30%. For small cars, test revealed an increase of 5.8% for every extra 100kg.

f) Auxiliary systems

Some of this equipment are controlled by drivers, other are necessary during normal operation (like Hydraulic/ electric steering assist, hydraulic brakes, engine management, fuel injection, lamps, lights, wipers, windscreen heaters) are raising consumption with 5-7.6%.

g) Fuel characteristics

Depending on fuel type and fuel blend, consumption can raise with 1-3.6%.

h) Usage

A used truck may have higher consumption, with 5-8% compared to a new one.

4.2 Maintenance factors

a) Maintenance and service

Maintenance and service according to manufacturer's specifications improve safety and reduces unusual fuel consumption, or costs related to defects troubleshooting.

b) Tyres

Proper tyre alignment is important for safety and low effects on brakes, steering, bearings, etc. A lower pressure tyre is also raising consumption (up to 1% per each 0.2 bar).

c) Other

Poorly tuned engine and clogged air filters can increase consumption with up to 3.5%.

4.3 Local factors

a) Temperature

Temperature is affecting engine and transmission efficiency. Compared with a normal operational temperature of 20°C, operations at 0°C raises consumption with over 10% (another 10% at -20°C).

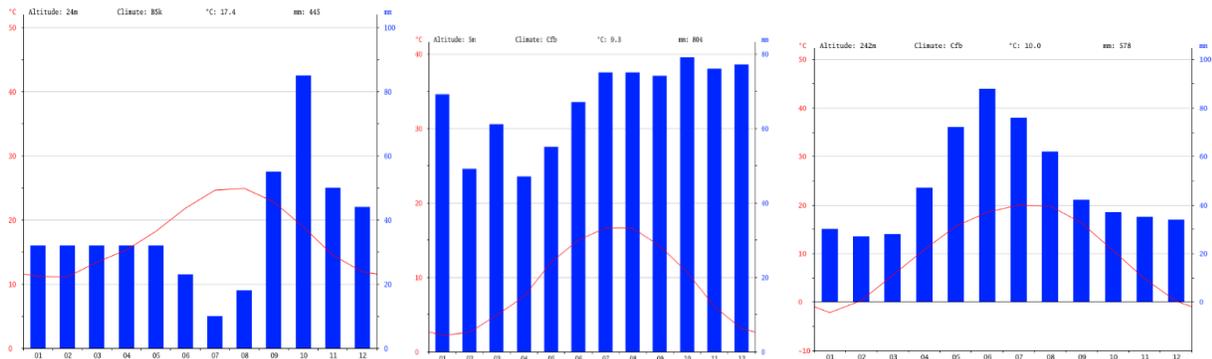
b) Rain / Snow

During rain, wheels have to push through water, increasing consumption with 10-15%. Snow has an even more important effect, because dry winter air is 11% denser than summer air, increasing aerodynamic resistance and friction and raising consumption with up to 30%.

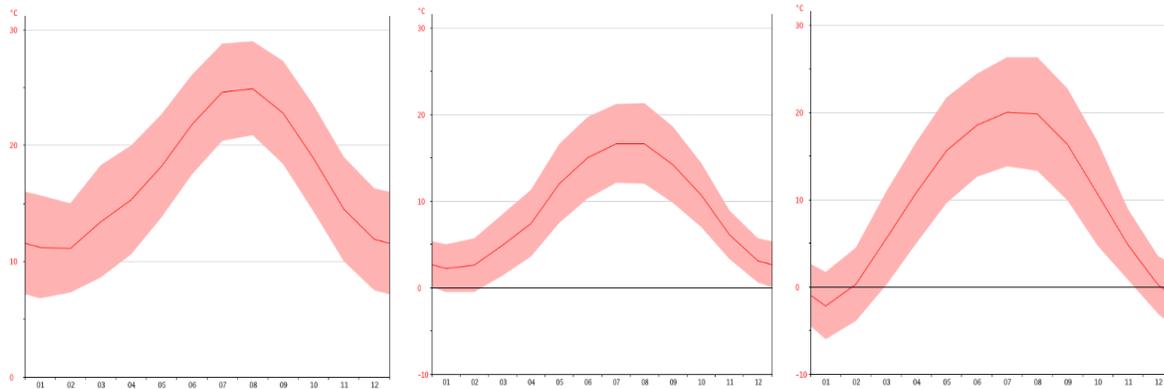
The pilot cities have completely different climate settings, being situated in western, central and eastern Europe, from warm and dry (Valencia) to humid (Utrecht) and continental (Alba Iulia). In the following table, average temperatures and humidity are presented for the pilot cities.

City		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average/ Total	
Valencia	Avg. Temperature (°C)		11.2	11.1	13.4	15.3	18.2	21.8	25	24.9	23	18.9	14.5	11.9	17.38
	Min. Temperature (°C)		6.8	7.3	8.6	10.6	13.8	17.5	20	20.9	18	14.3	10	7.5	
	Max. Temperature (°C)		15.7	15	18.3	20	22.7	26.1	29	29	27	23.5	19	16.3	
	Precipitation / Rainfall (mm)		32	32	32	32	32	32	23	10	18	55	85	50	
Utrecht	Avg. Temperature (°C)		2.2	2.6	4.9	7.4	12	15	17	16.6	14	10.7	6.1	3.1	9.28
	Min. Temperature (°C)		-0.5	-0.5	1.4	3.6	7.5	10.3	12	12	9.8	7	3.3	0.6	
	Max. Temperature (°C)		5	5.7	8.5	11.3	16.6	19.7	21	21.3	19	14.4	8.9	5.7	
	Precipitation / Rainfall (mm)		69	49	61	47	55	67	75	75	74	79	76	77	
Albalulia	Avg. Temperature (°C)		-2.2	0.3	5.5	10.8	15.6	18.5	20	19.8	16	10.6	4.8	0.2	10.02
	Min. Temperature (°C)		-6	-3.9	0.2	5	9.6	12.6	14	13.3	9.9	4.7	0.8	-3.1	
	Max. Temperature (°C)		1.7	4.5	10.9	16.6	21.7	24.4	26	26.3	23	16.6	8.9	3.5	
	Precipitation / Rainfall (mm)		30	27	28	47	72	88	76	62	42	37	35	34	

Climate graph > Valencia > Utrecht > Albalulia



Temperature envelope for pilot cities > Valencia – Utrecht – Alba Iulia³⁶



It is easy to see that compared to Valencia, there are lower temperatures and more rainy days in Utrecht, but Alba Iulia has lower temperatures and snow is expected during winter. According to project plan, pilot will be in summer – autumn for Valencia, autumn – winter for Utrecht and winter – spring for Alba Iulia. In this condition, expectations are that Utrecht and Alba Iulia to have bigger specific consumptions compared with Valencia, even for trucks with similar technical specifications.

c) Road conditions

Roads affected by roughness and unevenness, tend to raise consumption by 2.7%. As main used roads in all three pilot cities is covered with asphalt, we are not expecting an important contribution of this aspect.

Road grade (2-5%) increases consumption uphill up to 13.3%, because these trucks don't have regenerative brakes and energy used to climb hills is lost when driver is forced to use brakes downhill.

Trip type also can influence consumption, because short trips require cold start and lower engine operation, raising consumption with up to 10%.

Roads with many curves, low speed, increased idle time, many starts and stops and traffic congestion, will generate an increased fuel consumption with up to 30%.

City	Population	Surface	Elevation	Roads	Highway, km	Truck trip
Valencia	809200	136km ²	10-57m (27m)	5311km	180	96-105 km
Utrecht	345000	103km ²	7m	3883km	120	80km
Alba Iulia	74000	98km ²	203-304m	350km	0	30km

³⁶ Climate Data Org (<https://en.climate-data.org/location/4543/>)

4.4 Driving style

- a) Auxiliary systems
Extensive **usage of air conditioning/ heating can increase consumption with up to 5%, while driving with open windows at high speed (> 100km/h) raises consumption with 4.8%.**
- b) A **“sportive” driving style, increases consumption with 11% compared with a normal one, while an “aggressive” one (high acceleration/ deceleration and speed) raises consumption with 26%.**
- c) An eco-driving style, with optimal gear shifting, smooth accelerations and decelerations, anticipation of movement and traffic, steady speed, and green light optimal speed, can decrease consumption with 6.5%.

4.5 Impact of idling on fuel consumption

Some relevant information on this topic is offered in study conducted by the University of Kuala Lumpur³⁷. One of the major problems currently faced by the truck industry is the issue of engine idling. During rest time, the drivers keep the engine idling in order to maintain cab comfort and to provide power to the loads in the cab, such as heating and air conditioning. When the engine is running in idle conditions, it takes a rich mixture of air and fuel, such that the fuel consumption rate is high. Furthermore, during idling, the engine is not able to work at peak operating temperature and the combustion of fuel is incomplete which leaves fuel residues in the exhaust and thus, emission levels increase.

When the duration of idling is longer than 10 s the engine consumes more fuel compared with restarting it. The fuel consumed during 8 kilometers of driving is equivalent to just 10 min idling and 10 min of idling per day will consume more than 105l of fuel per year. Idling fuel consumption is estimated to be approximately 8 billion liters per year. Engines run at 30% efficiency (thermal) throughout highway operation, but at only 3–11% efficiency during idling. A study by Argonne National Laboratory indicated that, on average, a heavy-duty truck idles for up to 1818 h per year, is equivalent to 30.000 extra km of engine wear, burning 2.500 liters of diesel fuel, and adding operational costs with about US\$4000

³⁷ Impact of idling on fuel consumption and exhaust emissions and available idle-reduction technologies for diesel vehicles - S.M. Ashrafur Rahman, H.H. Masjuki, M.A. Kalam, M.J. Abedin, A. Sanjid, H. Sajjad Centre for Energy Sciences, Faculty of Engineering, University of Malaya, 50603 Kuala Lumpur, Malaysia
<https://pdfs.semanticscholar.org/1f2c/99f754c53507b6aefa080621ce41657e888a.pdf>

per truck per year. Thus, idling not only increases fuel consumption costs, but also decreases the time interval between oil changes and increases maintenance and repair costs.

Health problems related to increased emissions from idling engines include an increased risk of cardiac events, difficulty breathing, nausea, light-headedness, development of chronic bronchitis, asthma, decreased lung function, irregular heartbeat, or even possibly death.

In response to the increasing awareness of the adverse effects of idling engines on human health and the environment, many cities around the world have instituted idling restrictions and bans. Furthermore, it has motivated automobile industries to search for technically and economically feasible substitutes for idling. Some technologies that are considered as major alternatives to idling are auxiliary power units, direct fire heaters, fuel cells, thermal storage system, inverters, and truck stop electrification. The complete utilization of these technologies could offer a significant reduction of emissions (NO_x, PM, CO, and HC) and fuel consumption during idling.

The exhaust from a diesel engine includes a wide range of gaseous and particulate phase organic and inorganic compounds, which have greater quantities of aromatics and sulfur. Hundreds of chemicals are adsorbed onto the surfaces of these particles, such as the many recognized or suspected mutagens and carcinogens. The gaseous stage also has irritants and noxious substances, which have serious effects upon human health and have a severe environmental impact. The composition of diesel exhaust varies with operating condition: (i) engine type, (ii) fuel, (iii) presence of an emission control system, and (iv) lubricating oil. Diesel engine pollutants can be classified into three groups: Nitrogen oxides or NO_x, hydrocarbons and CO, and particulate matter.

Heavy-duty trucks spend a large amount of time with their engines idling. This can be separated into following parts: **non-elective idling and elective idling. The former arises just after the engine is started and intermittently during heavy traffic. The latter arises during stand-by periods in rest stops and throughout loading/unloading. In these situations, the engine idling is performed to maintain comfort levels.**

Behavior modification and technical applications are two strategies that could be employed to reduce vehicle idling.

The first option is generally low-cost, targeting voluntary idling, which might consist of training and workshops, signage, marketing tools, and initiatives, etc.

The latter option offers technical substitutes to engine idling.

5. Implementing eco-driving in PlastiCircle

Based on factors influencing fuel consumption and eco-driving tips, an efficient driving module will be developed and will be providing real-time feedback to drivers in order to change their driving style. In the specific case of waste trucks, main operating aspects should be considered: maintenance, cold/ hot start, driving style in traffic, idling in traffic, idling near containers location, load variance, local conditions variance, emptying containers, emptying load.

The truck traceability system allows to monitor the speed, acceleration, RPM and engine load. The system allows to detect speeding, high acceleration and braking during a route. Monitoring the speed, RPM and engine load allows to identify important events as container emptying, load emptying and excessive idling. The truck traceability system allows to monitor the engine load from the OBD II protocol. This is useful for the optimization of the engine performance during a mechanical process as the use of the power take off. Reducing the time of use of the PTO in the process of emptying the containers and making the collectors to work at the optimum RPM (i.e., in the optimum power curve and consumption) will significantly reduce the fuel consumption. The data from the sensors will be sent via GPRS in a programmed way and saved in a digital cloud platform.

In case of lack of GPRS coverage, the information will be stored in the on-board computer, and ready to be sent when the GPRS coverage is restored. Once the information is received in the server, the information will be processed to be available in the cloud platform. After analysing the curves of maximum RPM, PTO or idling time, the hardware installed in the waste collectors will be programmed with the optimal operating values. A traceability system will be defined and developed with GPS, GPRS, and CAN data capabilities. The information generated will be communicated with the PlastiCircle platform and defined in a way that it is portable and easily adaptable for different trucks. The system will be tested in real applications and optimized.

Vehicle emissions depends on driving behaviour such as acceleration and speed. Monitoring, excessive idling, unnecessary accelerations and braking will give information that can be used to significantly reduce the fuel consumption.

This module will have a programming interface for the engineers, in order to input the parameters that define efficient driving for each truck type, and together with the data from the truck traceability module, give instructions to the driver to minimize the fuel consumption and the CO₂ emission. As already presented in this document, vehicle consumption and emissions depend on driving behaviour such as acceleration, braking, speed, idling and sensors will give information that can be used to significantly reduce the fuel consumption. An Android application will be developed to manage the

data from the GPS and the OBD II reader from the vehicle. The data is sent by the application to the remote server via GPRS/ 3G. An Android application will be developed to manage the data from the GPS and the OBD II reader from the vehicle. The data is sent by the application to the remote server via GPRS/3G.

In this system, the Android application will emit a visual and sound alarm when driver exceeds the correct parameters established on the driving behaviour guidance. It is expected to have a significant impact in the reduction of economic and environmental costs of the waste collection, in terms of fuel consumption and GHG emissions. Fuel consumption can be reduced between 5 to 20% [5,6].

Taking advantage of the use of a tablet on board of the truck, the optimized routes (in function of the filling level of the containers) will be displayed in the Android application together with the track traceability and efficient driving systems.

The truck traceability together with the efficient driving and route optimization systems will be implemented and tested in the city pilots as described in the PlastiCircle project.

5.1. Main information/ data available from tracking system

In this moment, there are tested various data available from truck sensors in order to transmit them to PlastiCircle cloud platform, like:

a) Data from GPS system:

- Position
- Speed
- Acceleration

b) Data from CAN Bus/ OBDII:

- RPM
- Speed
- Engine load
- Other Technical (like Temperature, Fuel Pressure, Consumption)

c) Data to be checked if available (probably truck type dependant, or requiring supplementary sensors)

- Total number of km (Mileage)
- Km between 2 stops/ km per day/ month
- Consumption between 2 stops/ per day/ per month
- Exterior Temp
- Cabin temp
- Pre-heating engine

- Low/ High idling
- Gear
- Air conditioning/ Heating
- Open windows
- Hydraulic pressure
- Container weight (useful for “pay as you throw” developments)
- Waste container ID

5.2. Using data and application for driver guidance

Based on sensor readings, application can provide info for all important operations/ driving aspects, or requirements for manual actions, in order to achieve eco-driving skills and higher efficiencies:

Pre - start maintenance: check tyres, windshield, brakes, existing equipment; can be implemented as a check list before starting engine

Pre-start: pre-heating engine, according to exterior temperature; needs exterior temperature, oil temperature, pre-heating control; important especially in bellow 0 environments (ex. winter in Alba Iulia)

Cold start, short idling, slow motion for engine and transmission uniform heating; needs RPM, speed, temperature; application can recommend slow movement for first minutes, in 15 sec – 1 min after start (depending on engine type and temperature), attention for high RPM with cold engine

Normal/ Excessive Driving (acceleration/ deceleration, speed, change gear, instant consumption); needs RPM and speed for attention on excessive acceleration/ deceleration; optional, if gear position and consumption are available, application can recommend changing gears, or moderate acceleration/ braking, considering also instant consumption

Low/ High idling, excessive idling, recommendation for power-off for over 1 min idling; is based on RPM, speed; two aspects must be considered: correct setting of idling RPM (depending on engine and temperature) and avoidance of excessive time in idling, in stationary positions, in traffic, in preparing for emptying containers, or emptying load; application will recommend engine stop if idling is over 1 min; to be considered if necessary with special equipment (like start-stop blue motion) if available, knowing that re-starting engine has lower consumption than 20 sec of idling

Emptying containers, compressing waste, emptying load; this operation is easy to recognize by high RPM/ engine load with no movement; application can provide recommendations in case of too high RPM/ engine load/ consumption; load can be estimated by number of emptied containers; if there are optional sensors for container ID, container weight and container waste volume (based on container ultrasonic sensors),

much better values for volume, load weight, compression rate, can be obtained, allowing correct usage in terms of consumption related to load

Usage of accessories – this option needs extra signals for various sensors (like lights on, heating/ air conditioning functioning, open windows, external/ cabin temperature, etc.); if implemented, signals will recommend closing heating/ air conditioning when cabin temperature is too high/ too load, or opening windows at convenient temperatures and low speed, or closing windows at high speed (for example on a highway)

Driving recommendations – can be provided after data processing for each trip/ day, considering driving style parameters (number of notifications received, number and duration of aggressive acceleration/ braking, fuel consumption vs. optimal, idling time/ total time, gear changing, RPM during emptying containers/ load, usage of accessories, etc.)

5.3. Using data for fleet management

As previously mentioned, fuel consumption is a major factor of **operational cost for waste management companies. From the very beginning, when deciding containers type, local and street configuration, loading type, waste trucks type, estimated collection frequency and costs at a specified quality of service, management of companies must consider various aspects in their decision, many times initial price not being the most important one.**

- 1) Real consumption/ pollution of a specific truck; manufacturer data must be checked against simulation software (like VECTO, developed by EC) **and real operation consumption test in various scenarios**
- 2) Tyres type must be carefully checked for safety and rolling resistance; special attention must be taken in choosing winter tyres where necessary (like in Alba Iulia) and proper replacement **of summer tyres**
- 4) Fuel and oil must respect recommendations of manufacturer
- 5) Proper service and maintenance are critical for low/ normal consumption and long operating life; an application can recommend based on number of km, estimated weather and **possible functioning alerts, proper maintenance planning**
- 6) Most of actual fleet trucking systems are using just GPS data, useful for position history, trip map and duration. Information is useful but combined with real time CAN Bus/ OBD II data and extra sensors, **can provide a much more accurate image of process efficiency, fuel consumption, driving behaviour or comparative reports, able to conduct to important reductions of operational costs and increased efficiency.**

6. Future developments of waste collection trucks

Estimated to have a contribution of up to 27% of greenhouse emissions at the EU level, road transport includes about 5% of commercial vehicles, while their contribution to pollution is estimated to up to 20%, because they include mainly high power Diesel trucks.

There are several EU, governments or city initiatives to ban new petrol and diesel trucks by 2040, imposing car manufacturers to develop mainly hybrid and full electric new vehicles. This tendency is expected to be fuelled by companies and councils in their attempt to adapt to recent EU negotiations³⁸ imposing a 35% reduction of car emissions by 2030 compared to 2020 levels. If car manufactures consider this target too ambitious, with possible side effects as job losses, lower profits and high dependency on Asian batteries, many governments recommended a 40% reduction of emissions, considering the UN Climate Change report, which warns that nations must cut emissions much faster. It is expected that over 35% of new cars sold in Europe by 2030 to be very low emissions ones.

Beginning with 2013, a fleet of electric waste collection trucks is tested in France (Neuilly sur Seine) by SITA and Suez, with very good results in terms of pollution (90% less emissions), noise and operational costs. Tested autonomy is of up to 6 hours, making it ideal for small communities and short routes³⁹.

An interesting initiative is conducted by FCC Environment from UK in Spain (Madrid) for several years already, using full electric operation in city and a compressed natural gas engine for emergency charging on route to the treatment facility. With up to 60% less energy consumption, zero emissions in city and very low noise, trucks can be easily operated during night, allowing further reductions of operational costs⁴⁰.

Veolia is testing 5 electric trucks for waste collection, estimating an important reduction of up to 78 tons of carbon dioxide per year

New trucks are under development by companies like Geesinknorba and E Moss⁴¹, a Netherland company specialized in electric trucks who managed to improve its range of trucks from 7 up to 24 tons, with battery packs providing a range of up to 300km. E Moss is also involved in an interesting project in New Zealand, where 20 electric waste collection trucks⁴² are tested as part of a complete circular economy, electricity being generated from waste.

³⁸ <https://www.ft.com/content/2075038a-cc58-11e8-b276-b9069bde0956>

³⁹ A video about these electric waste collection trucks can be watched here:
<https://www.youtube.com/watch?v=QsxPYH0m1Uk/>

⁴⁰ Further details can be found here: <https://resource.co/article/all-electric-waste-collection-vehicle-tours-uk-12771>

⁴¹ <http://www.emoss.nl/en/electric-vehicles/full-electric-truck/>

⁴² <http://www.scoop.co.nz/stories/BU1709/S00167/first-electric-kerbside-waste-collection-truck-in-nz.htm>

7. Conclusions

Based on previous participants experiences, other EU projects and extensive research studies, PlastiCircle project is addressing the circular economy of plastic and the necessary developments for each of its stages.

An important stage, in terms of operational costs and efforts, but also regarding environment pollution, is represented by the collection of waste, from bring banks or containers to the sorting facilities, using specialized trucks. That's why, important efforts are dedicated to a specialized, viable and affordable tracking system for waste trucks fleet management.

If most of actual tracking systems are using GPS data, providing a valuable information of the location, speed, acceleration and production time, other data from the CAN bus or other sensors, provides many information of the vehicle like speed, RPM, and the applied torque, temperature, pressure, engine load rate, etc., providing important conclusions on process efficiencies.

Vehicle emissions depends also on driving behaviour such as acceleration and speed. Monitoring the speed, excessive idling, unnecessary accelerations and braking can significantly help to further reduce the fuel consumption [5,6].

An Android application will manage the data from the GPS and the OBD II reader. This application communicates with OBD II reader via Bluetooth to obtain parameters in real-time from the vehicle. The data retrieved at 1 Hz was GPS location, speed, RPM and engine load. The data is temporarily stored and sent to a cloud application, via GPRS/3G. Dispatch fleet management application will provide important notifications and recommendations to drivers regarding their eco-driving behaviour, together with complete details regarding fleet management and process efficiencies. Our expectations are to see a realistic reduction of fuel consumption of 8-12% based mainly on improved operations and driving behaviour.

This material reveals important operational differences between the pilot cities, which will be reflected in training materials for drivers, applications and real test in pilot phase, able to provide further system improvements.

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