



A simulation-based methodology for quantifying European passenger car fleet CO₂ emissions[☆]



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HIGHLIGHTS

- A new modeling approach is proposed for calculating CO₂ emissions and energy demand from light duty vehicles.
- Methodology combines large publicly available data, vehicle simulation techniques and elements from emission inventories.
- Emissions of the new passenger car registrations in Europe were calculated for NEDC and WLTP.
- WLTP introduction is estimated to increase officially reported emissions about 20%.
- 3 Scenarios for post 2020 CO₂ emissions evolution are analyzed and discussed.

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ABSTRACT

Common approaches to assess the evolution of CO₂ emissions from road vehicles are usually based on (a) estimates of future fleet composition, where most approaches consider vehicles at a rather aggregated level, and (b) emission factors, which are either based on CO₂ certification data or statistically-provided functional relationships obtained from real world test data, or a combination of the two. This approach has certain limitations in capturing the effect of new technologies on CO₂ emission related policy initiatives. The present study proposes a new method for the detailed calculation of the European light duty vehicle fleet CO₂ emissions, which could help to overcome such limitations, achieve better results when making CO₂ emissions projections and better support future policies. Simulation at individual vehicle level is combined with fleet composition data, retrieved from the official European CO₂ emissions monitoring database, and publicly available data regarding individual vehicle characteristics in order to calculate vehicle CO₂ emissions and fuel consumption over different conditions and vehicle configurations. The methodology is applied to analyze and assess the impact of the introduction of the new certification procedure, the Worldwide Light duty vehicle Test Procedure (WLTP), on the European car fleet CO₂ emissions. Results show an average WLTP to NEDC CO₂ emissions ratio of approximately 1.2. The increases in CO₂ emissions are higher for cars exhibiting lower NEDC emission values (additional 29 and 25 gCO₂/km for vehicles emitting 100 and 119 gCO₂/km, respectively). At higher emission levels (about 250 CO₂ g/km) WLTP and NEDC present comparable results. Three possible scenarios for the translation of projected NEDC CO₂ emissions to WLTP-based ones are quantified.

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1. Introduction

Road transport currently contributes about one-fifth of the European Union's (EU) total CO₂ emissions. Light-duty vehicles only – passenger cars and vans – produce around 15% of the EU's

CO₂ emissions [1]. Regulations (EU) No 443/2009 sets the target of average CO₂ emissions from passenger cars to 130 gCO₂/km and 95 gCO₂/km, for 2015 and 2020, respectively.¹ The aim is to incentivizing investments in new technologies by the car industry that will improve fuel efficiency and decrease CO₂ emissions [2]. In order to respect the competitiveness and diversity among different manufacturers, manufacturer-specific targets are defined according to a limit-value line, proportional to the sales-weighted average

[☆] The views expressed in the paper are purely those of the authors and may not be considered under any circumstance as an official position of the European Commission.

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¹ Regulation (EU) 510/2011 sets the targets for vans.

Nomenclature

EU	European Union	$a, b, c, a2$	Willans lines model thermodynamic efficiency parameters (–)
EC	European Commission	$l, l2$	Willans lines model engine losses parameters (–)
NEDC	New European Driving Cycle	k	exponential parameter (–)
WLTC	Worldwide Light duty vehicle Test Cycle	T	engine temperature (°C)
WLTP	Worldwide Light duty vehicle Test Procedure	T_{trg}	engine target operating temperature (°C)
REESS	Rechargeable Electric Energy Storage System	T_{thres}	engine thermostat temperature (°C)
CO ₂ MPAS	CO ₂ Model for PAssenger and commercial vehicles Simulation	T_{max}	engine max allowed temperature (°C)
PyCSIS	Passenger Car fleet emissions Simulator	N	engine speed (RPM)
ICE	Internal Combustion Engine	s	engine stroke (mm)
S/S	start/stop system	CC	engine displacement (cc)
2WD	2 wheel drive	FC	engine fuel consumption (g/s)
4WD	4 wheel drive	FLHV	fuel lower heating value (kJ/kg)
P_{dtr}	drivetrain power (kW)	ΔT	delta temperature (°C)
F_0, F_1, F_2	road load coefficients (N, N/(km/h), N/(km/h) ²)	ΔQ	delta heat (J)
m	vehicle mass (kg)	eng_{m*cp}	engine heat capacity (J/K)
v	vehicle velocity (km/h)	cc	cooling constant (–)
α	vehicle acceleration (m/s ²)	$cool_{m*cp}$	coolant heat capacity (J/K)
φ	road gradient (radians)	$cool_{flow}$	coolant flow (g/s)
g	acceleration of gravity (m/s ²)	EEA	European Environmental Agency
η_{trn}	transmission efficiency (%)	AP	Affinity Propagation
P_{eng}	engine power (kW)	CO ₂ ^{fleet}	fleet sales weighted CO ₂ emissions (g/km)
P_{elc}	vehicle electrical system power (kW)	CO ₂ ^{model}	individual model CO ₂ emissions (g/km)
P_{mec}	vehicle auxiliaries mechanical power (kW)	r_{model}	individual model registrations (–)
t	time (s)	m_{fleet}	fleet sales weighted mass (kg)
FMEP	Fuel Mean Effective Pressure (bar)	m_{model}	individual model mass (kg)
BMEP	Brake Mean Effective Pressure (bar)	TA	type-approval
Cm	Engine Mean Piston Speed (m/s)		

mass of their fleet. The fleet-wide emission target corresponds to the sales-weighted average mass of the EU fleet. This approach provides that higher targets apply for manufactures that produce heavier vehicles and lower targets apply for manufactures with lighter vehicles, while the fleet-wide emissions need to comply with the targets set in the Regulation [3]. Manufacturers failing to achieve their targets are subject to costly penalties.

The current test protocol and associated test cycle (NEDC), on which the CO₂ targets are based, has received criticism regarding its effectiveness to reduce CO₂ emissions in real world operating conditions. It has been demonstrated that CO₂ emissions measured during certification are consistently lower than those occurring in real life [4–10], while this difference, also referred to as the “gap”, is increasing with time [5]. There are multiple reasons contributing to the gap: the New European Driving Cycle (NEDC) itself [4,11], the flexibilities of the current test procedure, i.e. the interpretation made on various loosely defined boundaries [12], and possible strategies whereby the operation of the car under laboratory conditions is different compared to that over real life conditions [13].

In order to address these issues and to strengthen the effectiveness of existing policies, the European Commission is introducing a new, more realistic test procedure in the type-approval process. The new World-wide harmonized Light duty Test Cycle (WLTC) and the new World-wide harmonized Light duty Test Procedure (WLTP) were developed as a global standard for determining pollutant and CO₂ emissions. The objective of WLTP was to provide a more robust test-basis and a procedure which is more representative of actual on-road vehicle operation [14–17]. WLTP significantly differs from NEDC; its main differences affecting fuel consumption include the test cycle and gear-shifting sequence, vehicle mass definition, road load determination, chassis dynamometer preconditioning, temperature, and REESS (Recharge-

able Electric Energy Storage System) Charge Balance correction. Tsokolis et al. [16] provide an in-depth analysis of the differences between the two cycles and the expected effects on fuel consumption and CO₂ emissions.

The WLTP will be introduced in the European type-approval process starting on September 2017, in parallel with the introduction of the final Euro 6c emission limits [18,19] and following the recently established procedure for measuring Real Driving Emissions [20,21]. These three pillars create a very robust framework for pollutant and CO₂ emission control in Europe. However, WLTP introduction will have an effect on the monitored CO₂ emission values and consequently to the regulated targets for year 2020. The latter were agreed based on the experience and practices of the existing test-protocol (NEDC). A dedicated study has been carried out with the final objective to identify the most appropriate strategy to introduce the WLTP procedure without having to amend the targets set for the 2015–2021 period. As a result, until 2021, the existing CO₂ targets will not change, and CO₂ emissions measured at type-approval using the WLTP procedure will be translated into the corresponding NEDC-based value using a technology-based vehicle simulation model, CO₂MPAS (CO₂ Model for PAssenger and commercial vehicles Simulation) [22], developed by the European Commission. In 2020, the difference between the average sales-weighted NEDC-simulated emissions and the manufacturer-specific target will be applied to the WLTP-measured, sales-weighted CO₂ emissions to identify, per each vehicle manufacturer, a specific WLTP-based target for 2021 and thereafter [23,24].

The exact effect of WLTP introduction on fleet-wide CO₂ emissions is difficult to estimate and limited literature on the topic is available. Most studies published to date estimate the effect of the WLTP introduction on individual cars. This is achieved by

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