



On a pathway to
Decarbonization

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Urban Pathways

A comparison of new
passenger car CO₂ emission
standards and taxation
measures in the
G20 countries





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Abstract

Considering the role of transport for a 1.5 Degree stabilization pathway and the importance of light-duty vehicle fuel efficiency within that, it is important to understand the key elements of a policy package to shape the energy efficiency of the vehicle fleet. This paper presents an analysis focusing on three types of policy measures: (1) CO₂ emission standards for new vehicles, (2) vehicle taxation directly and indirectly based on CO₂ emission levels, and (3) fuel taxation. The paper compares the policies in the G20 economies and estimates the financial impact of those policies using the example of a Ford Focus vehicle model. This analysis is a contribution to the assessment of the role of the transport sector in global decarbonisation efforts. The findings of this paper show that only an integrated approach of regulatory and fiscal policy measures can yield substantial efficiency gains in the vehicle fleet and can curb vehicle kilometres travelled by individual motorised transport. Using the illustrative example of one vehicle model, the case study analysis shows that isolated measures, e.g. fuel efficiency regulation without corresponding fuel and vehicle taxes only have minor CO₂ emission reduction effects and that policy measures need to be combined in order to achieve substantial emission reduction gains over time. The analysis shows that the highest level of impact is achieved by a combination regulatory and fiscal policies rather than only one policy even if this policy is more aggressive. When estimating the quantitative effect of fuel efficiency standards, vehicle and fuel tax, the analysis shows that substantial gains with regard to CO₂ emission are only achieved at a financial impact level above 500 Euros over a four year period.

1. Introduction

The transport sector is a major contributor to global anthropogenic greenhouse gas (GHG) emissions, accounting for about 23% of the total energy-related CO₂ emissions (Sims et al., 2014; Miller and Façanha, 2014). Road transport accounts for about 74% of total transport emissions, and within road transport – on a global average – about 54% of CO₂ emissions are caused by light-duty vehicles (mostly passenger cars) and 46% by heavy-duty vehicles (mostly trucks).

An integrated approach that avoids unnecessary travel through compact and polycentric urban design, shifts trips to low-carbon modes, and improves the efficiency of the vehicle fleet is vital to move toward a low-carbon development pathway and generate wider sustainable development benefits (Figuerola et al., 2014). This paper focuses on the last part of this strategy and some key policy measures to boost fuel efficiency and initiate a full de-carbonization of the road transport vehicle fleet by 2050 (Miller and Façanha, 2014; Kromer et al., 2010; GFEI, 2014).

There is a potential of GHG emission reductions in the transport sector of 40%–50% based on existing technologies (Sims et al., 2014; GFEI, 2014). Yet there are a number of barriers to fully utilize this potential that require policy action to regulate the efficiency of the vehicles, steer consumers toward more efficient vehicles, and encourage more efficient use of vehicles.

This paper focuses on national policy measures, but it is acknowledged that local policy measures, in particular compact city planning and the provision of low-carbon transport modal alternatives, such as public transport, walking, and cycling, are a vital component of a low-carbon transport strategy.

There are a variety of policy measures that can be applied to reduce CO₂ emissions from land transport. Several studies indicate that the following policies are vital measures to improve the efficiency of the light duty vehicle fleets and manage vehicle use:

(1) mandatory standards for new vehicles that regulate vehicle efficiency and thereby fuel consump

tion and CO₂ emission levels,

(2) taxes imposed upon vehicle purchase and/or vehicle ownership and directly or indirectly linked to the CO₂ emission level of a vehicle, and

(3) taxes imposed upon fuel purchase, thereby being linked to the amount of fuel burned and the CO₂ emissions caused while driving a vehicle.

While these policies are common in many G20 countries, the level of these measures and their combination varies greatly among countries. Previous studies have argued that the combination of these measures is important to minimize rebound effects and achieve actual emission reductions (Sims et al., 2014; Kromer et al., 2010; Lah, 2015, 2017). For a better picture on the feasibility of global transport decarbonisation pathways.

The main barriers that the policies selected for this analysis can help overcome are the split incentives between individual and societal costs and benefits and the rebound effects. The split incentive between individual-cost and economy-wide benefits refers to the fact that vehicle purchases are made by individuals who apply high discount rates, thereby largely neglecting cost savings from fuel efficiency beyond a two- to three-year time frame (Lah, 2015; Eriksson et al., 2010). This, however, takes into account only a fraction of the economy-wide benefits over the roughly 15-year lifetime of the vehicle. Fiscal incentives and disincentives and regulatory frameworks can help bridge this gap between individual and societal costs and benefits.

Even if a consumer has purchased an efficient vehicle, the rebound effects may still undermine some of the efficiency gains. The effect refers to the tendency that improved vehicle efficiency may see some of the efficiency gains taken back by increased travel (Sorrell, 2010; Gillingham et al., 2013). The rebound effect for the transport sector was estimated to be between 10–30% for road transport (Lah, 2015; Fulton et al., 2013).

While previous studies have already provided qualitative comparisons of different CO₂ emission/fuel

economy policies (Sims et al., 2014; He and Bandivadekar, 2015; Mahlia et al., 2013) and analyses of the impact of some policies on vehicle CO₂ emission individually (Mabit, 2014; Klier and Linn, 2013, 2016), this paper aims to answer (1) how the financial impact of fuel efficiency standards, CO₂-related vehicle tax, and fuel tax compare with each other across different markets; (2) whether the financial impact of the policies is related to the real impact of fleet average CO₂ emission level; and (3) which policies allow the reduction of vehicle CO₂ emission more efficiently.

The assessment within this paper is aiming to provide a quantitative comparison of the fiscal impact of the respective mix of policies that are in place in the largest markets, the G20 countries. Furthermore, the results of the quantitative fiscal assessment are compared with the actual new vehicle fleet CO₂ emission levels to see whether and how the fiscal impact level of these policy measures directly influence the emission levels of the fleet. For the assessment, we focus on passenger car policies in the G20 countries, as the fuel economy policies on passenger cars are relatively mature compared with other transportation modes (Miller and Façanha, 2014).

The following section explains the scope of study, methodology applied, and relevant assumptions. Section 3 then summarizes the results of the quantitative assessment of the financial impact of policies in place as well as the comparison between the policies in place and the CO₂ emission levels observed for the respective vehicle fleet. Section 4 provides a discussion of the results observed, and Section 5 draws conclusions and policy recommendations for the future.



2. Scope, methodology and assumptions

2.1. Scope

The paper compiles and compares vehicle CO₂-related policies in the Group of Twenty (G20) countries, which brings together the 19 biggest industrialized and emerging economies and the European Union (EU). Together they account for 90% of global gross domestic product (GDP) and also more than 90% of the 65 million global new passenger car sales.¹ Fig. 1 provides an overview of the G20 member countries and their respective share of the global new passenger car sales market. During the 2014 G20 Summit, a G20 Energy Efficiency Action Plan was adopted, with the aim to increase collaboration on energy efficiency improvement (G20, 2015).

In preparation for the 2015 G20 Summit in Turkey, specific recommendations for increasing the efficiency of road vehicles were developed (Kodjak, 2015). Given the relevance of the G20 markets in terms of vehicle production and vehicle efficiency, the analysis within this paper focuses on the policy measures in place in the G20 countries.

This paper focuses on three policy measures – vehicle CO₂ emission standards, vehicle CO₂-related tax, and fuel tax – that are vital elements for transport climate change mitigation strategies. These measures have great potential to reduce emissions from road transportation (Mahlia et al., 2013; Kodjak et al., 2010), can generate substantial co-benefits (Figueroa et al., 2014; Schultz et al., 2007) and are widely adopted by countries around the world. Although there are studies suggesting that the market reaction to fuel tax (i.e., fuel price) differs significantly by regions and various factors (Klier and Linn, 2013; Griffin and Schulman, 2005; Huntington, 2006), we include fuel tax as part of the analysis to observe its impact on fuel efficiency over the long term. It is estimated that worldwide about 80% of new passenger vehicle sales are currently subject to CO₂ emission standards (Miller and Façanha, 2014). Similarly, the majority of governments around the world impose vehicle and fuel taxes (ACEA, 2014). Some fuel efficiency policies, such as fuel efficiency labeling programs, are widely adopted, but they usually play supplementary roles to other fuel efficiency policies, and their impact on improving fuel efficiency is difficult to separate

at the financial impact of the three measures mentioned above. As these policies change and evolve periodically, this paper focuses on policies by the end of 2013.

2.2. Methodology

The paper defines the financial impact of the policy measures as the cost that consumers can save by purchasing more fuel-efficient cars under each policy, including the amount of fuel saving, the level of vehicle tax, and fuel tax saved as a result of vehicle efficiency improvements. Table 1 defines the financial impact of each policy measure that are quantified in this research. The actual evaluation of financial impact are specified in Section 3. The impact on vehicle price due to the improvement of fuel efficiency is not taken account in this study because the car price is found stable compare to inflation to other items (Comings and Allison, 2017) and the cost increase from efficiency improvement is disputable to attribute to certain policy measure.

As the specific financial impact depends on the actual technical characteristics of individual vehicles, in order to allow for a quantitative comparison of measures in different countries, it was decided to choose a vehicle model that is of relevance for all, or at least most, of the G20 markets. Although the chosen example model cannot represent the exact financial impact of the entire vehicle fleet in all markets, it is a proxy to mimic and compare the level of financial impact of policy measures using the same baseline vehicle. We chose the Ford Focus as the example model as it is one of the top-five-selling passenger cars around the world (Priddle and Woodyard, 2015).

The vehicle was also introduced to the market more than two decades ago, which is long enough to take account of technology development over the long term. The Ford Focus was first introduced to Europe in 1998 and then to the United States in 1999. Its sales ranked sixth among passenger cars in the EU in 2013 (ICCT, 2016), ninth in the United States in 2013 and 2014 (Cain, 2013, 2014), and first in China in 2014 (CAAM, 2014). Moreover, the version of the baseline Ford Focus chosen uses moderate technologies



used to compare the level of strength of the respective policies in the respective country.

Table 2 lists the main technical characteristics of the two Ford Focus models used for calculations within this paper. The 2006 model year vehicle is assumed to be a gasoline version, with a 1.6 liter (L) 74 kilowatt (kW) combustion engine and a manual transmission. The weight of the empty vehicle is 1276 kilogram (kg) and the size of the vehicle in terms of its footprint is 4 square metres (m²). The CO₂ level, measured in the New European Driving Cycle (NEDC) is 161 grams per kilometer (g/km), which corresponds to a fuel consumption of 6.9 L per 100 km (L/100 km). The 2014 model is equipped with a 1.0 L 92 kW turbocharged engine and a manual transmission. The weight and size of the vehicle are slightly higher than those of the 2006 model.

As one of the top three passenger car markets, China did not introduce the Ford Focus model until 2006; thus, we aim to select a 2006 model from the EU and U.S. market. Because the average vehicle characteristics in the EU is closer to other countries compared with the U.S. fleet (ICCT, 2014), the selected baseline

that are well penetrated in most markets. Thus, the Ford Focus is used as an example of a passenger car model that is available in many markets throughout the world and that reflects the general trend of technological improvements.

In order to capture any long-term effects of CO₂-related vehicle policies, for the assessment we choose 2006 as the base-line year – at a point in time when CO₂-based vehicle standards and taxation schemes were not yet widely in place. We then choose a 2014 Ford Focus model to reflect the technology and design evolvement of the same model in recent years. We apply current CO₂ regulation and taxation schemes to the identified models, thereby determining the financial benefit that would come along with reducing the



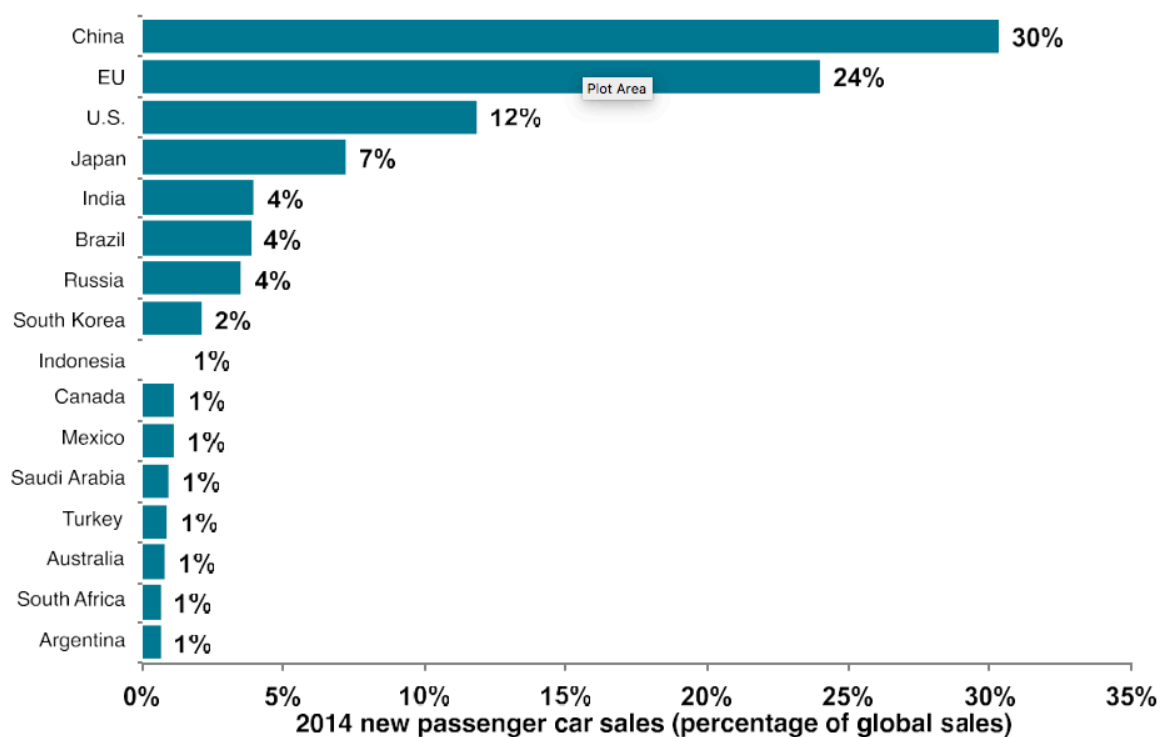


Table 1
Financial impact of CO₂-related policy measures.

Policy measure	Parameter for evaluating financial impact
Fuel efficiency/CO ₂ emission standards	Amount of fuel cost savings by purchasing and driving more efficient vehicles that are available on the market
Vehicle tax directly or indirectly based on CO ₂ emission or fuel efficiency	Amount of tax saving by purchasing more efficient vehicles
Fuel tax	Amount of tax saving by driving more efficient vehicles

Table 2
Technical characteristics of the Ford Focus vehicle used for the analysis.^a

	Ford Focus 2006	Ford Focus 2014
Fuel type	Gasoline	Gasoline
Engine power [kW]	74	92
Engine displacement [L]	1.6	1.0 (turbo)
Transmission type	Manual	Manual
Empty weight vehicle [kg]	1276	1348
Footprint [m ²]	4	4.1
CO ₂ emission [g/km in NEDC]	161	126
Fuel consumption [L/100 km in NEDC]	6.9	5.4
Purchase price (in Germany) excluding taxes [in 2006 euro]	15,190	16,171

^a Data source: based on purchased raw database on new vehicle registration in European countries.

vehicle configuration represents the top-selling gasoline version of the Ford Focus in the EU in 2006, leaving aside high-efficiency optimized vehicle versions.

This is because for a comprehensive global comparison, it is better not to focus on a high-end vehicle version that may only be available in a few markets, but instead on a version that may be less technically advanced while being available for sale in most considered markets. For the 2014 model, we select a version with a turbocharged engine, taking account of the prominent trend of engine downsize and increasing penetration of turbochargers (Henr, 2015). Furthermore, this 2014 configuration is expected to also adequately capture other changes to vehicle technologies and design over time and their impact on vehicle weight and size.

The focus of the analysis is on gasoline vehicles, as gasoline vehicles dominate the global passenger car market. Diesel cars are only of relevance in the EU (with about a 55% market share) and India (about a 40% market share), while other fuel types and electric vehicles still only account for a marginal amount of new vehicle sales (ICCT, 2014). For electric vehicles, a detailed comparison of policy measures around the world was presented in a previous study (Mock and Yang, 2015).

To assess the financial impact of fuel efficiency standards, we firstly assume the 2014 Ford Focus is built to meet 2016 CO2 emission standards, as it usually takes several years to redesign the model and manufacturers need to plan ahead in order to meet future standards. The year 2016 is chosen to reflect the level of CO2 emission a 2014 Focus is built to meet, assuming that a Focus model built in 2014 is designed to meet the 2016 standards two years in advance. The 2016 targets of Focus are calculated according to the respective regulatory guidelines.

For countries for which there is no interim target for 2016, the 2016 target value is estimated, assuming a constant annual improvement rate between the baseline and the closest target year (e.g., in the case of Brazil, going from 2014 to 2017) or between two defined target years (e.g., in the case of Japan, going from 2015 to 2020).

Then the required CO2 emission reductions are translated into a quantitative effect. The main benefit of the improvement of fuel efficiency to consumers is saving fuel cost for the same distance of driving. For this, we calculate the amount of the fuel cost that consumers can save by driving a Focus that meets 2016 standards in comparison with the 2006 Focus model. We only take account of the fuel base price as the impact of fuel tax is covered in the following section.

For a quantitative comparison of the financial impact of taxation measures, the respective tax levels for the 2006 Ford Focus model version are calculated for each of the G20 countries. The tax takes account of all applicable one-time tax and sum of the annual tax of the first four years of ownership. For those taxation measures that are linked to a vehicle’s CO2 emissions only indirectly, a discount factor is assumed.

This is due to the fact that, while there generally is a correlation between a vehicle’s engine size/engine power/weight and its CO2 emissions, it is by no means a perfect correlation. In a previous analysis it was found that the correlation factors between these vehicle characteristics and CO2 emissions are in the range of approximately 0.5–0.6 (Mock, 2015a). For the analysis, for vehicle taxation measures that only indirectly address CO2 emissions, only 50% of the effect are therefore taken into account. For example, if a vehicle tax is based on engine size and amounts to 100 euros, only 50 euros are taken into account for estimating the CO2 emission-reduction effect of the respective vehicle tax.

We then compare the vehicle tax difference between the 2006 Focus model and the 2014 model that meets 2016 CO2 emission standards. It is a combination of the reduction of CO2 emissions, changes in technical parameters (e.g., engine power and displacement), and vehicle price between 2006 and 2014 that explain the impact in terms of taxes for the Focus vehicle model.

For assessing the financial impact of fuel tax, we calculate the fuel tax that a consumer can save by driving a Focus that meets 2016 standards in comparison with the 2006 Focus model. As with the evaluation of the vehicle tax, the level of CO2 emission of the 2014 Focus is assumed to meet the 2016 CO2 emis-

C2 (g CO ₂ /km)	C1 (g CO ₂ /km)	a	d (g CO ₂ /km)
NEDC	CAFE (Corporate Average Fuel Economy)	1.1325	–13.739
NEDC	JC08 (Japanese test cycle)	0.8457	24.840

sion standard level in countries that have standards in place or alternatively is assumed to follow an annual decrease of 0.5% from 2006 to 2016 in countries that do not have standards in place.

To study the relationship between the financial impact of various policies and real fleet average CO₂ emission level, we take into account the difference of test procedures under which the vehicles are tested in each economy. All CO₂ emission values were converted into the NEDC, based on previously derived conversion equations listed below (Kühlwein et al., 2015):

$C2 = \frac{1}{4} a + C1 \cdot b$

C1 CO₂ emissions of the driving cycle being converted, C2 Converted CO₂ emissions of the target driving cycle, a Regression coefficient applied to C1, b Regression intercept.

2.3. Assumption

It is acknowledged that the details of the vehicle model configuration may vary across different countries, depending on the local market demand. However, to allow for a meaningful quantitative comparison, it is assumed that the vehicle configuration from Table 2 is available in all G20 countries included for this analysis. It is furthermore assumed that the base vehicle price (excluding taxes) is the same in all G20 countries. For this study, the vehicle base price for Germany was used as a proxy for all G20 countries. While pricing strategies of vehicle manufacturers differ between countries, from a technical point of view this assumption makes sense, given that vehicle manufacturers operate globally, thereby in principle being able to offer the same vehicle configuration for the same base price in all major car markets.

An annual mileage of 15,000 km is assumed. For the EU, a recent study on behalf of the European Commission found that the annual mileage during the first year of a passenger car's lifetime is about 14,000 km for gasoline and about 26,000 km for diesel cars (Kollamth, 2015). For the United States, the Federal Highway Administration reports that the average annual mileage per driver is around 20,000 km (FHWA, 2015). A sample analysis in China (CATARC, 2014) finds that the average annual mileage of passenger cars in 2013 ranged from 17,500 to 21,500 km in different cities and predicts that the annual mileage will decrease to 16,000 km by 2020. To allow for a comparison of vehicle ownership costs across G20

countries, an average annual mileage of 15,000 km is assumed for new gasoline cars.

It is furthermore important to note that for the analysis we focus on the first four years of the lifetime of a vehicle (i.e., we calculate vehicle purchase and ownership costs over a four-year holding period). This is in line with previous studies, taking into account the fact that consumers generally do not account for the total costs of ownership over the full vehicle's lifetime (Mock and Yang, 2015; Turrentine and Kurani, 2007; Jin et al., 2015). Instead, they strongly discount future costs and savings (Greene et al., 2008). As a result, researchers have developed a rule of thumb, assuming that a four-year holding period, not taking into account any depreciation, provides an accurate representation of a typical customer's view at vehicle purchase (Mock, 2015b).

3. Review and quantification of existing policies

3.1. New vehicle CO₂ emissions standards

Mandatory CO₂ emission standards are a popular measure to ensure that vehicle CO₂ emission levels decrease over time. Contrary to vehicle purchase or ownership taxes that primarily target consumer behaviour and thereby vehicle demand, CO₂ emission standards address vehicle manufacturers and thereby the vehicle supply side, and primarily the level of efficiency technology installed in the vehicle. To date, 13 out of the G20 countries have introduced or proposed passenger car CO₂ standards (Kodjak et al., 2010).

Table 3 provides an overview of the passenger vehicle CO₂ emission standards currently in place in the G20 countries. As can be seen from the table, countries chose different metrics for regulating, including CO₂ or GHG emissions and fuel consumption or fuel economy. The choice for an underlying metric is usually based on specific objectives of the regulations and also on historical preferences. Despite these differences in metrics, all of the standards in place address the same issue, expressed as reducing vehicle CO₂ emissions for the purpose of this paper.

The target years of passenger car CO₂ emission standards currently in place range from 2015 to 2025, often with different phases of regulation for different time periods. Currently, the most forward-looking target year is the U.S. passenger car standard, regulating new vehicle emissions up to the year 2025. However,

preparations for post-2020 standards for the EU and other markets are already under way (Mock, 2013).

Another relevant aspect of vehicle CO₂ standards is the test procedure that is the basis for determining vehicle CO₂ emissions. Here, the EU, China, and India currently make use of the NEDC, and Japan makes use of the JC08 test procedure. The other G20 markets that have passenger car CO₂ standards in place apply the U.S. combined test procedure. For the future, the EU and other markets plan to adopt a new test procedure, the World Harmonized Light-Duty Vehicles Test Procedure (WLTP) Mock et al., 2015.

Finally, vehicle CO₂ emission standards generally take into account the respective fleet structure of a vehicle manufacturer and put the absolute CO₂ emission levels into context by applying an underlying technical parameter. For the EU and some other G20 markets, this underlying parameter currently is the average weight of the vehicle fleet (EC, 2009). As a result, the heavier the fleet of a vehicle manufacturer, the higher the CO₂ emission level that it is allowed to emit. For the United States and some other markets, the underlying parameter is the average size (in terms of length x width) of the vehicle fleet (Environmental Protection Agency, 2017). As has been shown in previous studies, weight-based CO₂ emission standards discourage the application of light-weighting as a measure to reduce CO₂ emissions, and thereby are not technology neutral (Mock, 2015a; German and Lutsey, 2015; Hui and Yang, 2015).

The target year, target value (adjusted for weight or size), and test procedure together decide the comparative stringency of the CO₂ emission standard, as well as the required annual improvement rate. Fig. 2 summarizes the respective 2016 CO₂ emission targets in comparison with its 2006 starting point value. It can be seen that the level of CO₂ emission reduction required by the standards varies across countries. The EU requires as high as a 27% reduction from 2006 to 2016, followed by South Korea (22%) and Japan (20%). If a more long-term time horizon would be applied, the results would come out differently, however. In particular, for the United States and Canada, 2016 CO₂ standard emission targets are comparably lenient, while they become significantly more stringent toward the 2025 time range.

Following the methods to assess the financial impact of fuel efficiency standards, Fig. 3 shows the amount of fuel saving from driving the vehicle that meet fuel

efficiency standards in each market for the first four years of ownership with 15,000 km of driving annually. It can be seen that the resulting fuel cost savings for the EU countries differ, even though the CO₂ reduction target is the same. This is because fuel base prices vary slightly between markets (GIZ, 2013).

3.2. Vehicle taxation

In contrast to CO₂ emission standards, which are mainly targeted toward vehicle manufacturers, vehicle taxation measures have a larger impact on consumer behaviour by influencing vehicle purchase decisions (Haan et al., 2009). Indirectly, however, vehicle taxation can also influence the technical characteristics of the vehicles that a manufacturer is offering, depending on the design of the vehicle taxation.

Table 4 summarizes vehicle taxation measures that are currently in place in the G20 countries. Except for Argentina, Mexico, and Saudi Arabia, all G20 countries have at least one vehicle taxation element in place that is related to vehicle CO₂ emission performance. Vehicle taxation measures can be divided into two categories: (1) one-time taxation measures, usually at the point in time when the vehicle is purchased (often referred to as “purchase tax,”) and (2) annual taxation measures during the lifetime of the vehicle (often referred to as “ownership tax”).

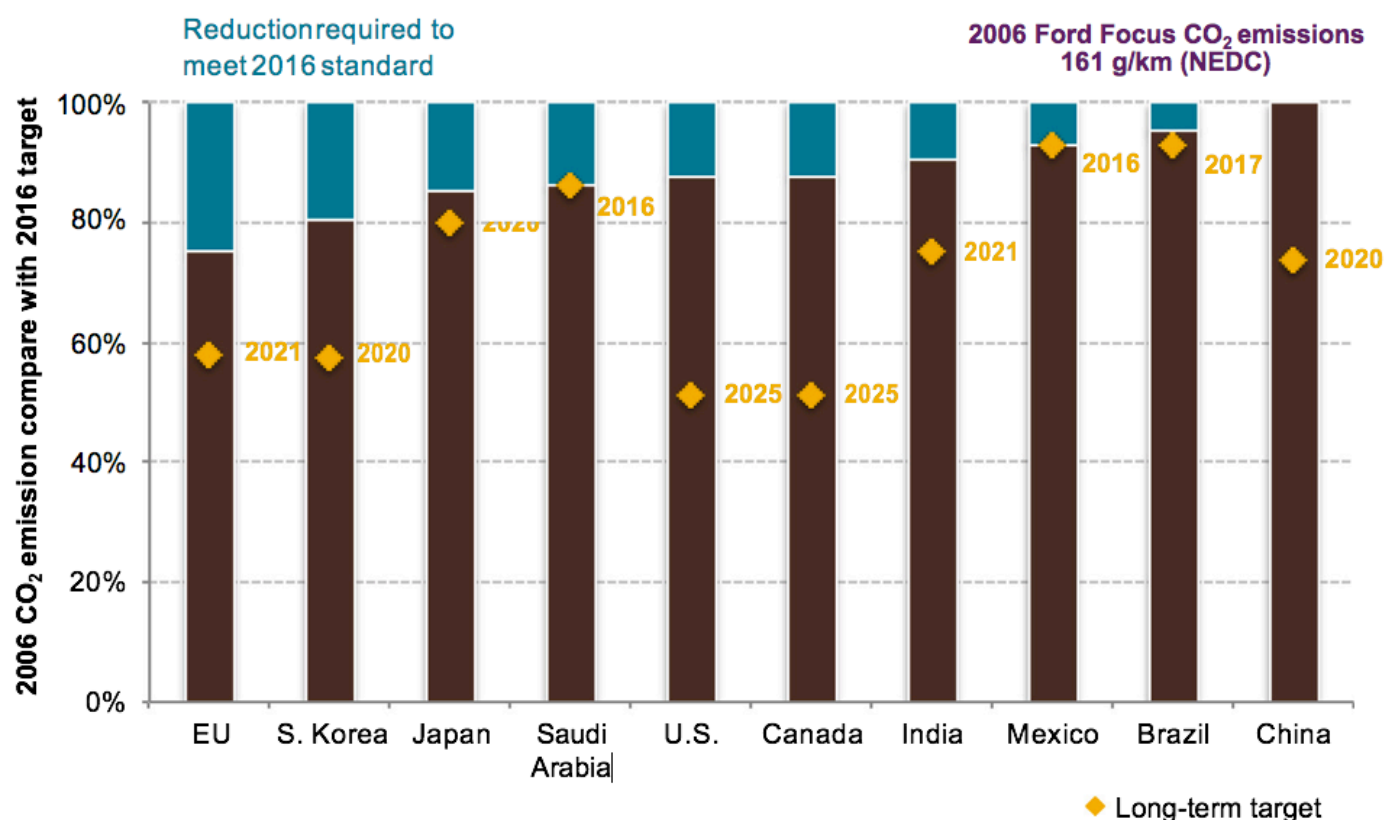
Furthermore, for the purpose of this paper it is important to distinguish between two subcategories of vehicle taxation measures: (1) those that are directly linked to the CO₂ emission level of a vehicle (being based on CO₂, fuel consumption, fuel economy, or energy efficiency), and (2) those that are indirectly linked to CO₂ emissions (being based on vehicle weight or vehicle engine size). For example, a vehicle tax based on engine size provides an incentive to consumers to purchase vehicles with smaller engines, as those would be taxed less. Because there is some correlation between engine size and vehicle CO₂ emission levels (Mock, 2015a), choosing a smaller engine will also help to reduce CO₂ emissions, although not as efficiently as taxing CO₂ directly.

Fig. 4 shows the CO₂-related tax of the 2006 Ford Focus in G20 countries, differentiating between one-time vehicle purchase taxes that are directly or indirectly based on CO₂ emissions, as well as annual vehicle taxes that are directly or indirectly based on CO₂ emissions. All vehicle taxes that are not directly

Table 3

Overview of current new passenger car CO₂ emission standards in the G20 countries.

Country	Market share	Target year	Metric ^f	Target value ^g	Parameter	Test procedure
China	30%	2015	FC	6.9 L/100km	Weight	NEDC
		2020		5.0 L/100 km		
EU ^a	20%	2015	CO ₂	130 gCO ₂ /km	Weight	NEDC
		2021		95 gCO ₂ /km		
U.S.	12%	2016	FE/GHG	36.2 mpg ^b or 225 gCO ₂ /mi	Footprint	U.S. combined
		2025		56.2 mpg ^c or 143 gCO ₂ /mi		
Japan	7%	2015	FE	16.8 km/L	Weight	JC08
		2020		20.3 km/L		
India	4%	2016	CO ₂	130 g/km	Weight	NEDC
		2021		113 g/km		
Brazil	4%	2017	FC	1.82 MJ/km	Weight	U.S. combined
Russia	4%	—	—	—	—	—
South Korea	2%	2015	FE/GHG	17 km/L or 140 gCO ₂ /km	Weight	U.S. combined
		2020		24 km/L or 97 gCO ₂ /km		
Indonesia	1%	—	—	—	—	—
Canada	1%	2016	GHG	217 gCO ₂ /mi ^d	Footprint	U.S. combined
		2025		N/A ^e		
Mexico	1%	2016	FE/GHG	39.3 mpg or 140 g/km	Footprint	U.S. combined
Saudi Arabia	1%	2020	FE	17 km/L	Footprint	U.S. combined
Turkey	1%	—	—	—	—	—
Australia	1%	—	—	—	—	—
South Africa	1%	—	—	—	—	—
Argentina	1%	—	—	—	—	—

^a EU for G20 includes France, Germany, Italy, and UK, as well as the EU itself.^b Assumes manufacturers fully use air-conditioning credits.^c Proposed Corporate Average Fuel Economy (CAFE) standard by the National Highway Transport Safety Administration (NHTSA). It is equivalent to 163 g/mi plus CO₂ credits for using low-GHG warming potential air-conditioning refrigerants.^d In April 2010, Canada announced a target for the light-duty vehicle fleet of 246 g/mi for model year 2016. The separated targets for the car and light truck fleet are estimated by ICCT based on the overall target.^e Canada follows the U.S. standards in the proposal, but the final target value will be based on the projected fleet footprints.^f FC = fuel consumption, FE = fuel economy, GHG = greenhouse gas emissions.^g g/mi = grams per mile, mpg = miles per gallon, MJ/km = megajoule per kilometer.

or indirectly based on the CO2 emissions of a vehicle are not included in the comparison. All taxes are at the national level without consideration of state level taxes (e.g., in the United States and Australia).

In comparison, the level of CO2-based taxation is the highest in Indonesia, being entirely made up of a purchase tax that is only indirectly based on vehicle CO2 emissions. France has the highest direct CO2 tax for the 2006 Focus. South Korea and Turkey are the two countries with the next-highest level of vehicle taxation, both applying a mix of purchase and annual taxes that are again only indirectly based on vehicle CO2 emissions. Vehicle taxes that are directly linked to CO2 emissions and that are of relevance in an international comparison are only in place in France, the UK, Germany, and South Africa. In some countries, like the United States, the selected Ford Focus model version would not be taxed on any CO2-related factors at all.

Fig. 5 compares the vehicle tax difference between the 2006 Focus model and the 2014 model that meets 2016 CO2 emission standards. As it shows, in most markets the 2014 vehicle model is subject to a lower tax. In the case of France, for example, the tax is substantially lower because the vehicle has lower CO2 emissions than in 2006 and can therefore benefit

from a French bonus system that provides tax breaks for vehicles with lower CO2 emissions. In Turkey, on the other hand, it is the lower engine displacement of the 2014 vehicle that results in a lower amount of taxes to be paid. In some markets the tax level of the 2014 vehicle is higher, though, than for the 2006 model version. For example, in Italy this is due to the fact that the vehicle taxation scheme is based on engine power and that the 2014 vehicle version has a higher vehicle power than the 2006 version.

3.3. Fuel taxation

Besides vehicle CO2 emission standards and vehicle taxation, fuel taxation is another measure to influence the CO2 emission level of a country's vehicle fleet. The underlying principle is that because fuel taxation increases the ownership costs for a vehicle, it provides an incentive for consumers to opt for a vehicle that uses less fuel (and thereby emits less CO2) and to drive fewer kilometres.

While the market price for crude oil is largely the same for every country, retail prices for fuels vary widely between different countries. This is because fuel taxation levels differ significantly across countries.

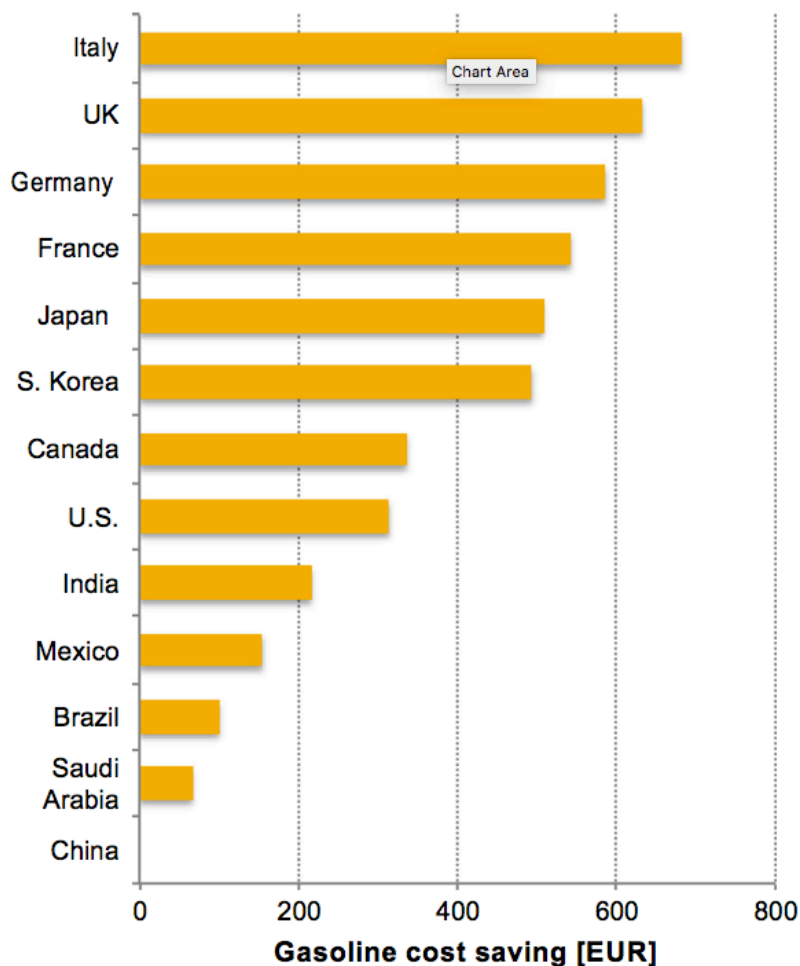


Table 4

Overview of current passenger car taxation measures in the G20 countries with relevance for vehicle CO₂ emissions.^a

Country	Incidence	Directly linked to CO ₂	Indirectly linked to CO ₂
Argentina	—	—	—
Australia	One time	<i>Stamp duty</i> in some states based on <i>Green Vehicle Rating</i>	<i>Stamp duty</i> in some states based on engine size
	Annual	—	<i>Vehicle tax</i> based on vehicle weight
Brazil	One time	—	<i>Registration tax</i> based on engine size (and manufacturers' fleet average efficiency)
			<i>Registration taxes</i> based on engine size
Canada	One time	<i>Excise tax</i> on high CO ₂ vehicles	—
China	One time	—	<i>Excise tax</i> based on engine size
	Annual	—	<i>Vehicle and vessels fee</i> based on engine size
France	One time	<i>Bonus-malus</i> (feebate) based on CO ₂	<i>Registration tax</i> based on engine power
	Annual	<i>Tax</i> on high CO ₂ cars	—
Germany	Annual	<i>Circulation tax</i> partly based on CO ₂	<i>Circulation tax</i> partly based on engine size
India	One time	—	<i>Excise tax</i> based on engine size
	Annual	—	<i>Vehicle tax</i> in some states based on engine size or engine power
Indonesia	One time	<i>Luxury tax</i> reduction for efficient vehicles	<i>Luxury tax</i> based on engine size
Italy	One time	—	<i>Registration tax</i> based on engine power
	Annual	—	<i>Ownership tax</i> based on engine power
Japan	One time	—	<i>Acquisition tax</i> based on engine size
	Annual	—	<i>Tonnage tax</i> based on vehicle weight
			<i>Auto tax</i> based on engine size
Mexico	—	—	—
Russia	One time	—	<i>Excise tax</i> based on engine power
	Annual	—	—
Korea	One time	—	<i>Transport tax</i> based on engine power
			<i>Individual consumption tax, acquisition tax, and public bond</i> based on engine size
	Annual	—	<i>Annual vehicle tax</i> based on engine size
Saudi	—	—	—
Arabia			
South	One-time	<i>Registration tax</i> based on CO ₂	—
Africa			
Turkey	One time	—	<i>Consumption tax</i> based on engine size
	Annual	—	<i>Motor vehicle tax</i> based on engine size
UK	One time	<i>First-year special registration tax</i> based on CO ₂	—
	Annual	<i>Circulation tax</i> based on CO ₂	—
U.S.	One time	<i>Gas-guzzler tax</i> on high-CO ₂ vehicles	—
	Annual	—	In some states tax based on vehicle weight

^a Special tax reductions for hybrid and electric vehicles as well as special tax measures for company cars are not included here.

Some countries even subsidize fuel prices (i.e., impose a negative fuel tax), so that as a result the market fuel price ends up being lower than the price for crude oil. Fig. 6 summarizes 2012 (the most recent year for which global data is available) gasoline market fuel prices in the G20 countries and adds an estimate of the taxation level to the comparison (based on data from GIZ, 2013; with additional data collected within the research for this paper (Energypedia, 2016). The categorization of the fuel taxation level is defined in the report (GIZ, 2013).

Among countries that levy fuel tax, fuel taxation levels are comparably low in Mexico, the United States, and Russia. Indonesia and Saudi Arabia provide high fuel subsidies so that the retail price of gasoline is lower than the cost of crude oil in the international market. The highest fuel taxation levels are observed in Turkey, the EU countries, Japan, and South Korea. The higher the fuel tax is, the higher the fuel saving benefit will be for the consumer when buying a more efficient vehicle. Using the data collected, the amount of fuel tax saving over a four-year holding period for

the Ford Focus vehicle is calculated for each of the G20 countries. Fig. 7 provides a summary of the results.

Fuel tax savings vary widely between countries, with the level of tax saving for the Ford Focus in Italy, the UK, France, Germany, Korea, and Japan being more than 10 times higher than in the United States, Russia, and Mexico. As Indonesia and Saudi Arabia subsidize fuel instead of taxing it, there is no tax saving due to vehicle efficiency improvements. It should be noted, though, that Indonesia recently decided to reduce its fuel subsidy levels – a recent development that is not yet reflected in this estimation as we focus only on policies that were in place in 2013 (Chambliss, 2015).

3.4. Overall financial impact of policy measures

Adding up the quantitative effects of new vehicle CO₂ standards, vehicle taxation directly or indirectly based on CO₂ emissions of a vehicle and fuel taxation allows for some insights into how much of financial incentives these policy measures provide for each

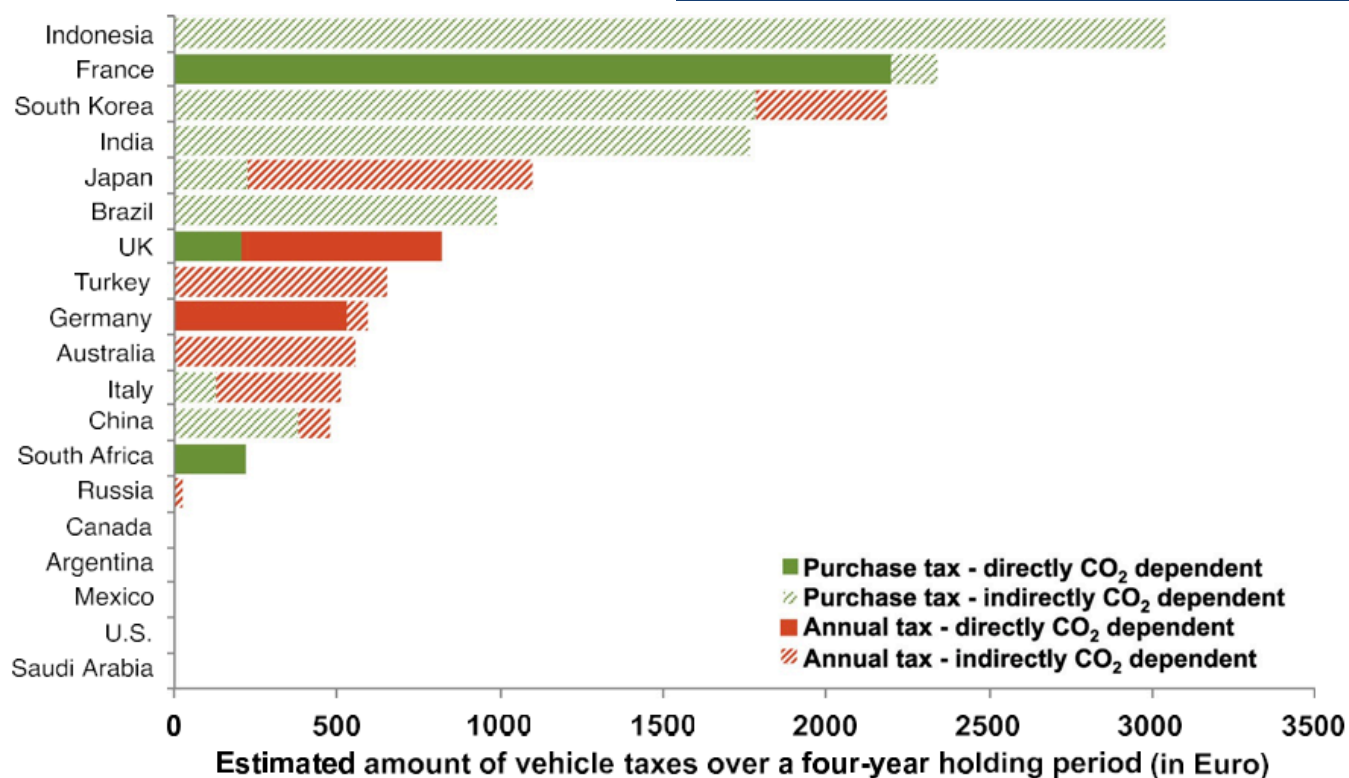
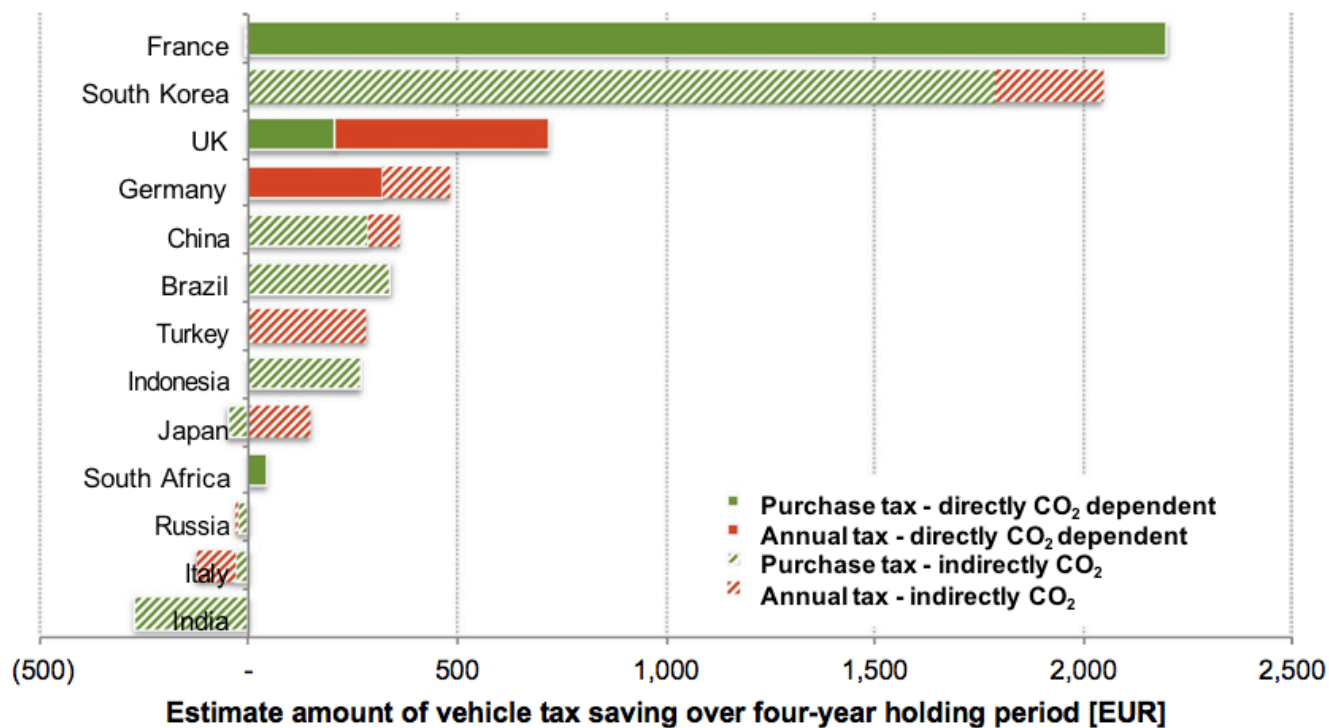


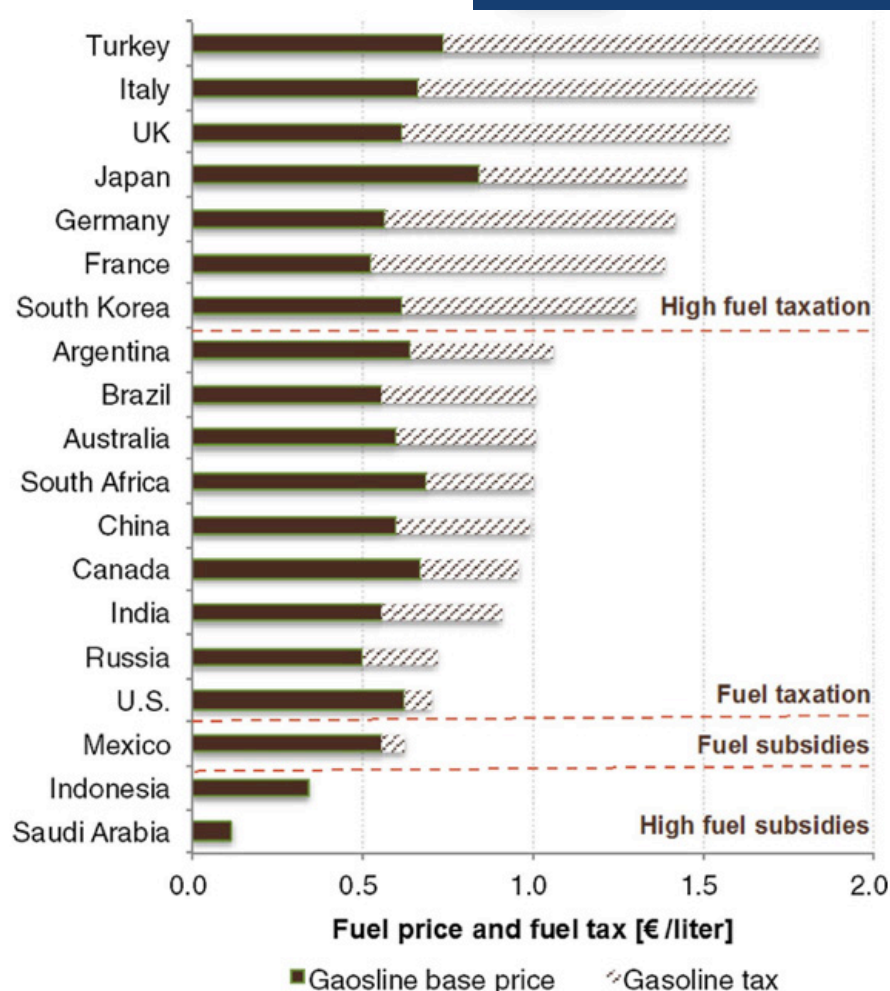
Fig. 4. Estimated amount of vehicle taxes for a Ford Focus over a four-year holding period for the G20 countries.



of the G20 countries in terms of reducing the CO₂ emission level of the new passenger car fleet. The financial savings from efficiency gains and CO₂ reductions are a clear incentive for the purchase of a more efficient vehicles and send similar signal to vehicle manufacturers. Similarly, the taxes on inefficient vehicles are a disincentive that also steers behaviour towards investments of efficient vehicle technologies. Fig. 8 summarizes the combined savings of regulatory and fiscal policy measures. The total financial impact varies widely, from close to zero in Russia and Saudi Arabia to around 3600 euros in France. In addition, the share of the different policy elements differs significantly from each other. France, UK, and Germany are the only three countries that show an impact from all three policies. In addition, vehicle taxes directly linked to CO₂ play a role in South Africa. The level of financial impact of vehicle CO₂ standards are significant in many countries, especially in countries with a medium level of total policy impact, such as Canada, India, the United States, Brazil, and Mexico. Fuel taxation is the most common approach, with Indonesia and Saudi Arabia being the only G20 countries not making use of this policy.

3.5. Financial impact of CO₂-related policy measures versus fleet emission levels

Assessing the co-relation between the level and the combination of the selected policy measures with the impact on the fleet average CO₂ emissions is a core objective of this paper. Fig. 9 below shows the estimated total financial impact of the three measures (CO₂ emission standards, CO₂-based vehicle taxation, and fuel taxation) that were quantified above on the x-axis. On the y-axis it compares these values against the 2013 average new passenger vehicle CO₂ levels for each of the G20 countries. Furthermore, the pie charts for each of the countries provide an indication of the split between the different policy instruments, contributing to the total quantitative impact. The example of France illustrates how a combination of measures (direct CO₂ tax, fuel tax and CO₂ standards) at a high level can significantly improve the average fuel efficiency of the vehicle fleet. France is the G20 country with the highest total quantitative effect, with a combination of CO₂ standards, vehicle CO₂ taxation as well as fuel taxation. In terms of CO₂ emission fleet levels, France has the fleet with the lowest average CO₂ emission. The total quantitative effect for the other EU countries is between 1500 and 2500 euros. Together with Japan, South Korea, India, and Turkey, the abovementioned countries have new car fleets with CO₂ emission levels of about 145 g/



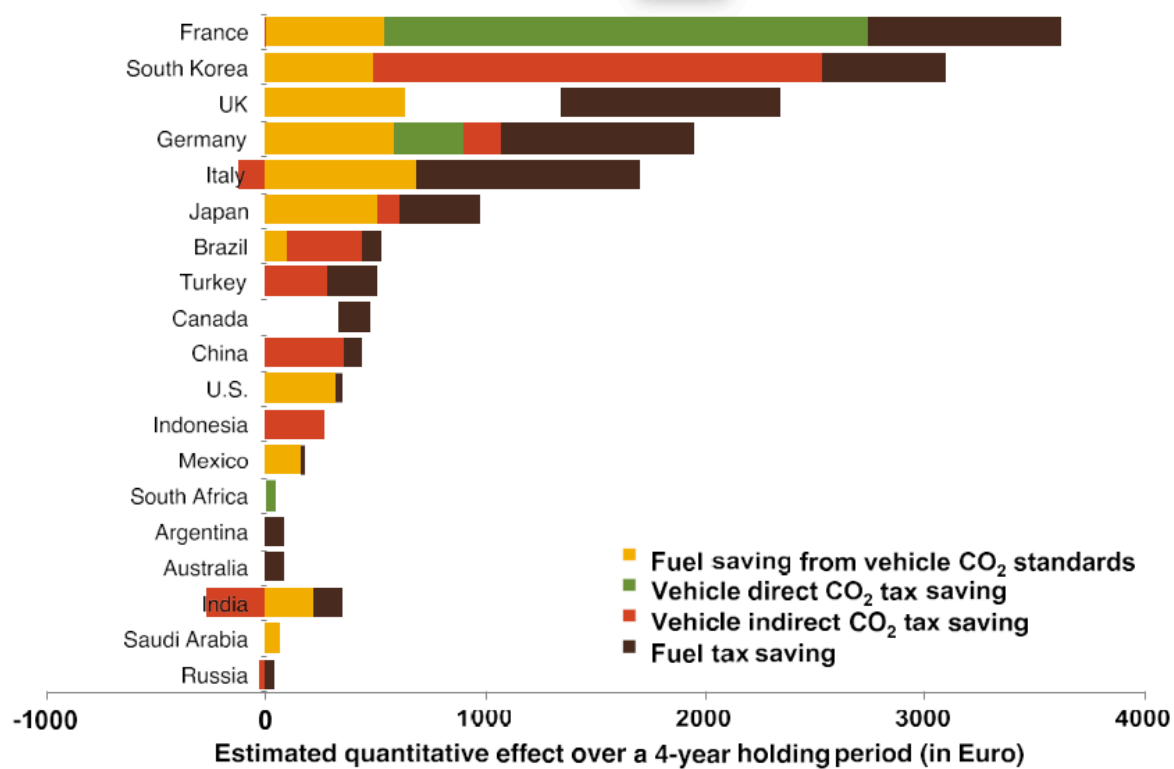
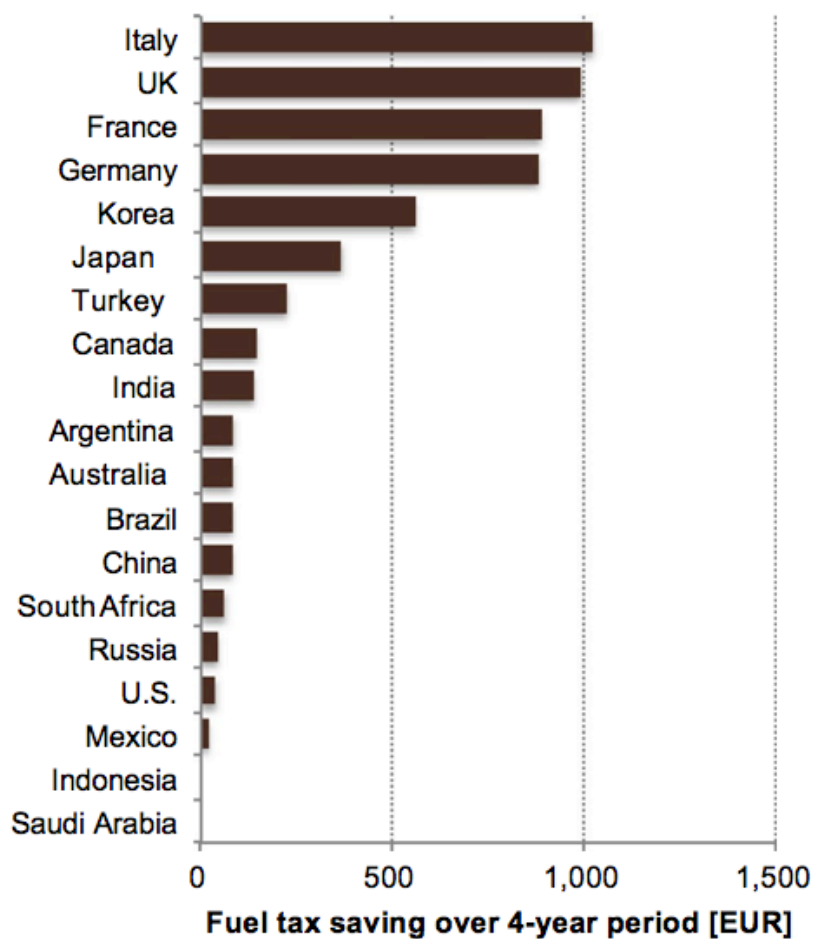


Fig. 8. Estimated quantitative effect of new vehicle CO₂ standards, vehicle CO₂ taxation, and fuel taxation for a Ford Focus over a four-year holding period for the G20 countries.

km or below. The rest of the G20 countries have CO₂ emission fleet levels that are above 150 g/km, with those countries where the total financial impact is less than 500 Euros showing CO₂ emission levels of around 160 g/km.

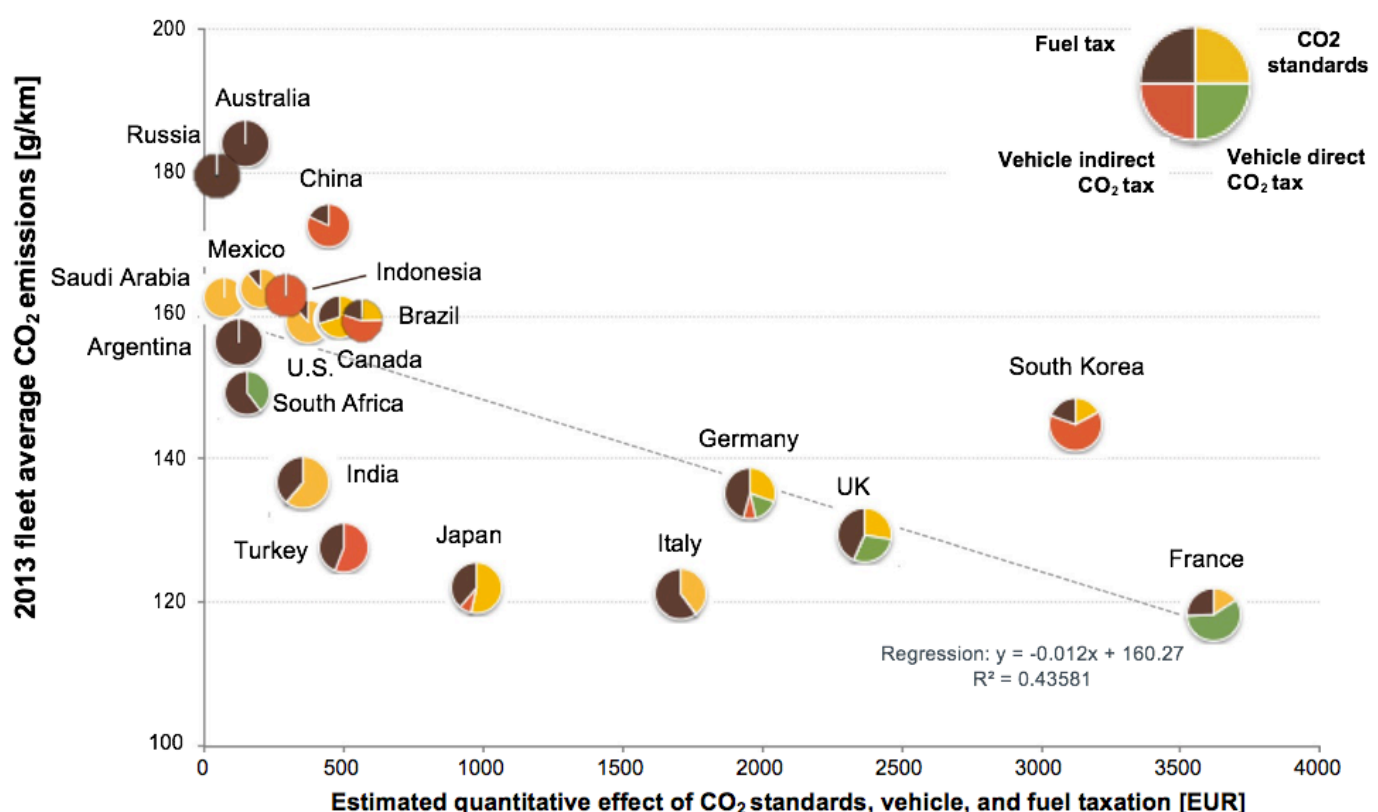
Fig. 10 shows how the estimated total financial impact compares against the new passenger vehicle CO₂ reduction rate from 2005 to 2013 for each of the G20 countries. The fleet average CO₂ emissions of 2005 come from a GFEI report, which calculated sale-weighted fleet average CO₂ emission based on new vehicle registration database for each country (GFEI, 2014).

Comparing Figs. 9 and 10, most countries that have a relatively low CO₂ emission fleet in 2013 have experienced a significant CO₂ emissions drop from 2005 to 2013, such as Japan, Italy, Germany, UK, Korea, and France. All these countries have CO₂ emission standards with an evaluated financial impact around or over 500 EUR.

There are several outliers that can be explained with country-specific situations. Japan, despite of its lower

has made top efficiency improvement and therefore becomes an outlier in the figure. The achievement of CO₂ reduction in Japan attributes to the dramatic increase of hybrid electric vehicles (HEVs) from 1% in 2005 to 23% in 2013 thanks to an successful incentive program during 2009 to 2012 to promote hybrid electric vehicles that is not taken account of in this analysis.

Turkey, with 73% of new cars imported from abroad and 80% of produced cars being exported, was influenced by fuel efficiency policies in other countries, especially EU countries, even as its policy impact is not as significant as others'. Australia has its fleet average CO₂ emissions dropped as fast as other leading countries, but note that its absolute average CO₂ emission level is the highest across all G20 markets.



4. Discussion

To move forward towards utilizing the technological potential of fuel efficiency in the light-duty vehicle fleet, it is important to understand the role of individual policy measures and their interaction.

Fig. 9, which summarizes the main analysis of this paper, indicates that a combination of measures and the level of ambition are vital drivers of fuel efficiency improvements. It also indicates that there is a positive relationship between the total financial impact of CO₂-based vehicle policy measures and the average CO₂ emission level of the respective new car fleet. The higher the financial impact of CO₂-based vehicle policy measures, the lower CO₂ level the fleet emits. Those countries that enable larger savings for purchasing and driving vehicles with lower CO₂ emissions tend to have a new vehicle fleet with a lower CO₂ emission level. A regression analysis was carried out to verify the robustness of the relationship, with the following results:

$$y = -0.012x + 160.2$$

$$p = 0.00280; 0.0016 \quad R\text{-square} = 0.4385$$

x Financial impact of three major policy measures, y Fleet average CO₂ emission level.

It can be concluded that the financial benefit of these three policy measures together have a significant impact on the CO₂ emission level of the vehicle fleet. The R-square level indicates that there are other aspects that have not been taken into account, such as the length of adoption of each policy, the impact of other policies, and the local demand that determines the characteristics of the fleet. It is also noticeable that the high financial impact is contributed by a combination of two or three policies rather than only one aggressive policy, such as in France, Germany, Korea, the UK, Italy, and Japan.

With respect to individual policies, all countries where the 2016 CO₂ vehicle standards have a financial impact above 500 euros are found to have a vehicle fleet CO₂ emission level significantly lower than for most other countries. In the EU, the annual CO₂ emission reduction was around 1% before the introduction of the mandatory CO₂ emission standards in 2008/09, but increased to around 4% thereafter (ICCT, 2014). The adoption of CO₂ standards also indirectly influences the financial impact of the other two policies, as the calculation basis of vehicle and fuel tax saving is impacted by reduced CO₂ emission levels as a result of the 2016 standards.

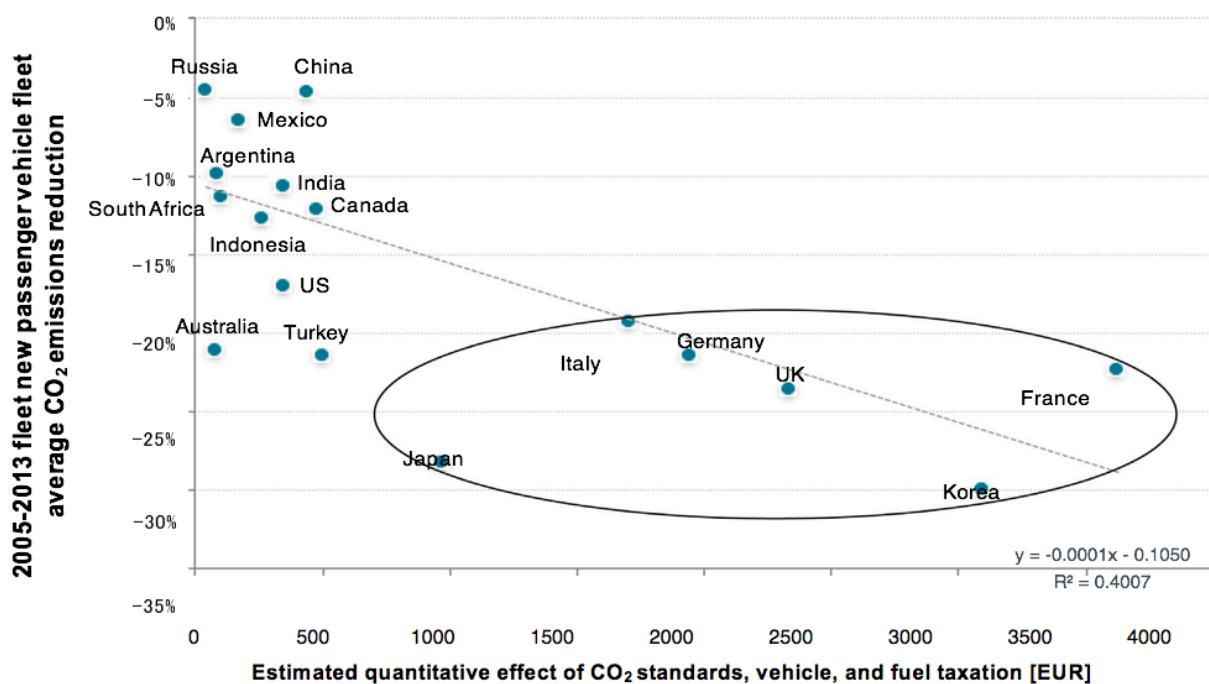


Fig. 10. Estimated financial impact of vehicle CO₂ standards, CO₂-based vehicle taxation, and fuel taxation for a Ford Focus over a four-year holding period versus the 2005 to 2013 new vehicle fleet average CO₂ emission reduction for the G20 countries.

There are other factors that we have not taken into account because we evaluated the financial impact of CO₂ standards only ranging from 2006 to 2016. For some countries, the mandatory vehicle CO₂ emission target is a relatively new policy instrument. For example, Brazil adopted the standards in 2013 while Saudi Arabia and India adopted the standards in 2014. It will take time for the policy to have an impact on the fleet. Meanwhile, for some countries, a longer-term standard has been established, which will influence the policy financial impact over time. For example, the U.S. 2025 new car CO₂ standards reduce the average emission level from the current 160 g/km to around 90 g/km. The China 2020 new car CO₂ standard is more stringent than the 2015 standard. These standards will have a significant effect for vehicle models in the long run.

Vehicle CO₂-based taxes, though only adopted by several countries, show an influence on fleet CO₂ emission levels. The three European countries that have direct CO₂ taxes (Germany, the UK, and France) all have a fleet with relatively low CO₂ emission levels. When countries adopt CO₂ emission standards with similar financial benefit, the one that implements a CO₂-based tax with a higher financial impact is more likely to have a fleet with lower average CO₂ emission. South Africa has implemented direct CO₂ taxes, but its quantified impact is too small to make a noticeable impact on fleet CO₂ emissions. The contribution of indirect CO₂-based taxes to cost saving varies between countries. The high, indirect CO₂ vehicle taxation could encourage consumers to purchase vehicles with lower CO₂ emissions on average, such as South Korea and Turkey, but their impact on the fleet CO₂ emission level is not as strong as vehicle CO₂-based taxes. For instance, South Korea shows a large indirect CO₂-based tax saving, but its fleet CO₂ emission levels still falls behind countries where CO₂-based taxes with similar financial impact level are in place (e.g., France). It is also important to keep in mind that the introduction and enforcement of taxation schemes is generally easier than compared to the enforcement of vehicle CO₂ emission standards. The latter requires a good understanding of the technical characteristics of the current vehicle fleet and future CO₂ emission reductions. It also requires a legal framework and staff resources to monitor CO₂ emission developments for all new vehicles on sale in a country and to impose penalty payments upon vehicle manufacturers, in case emission targets are not met.

It is more challenging to separate the impact of fuel taxes on fleet CO₂ emission levels as countries in which the fuel tax has high financial impact generally also have standards and a vehicle tax with high financial impact in place. For countries where fuel taxes dominate the current CO₂-related policy mix, the vehicle fleet CO₂ emission levels are relatively high, such as Australia, Russia, and Argentina. This implies that setting fuel tax solely with a low financial impact may not be effective in reducing vehicle CO₂ emission levels. In comparison, a fuel tax is easier to set up as fuel tax levels can be set without knowing many technical details about the vehicle fleet, and they can be enforced relatively easily at the refinery or fuel-distribution level.

5. Conclusions and policy implications

The assessment presented in this paper indicates that single policy measures, such as vehicle taxation or regulation implemented in isolation are likely to deliver smaller impacts with regard to fuel efficiency gains in the vehicles fleet compared to a more integrated policy approach that combines regulation with fuel and vehicles taxation. The analysis shows that markets adopting vehicle CO₂-related policy measures that provide higher financial benefits have a better chance of decarbonizing their vehicle fleet over time. Moreover, the highest financial impact is found to be achieved by a combination of two or three policies rather than only one aggressive policy. With respect to individual policies, markets with a financial impact of 2016 CO₂ vehicle standards above 500 euros are found to have a CO₂ emission level that is significantly lower than for most other markets.

When countries adopt CO₂ emission standards for light-duty vehicles, corresponding CO₂-based vehicle taxes are an important supporting measures to influence purchasing behaviour and countries are more likely to see a policy-led improvement of the efficiency of the vehicle fleet. While fuel taxes have only a limited impact on the fleet CO₂ emission level in the countries analysed in this paper, they have a substantial impact on the vehicle kilometres travelled, which in combination with the improvement in the carbon intensity of the vehicle fleet leads to reduced CO₂ emissions from light-duty vehicles (Thiel et al., 2016; Edelenbosch et al., 2016).

Based on the findings presented in this paper, for countries with slower decarbonizing progress of their passenger vehicle fleet, a stronger focus would be needed on stringent vehicle CO₂ standards, complemented by a tailored set of directly CO₂-based vehicle and fuel taxes. For countries like Turkey and Australia where the CO₂ emission level decreases with the global trend, adopting more accelerated emission reduction pathways than the current pace would accelerate the progress toward low-carbon vehicles. For countries like India and South Africa where the absolute CO₂ emission level is relatively low but CO₂ emission reduction has been slow, strengthening CO₂ related policies would show a larger impact over long term.

In addition, this paper provides methods to evaluate and compare the financial impact of different vehicle efficiency policies and a set of global data that policy makers can refer to when benchmarking the impact a set of efficiency policies with others. All efforts would enable the land-transport sector to make a substantial contribution to global climate change and sustainable development targets.

6. Limitations and opportunities for future research

The analysis presented in this paper provide some insights on the relevance and interplay of key vehicle fuel efficiency policy measures. However, there are limitations with respect to the analysis carried out in this paper:

(1) As it was explained, the assumptions regarding the configuration of the Ford Focus vehicle version and the year scope for policy impact influence the result in such a way that the Focus represents quite well the new market average in some countries (e.g., the EU) while it would be considered a small (e.g., in the United States) or relatively large (e.g., in India or Indonesia) vehicle in other markets. This is especially relevant when comparing the quantitative impact of the policy measures to the average new car fleet emissions in Section 3.5. Using the same vehicle for comparing across the G20 countries allows for a comprehensive international comparison and ranking of countries in terms of how much their policy framework incentivizes sales of low-CO₂ emission vehicles. It does, however, not allow for any conclusion about what level of policy measures would be ideal within one country to further drive down CO₂ emissions of the new vehicle fleet.

For example, while India is in the middle field of the G20 countries in terms of quantitative impact of CO₂-related policy measures and has a relatively low CO₂ emission level for its new car fleet, it is likely that with an effective CO₂ standard new vehicles in India could have even lower CO₂ emission levels, given that vehicles tend to be very small and low-powered compared with other G20 markets.

(2) The analysis only considers CO₂ vehicle taxation, direct and indirect CO₂ vehicle taxation, and fuel taxation. In reality, there are other additional measures that will have an influence on a country's vehicle market structure (International Transport Forum, 2017). For example, the density of public transportation could play a role in purchase decisions of consumers and thereby also influence CO₂ emission levels of the new vehicle fleet. Furthermore, the influence of electric vehicles and any policy incentive schemes in place to promote the purchase and use of electric vehicles are not considered here (Jochem et al., 2016, 2016). Given the low market share of electric vehicles at the moment, this impact is expected to be negligible, however.

(3) The market reaction to financial benefits, including consumers' and manufacturers' reactions, may change due to behavioural and perspective change. A number of studies have found that consumers value fuel efficiency/CO₂ as an increasingly important element (Esposito, unpublished; Grünig et al., 1999; Ipsos New Zealand, unpublished). On the one hand, consumers are interested in buying vehicles with a lower running cost (Esposito, unpublished;

PRR, 2016), while on the other hand, due to the impact of loss aversion and the uncertainty of future fuel savings, consumers usually discount the fuel economy benefit (Greene et al., 2008, 2013). A previous study found that households do not analyse their fuel costs in a systematic way in preparation for their vehicle purchases (Turrentine and Kurani, 2007). In some cases it was found that the consumer value for fuel economy is more than the actual cost saving, as social norms will influence consumers' environmental behaviour at the same time (Turrentine and Kurani, 2007; Schultz et al., 2007). The fluctuation of fuel price also influences the significance of financial impact of fuel tax. The fuel price used for this analysis is a static value. As fuel price increases, the financial benefit of mandatory standards and high fuel tax from reducing vehicle CO₂ emissions will increase accordingly.

For future research a review of global vehicle fuel efficiency policy in combination with other (e.g. local) policy measures would help to strengthen the case of policy integration even further. Another update of the assessment presented in this paper, carried out in 3–5 years would better reflect the impact of recently introduced or improved policies, which will reflect better the change of fleet fuel efficiency level as result of these measure. Improved research methods would include taking account of regional market difference (e.g. model availability, purchase power) while allowing for a fair comparison across countries and improving the method to weight in the financial impact of different types of efficiency policies on improving fuel efficiency.

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References

- ACEA, 2014. ACEA tax guide 2014. European Automobile Manufacturers Association. <<http://www.acea.be/publications/article/acea-tax-guide>> (accessed on October 5, 2014).
- CAAM, 2014. Top 10 Passenger Car Sales in China <<http://www.caam.org.cn/zhengche/20150116/1505144998.html>> (accessed on March 27, 2015).
- Cain, Timothy, 2013 year end U.S. passenger car sales ranking-top 158 best-selling cars in America. <<http://www.goodcarbadcar.net/2014/01/2013-usa-car-sales-rankings-by-model-december.html>> (accessed on Mar 27, 2015).
- Cain, Timothy, 2014 year end U.S. passenger car sales ranking-top 157 best-selling cars in America. <<http://www.goodcarbadcar.net/2015/01/usa-all-cars-sales-figures-2014-december-year-end.html>> (accessed on Mar 27, 2015).
- CATARC, 2014. Annual Report on Automotive Energy-Saving in China (2014). China Automotive Technology and Research Center.
- Chambliss, Sarah, 2015. Low Oil Price, High Time to Move off of Diesel Subsidies. <<http://www.theicct.org/blogs/staff/low-oil-prices-high-time-move-diesel-subsidies>> (accessed on March 31, 2015).
- Comings, T., Allison, A., 2017. More mileage for your money: fuel economy increase while vehicle prices remain stable. <<http://consumersunion.org/wp-content/uploads/2017/03/Synapse-CU-Affordability-Report-3-15-corrected-1.pdf>> (accessed on March 23, 2017).
- European Commission (EC), 2009. Regulation (EC) No 443/2009 of the European Parliament and the Council of 23 April 2009. <<http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32009R0443&from=EN>> (accessed on August 24, 2016).
- Edelenbosch, O.Y., McCollum, D.L., van Vuuren, D.P., Bertram, C., Carrara, S., Daly, H., Fujimori, S., Kitous, A., Kyle, P., Ó Broin, E., Karkatsoulis, P., Sano, F., 2016. Decomposing passenger transport futures: Comparing results of global integrated assessment models. *Transport. Res. Part D: Transport Environ.*, <http://dx.doi.org/10.1016/j.trd.2016.07.003>.
- Energypedia. Fuel Price India. <https://energypedia.info/wiki/Fuel_Prices_India> (accessed on August 19, 2016).
- Environmental Protection Agency, 2017. 2017 and Later Model Year Light-Duty Vehicle Greenhouse Gas Emissions and Corporate Average Fuel Economy Standards; Final Rule. 49 CFR Parts 523, 531, 533. et al. and 600.
- Eriksson, L., Nordlund, A.M., Garvill, J., 2010. Expected car use reduction in response to structural travel demand management measures. *Transport. Res. Part F: Traffic Psychol. Behav.* 13, 329–342. <http://dx.doi.org/10.1016/j.trf.2010.06.001>.
- Esposito, G., 2014. A Summary of Low CVP Research on the UK Fuel Economy Label and Recommendations for Future Label Designs, unpublished. Federal Highway Administration (FHWA), 2015. Average Annual Miles Per Driver by Age Group. <<http://www.fhwa.dot.gov/ohim/onh00/bar8.htm>> (accessed on March 27, 2015).
- Figuroa, M., Maria, J., Lah, O., Fulton, L.M., McKinnon, A.C., Tiwari, G., 2014. Annual review of environment and resources. *Energy Transport* 39 (1), 295–325. Fulton, L., Lah, O., Cuenot, F., 2013. Transport pathways for light duty vehicles: towards a 2° scenario. *Sustainability* 5 (5), 1863–1874. <http://dx.doi.org/10.3390/su5051863>.
- G20, 2015. G20 Energy Efficiency Action Plan: Voluntary Collaboration on Energy Efficiency. <https://g20.org/wp-content/uploads/2014/12/g20_energy_efficiency_action_plan.pdf> (accessed on March 27, 2015).
- German, J., Lutsey, N., 2015. Size or Mass? The Technical Rationale for Selecting Size as an Attribute for Vehicle Efficiency Standards. <<http://www.theicct.org/size-or-mass-technical-rationale-selecting-size-attribute-vehicle-efficiency-standards>> (accessed on June 15, 2015).
- GFEI. Fuel Economy State of the World 2014. <<http://www.fiafoundation.org/media/44209/gfei-annual-report-2014.pdf>> (accessed on June 16, 2015). Gillingham, K., Kotchen, M.J., Rapson, D., Wagner, G., 2013. Energy policy: the rebound effect is overplayed. *Nature* 493 (7433), 475–476. <http://dx.doi.org/10.1038/493475a>.
- GIZ, 2013. International Fuel Prices 2012/2013. <<https://www.giz.de/expertise/downloads/giz2014-en-international-fuel-prices-2013.pdf>> (accessed on June 15, 2015).
- Greene, D., German, J., Delucchi, M., 2008. Fuel economy: The case for market failure. In: Sperling, D., Cannon, J. (Eds.), Chapter 11 of Reducing Climate Impacts in the Transportation Sector. Springer Press, 2008. http://dx.doi.org/10.1007/978-1-4020-6979-6_11.
- Greene, D., Evans, D., Hiestand, J., 2013. Survey evidence on the willingness of U.S. consumers to pay for automotive fuel economy. *Energy Policy* 61, 1539–1550. <http://dx.doi.org/10.1016/j.enpol.2013.05.050>.
- Griffin, J.M., Schulman, C.T., 2005. Price asymmetry: a proxy for energy-saving technical change? *Energy J.*, 1–21.
- Grünig, M., Skinner, I., Kong, M., Boteler, B., 1999. Study on Consumer Information on Fuel Economy and CO₂ Emissions of New Passenger Cars. Implementation of the Directive 1999/94/EC. Brussels: European Parliament. <http://www.ieep.eu/assets/660/Study_on_consumer_information_on_fuel_economy_and_CO2_of_new_cars.pdf> (accessed on August 24, 2016).
- Haan, P., Mueller, M.G., Scholz, R.W., 2009. How Much Do Incentives Affect Car Purchase? Agent-based microsimulation of

- consumer choice of new cars-Part II: Forecasting effect of fee-bate based on energy efficiency. *Energy Policy* 37, 1083–1094.
- He, H., Bandivadekar, A., 2015. A Review and Comparative Analysis of Fiscal Policies Associated with New Passenger Vehicle CO₂ Emissions. <<http://www.theicct.org/review-and-comparative-analysis-fiscal-policies>> (accessed on March 30, 2015).
- Henry, J., 2015. Turbocharging is Taking Over. Get used to it. <<http://www.forbes.com/sites/jimhenry/2013/10/30/turbocharging-is-taking-over-get-used-to-it/>> (accessed on December 17, 2015).
- Hui, H., Yang, Z., 2015. Incentivizing Passenger Vehicle Mass Reduction Technologies in China. <<http://www.theicct.org/incentivizing-passenger-vehicle-mass-reduction-technologies-china>> (accessed on June 15, 2015).
- Huntington, H., 2006. A note on price asymmetry as included technical change. *Energy J.*, 1–7.
- ICCT, 2014. European vehicle market statistics: pocketbook 2014. <<http://www.theicct.org/european-vehicle-market-statistics-2014>> (accessed on Mar 27, 2015).
- ICCT, 2016. Global Transportation Roadmap Model. <<http://www.theicct.org/global-transportation-roadmap-model>> (accessed on August 24, 2016).
- International Transport Forum, 2017. ITF Transport Outlook 2017. OECD Publishing, Paris, France.
- Ipsos New Zealand, 2014. Vehicle Fuel Economy Labelling 2014: Car Buyers and Intended Car Buyers. Unpublished.
- Jin, L., Searle S., Lutsey, N., 2015. Evaluation of State-Level U.S. Electric Vehicle Incentives. <<http://www.theicct.org/evaluation-state-level-us-electric-vehicle-incentives>> (accessed on April 1, 2015).
- Jochem, P., Doll, C., Fichtner, W., 2016. External costs of electric vehicles. *Transport. Res. Part D: Transport Environ.* 42, 60–76. <http://dx.doi.org/10.1016/j.trd.2015.09.022>.
- Jochem, P., Rothengatter, W., Schade, W., 2016. Climate change and transport. *Transport. Res. Part D: Transport Environ.* 45, 1–3. <http://dx.doi.org/10.1016/j.trd.2016.03.001>.
- Klier, T., Linn, J., 2013. Fuel prices and new vehicle fuel economy-comparing the United States and Western Europe. *J. Environ. Econ. Manage.* 66, 280–300.
- Klier, T., Linn, J., 2016. The effect of vehicle fuel economy standards on technology adoption. *J. Publ. Econ.* 133, 41–63.
- Kodjak, D., 2015. Policies to Reduce Fuel Consumption, Air Pollution, and Carbon Emissions from Vehicles in G20 Nations. <<http://www.theicct.org/policies-reduce-fuel-consumption-air-pollution-and-carbon-emissions-vehicles-g20-nations>> (accessed on June 15, 2015).
- Kodjak, D., Posada, F., Segafredo, L., 2010. Policies That Work: How Vehicle Standards and Fuel Fees Can Cut CO₂ Emissions and Boost The Economy. <<https://cleanenergysolutions.org/sites/default/files/documents/CESC-ICCT-intro-slides.pdf>> (accessed on August 24, 2016).
- Kollamthodi, S., 2015. Understanding Vehicle Lifetime Mileage and Its Impacts on the Cost-Effectiveness of Light-Duty Vehicle CO₂ Regulations. Ricardo- AEA. <http://ec.europa.eu/clima/events/docs/0103/mileage_en.pdf> (accessed on June 15, 2015).
- Kromer, M., Bandivadekar, A., Evans, C., 2010. Long-term greenhouse gas emission and petroleum reduction goals: evolutionary pathway for the light-duty vehicle sector. *Energy* 35, 387–397.
- Kühlwein, J., German, J., Bandivadekar, A., 2015. Development of Test Cycle Conversion Factors Among Worldwide Light-duty Vehicle CO₂ Emission Standards. <<http://www.theicct.org/test-cycle-conversion-factors-methodology-paper>> (accessed on March 30, 2015).
- Lah, O., 2015. The barriers to low-carbon land-transport and policies to overcome them. *Europ. Transport Res. Rev.* 7, 5. <http://dx.doi.org/10.1007/s12544-014-0151-3>.
- Lah, O., 2017. Decarbonising the transportation sector: policy options, synergies and institutions to deliver on a 1.5 Degree stabilisation pathway. *WIRE Energy and Environment*, Special Issue: 0–17.
- Mabit, S., 2014. Vehicle type choice under the influence of a tax reform and rising fuel prices. *Transp. Res. Part A* 64, 32–42.
- Mahlia, T.M.I., Tohno, S., Tezuka, T., 2013. International experience on incentive program in support of fuel economy standards and labeling for motor vehicle: a comprehensive review. *Renew. Sustain. Energy Rev.* 25, 18–33.
- Miller, J.D., Façanha, C., 2014. The State of Clean Transport Policy: A 2014 Synthesis of Vehicle and Fuel Policy Developments. <<http://www.theicct.org/state-of-clean-transport-policy-2014>> (accessed on Mar 27, 2015).
- Mock, P., 2013. EU vote on cars CO₂: 95 g/km in 2020, 68–78 g/km in 2025 <<http://www.theicct.org/blogs/staff/eu-vote-cars-co2>> (accessed on June 15, 2015).
- Mock, P., 2015a. Evaluation of Parameter-based Vehicle Emissions Targets in the EU. <<http://www.theicct.org/evaluation-parameter-based-vehicle-emissions-targets-eu>> (accessed on June 15, 2015).
- Mock, P., 2015b. Entwicklung eines Szenariomodells zur Simulation der zukünftigen Marktanteile und CO₂-Emissionen von Kraftfahrzeugen (VECTOR21). Retrieved from <http://elib.uni-stuttgart.de/opus/volltexte/2011/5845/pdf/Mock_Peter_101130.pdf> (accessed on June 15, 2015).
- Mock, P., Yang, Z., 2015. Driving electrification: A global Comparison of Fiscal Policy for Electric Vehicles. <<http://www.theicct.org/driving-electrification-global-comparison-fiscal-policy-electric-vehicles>> (accessed on June 15, 2015).
- Mock, P., Kuhlwein, J., Tietge, U., et al. The WLTP: How A New Test Procedure for Cars will Affect Fuel Consumption Values in The EU. <<http://www.theicct.org/wltp-how-new-test-procedure-cars-will-affect-fuel-consumption-values-eu>> (accessed on June 15, 2015).
- Priddle, A., Woodyard, C., 2015. Focus is best-selling car in the world! USA Today. <<http://www.usatoday.com/story/money/cars/2013/04/09/most-popular-car-ford-focus-fiata-honda-civic-toyota-camry/2066187/>> (accessed on Mar 27, 2015).
- PRR, Inc., 2016. Environmental Protection Agency Fuel Economy Label Final Report. (EPA-420-R-10-909). <<http://www3.epa.gov/fueleconomy/label/420r10909.pdf>> (accessed on August 24, 2016).
- Schultz, P.W., Nolan, J.M., Cialdini, R.B., Goldstein, N.J., Griskevicius, V., 2007. The constructive, destructive, and reconstructive power of social norms. *Psychol. Sci.* 18 (5), 429–434.
- Sims, R., Schaeffer, R., Creutzig, F., Cruz-Núñez, X., D'Agosto, M., Dimitriu, D., Figueroa Meza, M.J., Fulton, L., Kobayashi, S., Lah, A.M., Newman, P., Ouyang, M., Schauer, J.J., Sperling, D., Tiwari, G., 2014. Transport. In: Edenhofer, O., Pichs-Madruga, R., Sokona, Y., Farahani, E., Kadner, S., Seyboth, K., Adler, A., Baum, I., Brunner, S., Eickemeier, P., Kriemann, B., Savolainen, J., Schlömer, S., von Stechow, C., Zwickel, T., Minx, J.C. (Eds.), *Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. pp. 603–650.

Sorrell, S., 2010. Energy, economic growth and environmental sustainability: five propositions. *Sustainability* 2, 1784–1809.

Thiel, C., Nijs, W., Simoes, S., Schmidt, J., van Zyl, A., Schmid, E., 2016. The impact of the EU car CO2 regulation on the energy system and the role of electro- mobility to achieve transport decarbonisation. *Energy Policy* 96, 153–166. <http://dx.doi.org/10.1016/j.enpol.2016.05.043>.

Turrentine, T.S., Kurani, K.S., 2007. Car buyers and fuel economy? *Energy Policy* 35 (2), 1213–1223. <http://dx.doi.org/10.1016/j.enpol.2006.03.005>.



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