



Short communication

Valuing the human health damage caused by the fraud of Volkswagen[☆]Rik Oldenkamp^{*}, Rosalie van Zelm, Mark A.J. Huijbregts

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ABSTRACT

Recently it became known that Volkswagen Group has been cheating with emission tests for diesel engines over the last six years, resulting in on-road emissions vastly exceeding legal standards for nitrogen oxides in Europe and the United States. Here, we provide an estimate of the public health consequences caused by this fraud. From 2009 to 2015, approximately nine million fraudulent Volkswagen cars, as sold in Europe and the US, emitted a cumulative amount of 526 ktonnes of nitrogen oxides more than was legally allowed. These fraudulent emissions are associated with 45 thousand disability-adjusted life years (DALYs) and a value of life lost of at least 39 billion US dollars, which is approximately 5.3 times larger than the 7.3 billion US dollars that Volkswagen Group has set aside to cover worldwide costs related to the diesel emissions scandal.

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1. Introduction

Since 2009, Volkswagen Group has installed software in eleven million diesel engines to circumvent emission tests (Brooks, 2015; Volkswagen AG, 2015a, d). On the road, passenger cars equipped with these engines emit on average 0.9 g of nitrogen oxides (NO_x) per kilometre driven (Thompson et al., 2014). This is approximately 21 times the amount legally permitted in the USA (0.043 g/km) (US EPA, 2015c), and approximately 5–11 times the amount legally permitted in the European Union (0.18 g/km from 2009 to 2013; 0.08 g/km from 2014) (Delphi, 2015).

NO_x emissions form fine dust particles (PM_{2.5}) in the atmosphere (Rao et al., 2012). After inhalation, these fine particles may cause or worsen respiratory disease, such as bronchitis and lung cancer, and can aggravate existing heart disease, leading to increased hospital admissions and premature death (Lelieveld et al., 2015; Pope et al., 2002; Tang et al., 2015). Increase in disability adjusted life years (DALYs) has been related to the emission of NO_x in different global geographical regions, based on changes in chronic mortality and respiratory disease-related morbidity (Tang et al., 2015). In addition to this physical measure

of health damage, the value of statistical life (VSL) provides a monetary way to express health damage in terms of US dollars of value lost. The VSL represents the extent to which an individual would trade consumption of other goods and services for small changes in his or her own mortality risk, also known as willingness to pay (Hammit, 2000). VSL has been used to quantify health impacts for cost-benefit analyses (Héroux et al., 2015). Here, we make an estimate of the human health damages resulting from the fraud by Volkswagen in Europe and the United States. We assess two scenarios, one in which the fraudulent cars are recalled and no additional NO_x emissions will occur from 2016 onwards, and one in which the fraudulent cars will fully complete their service lives.

2. Material and methods

In total, 482 thousand fraudulent passenger cars were sold in the USA, and 8.5 million in European countries (Table 1). The latter number is the amount of fraudulent cars that could be accounted for based on publicly available sources. In the USA, fraudulent cars were allocated to a year of sale between 2009 and 2015 based on Volkswagen Group sales data of TDI Clean Diesel cars (Table 2). In that period, 494,294 TDI Clean Diesel cars were sold, which is close to the 482 thousand fraudulent passenger cars reported. European fraudulent cars were allocated to a year of sale between 2009 and 2015 based on total amounts of passenger cars delivered by Volkswagen Group to customers in the European Union (Table 2).

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Table 1
Numbers of fraudulent cars sold in USA and European Union.

Country	Number of fraudulent cars sold	Source
United States of America	482,000	US EPA (2015b)
European Union	8,474,693	
of which:		
Germany	2,800,000	Martin and Barkin (2015)
United Kingdom	1,189,906	Ruddick (2015)
France	946,092	Labbé (2015)
Spain	683,626	Sánchez (2015)
Italy	648,458	Flak (2015)
Belgium	393,648	Fioretti (2015)
Austria	363,400	Luxemburger Wort (2015)
Sweden	224,746	Magnusson (2015)
Netherlands	160,000	Back (2015)
Czech Republic	148,000	Lopatka and Vodstrcilova (2015)
Norway	147,139	Jacobson (2015)
Poland	140,000	Szary (2015)
Switzerland	128,802	Franklin (2015)
Romania	105,000	Ilie (2015)
Portugal	94,400	Tonkin and Massey (2015)
Denmark	91,000	Tange and Heavens (2015)
Ireland	79,348	McAleer (2015)
Slovakia	46,000	Botíková (2015)
Luxembourg	43,000	Luxemburger Wort (2015)
Finland	26,000	The Associated Press (2015)
Greece	9000	Tomlinson (2015)
Latvia	5087	LETA (2015)
Estonia	2041	Tambur (2015)

Table 2
Allocation of fraudulent cars to year of sale.

	Year of sale								Source
	2009	2010	2011	2012	2013	2014	2015	2009–2015	
<i>United States of America</i>									
Total number of cars sold by VW Group	213,454	256,830	324,402	438,133	407,704	366,970	238,074 ^a	2,245,567	(PR Newswire, 2011, 2012; Volkswagen of America Inc., 2013, 2014, 2015a,b,c,d,e, f,g,h,i)
Fraction of cars sold as TDI Clean Diesel	0.219 ^b	0.220	0.216	0.206	0.235	0.216	0.223 ^c	—	
Number of TDI Clean Diesel cars sold	46,661	56,503	70,071	90,255	95,823 ^d	79,422 ^d	55,559	494,294	
Normalised to 482,000 fraudulent cars	45,500	55,097	68,328	88,011	93,440	77,447	54,177	482,000	
<i>European Union</i>									
Total number of cars sold by VW Group ^e	3,208,000	3,173,807	3,448,874	3,040,173	3,046,507	3,266,530	2,028,000 ^f	21,211,891	(Volkswagen AG, 2010, 2011, 2012, 2013, 2014, 2015b, c)
Normalised to 8,474,693 fraudulent cars	1,281,678	1,268,017	1,377,913	1,214,627	1,217,157	1,305,062	810,238	8,474,693	

^a Sales data for months January–August.

^b Average fraction of the years 2010–2014.

^c Average fraction over the months April–August; used for the months January–May.

^d Number of TDI Clean Diesel cars directly reported, thus not calculated from total number of cars sold and fraction TDI Clean Diesel cars thereof.

^e Combined sales for Western, Central, and Eastern Europe, minus sales in Russia.

^f Sales data for months January–June.

These data show that approximately 40% of passenger cars sold by Volkswagen Group in the European Union in the period 2009–2015 were fraudulent cars.

For every car sold in the USA, the yearly distance travelled was estimated for all years throughout its service life, based on data from the National Highway Traffic Safety Administration (NHTSA) (Lu, 2006). These yearly distances are corrected for vehicle age (the yearly distance travelled decreases over time), and the probability

of survival (the probability for a car to still be in operation also decreases over time). For cars sold in Europe, the relationship between yearly distance travelled and vehicle age was derived from a study on Italian passenger cars (Caserini et al., 2013) (Table 3). Based on the distances travelled, NO_x emissions by fraudulent cars were estimated for every year from 2009 onwards, using the test data from Thompson et al. (2014). The difference was then calculated between actual NO_x emissions by fraudulent cars and the

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