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Reducing CO_2 emissions from road transport in the European Union: An evaluation of policy options

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1. Introduction

Adopted in October 2014, the European Union's 2030 climate and energy framework established a binding target for GHG emissions of 40% below 1990 levels by 2030.[1] It has two components. Sectors covered by the EU emission trading system (ETS) must reduce emissions to 43% below a 2005 baseline by 2030. Non-ETS sectors, which include transport, buildings, and agriculture, must reduce emissions to 30% below a 2005 baseline in 2030. Of the non-ETS sectors, transport (including road, rail and inland waterways) is the largest contributor of GHG emissions. Radically reducing emissions from transport is essential to meeting the 2030 climate goals.[2]

This paper describes and evaluates potential low-carbon road transport policies for achieving the 2030 target for non-ETS sectors. It focuses on CO_2 from light-duty vehicles (LDV), which include passenger cars and vans, and heavy-duty vehicles (HDV), which include medium trucks, heavy trucks, and buses. Together, LDVs and HDVs account for 95% of GHG emissions from non-ETS transport[3] and one-fifth of total EU GHG emissions, and CO_2 accounts for 99% of GHG emissions from road transport.

Specifically, the paper:

- Separately summarizes the impacts of CO_2 standards for LDVs and HDVs
- Compares the marginal benefits of moderate and stringent CO_2 standards, including a policy option to reduce the gap between laboratory and real-world fuel consumption
- Evaluates direct CO_2 emissions, which are the focus of the 2030 climate target, as well as indirect emissions impacts of electric vehicles and biofuels
- Constructs sequential "narratives" (policy pathways) that allow comparison of the marginal benefits of individual policies as well as the impacts of multiple policies combined.

2. Methods

POLICY OPTIONS FOR LOW-CARBON ROAD TRANSPORT

We developed one or more policy options within each of six categories: inclusion of road transport in the EU ETS, LDV efficiency, HDV efficiency, electric-drive vehicles, biofuels, and fuel taxation. We then ordered and sequentially combined these policy options to construct the "narratives" described in the following section.

Inclusion of road transport in the EU ETS

One proposal for addressing road transport GHG emissions has been to include the sector in the EU ETS, effectively putting a price on GHG emissions from the combustion of fuels for road transport.[4] Based on an

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[1] European Commission (2016). "2030 climate & energy framework." Accessed 4 Apr 2016 at http://ec.europa.eu/clima/policies/strategies/2030/index_en.htm

[2] Transport & Environment (2016). How the European car industry plans to meet the climate challenge. Retrieved from http://www.transportenvironment.org/publications/how-european-car-industry-plans-meet-climate-challenge

[3] Domestic aviation emissions are covered by the EU ETS.

[4] ExxonMobil Petroleum & Chemical BVBA (2015). "Perspectives on the future of European transport." Retrieved from http://exxonmobil.com/Europe-English/Files/EU_Transportation.pdf; Martin, I. (2013). "RE: DG Climate Action consultation on the report from the Commission to the European Parliament and the Council – The state of the European carbon market in 2012." Royal Dutch Shell Plc. Retrieved from http://ec.europa.eu/clima/consultations/docs/0017/organisations/shell_en.pdf; Achtnicht, M., von Graevenitz, K., Koesler, S., Löschel, A., Schoeman, B., Angel Tovar Reanos, M. (2015) "Including road transport in the EU-ETS – An alternative for the

Table 1. Adjustment from NEDC to WLTP targets for passenger cars

Test cycle for vehicle certification	Variable			Moderate targets		Stringent targets		NTE	
		2014	2021	2025	2030	2025	2030	2025	2030
NEDC	Target [g/km]	**123**	95	78	60	68	42		
	Real-world gap [%]	38%	49%						
	Real-world CO_2 [g/km]	170	142						
WLTP	Target [g/km]		**109**	**90**	**69**	**78**	**48**	**78**	**48**
	Real-world gap [%]		23%	31%	31%	31%	31%	15%	15%
	Real-world CO_2 [g/km]		134	118	90	102	63	90	55
Adjustment from NEDC to WLTP targets				115%					

Bold indicates nominal targets for the active certification test cycle.

ETS certificate price of €5 per ton of CO_2, including road transport in the ETS would translate to an effective fuel tax of 1 Euro cent per liter.[5]

Light-duty vehicle efficiency

We developed four policy options for CO_2 standards that promote the efficiency of new LDVs.

Current policies

Under adopted EU standards, new cars and vans must meet targets of 95 g/km in 2021 and 147 g/km in 2020, respectively, as measured on the NEDC test cycle. The ICCT has documented an increasing gap between these official CO_2 values and real-world performance, from 8% in 2001 to 38% in 2014.[6] Under current policies, this gap could increase to 49% in 2020 if the NEDC test cycle were to continue being used for official CO_2 certification.[7]

Moderate targets

In April 2013, the European Parliament asked the European Commission to provide by the end of 2016 an impact assessment of LDV CO_2 standards with an indicative range of 68-78 g/km in 2025, as measured by the NEDC.[8] Assuming a conversion factor of 1.15 from NEDC to WLTP,[9] the 'Moderate targets' scenario assumes a WLTP target of 90 g/km for cars in 2025 (78 g/km on NEDC), tightening to 69 g/km in 2030 (60 g/km on NEDC), and equivalent percent reductions for vans.[10] The 'Moderate targets' scenario assumes that a switch to WLTP in 2017/18 decreases the real-world fuel consumption gap from 49% under the NEDC (with a 2021 target of 95 g/km) to 23% under the WLTP (with a 2021 target of 109 g/km), thereby improving real-world emissions from 142 g/km (under the NEDC) to 134 g/km (under the WLTP). The nominal and real-world targets for the 'Moderate targets', 'Stringent targets', and 'NTE' scenarios are shown in Table 1.[11]

Stringent targets

The 'Stringent targets' scenario assesses the impacts of a 78 g/km WLTP target for cars in 2025 (60 g/km on NEDC), tightening to 48 g/km in 2030 (42 g/km on NEDC) (Table 1).[12] As in the 'Moderate targets' scenario, similar percentage reductions are assumed for vans.

Stringent targets and not-to-exceed limit

The 'High ambition plus NTE' scenario evaluates the impact of adding a not-to-exceed (NTE) limit of 15% starting

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future?" ZEW. Retrieved from http://ftp.zew.de/pub/zew-docs/gutachten/RoadTransport-EU-ETS_ZEW2015.pdf

[5] Mock, P., Tietge, U., German, J., and Bandivadekar, A. (2014). "Road transport in the EU Emissions Trading System: An engineering perspective." Washington DC: International Council on Clean Transportation. Retrieved from http://www.theicct.org/sites/default/files/publications/ICCT_EU-ETS-perspective_20141204.pdf

[6] Tietge, U., Zacharof, N., Mock, P., Franco, V., German, J., Bandivadekar, A., Ligterink, N., and Lambrecht, U. (2015). "From Laboratory to Road: A 2015 Update of Official and "Real-World" Fuel Consumption and CO2 Values for Passenger Cars." ICCT, TNO and IFEU. Retrieved from http://www.theicct.org/laboratory-road-2015-update

[7] Ibid.

[8] Mock, Peter (2013, May 5). "EU vote on cars CO2: 95 g/km in 2020, 68-78 g/km in 2025." Washington DC: International Council on Clean Transportation. Retrieved from http://www.theicct.org/blogs/staff/eu-vote-cars-co2

[9] According to ICCT's assessment, the adjustment factor from an NEDC to a WLTP target from a technical point of view should not be higher than 1.08. At the same time, it is likely that the adjustment factor from the European Commission's NEDC-WLTP correlation exercise will be closer to 1.15, which is why a factor of 1.15 is assumed in this analysis. Source: Mock, P., Kühlwein, J., Tietge, U., Franco, V., Bandivadekar, A., and German, J. (2014). "The WLTP: How a new test procedure for cars will affect fuel consumption values in the EU." Washington DC: International Council on Clean Transportation. Retrieved from http://www.theicct.org/wltp-how-new-test-procedure-cars-will-affect-fuel-consumption-values-eu

[10] Hill, Nikolas (2016). "SULTAN modelling to explore the wider potential impacts of transport GHG reduction policies in 2030." Prepared by Ricardo Energy & Environment for the European Climate Foundation. Retrieved from http://europeanclimate.org/wp-content/uploads/2016/02/ECF-Transport-GHG-reduction-for-2030_Final_Issue21.pdf

[11] Tietge, U., Zacharof, N., Mock, P., Franco, V., German, J., Bandivadekar, A., Ligterink, N., and Lambrecht, U. (2015). "From Laboratory to Road: A 2015 Update of Official and "Real-World" Fuel Consumption and CO2 Values for Passenger Cars." ICCT, TNO and IFEU. Retrieved from http://www.theicct.org/laboratory-road-2015-update

[12] Hill, Nikolas (2016). "SULTAN modelling to explore the wider potential impacts of transport GHG reduction policies in 2030." Prepared by Ricardo Energy & Environment for the European Climate Foundation. Retrieved from http://europeanclimate.org/wp-content/uploads/2016/02/ECF-Transport-GHG-reduction-for-2030_Final_Issue21.pdf

in 2025. Such a limit would set a maximum legal difference between CO$_2$ emissions under reasonable real-world driving conditions and laboratory tests under the WLTP. Compliance with the NTE limit would be evaluated through confirmatory testing of in-production vehicles.

Heavy-duty vehicle efficiency

2020 introduction

The EU is expected to require mandatory CO$_2$ certification of HDVs starting in 2018. Considering this certification start date, HDV CO$_2$ standards could be introduced as early as 2020. Under this scenario, HDV CO$_2$ standards are assumed to require 3% annual improvements from 2020 to 2030. This assumption translates to a 26% reduction in CO$_2$ from new HDVs over the period 2020 to 2030.[13]

2025 introduction

Alternatively, if HDV CO$_2$ standards were introduced starting in 2025,[14] such standards might require 3% annual improvements from 2025 to 2030. This assumption translates to a 14% reduction in CO$_2$ from new HDVs in 2030 compared to a 2025 baseline.

Electric-drive vehicles

Current policies

While some markets have substantially higher EV market share (Norway had ~20% and the Netherlands had ~6% in 2015), most European markets had EV sales shares of less than 1% in 2015. On average, the EU had an EV market share of about 1%, including BEVs, PHEVs, and FCEVs. In the current policies scenario, the EV market share is conservatively assumed to remain at 1% in 2030. This conservative baseline assumption is intended to give credit to policies in the e-drive transition scenario for increased EV uptake rather than assume that EV sales will increase regardless. In addition, this assumption acknowledges that much of the EV uptake to date is driven by fiscal and non-fiscal incentives, and without these supporting policies, there is no guarantee that EVs will capture a substantial share of the LDV market.

E-drive transition

This scenario assesses the impacts of a decades-long transition to electrify the LDV fleet by strengthening and expanding international best practice policies to spur electric-drive (e-drive) vehicle deployment. Norway and the Netherlands have already adopted several of these policies and are now seeing “electric vehicle deployment that is more than ten times the international average” as identified in a survey of efforts to establish a global market for electric vehicles (EVs).[15] Policy actions in this scenario include consumer incentives, support for charging infrastructure, and continued support for R&D, driven by aggressive EV deployment goals.[16] Consistent with the results of this global survey, this analysis assumes e-drive vehicles account for 23% of new LDV sales in the EU by 2030 (including 8.8% plug-in hybrids, 12.8% battery electric, and 1.2% hydrogen fuel cell vehicles).[17]

Biofuels

Current policies

Under current policies, we assume first generation (1G) biofuels will reach 7% blending in 2020 and remain constant thereafter.[18] We assume the expansion of ethanol and biodiesel from current blend levels will be proportional to their current blend levels. Given current blend levels of 3.4% for ethanol in petrol and 5.3% for biodiesel in diesel, we assume 5.2% ethanol in petrol and 8% biodiesel in diesel to reach 7% blending overall.[19] We note that 8% blending of biodiesel in diesel exceeds the current EU blend limit[20] but that this may occur as a result of use of higher biodiesel blends such as B20 or B100.[21] We assume a split of 45% starch ethanol and 55% sugar ethanol for the 1G ethanol category based on a 2016 projection of feedstock use.[22] Second generation (2G) biofuels reach 0.5% in 2020 and remain constant thereafter. We assume this is 75% cellulosic ethanol and 25% cellulosic/waste-oil diesel

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[13] The scenarios for HDV standards consider only improvements to new HDV efficiency rather than in-use improvements. In-use improvements (such as ITS, green freight, and driver training) could potentially result in additional benefits; however, these in-use improvements are less likely than new vehicle standards to have fleetwide emission benefits (allowing time for vehicle turnover).

[14] While some might consider a later implementation date to be more realistic, HDV standards would have to be implemented at least several years before 2030 to have a meaningful impact toward the 2030 climate target.

[15] Lutsey, Nic (2015). “Transition to a global zero-emission vehicle fleet: A collaborative agenda for governments.” Washington DC: International Council on Clean Transportation. Retrieved from http://www.theicct.org/transition-global-zero-emission-vehicle-fleet-collaborative-agenda-governments

[16] While not all of these actions have been undertaken in each leading EV market, these actions have been identified as international best practice policies to promote EVs. Each market should choose the policies that are best suited to its socioeconomic, political and geographic characteristics.

[17] Ibid.

[18] Hill, Nikolas (2016). “SULTAN modelling to explore the wider potential impacts of transport GHG reduction policies in 2030.” Prepared by Ricardo Energy & Environment for the European Climate Foundation. Retrieved from http://europeanclimate.org/wp-content/uploads/2016/02/ECF-Transport-GHG-reduction-for-2030_Final_Issue21.pdf

[19] Ibid.

[20] Kampman, B. (CE Delft), Verbeek, R. (TNO), van Grinsven, A. (CE Delft), van Mensch, P. (TNO), Croezen, H. (CE Delft), and Patuleia, A. (TNO) (2013). “Bringing biofuels on the market: Options to increase EU biofuels volumes beyond the current blending limits.” Retrieved from https://ec.europa.eu/energy/sites/ener/files/documents/2013_11_bringing_biofuels_on_the_market.pdf

[21] Higher biodiesel blends could take longer to materialize due to vehicle and infrastructure requirements.

[22] Flach, B., Lieberz, S., Rondon, M., Williams, B., and Teiken, C. (2015). “EU Biofuels Annual 2015.” GAIN Report Number: NL5028. Retrieved from http://gain.fas.usda.gov/Recent%20GAIN%20Publications/Biofuels%20Annual_The%20Hague_EU-28_7-15-2015.pdf

Table 2. Assumed biofuel shares of petrol and diesel-equivalent fuels

Scenario	Conventional fuel	Biofuel	2015	2020	2025	2030
Current policies	**Petrol**	Starch Ethanol	1.5%	2.3%	2.3%	2.3%
		Sugar Ethanol	1.9%	2.9%	2.9%	2.9%
		Cellulosic Ethanol	0.0%	1.0%	1.0%	1.0%
	Diesel	Vegetable oil-based Biodiesel	5.2%	8.0%	8.0%	8.0%
		Cellulosic/Waste-oil Diesel substitute	1.0%	1.2%	1.2%	1.2%
New fuels	**Petrol**	Starch Ethanol	1.5%	1.5%	1.5%	1.5%
		Sugar Ethanol	1.9%	1.9%	1.9%	1.9%
		Cellulosic Ethanol	0.0%	1.0%	4.4%	7.7%
	Diesel	Vegetable oil-based Biodiesel	5.2%	5.2%	5.2%	5.2%
		Cellulosic/Waste-oil Diesel substitute	1.0%	1.2%	2.0%	2.7%

Table 3. Definition of low-carbon transport narratives

Narrative	Policy category					
	ETS	**LDV EFFICIENCY**	**HDV EFFICIENCY**	**E-DRIVE**	**BIOFUELS**	**FUEL TAXES**
1. Baseline	*Not included*	*Current policies*	*None*	*Current policies*	*Current policies*	*Current taxes*
2a. ETS only	**ETS**	*Current policies*	*None*	*Current policies*	*Current policies*	*Current taxes*
2b. Moderate LDV efficiency	**Not included**	**Moderate targets**	*None*	*Current policies*	*Current policies*	*Current taxes*
2c. High LDV efficiency	*Not included*	**Stringent targets**	*None*	*Current policies*	*Current policies*	*Current taxes*
2d. High LDV efficiency NTE	*Not included*	**Stringent targets and NTE**	*None*	*Current policies*	*Current policies*	*Current taxes*
3a. Moderate HDV efficiency	*Not included*	*Stringent targets and NTE*	**2025 introduction**	*Current policies*	*Current policies*	*Current taxes*
3b. High HDV efficiency	*Not included*	*Stringent targets and NTE*	**2020 introduction**	*Current policies*	*Current policies*	*Current taxes*
4. Electrification	*Not included*	*Stringent targets and NTE*	*2020 introduction*	**E-drive transition**	*Current policies*	*Current taxes*
5. Biofuels	*Not included*	*Stringent targets and NTE*	*2020 introduction*	*E-drive transition*	**New fuels**	*Current taxes*
6. Fuel taxation	*Not included*	*Stringent targets and NTE*	*2020 introduction*	*E-drive transition*	*New fuels*	**New taxes**

Italics indicate no change from previous narrative. **Bold** indicates change from previous narrative. Narrative fill colors will appear in figure legends.

substitute. In addition, we assume 2 million tonnes of oil equivalent (Mtoe) biodiesel from waste oils is produced in each year.

New fuels

In the 'New fuels' scenario, we assume 1G biofuels are capped at 2015 levels (3.4% ethanol in petrol; 5.2% biodiesel in diesel).[23] For 2G fuels, we assume a linear increase in blend levels from 0.5% in 2020 to 4% in 2030. As above, we assume that 75% of 2G fuels are cellulosic ethanol and 25% are Fischer-Tropsch (F-T) renewable diesel; and in addition, that 2 Mtoe biodiesel from waste oils is produced in each year. Table 2 summarizes the assumed biofuel shares of petrol and diesel-equivalent fuels for each biofuels scenario.

Fuel taxes

Current taxes

Current fuel taxes in the EU vary substantially across member states, from 0.36 to 0.75 Euros per liter for petrol and from 0.33 to 0.67 Euros per liter for diesel fuel.[24] These fuel taxes are reflected in the current and projected baseline.

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[23] Hill, Nikolas (2016). "SULTAN modelling to explore the wider potential impacts of transport GHG reduction policies in 2030." Prepared by Ricardo Energy & Environment for the European Climate Foundation. Retrieved from http://europeanclimate.org/wp-content/uploads/2016/02/ECF-Transport-GHG-reduction-for-2030_Final_Issue21.pdf

[24] European Environment Agency (2016). "Fuel prices." Accessed 4 Apr 2016 at http://www.eea.europa.eu/data-and-maps/indicators/fuel-prices-and-taxes/assessment-5

New taxes

In the absence of a specific proposal to strengthen fuel taxes across the EU, the 'new taxes' scenario assesses the potential impact of all member states increasing fuel taxes by an average of 20 Euro cents per liter for petrol and diesel fuel. Such a tax is assumed to phase in gradually, starting at 5 Euro cents in 2020, increasing to 10 Euro cents in 2025, and reaching 20 Euro cents in 2030.

NARRATIVES

For the purpose of evaluating the numerous possible policy combinations, we've constructed ten alternate "narratives" illustrating different possible policy trajectories (Table 3). Lettered narratives with the same number (e.g. '2a' and '2b') represent mutually exclusive futures: for example, the 'ETS only' narrative includes the road transport sector within the ETS but assumes no further adoption of low-carbon transport policies. Narratives are numbered sequentially in order of ease of implementation (starting with 'ETS only', then 'LDV efficiency', etc.). Within each number, the narrative with the letter closest to 'z' represents the most ambitious.

As illustrated in Table 3, narratives with higher numbers are additive, meaning they include the most ambitious option (letter) of each lower numbered narrative. Thus, narrative '6. Fuel taxation' includes all of the policies in narratives '2d', '3b', '4', and '5', as well as the policy for 'New taxes'. Further explanation of narratives is provided in Appendix D.

3. Results

DIRECT CO_2 EMISSIONS FROM 2005-2030

Figure 2 compares direct CO_2 emissions from LDVs and HDVs by policy narrative from 2005-2030.

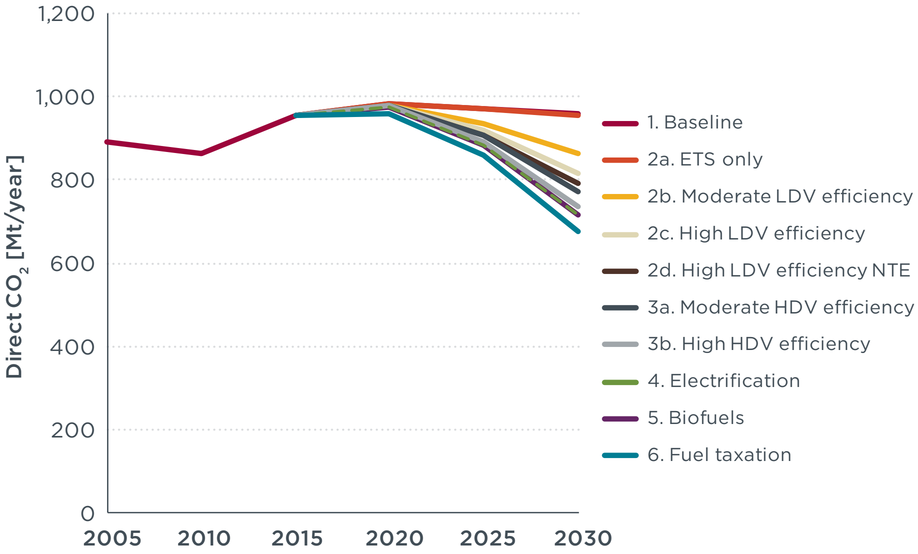

Figure 1. Direct CO_2 from LD and HD vehicles by narrative, 2005-2030. Numbered narratives are additive, such that narrative '6' includes 'Fuel taxation', 'Biofuels', 'Electrification', 'High HDV efficiency', and 'High LDV efficiency NTE.'

In the baseline narrative, direct emissions are projected to remain relatively flat from 2015-2030, with adopted LDV CO_2 standards largely offsetting projected growth in passenger and freight activity. Importantly, the numbered narratives are additive: that is, if narrative '6. Fuel taxation' were implemented (which includes all of the policies in narratives '2d', '3b', '4', and '5', as well as new fuel taxes), direct emissions in 2030 could be reduced to 677 $MtCO_2$ (hereafter abbreviated as Mt), or 24% below a 2005 baseline.

DIRECT CO_2 IMPACTS IN 2030

Figure 2 compares emissions estimates for each narrative in 2030 with the 2005 baseline. The short, transparent bars indicate the marginal CO_2 reduction from the previous narrative, starting with a comparison of the 'ETS only' narrative ('2a') against the baseline in 2030. Including road transport in the EU ETS would have a very small impact due to the low carbon price that is observed today (equivalent to about 1 Euro cent per liter fuel). In contrast, the 'Moderate LDV efficiency' narrative ('2b') could reduce emissions by 93 Mt compared to the 'ETS only' narrative, and 95 Mt[25] compared to the 2030 baseline. More stringent LDV targets ('2c') could reduce direct emissions by an additional 49 Mt in 2030 compared to moderate targets ('2b'), and adding a not-to-exceed limit of 15% to LDV standards ('2d') could further augment these reductions by 25 Mt. In total, ambitious LDV standards that include a not-to-exceed limit could reduce 169 Mt compared to the baseline in 2030 (narrative '1' minus '2d'), about 80% greater than the impact of moderate LDV CO_2 targets without such a limit.

Introduction of HDV standards in 2025 ('3a') could avoid 17 Mt in 2030. Earlier introduction of HDV standards in 2020 ('3b') could avoid 55 Mt by 2030 – more than three times the benefits of introduction in 2025. Assuming ambitious actions have already been taken to promote LDV and HDV efficiency ('2d' and '3b'), electrifying the LDV market ('4') could avoid 19 Mt in 2030. Expanding the deployment of 2G

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[25] Reported estimates are not rounded, whereas figures show estimates rounded to the nearest ton.

biofuels ('5') would only marginally reduce direct emissions, since most of the gains from 2G biofuels are classified as indirect emissions (see Figure 4). Finally, strengthened fuel taxes ('6') could reduce another 39 $MtCO_2$ in 2030, complementing the impacts of CO_2 standards, electrification, and biofuels.

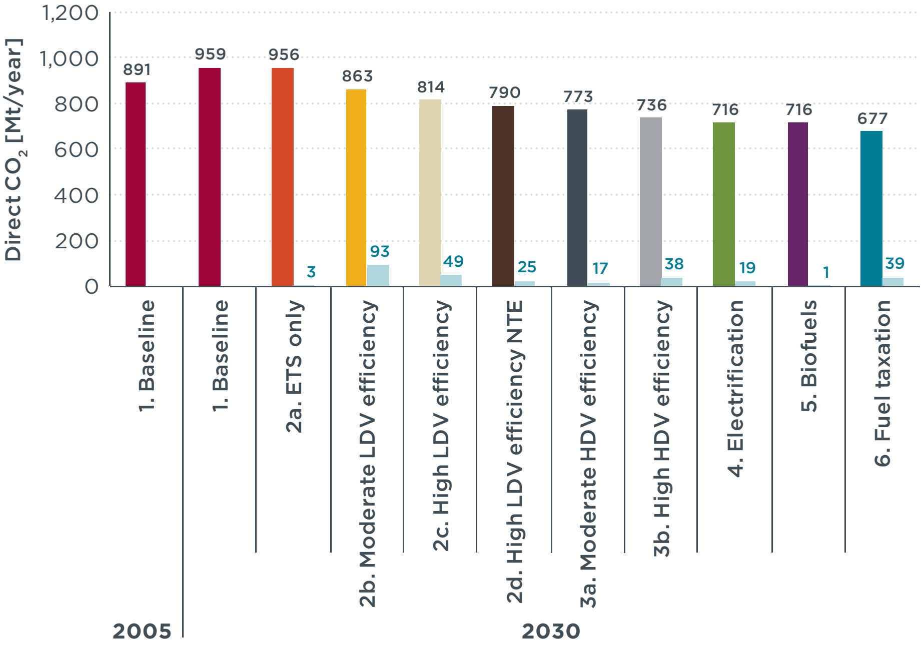

Figure 2. Direct CO_2 from LD and HD vehicles by narrative, 2005 and 2030. Solid bars indicate direct emissions for each narrative. Transparent bars indicate marginal CO_2 reductions (reflecting the benefits of new policies in a given narrative), starting with a comparison against the 2030 baseline.

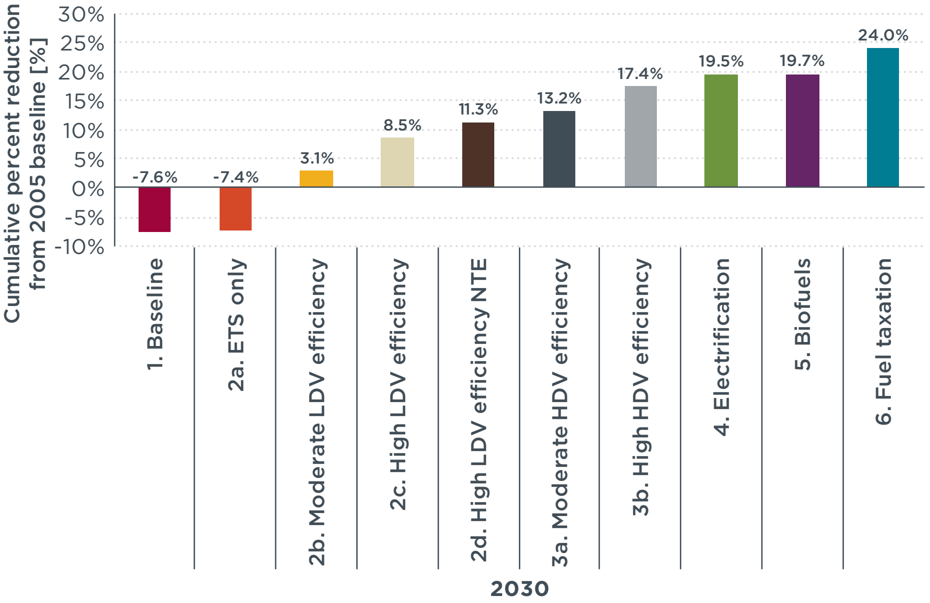

Figure 3. Cumulative percent reduction in direct CO_2 from 2005 baseline by narrative, 2030

DIRECT CO_2 COMPARED TO A 2005 BASELINE

Figure 3 reframes the absolute emissions results shown in Figure 2 in terms of a cumulative percent reduction from a 2005 baseline. Under the 'ETS only' narrative, direct emissions would be an estimated 7.4% higher in 2030 than in 2005.

DIRECT AND INDIRECT CO_2 IN 2030

Figure 4 summarizes the direct and indirect emissions impacts of each policy narrative in 2030. For policies that focus on reducing petrol and diesel consumption through efficiency or pricing measures (added in narratives numbered '2', '3' and '6'), the marginal indirect emissions benefits tend to be proportional to the direct benefits. For LDV electrification ('4'), indirect emissions from electricity generation would offset direct emissions benefits by 3 Mt in 2030. In contrast, for biofuels ('5'), considering indirect emissions (including production emissions and ILUC relative to conventional fuels) increases the net emission benefit by 26 Mt in 2030. These gains are attributable to the fuel lifecycle benefits of second generation biofuels (in the 'New fuels' scenario) relative to first generation biofuels (which are projected to eclipse 2G shares under current policies).

4. Conclusions

This analysis yields a number of findings that are relevant to near-term decisions on EU climate policy. These findings are summarized by policy category as follows:

- **Baseline:** Assuming no progress beyond current policies, we estimate a 7.6% increase in direct CO_2 from LDVs and HDVs over the period 2005 to 2030. In contrast, a recent Ricardo-AEA study estimated a 16% decrease in business-as-usual transport GHG emissions.[26] To

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[26] Hill, Nikolas (2016). "SULTAN modelling to explore the wider potential impacts of transport GHG reduction policies in 2030." Prepared by Ricardo Energy & Environment for the European Climate Foundation. Retrieved from http://europeanclimate.org/wp-content/uploads/2016/02/ECF-Transport-GHG-

the extent that regulators use these studies to inform their design of low-carbon transport policies, an increasing baseline indicates a greater level of policy action is needed to meet the 2030 climate target for non-ETS sectors.

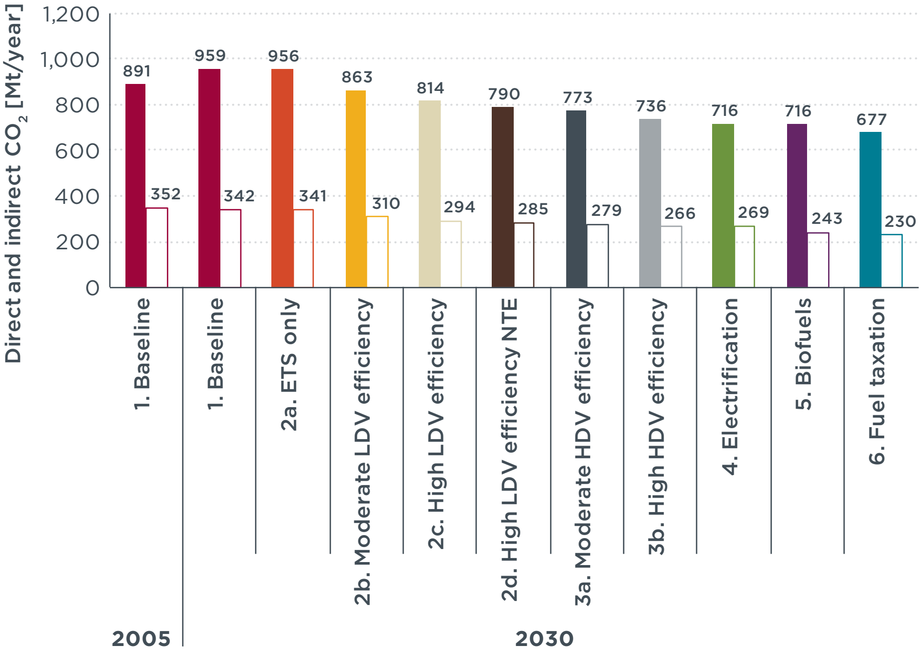

Figure 4. Direct and indirect CO$_2$ emissions from LD and HD vehicles by narrative, 2030. Solid bars indicate direct emissions, while grey filled bars indicate indirect emissions.

- **ETS inclusion:** An ‘ETS only’ approach is entirely insufficient considering the magnitude of GHG reductions targeted and the minimal fuel price impact of including road transport in the ETS. Even the ‘Fuel taxation’ narrative, at roughly 20 times the stringency of the ‘ETS only’ approach in terms of the assumed increase in fuel prices, would impact baseline emissions by less than 5% in 2030.[27]
- **LDV CO$_2$ standards:** While moderate LDV CO$_2$ targets could avoid 95 Mt in 2030, stronger targets could avoid 144 Mt in 2030 – equivalent to a more than 50% increase in emission benefits.
- **Real-world fuel consumption gap:** On top of the benefits of LDV CO$_2$ targets, closing the gap between laboratory and real-world fuel consumption to 15% could avoid 25 Mt in 2030.
- **HDV CO$_2$ standards:** Introducing HDV CO$_2$ standards in 2025 could avoid 17 Mt in 2030. Early introduction in 2020 could avoid 55 Mt in 2030 – more than three times the benefits of a 2025 introduction.
- **Electrification:** Transitioning the LDV fleet to electric-drive vehicles could avoid 19 Mt in 2030, even after assuming internal combustion and hybrid vehicles meet stringent CO$_2$ targets. Efforts to decarbonize the grid could further limit the indirect emissions from electricity supplied to EVs.
- **Biofuels:** New biofuel policies are not an attractive option if only aiming to reduce direct transport emissions, since biofuels and conventional fuels have similar direct combustion emission factors. Considering fuel lifecycle impacts, however, demonstrates that expanded deployment of 2G biofuels would have significant benefits compared to 1G biofuels (26 Mt in 2030), since 2G biofuels have lower indirect emissions.
- **Combined policies:** Implementing the most ambitious narrative considered (narrative ‘6’, which includes ‘High LDV efficiency NTE’, ‘High HDV efficiency’, ‘Biofuels’, ‘Electrification’, and ‘Fuel taxation’) could reduce direct emissions by 282 Mt compared to the baseline in 2030, equivalent to 24% below a 2005 baseline. Considering the 30% target for non-ETS sectors, the transport sector may need to follow an “all-of-the-above” approach for developing cost-effective low-carbon policies.

This analysis did not intend to capture all possible policy options for low-carbon transport, instead focusing on a more narrow set of technology options for clean vehicles and fuels, as well as fuel pricing policies due to their potential relevance to the EU ETS. Other studies have evaluated the potential impacts of additional measures, including improved infrastructure for public and non-motorized transport, freight intermodality, and driver training, among others.[28] Some of these measures could be combined with those evaluated in this ICCT study to achieve a 30% reduction in road transport GHG emissions by 2030.

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[27] The marginal benefit of fuel taxation alone (‘5’ minus ‘6’) would be somewhat larger if counted before any other policies, although far below the level of reduction targeted for non-ETS sectors in 2030.

[28] For example, Ricardo-AEA evaluated the potential impacts of a rapid deployment of Communicating Intelligent Transport Systems (C-ITS) technologies, assuming potential fleetwide efficiency improvements of 0.8% to 1.7% in 2030 depending on the vehicle type (Hill, 2016).

Table 4. Detailed CO_2 emissions by category and narrative

Emissions category / Narrative	CO_2 emissions from LDV and HDV [Mt]		Marginal reduction in 2030 [Mt]	Combined reduction of narratives in 2030 [Mt]	Cumulative percent reduction from 2005 baseline [%]	Cumulative percent reduction from 2030 baseline [%]
	2005	2030	2030	2030	2030	2030
DIRECT CO_2						
1. Baseline	891	959			-7.6%	0.0%
2a. ETS only		956	3	3	-7.4%	0.3%
2b. Moderate LDV efficiency		863	93	95	3.1%	9.9%
2c. High LDV efficiency		814	49	144	8.5%	15.0%
2d. High LDV efficiency NTE		790	25	169	11.3%	17.6%
3a. Moderate HDV efficiency		773	17	185	13.2%	19.3%
3b. High HDV efficiency		736	38	223	17.4%	23.3%
4. Electrification		716	19	242	19.5%	25.3%
5. Biofuels		716	1	243	19.7%	25.4%
6. Fuel taxation		677	39	282	24.0%	29.4%
INDIRECT CO_2						
1. Baseline	352	342			2.7%	0.0%
2a. ETS only		341	1	1	2.9%	0.3%
2b. Moderate LDV efficiency		310	31	32	11.8%	9.4%
2c. High LDV efficiency		294	16	49	16.5%	14.2%
2d. High LDV efficiency NTE		285	8	57	18.8%	16.6%
3a. Moderate HDV efficiency		279	6	63	20.5%	18.4%
3b. High HDV efficiency		266	13	76	24.4%	22.3%
4. Electrification		269	-3	73	23.5%	21.4%
5. Biofuels		243	26	99	30.9%	29.0%
6. Fuel taxation		230	13	112	34.6%	32.9%
DIRECT AND INDIRECT CO_2						
1. Baseline	1242	1301			-4.7%	0.0%
2a. ETS only		1297	4	4	-4.4%	0.3%
2b. Moderate LDV efficiency		1173	124	128	5.5%	9.8%
2c. High LDV efficiency		1108	65	193	10.8%	14.8%
2d. High LDV efficiency NTE		1075	33	226	13.4%	17.3%
3a. Moderate HDV efficiency		1053	23	248	15.3%	19.1%
3b. High HDV efficiency		1002	51	299	19.4%	23.0%
4. Electrification		986	16	315	20.7%	24.2%
5. Biofuels		959	27	342	22.8%	26.3%
6. Fuel taxation		907	52	394	27.0%	30.3%

Appendix

A. DETAILED EMISSION RESULTS

Table 4 includes the detailed emissions results that appear in the preceding figures. Since emissions estimates are rounded to the nearest million metric tons (Mt), some values may not exactly match if re-calculated using rounded values. Results are reported separately for direct/tank-to-wheel (TTW), indirect/well-to-tank (WTT), and direct and indirect combined/well-to-wheel (WTW). Blank cells indicate not applicable (for example, narrative results are only estimated for years after 2015). The following examples may help readers interpret the results:

- Baseline direct CO_2 emissions are

Table 5. Direct and indirect emissions by fuel type, including ILUC for biofuels

Conventional fuel	Fuel	TTW CO_2 (g/MJ)	WTT CO_2 (g/MJ)	WTW CO_2 (g/MJ)	Percent reduction from conventional fuel	
					TTW CO_2 (%)	WTW CO_2 (%)
Petrol	**Petrol**	73.4	17.2	90.6		
	Starch Ethanol	71.3	(21.6)	49.7	3%	45%
	Sugar Ethanol	71.3	(44.6)	26.7	3%	71%
	Cellulosic Ethanol	71.3	(73.6)	(2.3)	3%	103%
Diesel	**Diesel**	73.2	18.6	91.8		
	Vegetable oil-based Biodiesel	76.2	9.2	85.4	-4%	7%
	Cellulosic/Waste-oil Diesel substitute	72.6	(84.8)	(12.2)	1%	113%

Tank-to-wheel (TTW) emissions are commonly referred to as direct emissions.
Well-to-tank (WTT) emissions are commonly referred to as indirect emissions.
Well-to-wheel (WTW) emissions are equal to the sum of direct and indirect emissions.
Values in parentheses are negative.

projected to be 68 Mt higher in 2030 than in 2005 (959-891).

- While electrification ('4') would have direct emission benefits of 19 Mt in 2030, these benefits would be offset by 3 Mt due to indirect emissions from upstream electricity generation.

B. DIRECT AND INDIRECT EMISSIONS

Modeling of CO_2 emissions

Direct and indirect CO_2 emissions for LDVs and HDVs were estimated using the ICCT's Global Transportation Roadmap model,[29] which was initially calibrated to match IEA's energy balances for the EU-28 in 2010 as estimated in 2013.[30] For this analysis, historical baseline estimates of combined LDV and HDV CO_2 were replaced with those from the European Environment Agency (EEA) after subtracting 11 $MtCO_2$ for motorcycles.[31] These revised baseline estimates are within 1.5% of the previous 2010 baseline.

Carbon intensity of biofuels

While direct emissions are the focus of the ETS, this analysis considers both direct and indirect emissions in order to account for the fuel lifecycle impacts of low-carbon transport policies. Indirect emissions are especially important to consider for low-carbon fuel policies that promote 1G and 2G biofuels and electrification of road transport. For biofuels, indirect emissions are calculated as the net of production emissions and ILUC minus comparative fossil fuel emissions.

Indirect emissions are calculated as:

Indirect emissions = (production emissions + ILUC) – fossil fuel comparator

We took production emission values from typical emission values from the Renewable Energy Directive Annex V. For starch ethanol we used wheat ethanol (unspecified process fuel), for sugar ethanol we used sugarbeet, for cellulosic ethanol we used waste wood ethanol, for oil-based biodiesel we used rapeseed biodiesel, and for "Cellulosic/Waste-oil Diesel substitute" we used a combination of Fischer-Tropsch renewable diesel from waste wood and waste vegetable or animal oil biodiesel. For this category we assumed a split of 1/3 biodiesel, 2/3 renewable diesel. This was based on the current use of approximately 1.1 million tonnes of used cooking oil in biofuel,[32] a conversion efficiency of 0.96 to biodiesel, and a biodiesel energy content of 37.2 MJ/kg (these last two assumptions are from the UK Renewable Fuel Agency's default value spreadsheet), and an assumption that the "Cellulosic/Waste-oil Diesel substitute" category would account for 25% of all advanced biofuel in the EU. It seems reasonable to assume that more cellulosic ethanol will be used than cellulosic renewable diesel because the former is cheaper to produce; this assumption would result in a ratio of 9:2 cellulosic ethanol to cellulosic renewable diesel. The results of this analysis of direct and indirect emissions by fuel type are summarized in Table 5.

In Table 5, the biofuel TTW emission factors include biogenic carbon emissions; generally, within GHG inventory and lifecycle carbon accounting methodologies, these emissions are offset by carbon sequestration elsewhere in the fuel production lifecycle. TTW values were compared between Argonne

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[29] ICCT (2016, April). Global Transportation Roadmap Model. Documentation available from http://www.theicct.org/global-transportation-roadmap-model

[30] OECD/IEA (2013). "2010 Energy Balances."

[31] European Environment Agency (2015). "1.A.3.b - Road Transportation." *EEA greenhouse gas—data viewer*. Retrieved from http://www.eea.europa.eu/data-and-maps/data/data-viewers/greenhouse-gases-viewer

[32] Malins, C., Searle, S., Baral, A., Turley, D., and Hopwood, L. (2014). "Wasted: Europe's Untapped Resource." Prepared by ICCT and NNFCC for ECF. Retrieved from http://www.theicct.org/sites/default/files/publications/WASTED-final.pdf

National Laboratory's GREET model[33] and JEC's Tank-to-Wheels Report.[34] The GREET-derived TTW emission factors were taken from the "Results" sheet of the model. The bio-ethanol TTW emissions were assumed to be the same regardless of feedstock. The cellulosic/waste oil mix was a special case, as it was not a fuel mix included in the model. Therefore, a mix of 33% soy biodiesel (B100) and 66% forest-residue-derived renewable diesel (RD100) was assumed. The JEC results were taken from Table 3-1 of the report, which contained the main properties of the various fuels considered in the study. The TTW value of bio-ethanol (E100) was inferred via the TTW values of petrol and petrol E10. As with the GREET values, a mix of 33% biodiesel (FAME) and 66% Fischer-Tropsch renewable diesel was assumed.

Grid carbon intensity

To calculate indirect emissions from EVs, estimates of grid carbon intensity (grams CO$_2$ per MJ) were derived from IEA's World Energy Outlook (2014). Results were used for the New Policy scenario to reflect the expectation of additional progress (beyond the impacts of adopted policies) in decarbonizing the EU's power sector. Converting these estimates from g/kWh to g/MJ resulted in a value of 101 gCO$_2$/MJ in 2015 that decreases to 66 gCO$_2$/MJ in 2030.

C. FUEL PRICE ELASTICITIES

The potential impacts of increased fuel taxation were evaluated using fuel price elasticities for road passenger and freight demand. Passenger elasticities were assumed to apply to LDVs, and freight elasticities were assumed to apply to vans (LHDT), MHDT, and HHDT. These elasticities were not applied to buses. Average fuel price elasticity values were derived from a literature review of academic studies prepared for the UK Department for Transport, but considering results from many other countries: these values were -0.3 (with a range of mostly -0.1 to -0.5) for passenger demand and -0.33 (with a range of -0.25 to -0.4) for freight demand.[35] While this analysis conservatively applied average fuel price elasticity values, the authors of the literature review identified elasticity estimates of up to -0.79 for passenger demand (pertaining to holiday travel) and -1.07 for freight (from a literature review of papers using data collected before 1988).[36]

The percent change in fuel price with a 20 Euro cent per liter tax was derived from the average fuel price in December 2015 according to the European Environment Agency, and modeled as applying to both petrol and diesel fuels (rather than each fuel separately).[37] Given the differential between local air pollutant emissions from petrol and diesel vehicles, focusing a fuel tax increase on diesel fuel could result in additional environmental benefits.

D. ADDITIONAL EXPLANATION OF NARRATIVES

Narratives are lettered and numbered to facilitate two kinds of comparison:

1. Comparisons between lettered scenarios with the same number, which represent mutually exclusive policy choices. For example, a comparison of narratives '2b' and '2c' indicates the marginal benefit of setting ambitious LDV efficiency targets as opposed to moderate targets.
2. Comparisons between scenarios with different numbers, which yield the marginal impact of additive low-carbon transport policies. For example, a comparison of narrative '5' and '4' indicates the marginal benefit of new (bio)fuels, assuming stringent CO$_2$ standards have already been implemented for new LDVs and HDVs, and policy incentives have increased the uptake of electric-drive LDVs.

This approach treats most policy options as complementary rather than mutually exclusive, recognizing that progress needs to be made on many fronts in order to meet GHG reduction targets. For example, policymakers need not choose between implementing CO$_2$ standards for LDVs or HDVs: both policy options can be developed provided they are feasible and cost effective. Narratives are numbered roughly according to ease of implementation, favoring policy options that have a combination of historical precedent, political appeal, efficacy and cost-effectiveness; however, the order of implementation does not particularly matter when comparing the net impacts of multiple additive policy options.

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[33] Argonne National Laboratory (2015). "The Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation Model." 2015 version 1. Available from https://greet.es.anl.gov/index.php

[34] Hass, H., Huss, A., and Maas, H. (2013). "TANK-TO-WHEELS report version 4.a : WELL-TO-WHEELS ANALYSIS OF FUTURE AUTOMOTIVE FUELS AND POWERTRAINS IN THE EUROPEAN CONTEXT." Joint Research Centre of the European Commission, EUCAR and CONCAWE. Available from http://publications.jrc.ec.europa.eu/repository/handle/JRC85327

[35] Dunkerley, F., Rohr, C., and Daly, A. (2014). "Road traffic demand elasticities: A rapid evidence assessment." Prepared for Department for Transport by RAND Europe. Retrieved from https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/395119/road-traffic-demand-elasticities.pdf

[36] Ibid.

[37] European Environment Agency (2016). "Fuel prices." Accessed 4 Apr 2016 at http://www.eea.europa.eu/data-and-maps/indicators/fuel-prices-and-taxes/assessment-5