Road transport CO_2 emissions mitigation evaluation by means of a new software tool

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Abstract

In this paper, a new vehicle stock projection and scenario evaluation tool is used to assess different approaches which aim at CO_2 emissions mitigation from road transport, in view of the 2020 target of 95g/km CO_2 for passenger cars new registrations. Road transport emission reduction can be accomplished by a different technology/fuel mix. The authors have realised three different scenarios with respect to passenger car fleet development and technology mix focusing their study on Greece. Results show that electricity can be a highly beneficial and realistic solution towards CO_2 mitigation, particularly if upstream CO_2 can be reduced as well. This software approach can aid environmental policy formulation for air quality regulations.

Introduction

Emission calculations are considered an important part in the process of estimating climate change and developing mitigation campaigns. Carbon dioxide (CO_2) and related Green House Gases (GHG) emissions as well as air pollutants are the typical targets of emission reduction policies. Emphasis is often put on road transport activity and related emissions due to their contribution in CO_2 emissions, the flexibility offered by the evolution of vehicle eco-friendly technologies and the penetration of public awareness campaigns about individual contribution to environmental protection, public health and distribution of responsibility.

Although fleet technology mix plays an important role in CO_2 calculation, GHG and air pollutant emissions can be affected by the trip distribution and driving patterns, especially if modern technologies are taken into account. For instance, hybrid electric vehicles perform very well in terms of CO_2 in urban conditions, but this is not the case in the highway. Within this framework, fuel content should also be considered (e.g. biofuel blends, CNG/LPG as secondary fuelling options etc.). New technologies may emerge as viable solutions and eventually gain market share and older ones may evolve and perform better in the future.

All the aforementioned features can be utilised in the proposed tool and have been used to formulate plausible alternative scenarios which constitute different approaches aiming at CO_2 emission abatement. SIBYL (Emisia, 2012) is a novel software package which provides an elaborate framework for the creation and evaluation of alternative road transport scenarios with respect to a baseline scenario. The underlying model is a merge of already existing methodology (EMEP/CORINAIR, 2007) used in COPERT (Ntziachristos et al, 2009) and newly developed approaches regarding trip length and mileage distribution using mobility statistics (Eurostat, 2000), fuel customisation and state-of-the-art vehicle technology modelling. As a result, a plethora of scenario specifications can be realised by using these options.

SIBYL was designed as a vehicle stock, energy consumption and emission projection tool to facilitate the formation and execution of scenarios, policy assessment and target setting. Alternative scenario building mainly involves a change in the distribution of new vehicle registrations compared to a baseline mix. However, there are several parallel details to be defined such as the second- hand vehicle market and vehicle survival rates. Also, technology efficiency is not fixed and the rate of development due to technology breakthroughs and regulatory obligations can greatly affect CO_2 emissions. The same notion applies to the carbon intensity of electricity production, which indirectly affects the CO_2 mitigation efficiency of grid-powered electric cars.

In this work, three scenarios have been developed and studied in SIBYL, namely the Downsizing & Alternative scenario, the Hybridisation scenario and the Electrification scenario.

All the modifications were applied with respect to the original baseline scenario which, in turn, was compiled via feedback provided by a combination of higher-tier models and integrated in the EC4MACS project (EC4MACS, 2010). The stock growth of Greece served as the basecase scenario. All three scenarios modify the new registrations of passenger cars but also consider secondary developments, such as technology efficiency and fuel mix variations.

Modelling methodology

SIBYL was developed on a modular base; a series of virtually independent modules (Figure 1), each of them being responsible for the calculation of certain metric (e.g. stock, mileage distribution, energy consumption etc.). In this fashion, new modules can be added in the future and each one can be modified separately.

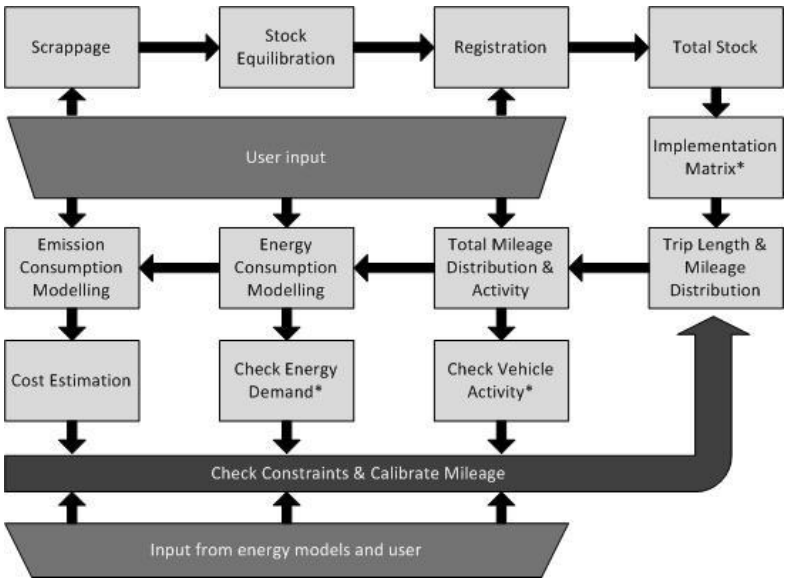

Figure 1: Model block diagram

Everything begins with the vehicle stock projection which can be manually altered based on desired assumptions. This is a bottom-up approach; new vehicle registrations are independently defined. Traditionally, new registrations are calculated as the difference between the total fleet expected, minus the surviving stock from the previous year. SIBYL offers the advantage that market growth numbers can be directly introduced into the scenario assumptions. For example, several countries have announced plans to introduce a specific number of electric vehicles up to some point in time. These targets could be directly inserted into the model as user input data.

Total stock size estimation will be introduced directly from the higher-tier models. The average mileage combined with the previously estimated stock will yield the total vehicle-kilometres. Stock classification will provide the average projected mileage per technology and energy source.

This approach was not deemed sufficient for certain vehicle technologies, e.g. electric vehicles with range extender, because the use of the ICE (Internal Combustion Engine) will not only depend on the driving speed, but also on the trip length. The idea behind the trip length distribution lies in the statistical processing of representative trip lengths of passenger cars in Europe (Adra and André, 2004, Eurostat, 2000, MESUDEMO, 2000, Swiss Federal Statistics Office 2010). Average trip length is a key parameter for the estimation of emissions in vehicles, as it has an influence on the cold start excess as well. For range-dependent vehicles, a statistical distribution describing the probability of a certain trip length was used to approximate the trip length behaviour. Adding the average number of trips per year yields the annual mileage allotment with respect to trip length.

Scenario building can benefit from the in-built advanced vehicle technologies offered by SIBYL in order to create a realistic mix of available passenger cars. Furthermore, this model highlights the impact that a variety of similar technologies can have – as opposed to a higher-tier model

where, e.g. Range-extender electric (REEV), Battery electric (BEV) and Plug-in Hybrid electric vehicles (PHEV) cannot be distinguished.

The calculation of activity per energy source in conjunction with fuel consumption and emission factors can then lead to energy consumption and emission estimation. SIBYL contains emission factors for a variety of modern vehicle technologies, based on extensive powertrain software modelling and simulations of real-world driving cycles (Andre 2004) as well as actual vehicle data. Real – life vehicle characteristics were used for the development of the vehicle models and the advertised performance and fuel consumption specifications served as feedback to calibrate the results.

Scenario formulation

The scenario simulation starts at 2013 and the time range of interest reaches 2020. All alternative scenarios assume that gasoline is blended with 7% bioethanol and diesel contains 7% biodiesel. Additionally, a 1.5% cumulative efficiency increase is considered for all technologies. This is a rough assumption, but it should reflect an effort to meet the CO_2 standards in the future. Specific scenario assumptions are illustrated in the table below (Table 1).

Table 1: Scenario and new vehicle registrations changes with respect to the basecase.

Vehicle Categories/ Scenarios	Downsizing & Alternative		Hybridisation		Electrification	
Years	2013	2020	2013	2020	2013	2020
Small Gasoline	+2%	+19%	-	-	+1%	8%
Medium Gasoline	-10%	-80%	-10%	-80%	-10%	-80%
Large Gasoline	-10%	-100%	-10%	-100%	-10%	-100%
Large Diesel	-10%	-100%	-10%	-100%	-10%	-100%
Small Diesel	+2.5%	+28%	-10%	-50%	+2.5%	+28%

Scenario 1 (Downsizing and Alternative) considers a strong trend towards smaller passenger cars; i.e. smaller vehicles increase at the expense of larger vehicles. Modifications imply a one-size step (for instance, large cars move towards medium cars). In addition to downsizing, alternative fuels such as biofuels, compressed natural gas (CNG) and liquefied petroleum gas (LPG) also increase in consumption, while conventional fuel consumption decreases i.e. bi-fuel vehicles (petrol and LPG/CNG) and flex-fuel vehicles (FFVs) substitute conventional petrol/diesel vehicles. FFVs are assumed to use 50% E85 and 50% gasoline in terms of mileage, while bi-fuelled cars opt for the alternative fuel for shorter distances and gasoline for the longer trips.

Scenario 2 (Hybridisation) considers an increased penetration of hybrid electric vehicles (full, mild, plug-in and luxury hybrid vehicles) at the expense of gasoline cars, with respect to the vehicle size. It also incorporates a small downsizing assumption (large diesel to small diesel cars) and a conversion of the latter ones to hybrid diesel vehicles. Furthermore, a small fraction of battery electric vehicles (BEVs) and range-extender electric vehicles (REEVs) are added to the mix.

According to Scenario 3 (Electrification), the previous downsizing trend has a lower effect; medium gasoline cars are partially substituted by small gasoline, battery electric and range extender cars, while large diesel are converted to small diesel cars. A strong shift towards current electricity technologies is promoted, though hybrids remain unchanged.

All three scenarios suppose rapid changes in fleet development and are expected to provide significant reductions of CO_2 emissions from passenger cars. Also, it must be noted below that a fraction of this CO_2 can be attributed to electricity production and biofuels.

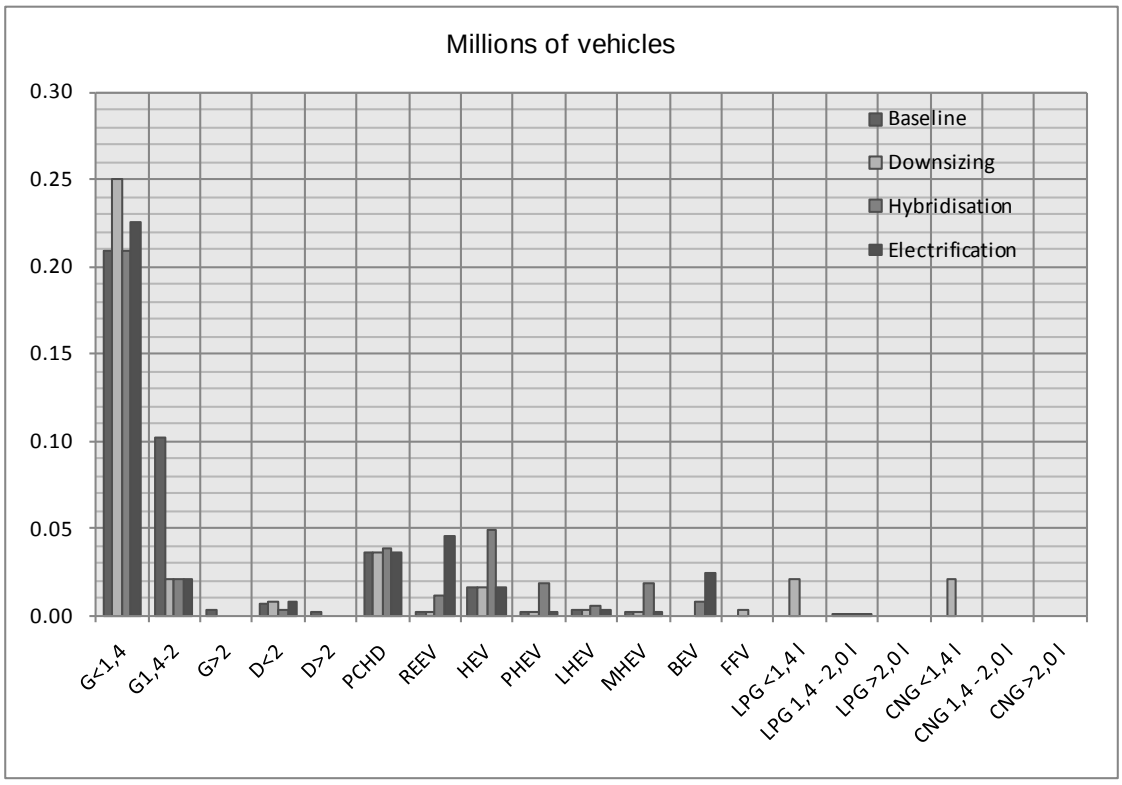

Figure 2: Vehicle new registrations in 2020

Results

The aforementioned scenarios were utilized as input using the step-by-step scenario formulation in SIBYL. The timeline covers the years from 2013 to 2020. Default (basecase) assumptions were made for every other option in SIBYL (e.g. survival rates). Figure 2 shows the new registrations for year 2020 for all four scenarios.

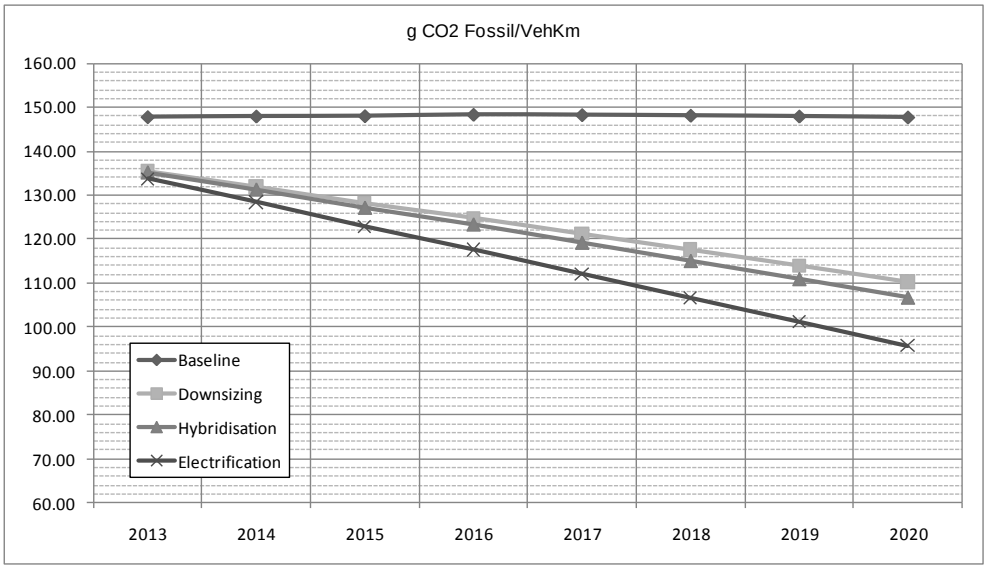

Figure 3: Tailpipe fossil CO_2 per veh-km for new registrations

In Figure 3, the tailpipe CO_2 due to fossil fuels (biofuels excluded) can be observed. It is obvious that although all three scenarios boast an aggressive substitution of conventional cars towards better CO_2 performing technologies and an optimistic efficiency assumption, only the rapid introduction of electric vehicles (BEVs and REEVs mainly) can reach the goal of 95gCO_2/km (Regulation 2009/443/EC, 2009) for new registrations by 2020. The other two scenarios can offer significant decrease of CO_2 emissions reaching below 110g/km by 2020, but more drastic measures need to be taken. Hybridisation is an appealing and plausible trend, but it is marginally better than the rapid downsizing approach.

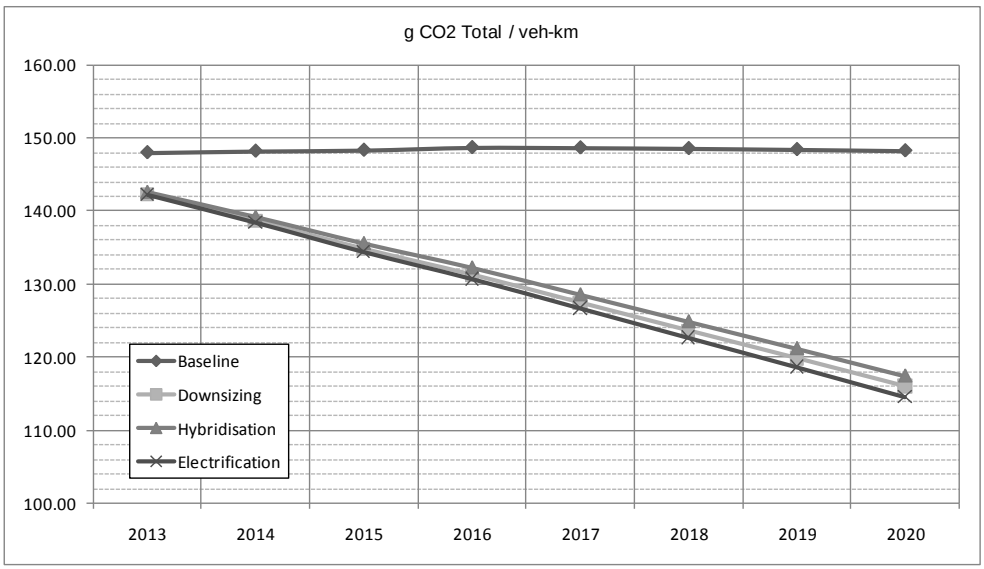

Figure 4: Total gCO2 per veh-km for new registrations

However, the advantage of the electrification scenario greatly diminishes if upstream CO_2 is taken into account (Figure 4), in addition to CO_2 from biofuels. In this illustration the downsizing and alternative scenario seems to perform better than the hybridisation scenario even if CO2 from biofuels is also calculated; it appears that the additional upstream CO_2 from the slight increase of BEVs and REEVs is quite significant. All scenarios achieve more than a 30g/km decrease in total CO_2.

This calculation was based on an average EU-27 carbon intensity assumption of 400gCO_2/KWh for electricity production (EEA, 2011). It is clear that road transport cannot move towards electrification without a similar eco-friendly campaign in energy production.

Finally, Table 2 presents the total CO_2 for each scenario distributed into fossil, upstream and biofuel CO_2.

Table 2: CO_2 total emissions in kT from new vehicles in 2020.

Source/Scenario	Baseline	Downsizing & Alternative	Hybridisation	Electrification
Fossil	283.97	223.30	203.50	184.19
Upstream	0.99	0.87	10.32	26.99
Biofuels	0.00	10.80	10.06	9.21

Conclusions

In this work, a software approach for the estimation of CO_2 was presented and scenarios were developed and evaluated for Greece, focusing on road transport and passenger cars, The evaluation illustrates a quantified comparison which concludes that, although electrification could aid towards decarbonisation goals in road transport, it should be matched by a carbon intensity reduction effort in the energy production. A shift to hybrid vehicles and/or a downsizing campaign in conjunction with complementary fuels such as LPG and CNG and possibly high-blend biofuels could also prove beneficial, though it will probably fail to reach CO_2 abatement goals. As a conclusion, the substitution of conventional fuels by a combination of all the above sources could eventually be a more down-to-earth approach. Moreover, further research can include a study on possible technology efficiency development and carbon intensity estimations. All in all, SIBYL can provide an easily customisable framework for scenario evaluation which can evolve into a valuable tool for emission projections.

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