BRIEFING

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Green vehicle replacement programs as a response to the COVID-19 crisis: Lessons learned from past programs and guidelines for the future

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In light of lockdown measures to confine the spread of COVID-19, new vehicle sales have decreased substantially. In response, purchase premiums and vehicle replacement programs are being discussed as recovery measures for the automotive industry in many countries worldwide. Looking back, this briefing reviews the environmental benefits and economic efficiency of vehicle replacement programs implemented in response to the global financial crisis of 2007-2008, with a focus on the largest program by financial volume, the Umweltprämie in Germany. Looking forward, the briefing estimates the greenhouse gas (GHG) and nitrogen oxide (NO_x) impact of replacing an average 15-year-old passenger car today with (a) an average 2020 car, (b) a car with a maximum of 110 grams of CO_2 per kilometer (g CO_2/km), and (c) a battery electric car. To inform policies currently being considered, this work quantifies the GHG and pollutant emissions impact of potential vehicle replacement programs in the largest European vehicle markets.

VEHICLE REPLACEMENT PROGRAMS IN RESPONSE TO THE 2007-2008 GLOBAL FINANCIAL CRISIS

OVERVIEW

In response to the global financial crisis of 2007-2008, most major car producing countries issued vehicle replacement programs to support their domestic automotive industries. In vehicle replacement programs, purchase premiums are issued under the condition that an old vehicle is scrapped in return. In addition, some countries also provided purchase premiums without the requirement of trading in an old vehicle.

As summarized in Table 1 in descending order of supported vehicles sales, the governments of Japan, Germany, Spain, the United States, France, Italy, Russia, China, and the United Kingdom incentivized several hundred-thousand new vehicle sales each. These programs are described in more detail in the following sections.

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At a smaller scale, Greece, the Netherlands, Slovakia, Portugal, Romania, Austria, Ireland, Cyprus, and Luxembourg also issued vehicle replacement programs, purchase premiums, or combinations of both. In each of these countries, less than 100,000 new vehicle sales were supported by the 2009-2010 schemes.[1]

Table 1. Selection of passenger car and light commercial vehicle (LCV) purchase incentive programs as a response to the 2007-2008 global financial crisis, listed in descending order of supported vehicle sales. All currencies converted into € based on 2009 exchange rates.

Country	Duration	Scrappage	Type of vehicle		CO_2 emission or fuel efficiency threshold	Amount of incentive per vehicle	Supported car and LCV sales	Total budget
Japan	06/2009-03/2010	yes	car	new	no limit (CNG, electric, diesel), 2010 fuel efficiency standard (gasoline)	€1,900	2,800,000[a]	€2.8 billion[a]
			LCV	new	no limit	€3,000		
		no	car	new	no limit (CNG, electric, diesel), 15% higher than 2010 fuel eff. stand. (gasoline)	€750		
			LCV	new	no limit	€1,500		
Germany	01/2009-12/2009	yes	car	new	no limit	€2,500	1,930,000	€5.0 billion
				used	no limit	€2,500		
Spain	09/2008-07/2010	yes	car	new	120 g/km, 140 g/km[b]	interest free loan	240,000	€1.2 billion
				used	no limit	interest free loan		
			LCV	new	160 g/km	interest free loan		
				used	no limit	interest free loan		
	06/2009-12/2010	yes	car	new	120 g/km, 149 g/km[b]	€500[c]	480,000	€240 million[d]
				used	no limit	€500[c]		
			LCV	new	160 g/km	€500[c]		
				used	no limit	€500[c]		
United States	07/2009-11/2009	yes	car	new	22 mpg and 4 or 10 mpg higher fuel efficiency than replaced car	€2,400-€3,100	680,000	€2.0 billion
			light truck	new	higher fuel efficiency than replaced light truck[e]	€2,400-€3,100		
France	12/2008-12/2009	yes	car	new	160 g/km	€1,000	600,000	€600 million
			LCV	new	no limit	€1,000		
Italy	02/2009-12/2009	yes	car	new	140 g/km, (130 g/km for diesel cars)	€1,500	590,000[f]	unknown
			LCV	new	no limit	€2,500		
		no	car	new	no limit (LPG), 120 g/km (LPG)	€1,500-€2,000		
					no limit (CNG), 120 g/km (CNG)	€1,500-€3,500		
			LCV	new	no limit (LPG), 120 g/km (LPG)	€1,500-€2,000		
					no limit (CNG)	€4,000		
Russia	03/2010-03/2011	yes	car	new	no limit	€1,200	500,000	€580 million
China	01/2010-12/2010	yes	car	new	no limit	€680-€2,000	460,000	€680 million
			LCV	new	no limit	€680-€2,000		
United Kingdom	05/2009-03/2010	yes	car	new	no limit	€1,250[g]	400,000	€500 million
			LCV	new	no limit	€1,250[g]		

[a] including also heavy-duty vehicles
[b] with Electronic Stability Control (ESC) and three-way catalytic converter (TWC) or exhaust gas recirculation (EGR)
[c] some regional governments provided another €500; for new cars and LCVs, another €1,000 were paid by the manufacturer
[d] contribution of regional governments not included
[e] for category 1 and 2 trucks, the amount of incentive was based on the difference in fuel efficiency
[f] until August 2009
[g] another €1,250 were paid by the car manufacturer

1 IHS Global Insight, 'Assessment of the Effectiveness of Scrapping Schemes for Vehicles Economic, Environmental, and Safety Impacts', March 2010, https://circabc.europa.eu/sd/a/b34363fe-8903-4d9c-a2f1-aa38733f0500/report_scrapping_schemes_annex_en.pdf.

JAPAN

Within the Green Vehicle Purchasing Promotion Measures, in effect from 2009 through 2010, the Japanese government allocated ¥370 billion (€2.8 billion) to subsidize the purchase of about 2.8 million light- and heavy-duty new vehicles. The program consisted of both a vehicle replacement program and a purchase subsidy which did not require the retirement of an old vehicle. For new cars and LCVs, a premium of ¥250,000 (€1,900) and ¥400,000 (€3,000), respectively was granted if an at least 13-year-old car was replaced. To qualify for the program, new gasoline cars had to comply with the 2010 fuel efficiency standard, while new diesel cars had to comply with the 2005 pollutant emission regulation. Electric cars, including battery electric vehicles, plug-in hybrid electric vehicles, fuel cell electric vehicles, as well as those that ran on compressed natural gas (CNG) were supported without further conditions. New LCVs only had to comply with the 2005 pollutant emission regulation.

Without the retirement of an old vehicle, the subsidy was ¥100,000 (€750) for cars and ¥200,000 (€1,500) for LCVs. Here, new gasoline cars had to exceed the 2010 fuel efficiency standard by 15% and comply with the 4-star emission standard, while diesel cars still only had to comply with the 2005 pollutant emission regulation. New CNG, hybrid electric, and electric cars were supported without further conditions. New LCVs had to comply with the 2015 fuel efficiency standard and improve the NO_x or PM level by 15% of the 2005 standard.[2] Since only 730,000 of the supported car sales were linked to a vehicle replacement, the Green Vehicle Purchasing Promotion Measures were mainly a purchase premium program.[3]

GERMANY

The largest vehicle replacement program during the financial crisis by financial volume was issued by Germany. With €5 billion, the Umweltprämie (often referred to as Abwrackprämie) stimulated the sales of a total of 1.9 million cars (1.6 million new and 0.3 million used cars), with a premium of €2,500 per car. Differing from most of the programs in other countries, the subsidized new car purchases were not limited by any environmental criterion beyond meeting the already-required Euro 4 standard, except that a car more than 9 years old needed to be retired.[4]

SPAIN

From 2008 to 2010, the Spanish national government stimulated car and LCV sales by two separate vehicle replacement programs. Within the Vehículo Innovador-Vehículo Ecológico (VIVE) plan, the government allocated €1.2 billion to pay the interest rates of about 240,000 car and LCV purchases. The program subsidized the purchase of cars and LCVs meeting the following conditions: (a) the vehicle had to be new or no more than 5 years old; (b) the vehicle had to cost less than 20,000 euros; and (c) for a new or used vehicle a 12-year-old or 15-year-old vehicle, respectively, had to scrapped. Furthermore, new cars had to either emit less than 120 g CO_2/km or emit less than 140 g CO_2/km and be equipped with electronic stability control (ESC) and a three-way catalytic converter (TWC) for gasoline cars or an exhaust gas recirculation (EGR) system for diesel cars. For new LCVs, the type-approval CO_2 emission threshold was 160 g CO_2/km. After the first two tranches of the VIVE plan were exhausted in April 2009, it was complemented by the Plan 2000e. Until 2010, this program subsidized

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2 IHS Global Insight, 'Assessment of the Effectiveness of Scrapping Schemes for Vehicles Economic, Environmental, and Safety Impacts.'

3 Shigemi Kagawa et al., Better Cars or Older Cars?: Assessing CO_2 Emission Reduction Potential of Passenger Vehicle Replacement Programs, *Global Environmental Change* 23, no. 6 (December 2013): 1807–18, https://doi.org/10.1016/j.gloenvcha.2013.07.023.

4 Bundesamt für Wirtschaft und Ausfuhrkontrolle, 'Abschlussbericht Umweltprämie' (Eschborn, Germany, November 2010), http://www.bafa.de/bafa/de/wirtschaftsfoerderung/umweltpraemie/publikationen/ump_abschlussbericht.pdf.

another 480,000 new or second-hand car and LCV purchases by €500 from the national government (€240 million in total) plus €500 from some of the regional governments. With broader conditions compared to the VIVE plan, Plan 2000e supported the purchase of a new car (below 120 g CO_2/km or below 149 g CO_2/km and with ESC plus TWC/EGR) or LCV (below 160 g CO_2/km), or any up to 5-year-old used car or LCV. For a supported new or used vehicle, the purchase price could be up to €30,000, and a 10-year-old or 12-year-old vehicle, respectively, had to be scrapped. For new cars, an additional €1,000 incentive was paid by the car manufacturer. By the end of 2009, 92% of the cars purchased in the Plan 2000e were new.[5]

These two vehicle replacement schemes were part of a series of programs intended to encourage the replacement of older vehicles. The VIVE plan and Plan 2000e were preceded by the Renove Plan (1994-1996) and PREVER Program (1997-2007), and were succeeded by the PIVE (since 2012) and PIMA Aire programs (2013-2014).[6]

UNITED STATES

In June 2009, after both General Motors and Chrysler LLC had declared bankruptcy, the U.S. government initiated a short-term stimulus program of $2.9 billion (€2.0 billion), the Consumer Assistance to Recycle and Save Act (CARS), colloquially referred to as Cash-for-Clunkers. The program supported the purchase of a new car or light truck with a retail price of up to $45,000 (€31,000) if a less fuel-efficient vehicle of up to 25 years old was scrapped. Depending on the vehicle type and the difference in fuel efficiency, the incentive was $3,500 or $4,500 (€2,400 or €3,100). For cars, the fuel efficiency had to be at least 20 miles per gallon based on real-world-adjusted values from the U.S. Environmental Protection Agency (roughly equivalent to 270 g CO_2/km for gasoline vehicles), while new category 1 and 2 trucks had to have at least 18 and 15 miles per gallon, respectively. Due to the high popularity of the program, the budget of the program was exhausted within a month and 680,000 new car and light truck sales were supported.[7]

FRANCE

From 2008 onwards, the French government granted a so-called super-bonus (prime à la casse) of €300, if an at least 15-year-old car was replaced by a new one with type-approval CO_2 emissions below 160 g CO_2/km. As a response to the economic crisis, this replacement bonus was increased to €1,000 and extended to cars and LCVs older than 10 years in December 2008. Over the course of 2009, the program supported the purchase of about 600,000 cars and LCVs (€600 million). In 2010, the rate of the super-bonus was reduced to €750 and €500 before finally returning to the original conditions set in 2011: a premium of €300 and a required age of the scrapped vehicle of 15 years.[8]

The French super-bonus should be viewed in the context of the CO_2 emission-based bonus-malus (feebate) system. From January 2008, a bonus of €300-€5,000 was granted for cars emitting less than 130 g CO_2/km in the New European Driving Cycle (NEDC), while a fee (malus) of €300-€2,700 had to be paid for cars emitting more than 160 g CO_2/km. Rather than incentivizing additional car purchases, the bonus-malus

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5 IHS Global Insight, 'Assessment of the Effectiveness of Scrapping Schemes for Vehicles Economic, Environmental, and Safety Impacts'.

6 Sandra Wappelhorst, *Spain's Booming Hybrid Electric Vehicle Market: A Summary of Supporting Policy Measures* (Washington, D.C.: ICCT, 26 May 2019), https://theicct.org/publications/spain-HEV-market-supporting-policy-measures.

7 Francisco Posada et al., *Survey of Best Practices in Reducing Emissions through Vehicle Replacement Programs* (Washington, D.C.: ICCT, 2 March 2015), https://theicct.org/publications/survey-best-practices-reducing-emissions-through-vehicle-replacement-programs.

8 IHS Global Insight, 'Assessment of the Effectiveness of Scrapping Schemes for Vehicles Economic, Environmental, and Safety Impacts'.

system shifts the demand from high- to low-emission vehicles. To remain cost neutral, the system has been adjusted on a yearly basis since 2010.[9]

ITALY

The 2009 vehicle replacement program in Italy, incentivi alla rottamazione, followed a series of schemes implemented in 1998, 2002, 2006-2007, and 2008. With similar requirements to past programs, the incentivi alla rottamazione supported the purchase of a new car below with emissions below 140 g CO_2/km (130 g CO_2/km for diesel) or any new LCV by €1,500 and €2,500, respectively, if an 9-year-old car or LCV was scrapped. To further stimulate the demand in mostly domestically produced liquified petroleum gas (LPG) and compressed natural gas (CNG) vehicles, the government granted another €1,500 to €3,500 for cars and €1,500 to €4,000 for LCVs without requiring that old vehicle was scrapped. Purchases of electric cars were supported by €3,500 and electric LCVs by €2,000. Until August 2009, a total of 590,000 car sales were supported by the vehicle replacement program, the purchase premiums, or both.[10] The high incentives on CNG and LPG vehicles boosted gas vehicle sales in Italy.[11]

RUSSIA

From March 2010, the Russian government incentivized the purchase of 500,000 cars with ₽25 billion (€580 million). To qualify for a bonus of ₽50,000 (€1,200), a car older than 10 years needed to be replaced by a new car. Unlike the incentive programs in the other countries reviewed here, the new car had to be produced domestically.

CHINA

In June 2009, the Chinese government initiated its first national vehicle replacement program. The program subsidized the replacement of yellow label passenger and freight vehicles, which refer to Euro 0 gasoline (pre-2000) and Euro 0, Euro 1, and Euro 2 diesel vehicles (pre-2008), with new vehicles by offering RMB 3,000 to RMB 6,000 (€300 to €600). Due to a low initial consumer response, the incentives were increased to RMB 6,000 to RMB 18,000 (€680 to €2,000) being in January 2010. Over the course of 2010, RMB 6.41 billion (€680 million) was spent to replace 460,000 vehicles, the majority of which being passenger cars. Before and after this national program similar programs were issued by local Chinese governments.[12]

UNITED KINGDOM

Within its 2009-2010 vehicle replacement program, the UK government supported any new car or LCV purchase by £1,000 (€1,250), if a car or LCV older than 10 or 8 years, respectively, was replaced. Another £1,000 was paid by the manufacturer. In total, the government spent £400 million (€500 million) to incentivize 400,000 new car and LCV sales.[13]

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9 Zifei Yang, 'Practical Lessons in Vehicle Efficiency Policy: The 10-Year Evolution of France's CO2-Based Bonus-Malus (Feebate) System', 12 March 2018, https://theicct.org/blog/staff/practical-lessons-vehicle-efficiency-policy-10-year-evolution-frances-co2-based-bonus; Sandra Wappelhorst, Peter Mock, and Zifei Yang, *Using Vehicle Taxation Policy to Lower Transport Emissions: An Overview for Passenger Cars in Europe*, December 2018, https://theicct.org/publications/using-vehicle-taxation-policy-lower-transport-emissions; Sandra Wappelhorst, 'Actions Speak Louder than Words: The French Commitment to Electric Vehicles', 16 January 2020, https://theicct.org/blog/staff/actions-speak-louder-words-french-commitment-electric-vehicles.

10 IHS Global Insight, 'Assessment of the Effectiveness of Scrapping Schemes for Vehicles Economic, Environmental, and Safety Impacts'.

11 Uwe Tietge, 'Italy's Car Market Needs to Make a U-Turn', 18 September 2017, https://theicct.org/blog/staff/italy-car-market-needs-u-turn.

12 Posada et al., *Survey of Best Practices in Reducing Emissions through Vehicle Replacement Programs*.

13 IHS Global Insight, 'Assessment of the Effectiveness of Scrapping Schemes for Vehicles Economic, Environmental, and Safety Impacts'.

EVALUATING THE ECONOMIC IMPACTS

Studies of the recovery programs in response to the 2007-2008 global financial crisis showed that the programs did not only incentivize additional vehicle sales but also (a) subsidized sales that would have taken place anyways, (b) pulled forward sales from the upcoming years, and (c) crowded out sales from car segments that were not eligible for the programs. In some cases, these effects largely reduced the economic effectiveness and long-term benefit of the programs, as the following sources suggest.

The short-term stimulus CARS program in the United States only had a modest and fleeting impact on production,[14] and the additional sales were already compensated for by the end of 2009.[15] For the German scheme, in which the incentive was not targeted to environmental criteria of the new cars, it was found that the majority of subsidized sales would have taken place anyways or were pulled forward.[16] In France and Spain, where the incentive was limited to new cars below a certain CO_2 threshold, it was also found that the sales of cars eligible for the incentive crowded out sales of non-eligible cars.[17]

In terms of employment, it was found that the European vehicle replacement programs forestalled or even prevented the loss of up to 120,000 jobs in the automotive industry.[18] However, when looking at the economy as a whole, the U.S. and German vehicle replacement programs appeared to divert private investments from other economic sectors, such as the retail sector.[19] Similarly, it was argued that the beneficial effects on employment in the automotive sector came at the cost of employment losses in other sectors.[20] Finally, from a societal perspective, it was argued that the economic benefit of vehicle replacement programs was reduced by destroying the assets of old vehicles.[21] In this paper, we do not seek to evaluate the economic and employment impacts of past or potential programs. Instead, we focus on the environmental impacts.

EVALUATING THE IMPACTS ON GHG EMISSIONS

From an environmental perspective, purchase premium and vehicle replacement programs need to be assessed by their impact on GHG emissions. Purchase premiums that are not linked to the scrappage of old vehicles have a positive effect on GHG emissions if they shift new vehicles purchases towards low emission vehicles. If they are designed to promote the total number of vehicle sales, however, they may enlarge the fleet and thereby increase total GHG emissions. At this point, the global vehicle fleet should be considered, because exporting old vehicles does not reduce their GHG emission impact.

14 Adam Copeland and James Kahn, The Production Impact of "Cash-for-Clunkers": Implications for Stabilization Policy, *Economic Inquiry* 51, no. 1 (17 February 2012): 288–303, https://doi.org/10.1111/j.1465-7295.2011.00443.x.

15 Shanjun Li, Joshua Linn, and Elisheba Spiller, Evaluating "Cash-for-Clunkers": Program Effects on Auto Sales and the Environment, *Journal of Environmental Economics and Management* 65, no. 2 (1 March 2013): 175–93, https://doi.org/10.1016/j.jeem.2012.07.004.

16 Gregor Pfeifer and Stefan Klößner, 'Synthesizing Cash for Clunkers: Stabilizing the Car Market, Hurting the Environment?' (Saarbrücken, Germany: Saarland University, July 2018), https://mpra.ub.uni-muenchen.de/88175/.

17 Laura Grigolon, Nina Leheyda, and Frank Verboven, Scrapping Subsidies during the Financial Crisis — Evidence from Europe, *International Journal of Industrial Organization* 44 (January 2016): 41–59, https://doi.org/10.1016/j.ijindorg.2015.10.004.

18 IHS Global Insight, 'Assessment of the Effectiveness of Scrapping Schemes for Vehicles Economic, Environmental, and Safety Impacts'.

19 Global Subsidies Initiative, 'Car-Scrapping Schemes: An Effective Economic Rescue Policy?' (Geneva, Switzerland, December 2009), https://www.iisd.org/library/car-scrapping-schemes-effective-economic-rescue-policy.

20 European Commission Joint Research Centre, 'Feebate and Scrappage Policy Instruments. Environmental and Economic Impacts for the EU27' (Seville, Spain, 2009), https://op.europa.eu/en/publication-detail/-/publication/5ab1fbef-dd8c-42ff-bdfa-4f2cd34965ae.

21 International Transportation Forum, 'Car Fleet Renewal Schemes: Environmental and Safety Impacts' (Paris, France, May 2011), https://www.itf-oecd.org/car-fleet-renewal-schemes-environmental-and-safety-impacts.

Vehicle replacement programs, in contrast, reduce overall GHG emissions even when promoting additional vehicle sales if the avoided GHG emissions of driving the new instead of the old car compensate for the emissions related to the production of the new one. Considering that the programs pull forward vehicle replacements that would otherwise happen later, the additional production and avoided usage GHG emissions both account with an amount proportional to the time they were shifted. Furthermore, the GHG emission impact of vehicle replacement programs depends on the emission difference of the supported new vehicles compared to the vehicles that would be bought, albeit later, in absence of the program. The programs should thus also address the emissions of the new vehicle purchases, by, for example, including a CO_2 emission threshold.

In the following, the GHG impact of the largest vehicle replacement program put in place after the financial crisis, the German Umweltprämie, is assessed in more detail. Since all new cars were eligible for the program, it could not direct purchases towards lower CO_2 emission vehicles. As reflected in the 2008 to 2011 new car registrations in Germany,[22] the disproportionally high share of smaller car segments in the 2009 program is due to additional and pulled forward car purchases, but not to a shift from larger car segments. Accordingly, we assess the GHG impact of the German program based on its effect on replacing the old vehicles earlier.

The average age of replaced cars in the German program was 14.3 years, which is similar to the average of 13-15 years in Spain, France, the UK, and the U.S.[23] Most of the cars (95%) were built between 1990 and 2000.[24] As depicted in Figure 1, the official CO_2 emissions[25] in these years were between 173 g CO_2/km and 188 g CO_2/km. Based on the deviation of real-world CO_2 emissions[26] to the type-approval NEDC values in 2001, the actual CO_2 emissions are assumed to be 5% and 8% higher for gasoline and diesel cars, respectively.[27] Weighted by the distribution of build years of the scrapped cars[28] the CO_2 emissions are estimated to be 181 g CO_2/km in NEDC and 191 g CO_2/km in real-world conditions. Since 93% of the scrapped cars referred to smaller vehicle segments (Mini, Small, Lower Medium, Medium),[29] the actual emissions of the scrapped cars are assumed to be at least 5% lower[30] than the average in these years: 182 g CO_2/km. When non-CO_2 GHG emissions, such as methane and nitrous oxide, and the GHG emissions related to fuel production[31] are also included, the average GHG emission level of the replaced cars is about 220 g CO_2e/km.

Since purchasers of smaller cars tend to be more price sensitive and thereby more likely to take advantage of a fixed amount rather than percentage based purchase premium, such as the German Umweltprämie, new cars purchased during this time

22 Peter Mock (ed.), *European Vehicle Market Statistics — Pocketbook 2019/20* (Berlin, Germany: ICCT, 2019), http://eupocketbook.org/.

23 IHS Global Insight, 'Assessment of the Effectiveness of Scrapping Schemes for Vehicles Economic, Environmental, and Safety Impacts'.

24 Institut für Energie- und Umweltforschung Heidelberg (ifeu), 'Abwrackprämie Und Umwelt - Eine Erste Bilanz' (Heidelberg, Germany, August 2009), https://www.researchgate.net/publication/280738101_Abwrackpramie_und_Umwelt_-_eine_erste_Bilanz.

25 Until 1995, the official CO_2 emissions refer to German Institute for Standardization (DIN) standard 70030, while New European Driving Cycle (NEDC) values are given since 1996.

26 As indicated by user reported fuel consumption values on the German web service Spritmonitor.de.

27 Uwe Tietge et al., *From Laboratory to Road: A 2018 Update* (Washington, D.C.: ICCT, 10 January 2019), https://theicct.org/publications/laboratory-road-2018-update.

28 Institut für Energie- und Umweltforschung Heidelberg (ifeu), 'Abwrackprämie Und Umwelt - Eine Erste Bilanz'.

29 Bundesamt für Wirtschaft und Ausfuhrkontrolle, 'Abschlussbericht Umweltprämie'.

30 In Germany, the average CO_2 emissions in these segments are 5%-10% below the total fleet average in 2001-2018 (KBA).

31 IPCC, *Climate Change 2014: Mitigation of Climate Change: Working Group III Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press, 2014), https://www.ipcc.ch/site/assets/uploads/2018/02/ipcc_wg3_ar5_full.pdf.

period were mostly from the Mini, Small, Lower Medium, and Medium segments (88%).[32] According to the distribution of segments in the supported new car sales and average CO_2 values for these segments in 2009, the average type-approval CO_2 value is estimated to be 149 g CO_2/km in NEDC[33] which corresponds to 175 g CO_2/km in real-world conditions.[34] Including non-CO_2 GHG emissions and GHG emissions of the fuel production results in overall GHG emissions of about 211 g CO_2e/km.

Considering that the scrapped cars on average were 14.3 years old[35] and assuming that passenger cars in Germany in the absence of a replacement program would usually be retired at an age of about 15 years,[36] those vehicles were replaced only one year early. Accordingly, the production GHG emissions are only attributed with the proportion of one year over a vehicle lifetime of 15 years. Including approximately 6 t CO_2e for the production[37] and assuming an annual mileage of about 14,000 km/a,[38] this adds a level of about 2 g CO_2e/km.

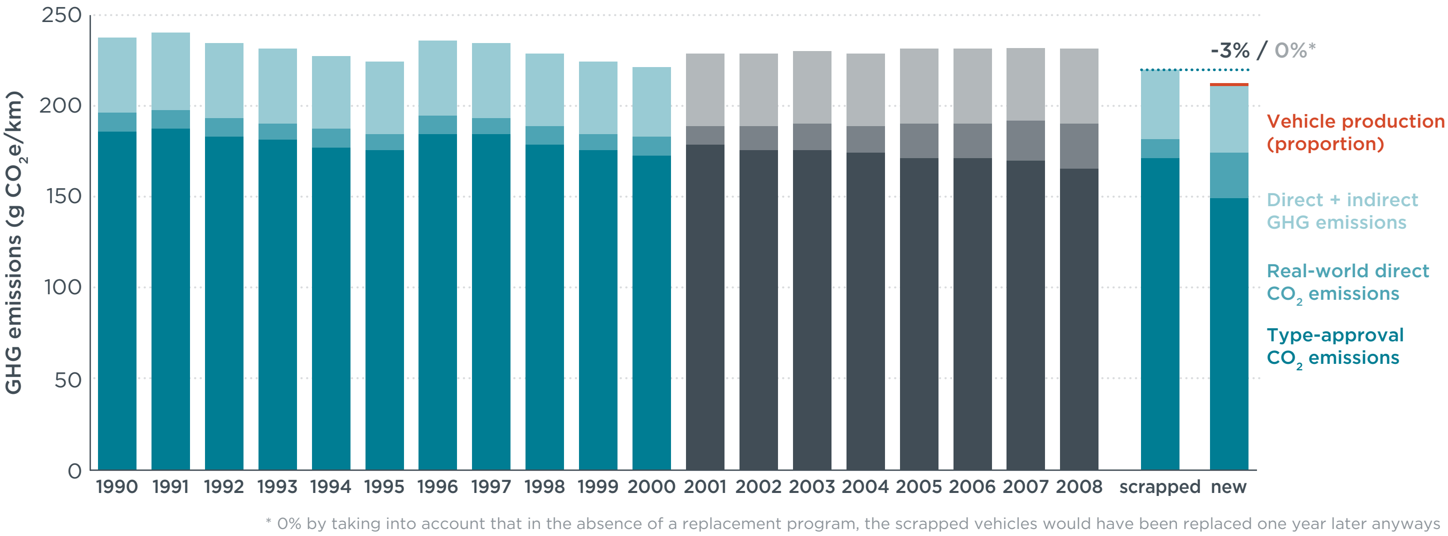

Figure 1. GHG emission impact of the German vehicle replacement program: average GHG emissions of cars first registered between 1990 and 2008 compared with the average scrapped and new cars supported under the program (incl. also proportion of production GHG emissions). (Type-approval CO_2 emissions from KBA; real-world deviation factors from Spritmonitor.de; GHG emission factors from IPCC, Working Group III Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.)

For each old car emitting 220 g CO_2e/km that is replaced by a new one emitting 211 g CO_2e/km plus 2 g CO_2e/km attributed to production, about 7 g CO_2e/km (-3%) were avoided.[39] In absence of the program, however, it was to be expected that these cars would have been replaced only one year later. Attributed over the entire lifetime of the vehicles, the amount of emissions avoided by driving the new instead

32 Bundesamt für Wirtschaft und Ausfuhrkontrolle, 'Abschlussbericht Umweltprämie'.

33 Mock (ed.), *European Vehicle Market Statistics — Pocketbook 2019/20*.

34 *Tietge et al., From Laboratory to Road: A 2018 Update*.

35 Institut für Energie- und Umweltforschung Heidelberg (ifeu), 'Abwrackprämie Und Umwelt - Eine Erste Bilanz'.

36 Umweltbundesamt and Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit, 'Altfahrzeug-Verwertungsquoten in Deutschland Im Jahr 2008' (Dessau-Roßlau and Bonn, Germany, June 2010), https://www.bmu.de/download/jahresberichte-ueber-die-altfahrzeug-verwertungsquoten-in-deutschland/.

37 Argonne National Laboratory, *The Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation Model (GREET)* - version 2019, 2019, https://greet.es.anl.gov/index.php.

38 Bundesministerium für Verkehr und digitale Infrastruktur, 'Verkehr in Zahlen 2019/2020' (Flensburg, Germany, September 2019), https://www.bmvi.de/SharedDocs/DE/Artikel/G/verkehr-in-zahlen.html.

39 In absence of solid real-world CO_2 adjustment factors, which became only available in later years, the 2009 study by the Institut für Energie- und Umweltforschung Heidelberg (ifeu) estimated a difference of 18 g CO_2/km (22 g CO_2e/km GHG).

of the old car one year earlier than it would have been the case without the program, 0.6 g CO_2e/km,[40] is actually lower than the emission of 2 g CO_2e/km related to the earlier production of the vehicle. Accordingly, the program did in fact not reduce GHG emissions.

A study by the International Transport Forum (ITF) considered the GHG emission impact of the program to be slightly positive.[41] However, considering the high cost of the program at €2,500 per vehicle replacement, plus the destroyed asset of the old car, these GHG emission savings were achieved at a cost of €15,000 per ton of CO_2.

Grigolon et al. found that vehicle replacement programs that were limited to new cars below a certain CO_2 threshold, as in the 2009 French or Spanish programs, had a more significant environmental impact than non-targeted programs, such as the German. In addition, the purchase of cars that met the CO_2 thresholds crowded out purchase of non-eligible cars, thus shifting the demand to low emission vehicles instead of pulling forward sales from the upcoming years.[42] Accordingly, the ITF study estimated the cost of CO_2 abatement to be €2,100 per ton of CO_2 in the case of the French program. Compared to the 2009 EU Emissions Trading System (ETS) price of €9 to €30 per ton of CO_2e, these costs are still disproportionately high.

For the U.S. program, the ITF study estimated the total cost of GHG emission savings to be €8,500 per ton of CO_2. Only considering the direct costs to the government results in estimates of €64 to €201 ($92 to $288)[43] or €420 ($600) per ton of CO_2[44]. Similarly, a cost of €266 ($380) per ton of CO_2 was estimated for the Japanese scheme.[45]

40 This value is calculated by the GHG emission difference of driving the old (220 g CO_2e/km) instead of the new car (211 g CO_2e/km), multiplied by replacing it one year later and divided by the whole lifetime of the vehicles (15 years).

41 International Transportation Forum, 'Car Fleet Renewal Schemes: Environmental and Safety Impacts'.

42 Grigolon, Leheyda, and Verboven, 'Scrapping Subsidies during the Financial Crisis — Evidence from Europe'.

43 Li, Linn, and Spiller, 'Evaluating "Cash-for-Clunkers"'.

44 Shoshannah M. Lenski, Gregory A. Keoleian, and Kevin M. Bolon, 'The Impact of `Cash for Clunkers' on Greenhouse Gas Emissions: A Life Cycle Perspective', *Environmental Research Letters* 5, no. 4 (October 2010): 044003, https://doi.org/10.1088/1748-9326/5/4/044003.

45 Kagawa et al., 'Better Cars or Older Cars?'

EVALUATING THE EFFECT ON POLLUTANT EMISSIONS

While the real-world GHG emissions of the German new car fleet remained relatively constant between 1990 and 2008, pollutant emissions decreased notably. Figure 2 shows the real-world NO_x emissions of gasoline and diesel cars from these years[46] and how they relate to the NO_x emission limits of the corresponding Euro standards.[47] For gasoline cars, a substantial reduction of the NO_x emissions in line with the continuously strengthened Euro standards is observed. For diesel cars, in contrast, the real-world NO_x emission levels decreased by a much lower extent. For Euro 3-6 cars, real-world NO_x emissions substantially exceed the indicated type-approval limits. The displayed values refer to a collection of 2011 to 2017 remote emission sensing data.[48] More recent data from remote emission sensing studies in London and Paris confirm the same trends.[49]

In the German vehicle replacement program, a mixture of pre-Euro 1 (15%), Euro 1 (40%), Euro 2 (44%), and Euro 3 cars (1%)[50] were replaced by a mixture of Euro 4 (79%) and Euro 5 cars (21%).[51] On average, the program thus replaced an about 670 mg NO_x/km emitting gasoline car by an about 120 mg NO_x/km emitting vehicle, resulting in 82% lower emissions. For diesel cars, in contrast, the replacement of an about 1,250 mg NO_x/km emitting car by a 1,000 mg NO_x/km vehicle achieved a significantly smaller emission reduction of 20%. Considering that these replacements would have occurred also in absence of the program, but were pulled forward by one year, the program reduced the lifetime NO_x emissions of each supported gasoline and diesel vehicle replacement by 37 mg NO_x/km (-24%) and 17 mg NO_x/km (-2%), respectively.[52]

Particular matter (PM) emissions have historically been comparatively low for gasoline cars, while for diesel cars, the replacing Euro 4 and Euro 5 vehicles have substantially lower PM emissions than the scrapped Euro 1, Euro 2, and Euro 3 vehicles.[53] For carbon monoxide (CO) emissions, which are more relevant for gasoline cars, the Euro standards of the replacing vehicles refer to lower values, as well.

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46 Starting from 2001, the official and real-world NO_x emission values are weighted by the share of Euro standards in the new gasoline and diesel fleets. For 1992-2000 it is assumed that the new car fleet completely referred to the newest Euro standard in that year. Due to a lack of real-world data for pre-Euro 1 vehicles, Euro 1 values were assumed for the new fleets before 1992. Especially for gasoline cars, however, the NO_x emissions of pre-Euro 1 cars are likely to be higher.

47 The Euro 1 and 2 standards set limits to the combined emissions of NO_x and HC, only, e.g. 970 mg/km in Euro 1.

48 Yoann Bernard et al., *Determination of Real-World Emissions from Passenger Vehicles Using Remote Sensing Data* (TRUE Initiative, 5 June 2018), https://www.theicct.org/publications/real-world-emissions-using-remote-sensing-data.

49 Tim Dallmann et al., *Remote Sensing of Motor Vehicle Emissions in London* (ICCT: Washington, DC, 18 December 2018), https://www.theicct.org/publications/true-london-dec2018; Tim Dallmann et al., *Remote Sensing of Motor Vehicle Emissions in Paris*, (ICCT: Washington, DC, 10 September 2019), https://theicct.org/publications/on-road-emissions-paris-201909.

50 Institut für Energie- und Umweltforschung Heidelberg (ifeu), 'Abwrackprämie Und Umwelt - Eine Erste Bilanz'.

51 Bundesamt für Wirtschaft und Ausfuhrkontrolle, 'Abschlussbericht Umweltprämie'.

52 These values are calculated from difference of driving the old (e.g. 1,250 mg NO_x/km for diesel) instead of the new car (1,000 mg NO_x/km), multiplied by replacing it one year later and divided by the whole lifetime of the vehicles (15 years).

53 Dallmann et al., *Remote Sensing of Motor Vehicle Emissions in London*; Dallmann et al., *Remote Sensing of Motor Vehicle Emissions in Paris.*

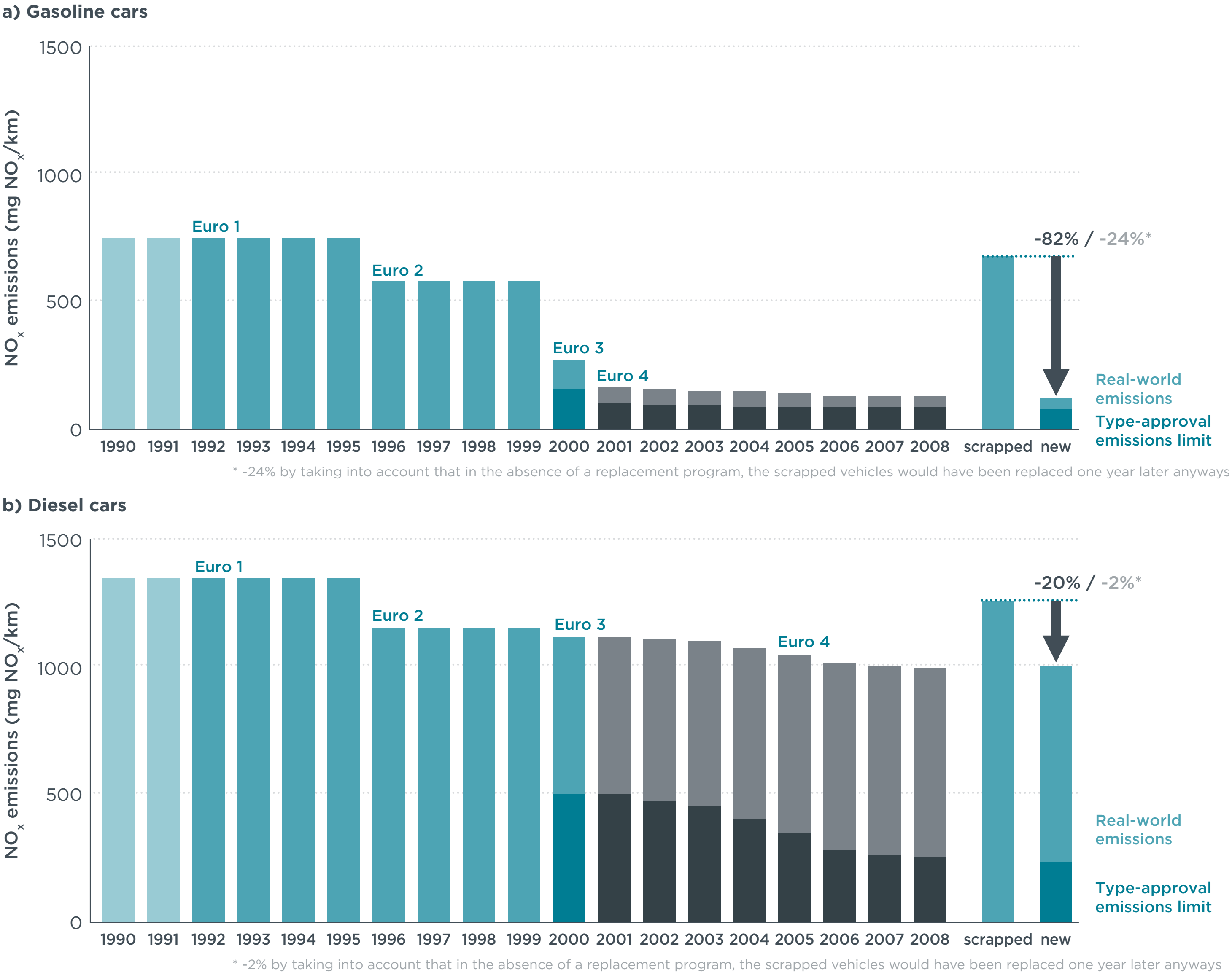

Figure 2. NO_x emission impact of the German vehicle replacement program: average NO_x emissions of a) gasoline and b) diesel cars first registered from 1990 to 2008 compared with the average scrapped and new cars supported under the program. (NO_x data taken from Bernard et al., 'Determination of Real-World Emissions from Passenger Vehicles Using Remote Sensing Data.'; Fleet composition data taken from KBA and Bundesamt für Wirtschaft und Ausfuhrkontrolle, 'Abschlussbericht Umweltprämie'.)

In result, as also pointed out in several studies, the 2009-2010 vehicle replacement programs had a much more significant impact on abating pollutant emissions than on reducing GHG emissions.[54] However, due to the high deviation of real-world NO_x emissions of diesel cars, as it became evident as a result of "dieselgate", this impact was estimated to be higher in the past than it actually was in reality. Instead, retrofitting of the car fleets with diesel particulate filter (DPF) or selective catalytic reduction (SCR) equipment might have been a more cost-efficient alternative.[55]

54 IHS Global Insight, 'Assessment of the Effectiveness of Scrapping Schemes for Vehicles Economic, Environmental, and Safety Impacts'; Institut für Energie- und Umweltforschung Heidelberg (ifeu), 'Abwrackprämie Und Umwelt - Eine Erste Bilanz'; International Transportation Forum, 'Car Fleet Renewal Schemes: Environmental and Safety Impacts'.

55 Posada et al., *Survey of Best Practices in Reducing Emissions through Vehicle Replacement Programs*.

VEHICLE REPLACEMENT PROGRAMS IN RESPONSE TO THE 2020 COVID-19 CRISIS

In the current economic downturn of the COVID-19 crisis, purchase premiums and vehicle replacement programs are once again being discussed to support the automotive industry. The following section investigates the GHG emission impact of hastening the replacement of old cars by (a) an average 2020 car, (b) a vehicle with a maximum emissions of 110 g CO_2/km as measured by the Worldwide Harmonized Light Vehicle Testing Procedure (WLTP), or (c) a battery electric vehicle (BEV). Following a more detailed discussion of the effect on the German car fleet, the analysis is expanded to other European countries. To examine the impact on air quality, the effect of an earlier replacement of old cars by Euro 6d-TEMP, Euro 6d, and battery electric vehicles is investigated.

GHG EMISSIONS

Figure 3 shows the average GHG emissions of the German new car fleet from 2001 to 2019. The figure reveals that the NEDC-based type-approval CO_2 emissions decreased continuously until 2016 but then slightly increased again in 2017 and 2018 (dark blue and grey bars). In parallel, as monitored in the ICCT From Laboratory to Road series, the gap between real-world CO_2 emissions and type-approval values increased to about 40% in 2017 and 2018 (lighter blue and grey bars).[56] Since 2019, NEDC CO_2 type approval values have been replaced by WLTP values, with the real-world gap estimated to be around 15%.[57] As shown, real-world tailpipe CO_2 emissions of the average German new passenger car remained nearly constant over the past three decades (compare also Figure 1). When non-CO_2 GHG emissions and GHG emissions related to fuel production[58] (light blue and grey bars) are included, the total GHG emissions of driving cars that were registered between 2001 and 2019 are estimated to be between 213 g CO_2e/km and 232 g CO_2e/km.

In the European vehicle replacement programs related to the 2007-2008 global financial crisis, the scrapped cars were, on average, 13 to 15 years old.[59] For the 2020 programs, we thus assume that the average replaced cars would be first registered in 2005. However, depending on the design of these programs (i.e. the amount of the incentive), the average age of the scrapped cars could also be higher or lower. The NEDC type-approval CO_2 emissions of an average car registered in Germany in 2005 would be 181 g CO_2/km, while real-world emissions are estimated to be 191 g CO_2/km. The GHG emissions would amount to about 231 g CO_2e/km (blue dotted line). Considering the usual lifetime of a car is 18 years,[60] these cars would be replaced three years early.

56 *Tietge et al., From Laboratory to Road: A 2018 Update*.

57 Jan Dornoff, Uwe Tietge, and Peter Mock, *On the Way to "Real-World" CO_2 Values: The European Passenger Car Market in Its First Year after Introducing the WLTP*, (ICCT: Washington, D.C., 19 May 2020), https://theicct.org/publications/way-real-world-co2-values-european-passenger-car-market-its-first-year-after.

58 IPCC, *Climate Change 2014: Mitigation of Climate Change: Working Group III Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*.

59 IHS Global Insight, 'Assessment of the Effectiveness of Scrapping Schemes for Vehicles Economic, Environmental, and Safety Impacts'; Institut für Energie- und Umweltforschung Heidelberg (ifeu), 'Abwrackprämie Und Umwelt - Eine Erste Bilanz'.

60 Umweltbundesamt and Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit, 'Altfahrzeug-Verwertungsquoten in Deutschland Im Jahr 2017' (Dessau-Roßlau and Bonn, Germany, July 2019), https://www.bmu.de/download/jahresberichte-ueber-die-altfahrzeug-verwertungsquoten-in-deutschland/.

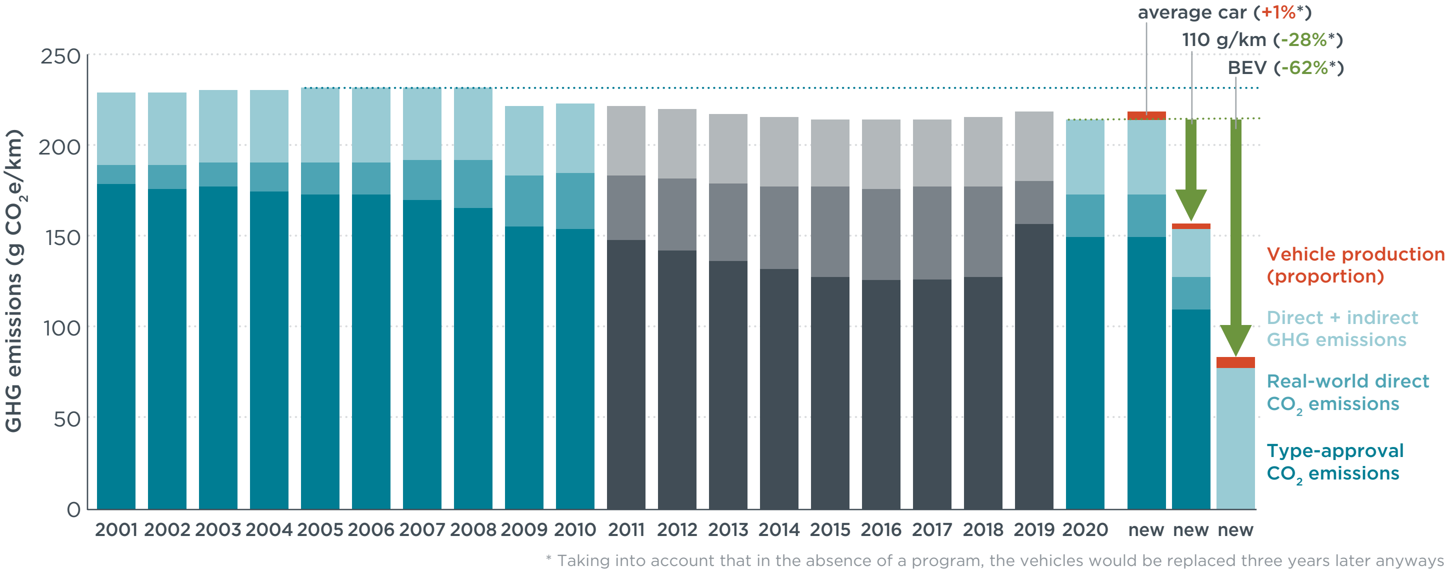

Figure 3: GHG emission impact of a hypothetical 2020 vehicle replacement program in Germany: average GHG emissions of cars registered in 2001 to 2019 compared with an average car of the first quarter of 2020, a passenger car with 110 gCO_2/km in WLTP, and a battery electric vehicle (incl. proportion of production-related GHG emissions). (Type-approval CO_2 emissions data are from KBA, real-world deviation factors from Spritmonitor.de; GHG emission factors are from IPCC, Working Group III Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.)

The average new car registered in Germany in the first quarter of 2020 corresponds to CO_2 emission levels of 149 g CO_2/km in WLTP.[61] If fuel and electricity production are included, the GHG emissions of the vehicle are 215 g CO_2e/km (green dotted line). Assuming 6 tons of CO_2e are produced during the manufacturing of a combustion engine car[62] and an annual mileage of 14,000 km,[63] another 4 g CO_2e/km are added for the early production of these cars (219 g CO_2e/km). Replacing an average car registered in 2005 car by an average 2020 car would therefore reduce GHG emissions by 12 g CO_2e/km (-5%). Taking into account that, in the absence of a program, a 2005 vehicle would likely be replaced within the next three years regardless of the program, the expedited replacement actually results in a slight increase of GHG emissions (+1%).[64]

For the years 2021 through 2024, the EU CO_2 standards set a target of about 110-115 g CO_2/km in WLTP (95 g CO_2/km in NEDC) for the average new car registered in the EU27, the UK, and the EFTA states. In 2020, the target has to be achieved by 95% of the new fleet. Especially when considering that many of the supported car purchases would be pulled forward from the upcoming years, CO_2 thresholds as part of potential vehicle replacement programs should at least not exceed this regulatory target value. For a vehicle emitting type-approved at 110 g CO_2/km in WLTP, the CO_2 emission level is estimated to be 127 g CO_2/km in real-world conditions and total GHG emissions are

61 Peter Mock and Uwe Tietge, *Market Monitor: European Passenger Car Registrations, January–March 2020* (ICCT: Washington, D.C., 28 April 2020), https://theicct.org/publications/market-monitor-european-pv-registrations-january-march-2020.

62 Argonne National Laboratory, *The Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation Model (GREET) - 2019 Version.*

63 Bundesministerium für Verkehr und digitale Infrastruktur, 'Verkehr in Zahlen 2019/2020'.

64 This value is based on the assumption that the 2005 cars would otherwise be replaced in three years by cars with similar GHG emissions as average 2020 (Q1) cars. Accordingly, the GHG emission difference of driving the 2005 car instead of an average 2020 (Q1) car for three more years (over a vehicle lifetime of 18 years) is opposed by the proportionate amount of GHG emission for the earlier production of the new vehicles. Due to the technology forcing effect of the EU vehicle CO_2 standards for 2021 and beyond, this assumption is considered conservative. Most likely, the potential GHG emissions savings of the programs would be lower.

estimated to be 153 g CO_2e/km. The earlier production would correspond to another 4 g CO_2e/km. Replacing an average 2005 car in Germany by an 2021-2024 European average car thus would result in GHG emissions savings of about 74 g CO_2e/km (32%). In comparison to replacing the old car at its regular retirement age with a car similar to the 2020 (Q1) average, the GHG emission reductions of its earlier replacement with a 110 g CO_2/km in WLTP emitting vehicle are still 28%.

Battery electric vehicles already today have lower lifecycle GHG emissions than combustion engine cars in the vast majority of countries.[65] For the relatively carbon-intensive German electricity grid (397 g CO_2e/kWh in 2019),[66] the GHG emissions of driving an average battery electric vehicle consuming 19.4 kWh/100 km[67] amounts to 77 g CO_2e/km. Assuming an average battery capacity of 40-50 kWh, 65-100 kg CO_2e/kWh for the production of the lithium-ion battery,[68] and another 5 tons of CO_2e for the rest of the vehicle,[69] the production of a battery electric vehicle corresponds to 8-10 tons of CO_2e. The proportionate GHG emission of the earlier production of the vehicle is estimated to be 6 g CO_2e/km. Replacing an average 2005 car in Germany by an average battery electric car would result in substantial GHG emission savings of 148 g CO_2e/km, or 64%. Compared to replacing the old car at its regular retirement age with an average 2020 (Q1) car, GHG emissions would be reduced by 62%.

Following the same methodology applied to Germany, the GHG emission impact of potential vehicle replacement programs can be estimated for other European countries. Table 2 provides the GHG emissions of the countries' average car fleets in 2005 and in the first quarter of 2020. These values are being compared with the GHG emissions of a) an average 2020 combustion engine car, b) a vehicle with 110 g CO_2/km (in WLTP), and c) a battery electric vehicle. Finally, the table presents the GHG emission impact (in %) of the replacement programs in comparison to what is assumed to happen in absence of the programs: the old cars would be replaced by vehicles with similar GHG emissions as an average 2020 (Q1) car, but about three years later. This estimation includes the proportionate GHG emissions of the earlier vehicle production and of the continued use of the old car.

65 Agora Verkehrswende, 'Klimabilanz von Elektroautos - Einflussfaktoren Und Verbesserungspotenzial' (Berlin, April 2019), https://www.agora-verkehrswende.de/veroeffentlichungen/klimabilanz-von-elektroautos/; Florian Knobloch et al., 'Net Emission Reductions from Electric Cars and Heat Pumps in 59 World Regions over Time', *Nature Sustainability*, 23 March 2020, 1–11, https://doi.org/10.1038/s41893-020-0488-7; Transport & Environment, 'How Clean Are Electric Cars? T&E's Analysis of Electric Car Lifecycle CO_2 Emissions' (Brussels, April 2020), https://www.transportenvironment.org/what-we-do/electric-cars/how-clean-are-electric-cars.

66 Agora Energiewende and Sandbag, 'The European Power Sector in 2019: Up-to-Date Analysis on the Electricity Transition' (Berlin, February 2020), https://www.agora-energiewende.de/en/publications/the-european-power-sector-in-2019/.

67 The sales-weighted average energy consumption of the ten most popular battery electric vehicles in 2019 (KBA) is 16.3 kWh/100 km in WLTP and 19.4 kWh/100 km in the ADAC Ecotest (incl. charging losses).

68 Jarod C. Kelly, Qiang Dai, and Michael Wang, 'Globally Regional Life Cycle Analysis of Automotive Lithium-Ion Nickel Manganese Cobalt Batteries', *Mitigation and Adaptation Strategies for Global Change*, 28 August 2019, https://doi.org/10.1007/s11027-019-09869-2.

69 Argonne National Laboratory, *The Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation Model (GREET)*.

Table 2. Comparison of the estimated real-world GHG emissions of average cars registered in 2005 compared with a) average 2020 (Q1) cars b) vehicles with 110 g CO_2/km in WLTP, and c) battery electric vehicles using carbon intensities of the 2019 electricity grids. The percentage terms refer to the relative GHG emission impact of replacing a 2005 car three years earlier than its regular average retirement, including the proportional amounts of additional production and avoided usage GHG emissions. (2020 (Q1) data from AAA DATA (France), SMMT (UK), Dataforce (all other markets), real-world deviation factors from Spritmonitor.de, GHG emission factors are from IPCC, Working Group III Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, carbon intensity of power supply from Agora Energiewende and Sandbag, 'The European Power Sector in 2019: Up-to-Date Analysis on the Electricity Transition'.

	2005: average car	2020: average car		2020: 110 g CO_2/km (in WLTP) vehicle		2020: battery electric vehicle	
	[g CO_2e/km]	[g CO_2e/km]		[g CO_2e/km]		[g CO_2e/km]	
Austria	221	201	0%	153	-23%	17	-89%
Belgium	210	176	-1%	153	-14%	26	-82%
Finland	239	188	-2%	153	-20%	32	-81%
France	206	168	-1%	153	-10%	9	-92%
Germany	231	215	+1%	153	-28%	77	-62%
Greece	221	170	-3%	153	-12%	103	-39%
Ireland	221	169	-3%	153	-12%	51	-68%
Italy	202	158	-2%	153	-5%	51	-65%
Luxembourg	227	217	+1%	153	-28%	16	-90%
Netherlands	226	166	-3%	153	-11%	64	-60%
Spain	212	174	-1%	153	-13%	38	-76%
Sweden	257	180	-5%	153	-19%	7	-93%
UK	226	186	-1%	153	-18%	34	-79%
EU27 + UK	218	185*	-1%*	153	-18%*	52	-70%*

* Data for 2020 (Q1) CO_2 emission levels omit Bulgaria, Croatia, Denmark, Hungary, Lithuania, Malta, Poland, Portugal, and Romania (together about 11% of the total EU27 + UK market).

In all investigated countries, expediting the replacement of average cars registered in 2005 with average 2020 (Q1) cars would have practically no impact on GHG emissions. In countries in which the 2020 new car fleets have significantly lower emission levels than the 2005 fleets, an earlier replacement results in slightly decreased GHG emissions, such as a 5% reduction in Sweden. The emissions would increase in countries in which the emission levels of the 2005 and 2020 fleets remained more constant, such as a 1% increase in Germany. In contrast, the GHG savings of an early replacement with vehicles with a WLTP type-approval value of 110 g CO_2/km are most significant if the current car fleet has comparably high emissions, such as in Germany where the reduction would be 28%. In most countries, however, the GHG emission saving would be below 20%; for example, GHG emissions would be reduced by only 5% in Italy. Replacing the old cars by battery electric vehicles results in the highest GHG emission savings in all evaluated countries. Due to large variation in the carbon intensity of power supply[70], these savings reach from 39% in Greece to 93% in Sweden.

AIR POLLUTANT EMISSIONS

A hypothetical 2020 vehicle replacement program in Germany and the other European countries would lead to the replacement of Euro 3 and 4 gasoline and diesel cars by Euro 6d-TEMP, Euro 6d, or battery electric vehicles.

70 Agora Energiewende and Sandbag. 'The European Power Sector in 2019: Up-to-Date Analysis on the Electricity Transition'.

Figure 4 depicts the NO_x emissions of average gasoline and diesel cars registered in Germany from 2001 to 2020, weighted by the distribution of Euro standards in the gasoline and diesel cars in these years in comparison with potential NO_x emissions of Euro 6d-TEMP, Euro 6d, and battery electric vehicles. The emission values of Euro 4 to Euro 6b/c vehicles are based on real-world remote sensing data.[71] For Euro 6d-TEMP and Euro 6d cars, the emissions are assumed to be similar to the Euro 6b/c in case of gasoline cars, while they are assumed to be in line with the type-approval NO_x emission level multiplied with the conformity factors (allowed deviation) of 2.1 and 1.43, respectively, for diesel cars. Preliminary remote sensing data on Euro 6d-TEMP vehicles supports this assumption.[72]

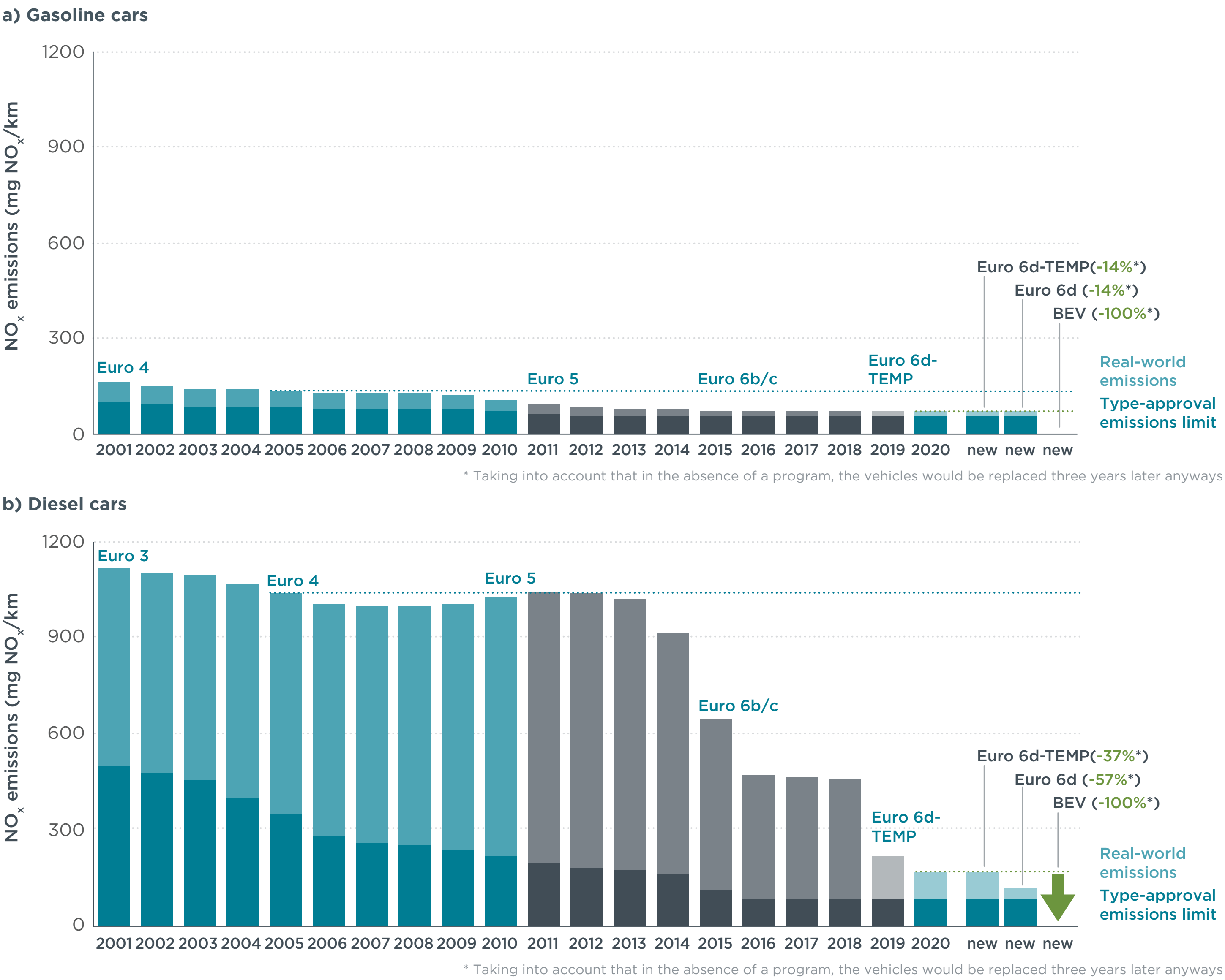

Figure 4: Estimated impact of a hypothetical 2020 vehicle replacement program in Germany on NO_x emission levels: real-world NO_x emissions of driving average 2001-2019 a) gasoline and b) diesel cars compared with 2020 Euro 6d-TEMP, Euro 6d and battery electric vehicles. (NO_x data from Bernard et al., *Determination of Real-World Emissions from Passenger Vehicles Using Remote Sensing Data*, fleet composition data from KBA)

71 Bernard et al., *Determination of Real-World Emissions from Passenger Vehicles Using Remote Sensing Data.*

72 Dallmann et al., *Remote Sensing of Motor Vehicle Emissions in Paris.*

For gasoline cars, the type-approval and real-world emissions are at a comparatively low level since the introduction of Euro 3 and 4 standards. Replacing an average 2005 gasoline car with emissions of about 140 mg NO_x/km with a new Euro 6d-TEMP or Euro 6d vehicle with assumed Euro 6b/c emission values of about 70 mg NO_x/km would result in a reduction of 70 mg NO_x/km, or 50%. In comparison to the reduction of 550 mg NO_x/km as the result of the 2009 Umweltprämie, this effect is relatively low. In absence of the vehicle replacement programs, the old cars would be replaced about three years later and most likely by cars meeting the Euro 6d standard, which are mandatory from 2021. The NO_x emission savings of pulling forward this replacement would then amount to only 14%.[73]

For diesel cars, real-world NO_x emissions (light blue and grey bars) of Euro 3 to Euro 5 cars are found to be above 1,000 mg NO_x/km, although the regulatory limits (dark blue and grey bars) were set at 500 mg NO_x/km, 250 mg NO_x/km, and 250 mg NO_x/km, respectively. Replacing an average 2005 diesel car with emissions of 1,040 mg NO_x/km by a Euro 6d-TEMP with emissions of 168 mg NO_x/km or Euro 6d vehicle (114 mg NO_x/km), would result in 872 mg NO_x/km and 926 mg NO_x/km less emissions, or a 84% and 89% reduction, respectively. Considering that the old cars would be likely replaced by a Euro 6d vehicle within the next three years, the actual NO_x emission savings due to the programs would be only 37% if a Euro 6d-TEMP vehicle is purchased and 57% if a Euro 6d vehicle is purchased.

Replacing old Euro 3 and 4 diesel cars with Euro 6d-TEMP and Euro 6d vehicles would further reduce PM emissions, while replacing old gasoline cars would help to lower CO emissions.[74] Replacing combustion engine cars by battery electric vehicles would avoid 100% of the local NO_x emissions in all cases.

73 As for GHG emissions, this value is calculated by the NO_x emission difference of driving the old car instead of a Euro 6d vehicle, multiplied by replacing it three years later and divided by the whole lifetime of the vehicles (18 years).

74 Dallmann et al., *Remote Sensing of Motor Vehicle Emissions in London*; Dallmann et al., *Remote Sensing of Motor Vehicle Emissions in Paris*.

SUMMARY AND CONCLUSIONS

Experiences from vehicle replacement programs in response to the 2007-2008 financial crisis show that relatively low GHG emission and air pollutant savings were achieved at high cost. Programs that set a certain CO_2 emission threshold, like in France and Spain, had a higher effect on GHG emissions. Since they also shifted the demand from non-eligible high emission vehicles to eligible cars instead of pulling forward sales from the following years, their effect was more sustainable.

Hypothetical 2020 vehicle replacement programs would achieve the largest environmental benefit if they were limited to battery electric vehicles only. In addition to avoiding 100% of the local NO_x and CO emissions, as well as most of the PM emissions, incentivizing an earlier exchange of old cars with battery electric vehicles in comparison to their later replacement by average cars would reduce 89-93% of GHG emissions in Austria, France, and Sweden, while 62% of the GHG emissions would be avoided in Germany. With a decreasing carbon intensity of power supply, these savings will grow in future years. Considering that the electric vehicle sales share reached 7% in the first quarter of 2020 in Europe, and sales were distributed across most manufacturers,[75] recovery plans for the automotive industry should support this trend and guide the transition toward low emission, electric mobility.

In most European countries, the real-world GHG emissions of the 1990 to 2020 new car fleets remained comparatively constant despite a decrease in the official CO_2 emission values. Vehicle replacement programs without a CO_2 threshold would thus have practically no GHG emission impact. In addition, providing purchase premiums for vehicles above the mandatory 2021-2024 CO_2 target of 110-115 g CO_2/km in WLTP (95 g CO_2/km in NEDC) would contradict the rationale of the EU CO_2 fleet regulation.

Restricting vehicle replacement programs to a CO_2 threshold of 110 g CO_2/km in WLTP would result in about 28% less GHG emissions in Germany, while only 5-11% would be saved for the lower-CO_2 vehicle fleets in Italy, France, and the Netherlands.

Reductions in NO_x and PM emissions are likely to occur if old diesel cars are replaced by vehicles meeting the current Euro 6d-TEMP and 2021 Euro 6d standard, while only little improvements would be achieved if older gasoline cars are replaced. Instead of scrapping the old cars, however, retrofitting them, e.g. with a diesel particulate filter or selective catalytic reduction equipment might be a more cost-efficient alternative. Replacing diesel and gasoline cars by battery electric vehicles would save 100% of the local NO_x and most of the PM emissions.

In the long term, a bonus-oriented support of low emission vehicles puts a strain on the national budget and the average taxpayer. For this reason, and to increase the incentive towards buying lower-emitting vehicles, bonus payments should be complemented by a higher tax (malus) on the purchase of high emission vehicles, as in bonus-malus (feebate) systems.

75 Mock and Tietge, *Market Monitor: European Passenger Car Registrations, January–March 2020*.