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The impact of energy policies in scenarios on GHG emission reduction in passenger car mobility in the EU-15

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ABSTRACT

This paper compares and discusses possible greenhouse gas (GHG) emission reductions due to different policy measures implemented in passenger car transport in the EU-15. The major instruments analyzed are fuel and registration taxes, support measures for biofuels as well as standards for specific CO_2 emissions from new passenger cars.

The methodology applied is based on scenarios for the dynamic development of GHG emissions and energy consumption depending on implemented policies. Using the ALTER-MOTIVE model, created in the scope of an EU-funded project, in a dynamic framework a Business as usual and a Policy scenario are compared to extract the impacts of policies up to 2030.

The major result is that in total, GHG emissions could be reduced at least by 33% in a selected Policy scenario compared to a Business-as-usual scenario up to 2030. In the future only a broad portfolio of different policy instruments and alternative technologies and fuels can reduce energy consumption and the resulting GHG emissions remarkably.

Contents

1. Introduction

Between 1990 and 2012 in the EU-28 the share of transport on final energy consumption increased from 23% to 32%. Currently, the transport sector is responsible for about 20% of the total greenhouse emissions (GHG) in the EU-28. The largest part of these emissions, about 72%, is caused by road transport [1]. In spite of the fact that a broad portfolio of policies is already implemented in the EU, emissions from the transport sector have been, in contrary to other sectors, continuously increasing from 1990 to 2007 as shown in Fig. 1.

To implement efficient policy portfolio which can contribute to the reduction of GHG emissions, it is necessary to understand how different policies work and to identify the possible interactions between them [3]. However, policy measures implemented in the transport sector have been developed in different ways in different EU-countries. Some of the measures (e.g. CO_2 emission standards for cars) are set at the EU level, and some (e.g. various taxes) are implemented on national level driven by different goals (e.g. to reflect environmental impacts, to increase government revenues, to reflect road damage costs, to promote alternative fuels and vehicles, etc.) [4].

In literature a wide range of policies and strategies for the reduction of GHG emissions from road transport is investigated [5–10]. Most common strategies are promotion of alternative fuels [11,12] and alternative automotive technologies [13,14] as well as implementation of standards and various types of taxes [15,16].

Since passenger cars account for approximately 72% of total passenger transport activities in the EU-28 by, this paper focuses on policies that impact passenger car transport [1]. In detail, this paper

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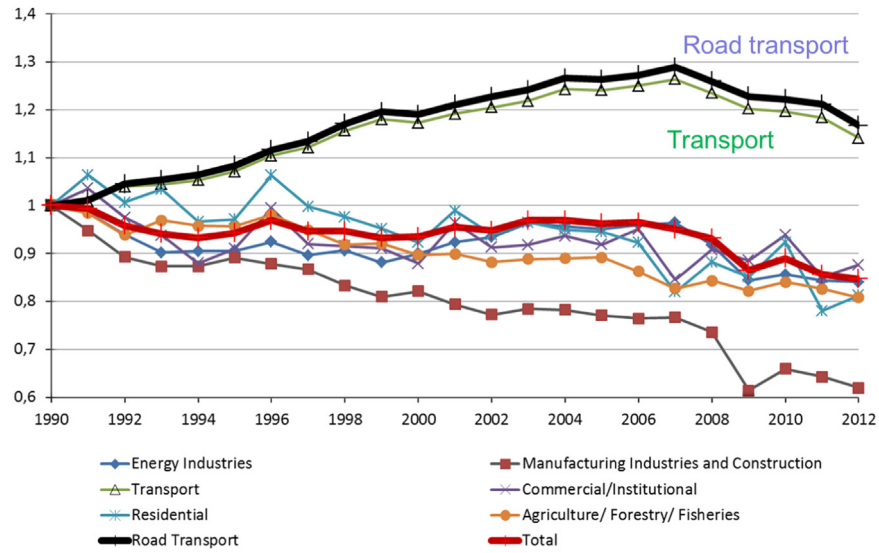

Fig. 1. Development of GHG emissions in EU-28 countries (1990=1) [2].

investigates the effects of different policy measures in the long-term and their contribution to the reduction of GHG emission in the EU-15.[1] Major policies implemented at the national level (such as taxes, support for biofuels, etc.) as well as at EU level (such as standards for the CO_2 emissions from the new passenger cars) are considered. This paper provides an update of the scenarios derived within the project ALTER-MOTIV funded by European Commission, see [17]. A partial equilibrium model which is created in the scope of this project is used in this paper to derive long-term scenarios showing the impact of different policy strategies.

The paper is organized as follows: Section 2 describes policies currently implemented and EU energy and transport targets. Next, the methodology is described in Section 3. Section 4 presents the results of two scenarios derived, a Business-as-usual and Policy scenario. Finally, the main conclusions of this work can be found in Section 5.

2. Review: policies and targets in the EU

The major challenges for EU climate and energy policies are to implement effective policies and measures to mitigate global warming, to improve air quality and to reduce fossil energy consumption. Since transport contributes by about one-quarter of the EU's total GHG emissions, a large part of EU policies and targets is directed towards road transport. A wide range of EU policies to lower emissions from passenger car transport is already in place, such as emissions targets for new cars, targets to reduce the greenhouse gas intensity of fuels, labeling requirements, etc.

To be able to implement successful policies, it is important to know how CO_2 emissions in passenger car transport come about and how they can be reduced. They depend in principle on the total amount of energy used for transport and the specific CO_2 emissions coefficient of different fuels used. This coefficient can be improved for example with better quality of fossil fuels, better ecological performance of biofuels or increasing use of electricity from renewable energy sources for mobility.

Total energy consumption can be reduced with better fuel efficiency of cars, lower travel activity, smaller cars (less kW) as well as with better individual driving behavior [5–7,18]. To reach this a broad range of policy instruments can be used to (i) increase fuel efficiency of cars (e.g. standards, registration taxes), (ii) support "eco-driving" (e.g. education), (iii) reduce number of km driven (e.g. by increasing fuel taxes), and (iv) support the use of alternative and more environmentally friendly fuels (with e.g. subsidies and quotas).

However, different policies can have multiple and even contradicting impacts. For example, the total number of vehicle kilometers driven can be reduced by increasing fuel taxes, and it can be increased by fuel efficiency improvements due to the rebound effect [3].

In the EU some policies are set at a national level such as various taxes (e.g. fuel-, registration-, ownership taxes), and they vary across EU countries. Moreover, there are also common measures implemented on the EU level such as limits on emissions from new cars (Regulation on CO_2 from cars 2009/443/EC [19]) and support to biofuels (Biofuels directive 2003/30/EC [20]).

The earliest agreements with car manufactures regarding the limits on emissions from new cars were based on voluntary agreements. In 1998, the European Automobile Manufacturers' Association (ACEA) adopted a commitment to reduce average emissions from new cars sold to 140 g CO_2/km by 2008 and, in 1999, the Japanese Automobile Manufacturers' Association (JAMA) and the Korean Automobile Manufacturers' Association (KAMA) adopted a commitment to reduce average emissions from new cars sold to 140 g CO_2/km by 2009 [21].

Since these targets were not met on time the first mandatory CO_2 emission standards for cars were adopted in the EU [22]. According to the Regulation (EC) No. 443/2009 [21] average CO_2 emissions from new cars should not exceed 130 g CO_2/km by 2015 and should drop further to 95 g CO_2/km by 2020 [23]. Currently, no specific targets after 2020 are defined.

However, as discussed in Ajanovic et al. [3], to make measurements between manufacturers comparable, the specific CO_2 emissions of a vehicle type are determined using an approval test cycle (i.e. the New European Driving Cycle (NEDC)) under laboratory conditions. The problem is that NEDC cycles represent an artificial driving speed pattern with low accelerations, constant speed cruises and many idling events. As a result, the measured emission levels can be different from those in real-world conditions [24].

In addition, it was found that the German automaker Volkswagen Group had intentionally programmed turbocharged direct injection diesel engines to activate certain emissions controls only during laboratory emissions testing. The programming caused the

[1] The EU-15 comprises the following 15 countries: Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain, Sweden, and United Kingdom.

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vehicles' nitrogen oxide (NO_x) output to meet US standards during regulatory testing, but emit up to 40 times more NO_x in real-world driving [25]. Volkswagen put this programming in about eleven million cars worldwide, and in 500,000 in the United States, during model years 2009 through 2015 [26,27].

The current data show that the average emissions level of a new car sold in 2014 was 123.4 g of carbon dioxide (CO_2) per kilometer, significantly below the 2015 target of 130 g. However, following a statement by the Volkswagen Group that CO_2 emission values for some of their models are incorrectly stated, the EU fleet average emissions cited above may be too low [28].

Regarding the use of alternative fuels, especially biofuels, there are common EU targets. Cansino et al. [29] has provided a review of the public measures undertaken in the EU-27 for the promotion of biofuel consumption in the transport sector.

Biofuels, as currently most important alternative fuels, have been widely discussed regarding the impacts of their expansion [30], their environmental impacts and sustainability [31], their impacts on biodiversity and land use [32,33], as well as their competition with food production [34,35].

Since the discussion on the promotion of biofuels has become very ambiguous – on the one hand benefits like the reduction of greenhouse gas emissions and the increase in energy supply reliability were expected, on the other hand low effectiveness with respect to reducing greenhouse gas emissions and high costs have been criticized – in Ajanovic [36] sound investigations on the market prospects of biofuels within a dynamic framework until 2030, considering the most important impact factors such as feedstock costs, investment costs, fixed and variable operation and maintenance costs, distribution and retail costs, as well as policies implemented (e.g. subsidies, taxation or tax exemption on alternative fuels) is conducted.

The first experiences with biofuel production and use have provided more accurate information on the impacts of biofuel targets. The precise requirement of 5.75% of all transportations fuels to be replaced by biofuels by 2010 (Biofuels directive 2003/30/EC) is replaced in the scope of the 2020 climate and energy package (20-20-20) [37] with the target of 10% share of renewable energy in the transport sector. According to the current developments, it can be expected that the largest part of this amount will be covered by biofuels but this document provides also support for use of other alternatives such as electricity from renewable energy sources.

The new 2030 Energy Strategy goals for climate and energy (40-27-27) [38] do not include specific targets for emission reductions in the transport sector as well as regarding future biofuels policy. But to some extent three major targets of the 40-27-27 agreement to reduce GHG emissions, to improve energy efficiency, and to increase the share of renewable energy indirectly support also more sustainability in transport sector.

However, without clear targets and action plans it will be very difficult to reach goals set in 2011 in the White Paper on Transport [39]. One important goal of the White Paper is to halve the use of conventional cars in urban areas by 2030, and to ban conventional cars completely from urban areas by 2050, see Fig. 2. The problem is that progress in the development and market penetration of alternative automotive technologies is rather slow [40]. In addition, it is important to stress, that electric vehicles and fuel cell vehicles will lead to significant reduction of GHG emissions only if they are powered by electricity and hydrogen produced from renewable energy sources [41].

3. Methodology

There is a wide range of recent publications related to the modeling of the developments in the transport sector showing a broad portfolio of scenarios. Scenario design and results are very dependent on the motivations and study scope, modeling frameworks, assumptions, data used and complexity of the work [42]. The analytical tools used for scenarios analysis vary significantly in technical complexity from relatively simple excel spreadsheets models to very large and complex models that require a huge amount of data [43–46]. The geographic scope of scenarios analysis is very broad covering different countries and regions (e.g. Austria [47], Brazil [48], Canada [49], China [50–52], Ireland [53], Japan [54], Thailand [55], the United Kingdom [56], Basque Country [57], the European Union [58], etc.). A comprehensive review of transport modeling techniques is provided by Ajanovic et al. [59].

In our work the effects of different policy measures and their contribution to the reduction of GHG emission in passenger car transport in the EU-15 are investigated. For scenario analysis we have used a partial equilibrium model which is created in the scope of the EU-project ALTER-MOTIVE. The effects of policies are identified by comparing the differences in a Business-as-usual (BAU) and a Policy scenario.

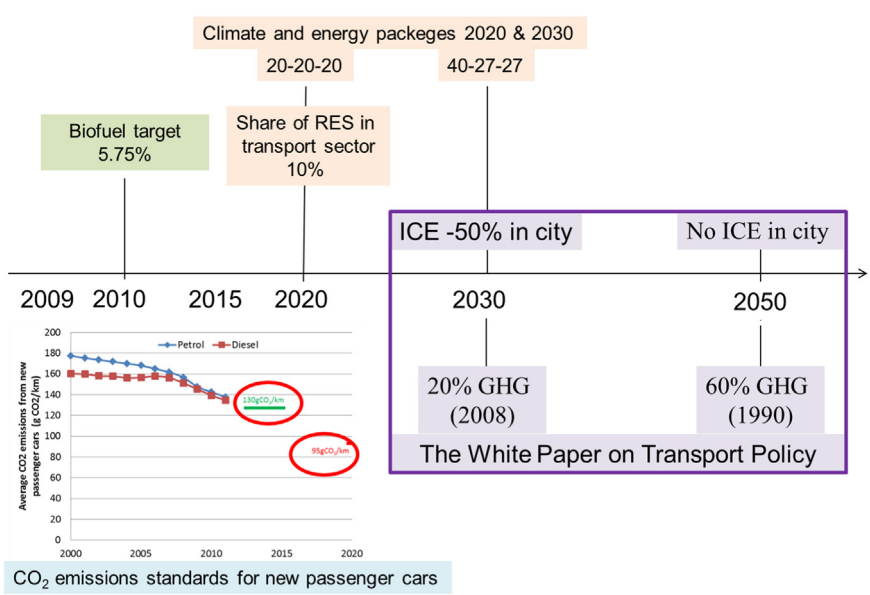

Fig. 2. Development of EU targets regarding reduction of GHG emissions in transport.

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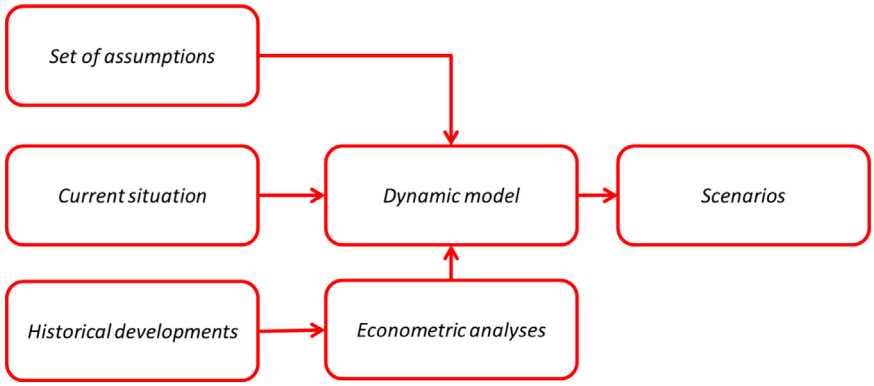

Fig. 3. Development of scenarios.

Starting from historical developments, current situation and major assumptions regarding future developments scenarios are derived using a dynamic partial equlibrium model, see Fig. 3. Moreover, we use econometric analyzes to identify elasticities with respect to prices, income, investment costs and other relevant parameters, see [16].

On the supply-side the analysis builds on modeling service using the following basic technical relationship between energy (E), fuel intensity (FI) and vehicle km driven (vkm):

$$E_t = \sum_{j=1}^{n} vkm_{j_t} \cdot FI_{j_t} \tag{1}$$

with j is type of car.

The CO_2 emissions are calculated using the fuel specific CO_2 factor f_{CO_2}

$$CO_{2_t} = \sum_{j=1}^{n} E_{j_t} \cdot f_{CO_{2_{j_t}}} \tag{2}$$

Our scenario analysis is based on a model that is driven by service (S_t) demand with fuel prices (P_F), GDP (Y), fuel intensities (FI) and investment costs (IC) as major endogenous drivers or slowers:

$$S_t = f(P_{F_t}, Y_t, FI_t, IC_t) \tag{3}$$

The service price (Ps) depends on the fuel price, a possible fuel tax (τ) and the fuel intensity:

$$P_{S_t} = (P_{F_t} + \tau_t) \cdot FI_t \tag{4}$$

The fuel intensity depends on possible technical standards (FI_0) and an autonomous technological trend:

$$FI_t = f(FI_{0_t}, \theta) \tag{5}$$

Using a production function approach we can write:

$$S_t = C \cdot P_{S_t}^{\alpha}\, Y_t^{\beta}\, IC_t^{\gamma} \tag{6}$$

where α, β, γ are the corresponding elasticities.

A dynamic model, based mainly on econometric estimates of service demand (e.g. number of new vehicles by category, vehicle km driven by country and category) from time series data, is used to extract the impact of different types of policies. Based on Eq. (6) this basic approach for any type of service is:

$$S_t = S_{t-1} \cdot (1+\alpha)^{\frac{P_{S_t} - P_{S_{t-1}}}{P_{S_t}}} \cdot (1+\beta)^{\frac{Y_t - Y_{t-1}}{Y_t}} \cdot \left(1+\gamma \frac{IC_t - IC_{t-1}}{IC_t}\right) \cdot \prod_{i=1}^{n} \left(1+\delta_x \frac{X_{i_t} - X_{i_{t-1}}}{X_{i_t}}\right) \tag{7}$$

where X_i are various additional variables covering cross-price and cross-investment costs effects, and δ_x are the corresponding elasticities.

From this basic equation in the case of mobility vehicle km driven (vkm) can be calculated as:

$$vkm_{j_t} = vkm_{j_{t-1}} \left(1+\alpha \frac{P_{S_{j_t}} - P_{S_{j_{t-1}}}}{P_{S_{j_t}}}\right) \cdot \left(1+\beta \frac{Y_t - Y_{t-1}}{Y_t}\right) \tag{8}$$

with j is type of car.[2]

The car fleet (V_{stock}) is modeled as:

$$V_{stock_{j_t}} = V_{stock_{j_{t-1}}} + V_{new_{j_t}} \tag{9}$$

New car registration (V_{new}) is calculated as:

$$V_{new\ j_t} = V_{new\ j_{t-1}} \left(1+\alpha \frac{P_{S_{j_t}} - P_{S_{j_{t-1}}}}{P_{S_{j_t}}}\right) \cdot \left(1+\beta \frac{Y_t - Y_{t-1}}{Y_t}\right) \cdot \left(1+\gamma \frac{IC_{j_t} - IC_{j_{t-1}}}{IC_{j_t}}\right) \tag{10}$$

Of specific interest in this equation are the investment costs. They are calculated depending on the net investment costs and the registration taxes (τ_{reg_jt}) and possible subsidies (σ_{jt}) as

$$IC_{j_t} = IC_{j_{t\_net}} + \tau_{reg\_j_t} - \sigma_{j_t} \tag{11}$$

To model the dynamic effects of changes (reduction) in specific investment costs over time, the technological learning approach is applied for deriving scenarios. Eq. (12) is used to express an experience curve by using an exponential regression depending on specific investment cost $IC_j(x)$, total number of produced units (x), the learning index (b) and the investment cost of the first unit (a):

$$IC_j(x) = a \cdot x^{-b} \tag{12}$$

The exponential regression is based on identified historical learning rates which in turn are based on time series analyzes of historical data. This approach has been used since the 1980s and is documented, e.g. in McDonald/Schrattenholzer [60]. We have adapted this approach by using different learning rates depending on the maturity of technological components.

Specific investment costs we have split up into a part that reflect the costs of conventional mature technology components $IC_{Con}(x)$ – "naked car"-and a part that reflects the costs of the new technology components $IC_{New}(x)$ such as fuel cells.

$$IC_j(x) = IC_{j_{Con}}(x) + IC_{j_{New}}(x) \tag{13}$$

For conventional mature technology components no more learning is expected. Actually, also these cars theoretically could become slightly cheaper in the future. However, increasing size of cars and improvements in the service quality with additional accessories (e.g. air-conditioner, heated seat, audio devices, GPS

[2] For every type of car there is one specific fuel.

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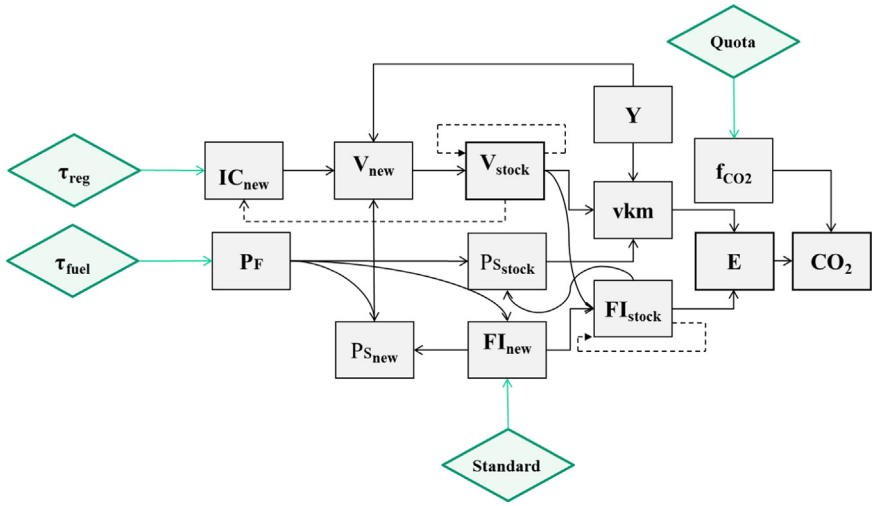

Fig. 4. Relationships between major variables for modeling energy consumption (*E*), vehicle stock (*V*), and CO_2 emissions in passenger car transport (time indices are neglected for simplicity) [17].

Table 1
Major assumptions in the scenarios.

Assumptions	BAU scenario	Policy scenario
Increase of:		
GDP	+2.5%/yr	+2.5%/yr
Gasoline price	+3.0%/yr	+3.0%/yr
Diesel price	+3.0%/yr	+3.0%/yr
CNG price	+3.0%/yr	+3.0%/yr
Electricity price	+3.0%/yr	+3.0%/yr
Fuel tax	0	0.5 cent/kg CO_2/yr (starting from 2016)
Registration tax	All 2%/yr	Small cars: 2%/yr Medium cars:4%/yr Large cars: 8%/yr
Biofuels	4%/yr	8%/yr
Reduction of:		
Specific CO_2 emissions of biofuels	−0.5%/yr	−0.5%/yr
Specific emissions of new cars in 2030	88 g CO_2/km	65 g CO_2/km
Fuel intensity reduction of new cars up to 2030	−2.3%/yr	−3.8%/yr

navigation) will virtually eat up the investment cost savings which will incur for the "naked" car due to learning.

Fig. 4 depicts the relationships between the major variables. The main inputs to the model are assumptions for example regarding income (Y), fuel price (P_F), investment costs and development of fuel intensity (*FI*) as well as portfolio of selected policies such as fuel taxes (τ_{fuel}), registration taxes (τ_{reg}), CO_2 emission standards, and biofuel targets/quotas. CO_2 emission standards lead to the assumptions for fuel intensity of new vehicles.

Based on the model described above two scenarios for future developments in passenger car transport in the EU-15 are examined:

– BAU scenario: It is assumed that the global dynamics of changes continue without considerable surprises and that energy supply and consumption patterns remain in line with the trends which are already in place.
– Policy scenario: A Policy scenario describes possible future developments in the case that a selected set of policy measures is applied in a definite time-frame.

These scenarios are modeled to demonstrate the impact of different policies on energy consumption in passenger car transport as well as development of the resulting CO_2 emissions until 2030. The focus of the analysis in these scenarios is on the EU-15. This focus is due to the fact that reliable data for time series on energy consumption of passenger cars are only available for this subset of countries and not for all EU countries.

Based on historical data up to 2012 (e.g. GDP, prices, new registrations and CO_2 emissions of new registered cars), existing knowledge about current situation, as well as major assumptions regarding (price, income, cost and technological developments) scenarios are modeled up to 2030.

The major assumptions in the scenarios are presented in Table 1. They are based on the corresponding figures reported by International Energy Agency [61–63].

The BAU scenario assumes that policy measures that have already been implemented continue to be used in the future with the same dynamic. Implementation of additional policies is not foreseen. All current developments – positive as well as negative – will be continued with the existing dynamics and trends. In this scenario it is assumed that prices of fossil fuels, feedstocks for biofuels and wood products will be increasing by 3%, 2% and 1% per year respectively.

The Policy scenario on the other hand assumes that the set of different policies described below will be implemented simultaneously. The portfolio of policies implemented in the Policy scenario includes the following:

- **Fuel tax:** It is assumed that currently used excise tax on fossil fuels is converted in a CO_2 based fuel tax which is then applied on all fuel (also alternative fuels) according to their CO_2 balances starting from 2016. The basis for the calculation of this tax is gasoline. This fuel tax increases by 0.5 cent/kg CO_2 per year. For the other fuels the tax as well as tax increases are calculated relative to their CO_2 emissions compared to gasoline.
- **Registration taxes:** Here, a differentiated scheme of registration taxes is implemented depending on the size (engine capacity) of cars. For small cars (up to 60 kW) tax increases by 2% per year; for medium-size cars (60–100 kW) the increase is 4% per year and for cars with engine capacities that exceed 100 kW the increase is 8% per year.
- **Standards:** an improvement in technical efficiency of 3.8% per year is assumed. This is projected to lead to CO_2 emission standards of 65 g CO_2/km by 2030.
- **Biofuels:** The amount of biofuels increases in the Policy scenario (a quota-based style) by 8% per year compared to 4% in the BAU-scenario. Moreover, the specific CO_2 emissions of biofuels

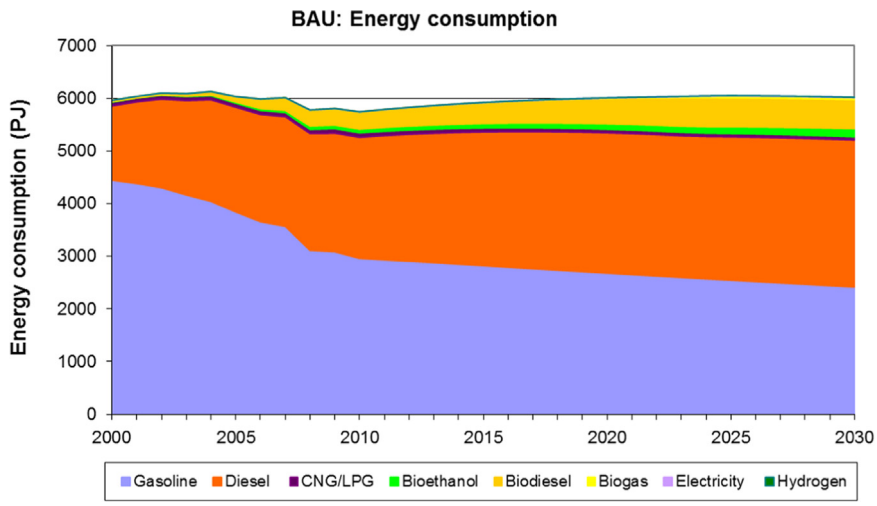

Fig. 5. Energy consumption in the BAU scenario for EU-15 countries.

Table 2
Results of different scenarios.

Results	BAU	Policy scenario
Stock of rechargeable electric vehicles 2030	1.39 Mill	1.58 Mill
Biofuels in 2030	742 PJ	916 PJ
CO_2 emissions in year 2012	486 Mill. tons CO_2	486 Mill. tons CO_2
CO_2 emissions in year 2030	487 Mill. tons CO_2	325 Mill. tons CO_2
CO_2 changes in 2030 compared to 2012	+0.2%	−33.0%
CO_2 changes in Policy scenario compared to BAU	–	−32.8%
Energy consumption in year 2012	5830 PJ	5830 PJ
Energy consumption in 2030	6020 PJ	4504 PJ
Energy consumption changes in 2030 compared to 2012	+3.3%	−22.7%
Energy consumption changes in Policy scenario compared to BAU	–	−25.3%

decrease by 5% per year in the Policy scenario compared to a decrease of 0.5% in the BAU-scenario.

4. Results

Figs. 5–10 highlight the effects of policy measures on energy consumption, resulting CO_2 emissions and the vehicle stock in the BAU-scenario in comparison to the Policy scenario up to 2030 for the EU-15. The specific results are documented in Table 2.

Due to standards for CO_2 emissions of new passenger cars as well as high fuel taxes that have already been implemented in the EU, energy consumption remains fairly stable under the BAU-scenario and in 2030 it is about 3% higher than in 2012, see Fig. 5.

The introduction of a CO_2 based tax in 2016 and tightening of existing policies (see Table 1) results in a reduction in energy consumption (approximately 23%) of passenger cars in the Policy scenario, see Fig. 6. Biofuels are currently as well as up to 2030 the major alternative fuel. In 2030 in the BAU-scenario consumption of biofuels is 12%, and in the Policy scenario 20%.

The resulting CO_2 emissions in the BAU scenario are shown in Fig. 7. From this figure it is clear that under currently implemented policies, the projected reduction of CO_2 emissions according to EU targets will not be realised. The current policy framework just prevents further increase of emissions.

Fig. 8 shows the development of CO_2 emissions in the Policy scenario. Although the set of policy measures selected under this scenario are on the conservative side, they can slow the increase in the vehicle fleet and contribute to the reduction of emissions. CO_2 emissions in the BAU-scenario remain stable up to 2030 (see Fig.7), and decrease in the Policy scenario by 33% up to 2030 compared to 2012, see Fig. 8.

The vehicle stock increases very moderate in the BAU-scenario, and slightly decreases in the Policy scenario. In 2030 the difference in total vehicles stock is about 16 millions, see Fig. 9.

The number of plug-in electric vehicles in the BAU scenario accounts for 1.39 million in 2030. Due to selected policy mix in the Policy scenario total number rechargeable electric vehicles is for about 190,000 higher, see Fig. 10.

5. Conclusions

The most important conclusions of this paper with respect to policy implications are as follows:

- A CO_2 emission standard is a central cornerstone in reducing fuel consumption and CO_2 emitted per kilometer driven. However, improving energy efficiency alone does not necessarily lead to an energy and CO_2 saving effect. Over the last decade an increase in the size of the cars purchased by Europeans has been observed. This has had the effect of reducing their potential saving effects due to efficiency improvements. In addition the vehicle km driven have increased to some extent due to lower service prices caused by lower fuel intensity.
- Moreover, there is a link between standards for CO_2 emissions and fuel taxes via the service price elasticity (for more in-depth analysis see [3,16]). Thereby the introduction of standards should be accompanied by the implementation of a CO_2-based fuel tax. The optimal mix is given by the magnitude of the service price elasticity. This would be a major measure to cope with the above-mentioned rebound effect.
- Biofuels will remain the most important alternative for fossil fuels until 2030 in both scenarios. However, there are a few major problems linked with the increasing use of biofuel: (i) a lack of acceptance due to the food-fuel competition; (ii) still moderate CO_2 emission reduction, and (iii) low progress regarding switch to advanced second generation biofuels.
- With respect to alternative powertrains the potentials for market penetration and CO_2 reduction of battery electric

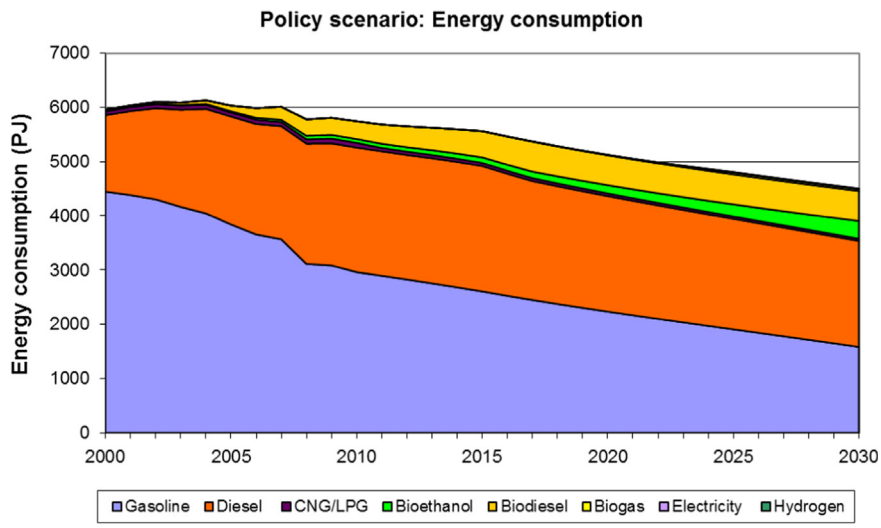

Fig. 6. Energy consumption in the Policy scenario for EU-15 countries.

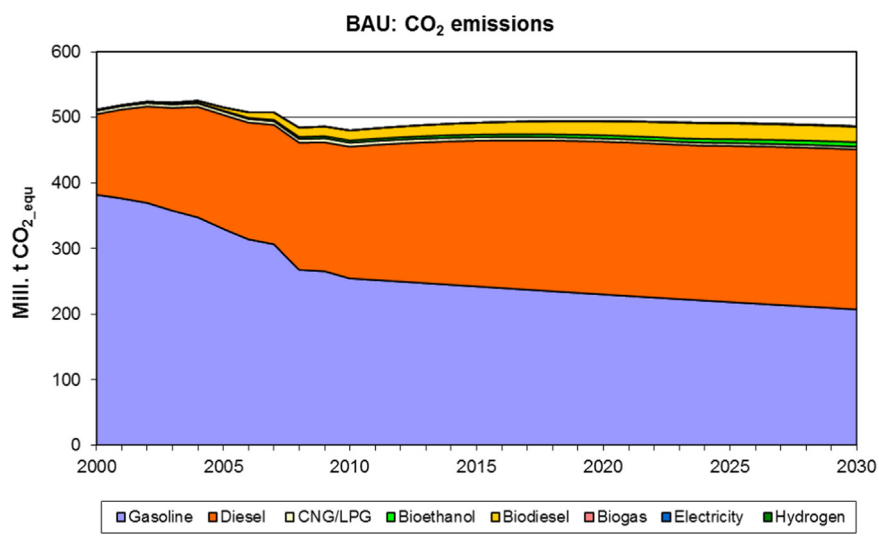

Fig. 7. BAU scenario – CO_2 emissions.

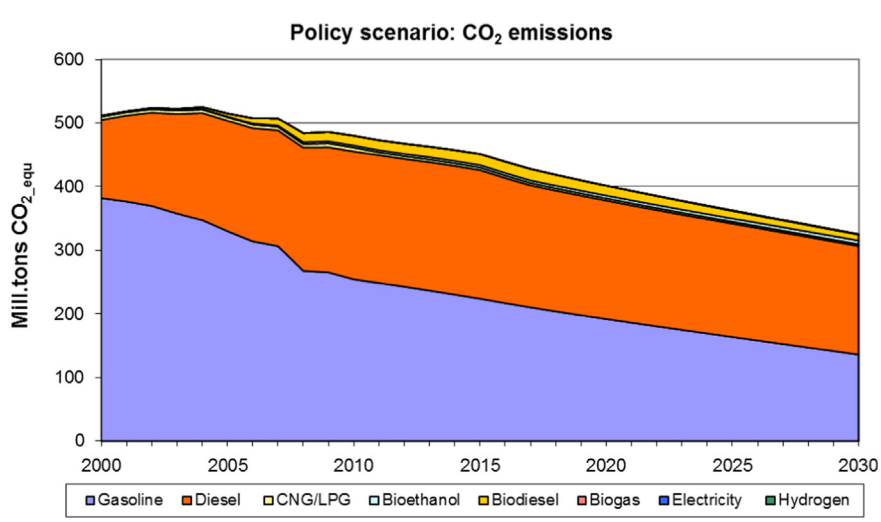

Fig. 8. Policy scenario – CO_2 emissions.

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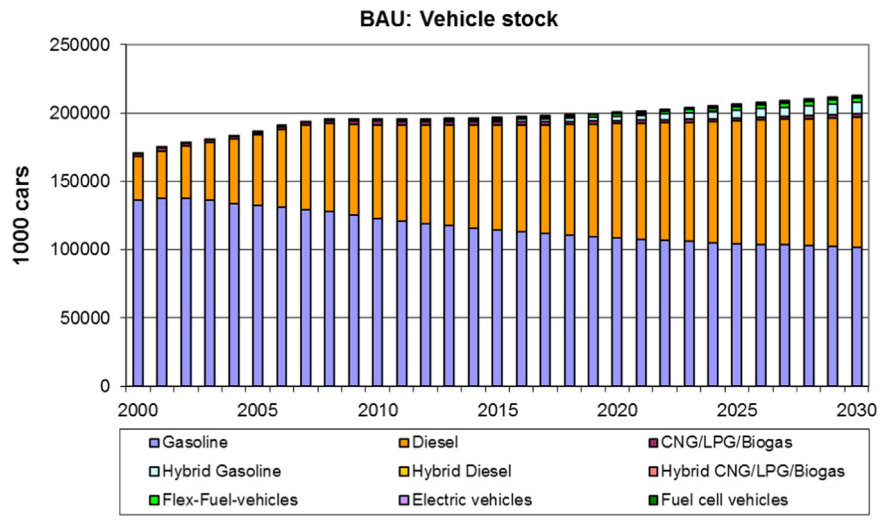

Fig. 9. BAU scenario – vehicle stock.

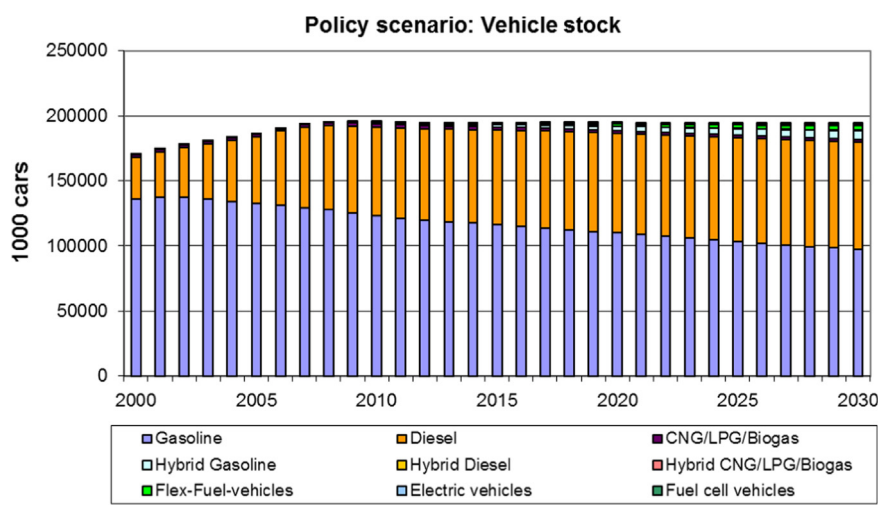

Fig. 10. Policy scenario – vehicle stock.

vehicles and fuel cell vehicles up to 2030 are very limited. If they may reach, in the Policy scenario, about 1% market share (of car stock) by 2030 they will only contribute at the maximum in the same range to CO_2 reduction.

- Since there is no single measure or technology that could solve all problems in passengers car transport, a broad portfolio of policy instruments (such as taxes, standards, quotas) as well as new technologies and fuels (such as battery electric vehicles, fuel cell vehicles, biofuels) is needed to reduce energy consumption and the resulting GHG emissions remarkably.

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