THE INTERNATIONAL COUNCIL ON CLEAN TRANSPORTATION

Meeting South Africa's new passenger vehicle CO_2 emission standards: The technology deployment costs, fuel savings, and consumer benefits

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Summary

In October of 2018, the Department of Transport of South Africa received cabinet-level approval to move the Green Transport Strategy (GTS) forward. The GTS is South Africa's governmental guidance document that sheds light on pathways to decarbonize the country's transport sector. New vehicle fuel-efficiency standards, which are equivalent to CO_2 emission standards, are one of the pillar programs that make up the GTS action plan. This study provides insights into how potential standards scenarios could be implemented, what that would imply in terms of vehicle technology adoption, and the associated costs.

The 2015 South African fleet averaged 148 g CO_2/km (see Figure ES 1). In this study, we assumed two potential scenarios for the implementation of new vehicle CO_2 emission standards: improving the average fleet to 120 g CO_2/km by 2025 or to 95 g CO_2/km by 2030. These two scenarios represent a 19% and 36% reduction in fleet average fuel consumption, respectively.

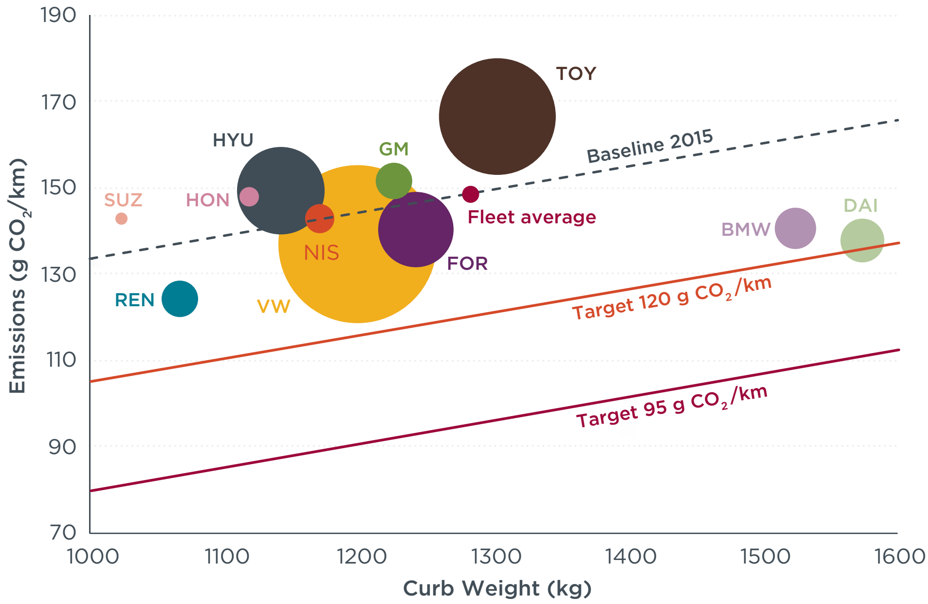

Figure ES 1. New vehicle sales-weighted CO_2 emissions and vehicle mass by manufacturer, 2015.[1] Circle diameters are proportional to sales numbers, dotted line corresponds to linearization of baseline 2015 sales-weighted data

1 BMW: BMW group (includes Mini), DAI: Mercedes Benz and Smart, FOR: Ford, GM: General Motors includes Chevrolet and Opel, HON: Honda, HYU: Hyundai and Kia, NIS: Nissan, REN: Renault, SUZ: Suzuki, TOY: Toyota, and VW: Volkswagen group (includes Audi).

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To analyze the technology needed to meet these targets and their costs, we modified the U.S. Environmental Protection Agency's (EPA) Optimization Model for Reducing Emissions of Greenhouse Gases from Automobiles (OMEGA) model, which calculates technology costs and benefits of fuel-efficiency standards, specifically for the South African fleet. The OMEGA model projects that for the average South African vehicle, most of the efficiency gains could be realized by improvements to conventional technologies, with very little market uptake required for more advanced powertrains. Conventional technologies include low-cost improvements, such as aerodynamic drag and low rolling-resistance tires; advanced powertrains are understood here as those found in electric and full-hybrid vehicles. In the 95 g CO_2/km scenario, EPA's technology pathways lead to some 48-volt mild-hybridization (4% market share) and a much lesser role for full-hybrid and battery-electric technologies.

The average costs and benefits under both targets have been summarized using EPA and ICCT technology cost estimates (see Table ES 1). The currency used across the report is the South African Rand (R), unless specified otherwise.

As the table shows, the average technology cost to meet the 120 g CO_2/km target is R 4,601–7,059 per vehicle. The average cost to meet 95 g CO_2/km is R 15,065–23,112. In both cases, consumers see net savings in one to three years, due to lower fuel costs. However, the 95 g CO_2/km target more than doubles the total fuel and net savings of the 120 g CO_2/km target.

Adopting new vehicle CO_2 emission standards, or fuel-efficiency standards, would result in large economic benefits for consumers and the economy in general, as it would reduce the need to import significant amounts of refined petroleum products. According to 2017 data from the South African Petroleum Industry Association, South Africa imported 1.9 billion liters of petrol.[2] Our analysis found that annual fuel savings from fuel-efficiency standards reached 0.8–1.3 billion liters by 2030 and 2.5–4.1 billion liters by 2050. This means that by adopting the standards, the amount of fuel saved by passenger car drivers in 2030 could be more than half of today's imports and doubled by 2050. That would free large monetary resources from international transactions that could be injected into the national economy. The savings under the 95 g CO_2/km target translate to more than R 20 billion by 2030 and nearly R 80 billion by 2050, compared to business-as-usual (BAU). The fuel savings also correspond to a 12% reduction in annual CO_2 emissions by 2030, compared to BAU.

Introduction

This report is the second of a two-part series that supports the decision process of South African policymakers to achieve their carbon emissions reduction goals. Here we present an analysis done by the ICCT of South Africa-specific technology pathways, costs, and benefits of adopting potential passenger vehicle greenhouse gas standards in 2025 and 2030. This report builds upon a previous report published in January 2018 on South Africa's new passenger vehicle CO_2 emission standards: baseline determination and benefits assessment (Posada, 2018).

Table ES 1. Summary of key results of cost analysis (USD 1 = R 14.7)

Results	Target 120 g CO_2/km		Target 95 g CO_2/km	
	Lower bound cost	**Upper bound cost**	**Lower bound cost**	**Upper bound cost**
Cost to meet the standard	R 4,601 (USD 313)	R 7,059 (USD 480)	R 15,065 (USD 1,025)	R 23,112 (USD 1,572)
Lifetime fuel savings*	R 36,503 (USD 2,483)	R 36,503 (USD 2,483)	R 90,925 (USD 6,185)	R 90,925 (USD 6,185)
Cash purchase				
Payback period, cash purchase	2 years	2 years	2 years	3 years
Savings at fifth year, cash purchase	R 12,323 (USD 838)	R 9,865 (USD 670)	R 26,935 (USD 1,832)	R 18,888 (USD 1,285)
Net lifetime savings, cash purchase	R 31,902 (USD 2,170)	R 29,444 (USD 2,003)	R 75,860 (USD 5,161)	R 67,813 (USD 4,613)
60-month loan				
Payback period, 60-month loan	<1 year	<1 year	<1 year	<1 year
Savings at fifth year, 60-month loan	R 11,628 (USD 791)	R 8,788 (USD 598)	R 24,651 (USD 1,677)	R 15,357 (USD 1,045)
Net lifetime savings, 60-month loan	R 31,206 (USD 2,123)	R 28,366 (USD 1,930)	R 73,576 (USD 5,005)	R 64,283 (USD 4,373)

*Lifetime in South Africa is assumed as distance-based metric: 316,000 km (see methodology section).

2 South African Petroleum Industry Association (SAPIA), "2017 Annual Report," http://www.sapia.org.za/Portals/0/Annual-Reports/SAPIA_AR%202017_FA_lowres.pdf

Such a comparison is relevant because in October of 2018, the Department of Transport of South Africa received cabinet-level approval to move the Green Transport Strategy (GTS) forward. The GTS is South Africa's governmental guidance document that sheds light on pathways to decarbonize the transport sector in the country. New vehicle fuel-efficiency standards, which are equivalent to CO_2 emission standards, are among several pillar programs that make up the GTS action plan.

The main objective of this report is to answer the questions: What are the technology needs and what costs will be incurred to comply with two potential CO_2 emission standards for passenger cars in South Africa? To answer these questions, the ICCT used one of the most advanced and publicly available tools for vehicle technology and cost-benefit assessment: the U.S. Environmental Protection Agency's Optimization Model for Reducing Emissions of Greenhouse Gases from Automobiles (OMEGA) version 1.4.56 of 2016 (U.S. Environmental Protection Agency [EPA], National Highway Traffic Safety Administration [NHTSA], and California Air Resources Board [CARB], 2016). The model evaluates the relative costs and effectiveness of vehicle technologies to reduce greenhouse gas (GHG) emissions and applies them to a defined baseline vehicle fleet to meet a specified CO_2 emission target.

Methodologies

This section presents the methodologies applied when using the OMEGA model to estimate the adoption rates and costs associated with meeting two potential vehicle emission targets in the 2025 and 2030 timeframe. The methodologies applied to the South African passenger vehicle fleet have been described and applied before in analysis for Mexico (Posada et al., 2014), the United States (Lutsey et al., 2017), and Canada (Posada et al. 2018b), and the reader is invited to review those documents for further details. This document only touches upon the methodological elements of the OMEGA model adaptations that are unique to South Africa. In addition, this section briefly describes the methodology for calculations related to payback analysis. This topic has been extensively explained before in other ICCT publications, (Miller ,2017; Posada, 2018c), and the reader is invited to look for those for further insights into the methods applied here.

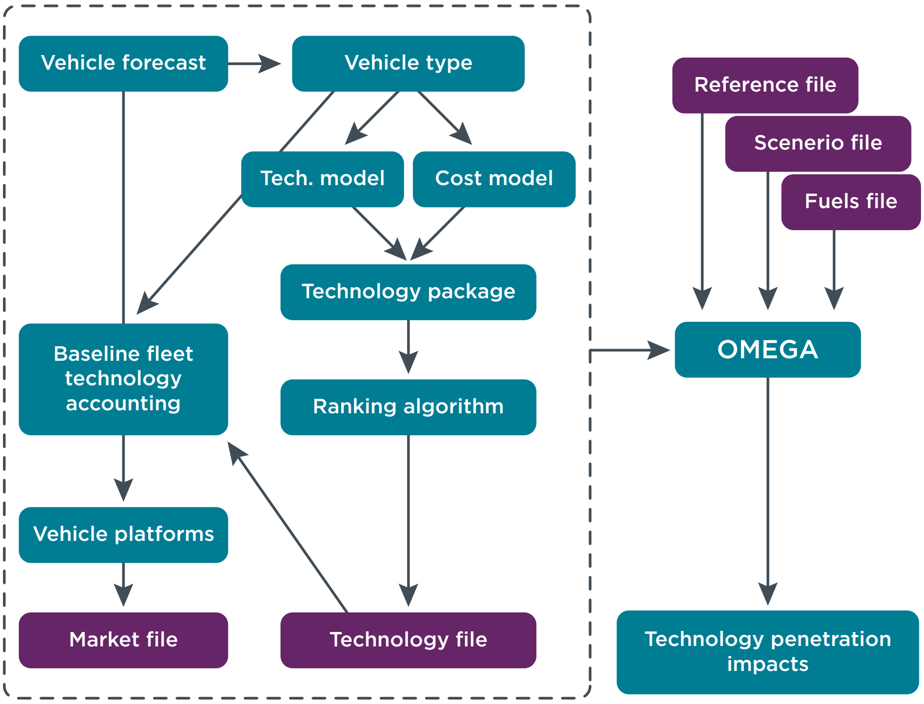

Figure 1. OMEGA model general structure and information flow (Posada et al., 2017)

OMEGA model description

OMEGA was developed by the EPA as a tool to evaluate the impact of the U.S. 2012–2016 GHG regulations for the light-duty vehicle (LDV) fleet. It was used again in the development and assessment of the 2017–2025 standards and updated in 2016 for the midterm review analysis (EPA, NHTSA, & CARB, 2016a).

The OMEGA model combines the technology and cost inputs with baseline fleet data to project how various manufacturers would apply the available technology to meet increasingly stringent CO_2 emission targets (EPA, NHTSA, & CARB, 2016b). The result is a description of the technologies that would need to be added to each vehicle platform, along with the resulting costs, to reach the CO_2 targets under various GHG standards. OMEGA is designed to apply technology in a manner similar to the way that a vehicle manufacturer might make such decisions. In general, the model considers the cost of the technology and the degree to which the technology moves the manufacturer toward achieving its fleet-wide CO_2 emission target. The model applies technologies to vehicles until the sales-weighted emissions average complies with the specified standard, or until all the available technologies have been applied.

OMEGA FILES

OMEGA includes several components, including a number of preprocessors that assist the user in preparing a baseline vehicle database, creating and ranking technology packages, and calculating the degree to which technology is present on baseline vehicles (see Figure 1). OMEGA's core model collates this information and produces estimates of changes in vehicle cost and CO_2 emission level. Based on this output, the technology penetration and costs of the new vehicle mix are calculated via postprocessors.

The OMEGA model uses five basic sets of input data: the vehicle market file, the technology file, the compliance scenario file, the fuels file, and the reference file. Following is a list of model input requirements that were modified in the ICCT analysis for use with the South African passenger car fleet. Note that the reference file, the fuels file, and the technology file are unchanged for the South African fleet. The reference file and the fuels file are only relevant for payback analysis as described in the next section (more detail on the role of those files can be found in Posada (2015).

The technology file was not modified as we are assuming that under the current global vehicle platforms manufacturing strategies implemented by most automotive companies (McKinsey & Company, 2013) there is no reason for efficiency technologies developed in the U.S., Europe, and Japan, and manufactured in a wide array of countries, to be unavailable for the South African market. U.S. data from the past two decades shows that once applied for the first time, new technologies can be deployed to a large fraction of the fleet quickly, thanks to platform sharing and improved manufacturing flexibility in the modern auto industry (Lutsey, 2012). Given the fact that South African vehicle manufacturers already export a large number of vehicles to Europe and other markets with fuel economy and CO_2 emission standards (AIEC, 2018), increasing production volume under a global sharing platform would reduce the cost of producing and installing that technology and improve the case for technology migration to South African vehicles.

VEHICLE MARKET FLEET CHARACTERIZATION FILE

OMEGA requires a detailed baseline fleet, including manufacturer, sales, base CO_2 emissions, footprint, and the extent to which efficiency technologies are already in use. This file is the input that describes the vehicle fleet composition used by the model to estimate costs. On a vehicle-by-vehicle basis, the market file is composed of:

a. Manufacturer
b. Model
c. Vehicle type number (OMEGA classifies all vehicles into 29 types).
d. Vehicle class
e. Sales
f. Tailpipe emissions, g CO_2/mile
g. Footprint, square foot (ft^2)
h. Fuel type
i. Efficiency technology penetration

The last input item, the efficiency technology penetration, contains information on all of the technologies that are designed to improve fuel consumption and are already incorporated in the baseline vehicle fleet. This basic set of information allows the model to avoid adding technology to models that are already sold with the technology. It follows that costs are also discounted. As an example, if a vehicle model sold in 2015 already has turbocharging technology, then the cost of that specific technology is removed from the technology package costs for that specific model.

One key adaptation to the market file was required to run the OMEGA model for South Africa. As described in the South African vehicle market characterization document (Posada, 2018), the original South African database lacked information on many of the efficiency technologies required to run the OMEGA model (i.e, item "i" on the list above). Filling in the missing efficiency technology fields was primarily performed by obtaining vehicle data from online sources. The full South African fleet market baseline dataset was composed of more than 2100 models from 27 manufacturers (Posada, 2018). Finding the level of technology detail required to map the entire South African PV fleet on OMEGA would have been resource-consuming. Instead, it was decided to proceed with technology mapping for the 30 most popular models sold in three vehicle segments: small, medium, and sport utility vehicles (SUV).

The decision to focus on these three segments is based on market characterization data from the South African fleet analysis by Posada (2018). That study shows that small (including mini) vehicles represent 40% of the market, medium size vehicles are 29%, and SUVs are 21%. The rest of the passenger car market is split among small shares of sport, off-road, and multi-purpose vehicles. More details on fleet characterization can be found in Posada (2018). From each of the three vehicle segments, the 30 most popular petrol models sold were researched for efficient technology adoption. Petrol was focused on because it comprises the vast majority of the South African fleet (83%) and represents the majority of the three vehicle segments considered. In total, 90 models were chosen that cover around 176,000 vehicle sales in calendar year 2015, out of 432,000 in total. The technology search included technical detailed information on fuel systems, such as gasoline direct injection (GDI), port fuel injection (PFI), air management, such as naturally aspirated and turbo/super-charged, start-stops systems, cylinder deactivation, mild and full hybridization, and electric accessories, such as power steering.[3]

Another adaptation converted the original CO_2 emission value, which was obtained under New European Drive Cycle (NEDC) testing, to the two-cycle combined Corporate Average Fuel Economy (CAFE)[4]. CAFE values combine the results of the U.S. Federal Test Procedure (FTP-75) and the Highway Fuel Economy Test (HWFET). The 2-cycle CAFE is the source of values used to develop the benefit and cost inputs in the OMEGA technology file. The cycle conversion ensures that technology benefits between the South African fleet technology and the US-based fleet technology are equivalent. The conversion from NEDC-based CO_2 values to two-cycle CAFE values is based on work by Kühlwein et al. (2014). The conversion is a linear regression developed from CO_2 and efficiency results simulated over a broad set of test cycles for a variety of vehicle and technology packages using a sophisticated vehicle emissions model developed by Ricardo Engineering. As an example, the South African NEDC fleet average CO_2 emission value of 148 g CO_2/km is 142.2 g CO_2/km, or 3.9% less, under the two-cycle CAFE.

SCENARIO FILE

The scenario file input defines regulatory scenarios and targets to be met by each vehicle manufacturer. Two scenarios were studied: a) low-ambition scenario that requires improving the average vehicle CO_2 emissions to 120 g CO_2/km by 2025, and b) high-ambition scenario set to match the current European target of 95 g CO_2/km, by 2030.[5] Both values are assumed as obtained under NEDC testing. Considering that the 2015 fleet average for South African passenger cars is 148 g CO_2/km, the 120 g CO_2/km scenario provides a 19% improvement, while the 95 g CO_2/km results in a 36% improvement.

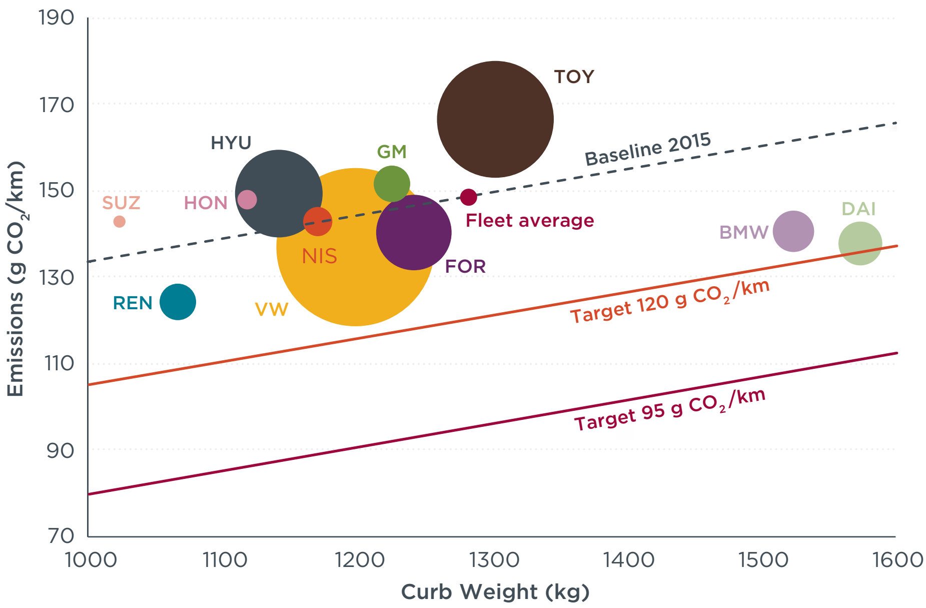

Figure 2. New vehicle sales-weighted CO_2 emissions by manufacturer, 2015. Circle diameters are proportional to sales numbers; dotted line corresponds to linearization of sales-weighted data; target 120 g CO_2/km corresponds to Equation 1; target 95 g CO_2/km corresponds to Equation 2

Manufacturer sales-weighted average CO_2 values and the linear representation versus the explored scenario targets of 120 g CO_2/km and 95 g CO_2/km have been shown for calendar year 2015 (see Figure 2). The equations describing the proposed target scenarios follow the CO_2 emission target structure implemented in Europe, where the target is a function of vehicle mass (see Equations 1 and 2).

M is the mass of the vehicle. The constant *Mo* is the South African sales-weighted average weight for passenger cars sold in 2015, calculated at 1,280 kg by Posada (2018). The slope of the linear function is defined by a weighted regression linearization performed on each of the manufacturer sales-weighted emissions and mass values (see Figure 2). This approach to defining the slope ensures that the summation of the differences between the manufacturer's CO_2 value and the linearization is a minimum. The targets were converted to g/mile and corrected to two-cycle CAFE values as explained before, which is required for running the OMEGA model.

Equation 1

$$CO_2Target_{120g/km} = 120 + 0.05386 \times (M-M_0)$$

Equation 2

$$CO_2Target_{95g/km} = 95 + 0.05386 \times (M-M_0)$$

3 Technology details were obtained from visiting the vehicle websites www.autotrader.co.za, www.cars.co.za, and selected vehicle manufacturer websites.

4 The Corporate Average Fuel Economy (CAFE) approach developed by the US EPA calculates the total CO_2 emissions taking into account both city (FTP) and highway (HWFET) driving. The distance-based results (g CO_2 / km) from the FTP75 and HWFET cycles are weighted as follows: CO_2 CAFE = 0.55 x $CO_{2\ FTP75}$ + 0.45 x $CO_{2\ HWFET}$

5 The European commission sets the new passenger car CO_2 emission performance via Regulation EC No 443/2009.

Methods for consumer and fleet-wide benefits analysis

Consumer benefits of passenger car efficiency technology under both scenarios were evaluated using two distinct measures: payback period, which refers to the number of years it takes for cumulative fuel savings to recover the initial investment in technology, and lifetime fuel savings, which reflects the cumulative fuel savings over the lifetime of the vehicle, including those that take place after the investment in technology has been fully recovered.

Of the two measures considered, lifetime fuel savings presents a more complete picture of consumer benefits than the payback period, since the former counts fuel savings that continue to accrue after the investment is paid back.

ICCT's analysis for South Africa applies the same underlying assumptions and methods as the EPA's, except that the ICCT analysis draws from South African inputs for fuel price, consumer economic valuation of future fuel savings, vehicle survival rates, and annual mileage driven. These payback methods apply detailed outputs from the OMEGA model for incremental vehicle technology costs and technology uptake time to meet corresponding annual CO_2 emission targets. The targets and baseline values are also corrected for real-world consumption factor, which increases the actual fuel consumed to better reflect the well documented fact that vehicles certified under the NEDC consume around 20% more fuel under real-world operation than what is calculated during the NEDC laboratory testing (Mock, 2019).

Fuel prices come from the South Africa Energy Price Report (DOE, 2017). Fuel prices in South Africa are defined by international crude oil fuel prices plus a somewhat steady set of taxes and levies, and the sales margin. Average petrol prices in 2016 were R 12.5/liter or USD 3.22/gal.[6] According to the energy price report, about 45% of the fuel price is defined by crude oil prices, 42% of the price is set by taxes and levies, and the rest is a regulated sales margin.

Fuel price projections were estimated as current values using World Bank's oil basket projections to 2030 and adding up a constant value for taxes, levies, and sales margin (WB, 2018).[7] Motor gasoline fuel projected prices per liter for calendar years 2025–2035 would range from R 16.01–16.07, equivalent to USD 4.60–4.62 per gallon.

For the economic valuation of future cash flows, the consumer benefits are estimated using a central discount rate of 7%. This is the average of actual interest rates (less inflation) on consumer mortgages and auto loans in South Africa. In 2015, nominal interest rates on the favorable end were quoted at 10.3% for mortgages from Standard Bank ZA, and 13% for auto loans offered by Wesbank. However, these rates are not necessarily indicative of the rates available to all consumers. Subtracting the 12-month inflation rate in 2018 (measured by the CPI index) of 4.7% (Statistics South Africa, 2018) from these consumer interest rates yields a real interest rate of 5.6% and 8.3% on the quoted mortgage and auto loan rates, respectively. The average of these two rates leads to the central discount rate of 7%.

Vehicle survival rates assume vehicle median lifetimes of 16 to 17 years, and average vehicle age near 12 years (Merven et al., 2012; Posada 2018). The annual mileage driven falls with vehicle age. The zero-age miles, or brand new car miles, was assumed as 22,000 km, and the average lifetime accrual for vehicles in South Africa is estimated to be approximately 316,000 km (Merven et al., 2012). For reference, EPA's analysis of U.S. consumer benefits assumes a lifetime average of approximately 273,600 km for passenger cars, and 316,600 km for light trucks. The higher lifetime mileage for cars in South Africa may be explained by higher retention rates for used vehicles related to lower average household net adjusted disposable income per capita[8] and economic challenges of accessing loans for new ones.[9]

Results

The results shown here illustrate the projected least-cost technology pathway toward compliance under two targets: a 120 g CO_2/km fleet average by 2025 and a 95 g CO_2/km fleet average by 2030. Manufacturers may choose other technology compliance pathways—including shifting their product mix to vehicles of larger or smaller weight than those currently sold or promoting SUV sales over compact cars—depending on marketing strategies, fuel price variations, local conditions, consumer preferences, and further technology development.

TECHNOLOGY DEPLOYMENT

For the two scenarios considered, we show the South African fleet-wide shift in technology market adoption rates from the baseline (CY 2015) for a selected group of technologies (see Figure 3). The model estimates that under both scenarios almost all vehicles (> 97%) are going to receive least-cost technology options, such as low rolling-resistance tires, reductions in engine friction, electrification

6 Assumes a currency conversion of R 14.7 per USD 1.

7 The World Bank anticipates that all three major benchmark oil prices—Brent, WTI, and Dubai—will continue to increase after 2020 to reach USD 70 per barrel in 2030 (The World Bank, 2018).

8 According to the OECD Better Life Index (OECD, 2019), the average South African household net adjusted disposable income per capita is USD 10,872 a year, much lower than the OECD average of USD 30,563.

9 South African banks' annual interest rates for new vehicle loans were around 12–15% in 2018, from a sample of bank websites.

of accessories (e.g., fuel pump, power steering, coolant water pump), and aerodynamic improvements.

The transition to a fleet that on average achieves a CO_2 emission target of 120 g CO_2/km would require only modest improvements in technology with respect to the South African CY 2015 baseline. This would be achieved with least-cost technology options, as listed above, as well as with improvements to transmissions. A very small increase, on the order of 1–2% adoption, is projected for technology uptake rates of gasoline direct injection (GDI), turbocharging, and start-stop systems. When compared to 2015 baseline, this unambitious technology shift would be reflected as small increases in cost and as small, fleet-wide benefits in avoided CO_2.

A transition toward a passenger car fleet that on average emits 95 g CO_2/km, which coincides with the numerical target for the European fleet in 2021, would require higher fuel-efficient technology uptake. Figure 3 shows a significant increase, almost 100% adoption of advanced transmissions with more than six gear ratios. GDI and start-stop systems are projected to experience a jump of more than 10 percentage points. Non-hybrid Atkinson engines, a technology that was absent in the South African 2015 baseline fleet, is projected to rise to 10% of the market as a manifestation of technology global market growth.[10] Cylinder deactivation is a technology traditionally applied to engines with six cylinders or more, but it is now being deployed in four-cylinder engines (EPA, 2016). This type of technology was also identified by EPA's research staff to become predominant in smaller vehicles and has been projected by the OMEGA model results to reach more than 60% of the South African market under a 95 g CO_2/km target.

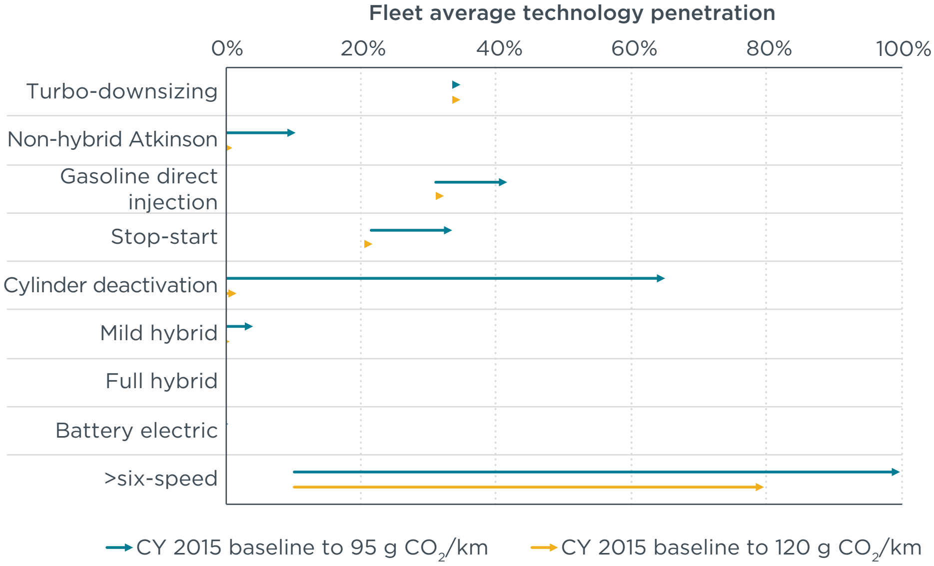

Figure 3. Estimated fuel-efficiency technology adoption as share of vehicle market. Baseline (CY 2015) data shown as line start-points

Table 1. Key technologies and preliminary costs (USD) needed to meet the 95 g CO_2/km and 120 g CO_2/km standards

Area	Technology	Target 120 g CO_2/km	Target 95 g CO_2/km
Advanced combustion	High compression ratio Atkinson/Miller	0.9%	10.3%
	Turbocharged and downsized	36.7%	34.7%
	Cylinder deactivation	1.5%	65.1%
Non-hybrid and non-electric		99.3%	95.5%
Hybrid	Mild hybrid	0.7%	4.0%
	Full hybrid	0.0%	0.1%
Electric	Plug-in hybrid electric	0.0%	0.0%
	Battery electric	0.0%	0.3%

The OMEGA model also projects that for the average vehicle, most of the efficiency gains are expected to be realized by improvements to conventional technologies, with very little market uptake required for more advanced powertrains, such as those in electric and full-hybrid vehicles. In the 95 g CO_2/km scenario, EPA's technology pathways lead to some 48-volt mild-hybridization (4% market share) and a much lesser role for full-hybrid and battery-electric technologies. The 48V mild hybrid offers roughly half of the benefits of a full hybrid at only a third of the cost (German, 2015). These vehicles permit acceleration assist and turbo lag reduction, both of which could prove attractive to the South African fleet, which, as of CY 2015, is more than 30% turbocharged.

A summary of the projected fleet rate of adoption for key technologies to meet the two potential CO_2 standards of 120 g CO_2/km and 95 g CO_2/km shows that improvements to conventional powertrains make up the vast majority of technology required to meet the targets (see Table 1). Such improvements—termed "advanced combustion" in the table—include Atkinson-cycle and Miller-cycle engines, cylinder deactivation, turbo-downsizing, and a suite of technologies that allow more precise control

10 Mazda uses Atkinson cycle technology on its Skyactiv gasoline engines with higher compression ratio. Toyota also uses Atkinson cycle technology in combination with variable valve timing and cooled exhaust gas recirculation.

over engine and transmission operation. Furthermore, automakers have recently announced plans for additional advanced combustion-efficiency technologies that were not incorporated into this analysis.[11]

Although electrification and full hybridization are not necessary to comply with these proposed CO_2 emission standards, the popularity of plug-in hybrids and fully electric vehicles will likely grow as battery technology improves and costs decline. Many automakers have publicly committed to offering fully electric vehicles in their biggest markets. Such commitments serve as further indication that manufacturers have many possible pathways to improve the efficiency of their fleets and meet future GHG emission standards. Accelerating the adoption of electric passenger cars would require additional programs and coordination between the South African government and the auto industry. South African stakeholders, vehicle manufacturers, the government, and financing institutions should aim for driving the uptake of EVs. South Africa is producing and exporting a significant number of conventional internal combustion engine (ICE) vehicles today. Looking at the near future, South Africa should develop a strategy that also makes EVs a success within the country, ensuring that some domestic EV production takes place in order to secure a long-term EV production network, regardless of the future of the ICE globally.

OMEGA results: cost per vehicle

The output from OMEGA shows that meeting the 120 g CO_2/km standard costs, on average, R 7,059 (USD 480) per vehicle, while meeting the 95 g CO_2/km standard costs, on average, R 24,303 (USD 1,653) per vehicle (see Table 2). These average values are lower for cars and higher for SUVs. Three vehicle segments were studied: small, medium, and SUV. The summaries include direct manufacturing costs, or the added costs incurred by manufacturers to meet the standards, as well as indirect costs, including overhead, marketing, distribution, warranty, and profit.

Table 2. OMEGA output: average cost per vehicle (USD)

Segment	Target 120 g CO_2/km	Target 95 g CO_2/km
Small cars	R 6,662 (USD 453)	R 23,690 (USD 1,612)
Medium cars	R 5,646 (USD 384)	R 21,325 (USD 1,451)
Small utility vehicles (SUV)	R 11,257 (USD 766)	R 32,375 (USD 2,202)
Fleet average	**R 7,059 (USD 480)**	**R 24,303 (USD 1,653)**

Discussion on cost estimates for South Africa

Costs shown are estimated from EPA's 2025 cost of technology projection and are presented here as the base for cost estimates applied to South Africa (see Table 2). Two more corrections have to be applied to the base to reach a more accurate analysis for South Africa. The first relates to newer and more cost-effective technologies that have entered the market since the OMEGA model was published, and the second accounts for the 95 g CO_2/km target proposed, which will be implemented five years after the cost evaluation. The five years between the evaluation year (2025) and the implementation year (2030) result in a cost reduction with respect to 2025 values due to production learning rates. The application of the cost corrections to the OMEGA outputs provide a range of possibilities for future costs to fall within lower and upper bounds.

Values shown in Table 2 for South African passenger vehicles are considered conservative, upper bound numbers. Although EPA's technology and costs assumptions used as inputs in OMEGA (V.1.4.56 of 2016) were rigorous and comprehensive, delays in obtaining and processing data meant that the latest developments in this fast-changing market were not included. To help evaluate the most recent technology development and inform the next phase of fuel economy standards in the United States and Canada, the ICCT conducted a study of emerging vehicle efficiency technologies and their emission benefits and costs for 2025–2030 (Lutsey et al., 2017). The analysis updates the technology cost and benefit inputs according to the latest research on emerging technologies, including cylinder deactivation, hybridization, lightweighting, and electric vehicles. These updates were conducted in cooperation with vehicle suppliers and draw upon peer-reviewed literature, simulation modeling, and auto industry developments. The ICCT estimates that compliance costs for the 2025 standards in the United States and Canada will be 35–40% lower than projected in the OMEGA model by EPA (Lutsey et al., 2017; Posada et al., 2018b).

We have also observed significant estimated cost reductions by studying European 95 g CO_2/km target adoptions. ICCT performed similar cost curve analyses in 2012 and 2013 using vehicle simulation data and technology costs developed by Ricardo and FEV, respectively (Meszler et al., 2016). The results were published in 2013 and predicted that the incremental total (retail-level) costs to reach the 95 g CO_2/km target in 2020 would be €1,036 for a 95 g CO_2/km passenger vehicle under the NEDC standard. ICCT hired FEV again in 2016 to update the cost

11 For example, Mazda will introduce a gasoline compression ignition engine in 2019 (Mazda, 2017), FCA's 2019 RAM pickup has a 48V hybrid system standard on the base V6 engine (FCA, 2019), and Infiniti's 2019 QX50 has a variable compression ratio, turbocharged engine (Infiniti, 2019).

analysis and estimate the impact for the 95 g CO_2/km and future potential targets for 2025 and 2030. The latest analysis (2016), which includes a broader set of technologies not covered in the 2013 work, shows that the CO_2 compliance cost estimates predict incremental costs in 2020 of between €261 (lower bound) and €807 (upper bound) for a 95 g CO_2/km passenger vehicle NEDC standard (Meszler et al., 2016). This translates to cost reductions between 22% and 75% from the older technology potential and cost analysis. It also highlights the need to carefully consider the latest technologies and cost reductions incurred in past years when evaluating the impact of CO_2 and fuel-efficiency standards in other markets.

South Africa would enjoy the benefits of adopting a CO_2 emission standard during years of strong technology development driven by global manufacturing strategies and fuel-efficiency standards. The conservative cost values reported by the OMEGA model projections, which come from pre-2015 technologies, can be adjusted to produce a picture for cost reductions driven by the impact of the latest cost-effective, fuel-efficiency technologies, as has been already determined by Meszler et al. (2016) in European markets and Lutsey et al. (2017) in the U.S. market. Thus, the OMEGA results for South Africa can be assumed as upper bound estimates, and lower bound values can be estimated by adjusting the OMEGA values by a factor that reflects the latest technology developments in the U.S. and European markets. The factor assumed in this analysis for lower bound costs was estimated as 35% reduction, which is a conservative choice for the U.S. market (35–40%) and within the 22–75% reduction observed in Europe. This results in lower bound cost estimates of R 15,839 (USD 1,077) and R 4,601 (USD 313) to meet the 95 g CO_2/km and 120 g CO_2/km target in 2025, respectively.

There is an additional correction for the 95 g CO_2/km target that accounts for cost reductions associated with production learning rates. The 95 g CO_2/km target is projected to be required by 2030, under a consistent 3.5% annual average CO_2 emission reduction rate for the new passenger car fleet entering the South African market. The cost of the technology listed in Table 2 is for the 2025 model year, while the target applies to 2030. A technology cost reduction rate of 1% per year due to production learning rates (EPA, NHTSA & CARB, 2016) is applied to both the 95 g CO_2/km conservative cost values (R 24,303) and to the lower bound values set by the new cost-effective technology estimate (R 15,065). This results in a fleet average cost of technology required to comply with the 95 g CO_2/km in 2030 of R 23,112 (USD 1,572) as a technology-conservative upper bound, and R 15,065 (USD 1,025) for the low bound, assuming newer cost-effective technologies. Note that the cost reduction due to production learning rates does not apply to the 120 g CO_2/km target costs as these are applicable in 2025, the year for which technology costs are evaluated.

Average vehicle efficiency costs to meet the studied targets in South Africa would most likely fall within these bounds (see Table 3). The payback and lifetime savings are presented in the next section using these values.

Counterintuitively, efficiency technology for small cars costs more than for medium cars (see Table 3). However, this result is an artifact of the limited number of models and platforms considered in the analysis. Only two manufacturers actually show higher compliance costs for their small cars and their sales represent both a sizeable fraction of all small car sales and a comparatively smaller fraction of medium car sales. Additionally, these small cars require the biggest efficiency improvements to meet their targets. These relatively big improvements are partly due to the fact that small cars weigh less and have stricter targets. The large efficiency improvements move small cars further up the cost curve than other vehicle types.

The Table 3 cost estimates for the set of high-sales vehicles that represent the South African passenger car market fall within close proximity to previous cost analyses performed by ICCT. The most recent one, performed to inform Canada's decision to adopt 2025 GHG emissions standards equivalent to 102 g CO_2/km, resulted in fleet average costs of USD 1,329, for a passenger fleet baseline of 143 g CO_2/km. Thus, the Canadian standard would require a 28% improvement on CO_2 emissions, resulting in an estimated cost per percent CO_2 reduction of USD 1,329 ÷ 28%, or USD 48 per percent reduction of CO_2. According to

Table 3. Summary of compliance costs for South African passenger vehicles

Scenario	Target 120 g CO_2/km by 2025		Target 95 g CO_2/km by 2030	
	Lower bound	**Higher bound**	**Lower bound**	**Higher bound**
Small cars	R 4,343 (USD 295)	R 6,662 (USD 453)	R 14,685 (USD 999)	R 22,529 (USD 1,533)
Medium cars	R 3,680 (USD 250)	R 5,646 (USD 384)	R 13,219 (USD 899)	R 20,280 (USD 1,380)
Small utility vehicles (SUVs)	R 7,337 (USD 499)	R 11,257 (USD 766)	R 20,068 (USD 1,365)	R 30,788 (USD 2,094)
Fleet average	**R 4,601 (USD 313)**	**R 7,059 (USD 480)**	**R 15,065 (USD 1,025)**	**R 23,112 (USD 1,572)**

Lutsey et al. (2017), reaching the same target in the U.S. showed USD 34–54 per percent benefit. The results of the analysis to meet the 95 g CO_2/km in 2020 show that the cost per percent of CO_2 reduced around USD 29. The current analysis shows that for South African passenger vehicles, the shift from 148 g CO_2/km to 120 g CO_2/km is equivalent to 19% reduction in CO_2 emissions, which results in USD 16–25 per percent benefit. The shift to 95 g CO_2/km is equivalent to 36% CO_2 reduction, which results in USD 28–44 per percent benefit, well within ICCT's previous cost/benefits results.

CONSUMER BENEFITS AND PAYBACK ANALYSIS

From the consumer perspective, the technologies adopted achieve benefits in terms of lower fuel consumption over the lifetime of the vehicle. Under all inputs, the upfront total manufacturing costs of more efficient technologies can be recouped within a few years of typical use, with further benefits accruing in the following years.[12] In this analysis four technology cost cases are studied: lower and upper bounds for meeting the 120 g CO_2/km target, and lower and upper bounds for meeting the 95 g CO_2/km target.

Cumulative savings are shown for each year of ownership associated with buying a vehicle outfitted with the technologies needed to meet the scenario targets, as well as the annual fuel savings associated with the efficiency improvements (see Tables 4–7). Each table shows that the average vehicle that complies with either of the standards would incur additional costs, but that the savings would quickly accumulate and overshadow these costs.

Two payment cases are studied: one where the vehicle cost is paid upfront, in cash, and the second case, which is more representative of new vehicle purchase transactions at dealerships, wherein payment is made under a 60-month credit agreement at 13% annual interest rate. The values in Tables 4 through 7 reflect a 7% discount rate, and projected fuel prices as described in the methodology section. Vehicle technology represents the cost of the higher fuel-efficiency technology implemented on the compliant average vehicle, as compared to a 2015 baseline vehicle. Cumulative savings simply represent the sum of all costs and fuel savings.

Results of the payback analysis for the 120 g CO_2/km target for lower and upper bounds show that consumers see net savings in the second year, assuming a cash purchase, and before the end of the first year, assuming a credit purchase (see Tables 4 and 5). Both positive results are achieved under lower and upper bounds technology cost assumptions. For cash purchases, after the second year, operational savings start accumulating and reach between R 9,800 and R 12,300 by the fifth year of ownership. Total vehicle lifetime fuel savings reach about R 36,500 after 30 years. Note that fuel savings are reduced over time to reflect vehicle use reductions.

For the ambitious target of achieving 95 g CO_2/km by 2030, payback is achieved within the second and third year of ownership under both lower and higher bound cost scenarios (see Tables 6 and 7). Although the cost of technology is higher than the cost required to meet the 120 g CO_2/km target, the 95 g CO_2/km target provides almost double the fuel savings. After the second year, operational savings start accumulating and reach between R 18,000 and R 27,000 by the fifth year. Lifetime fuel savings are estimated to be R 90,925—more than twice the lifetime fuel savings under the 120 g CO_2/km scenario.

Table 4. Technology costs, benefits, and payback period for the average model year 2025 meeting the 120 g CO_2/km target under lower bound technology cost assumptions

Year of ownership	Vehicle cost: Cash purchase	Vehicle cost: 60-month loan purchase	Fuel savings	Cumulative operational savings: Cash purchase	Cumulative operational savings: 60-month loan purchase
1	-R 4,601	-R 1,213	R 3,985	-R 616	R 2,772
2	R 0	-R 1,133	R 3,674	R 3,058	R 5,313
3	R 0	-R 1,057	R 3,374	R 6,432	R 7,630
4	R 0	-R 983	R 3,085	R 9,516	R 9,732
5	R 0	-R 912	R 2,807	R 12,323	R 11,628
6	R 0	R 0	R 2,549	R 14,872	R 14,176
7	R 0	R 0	R 2,301	R 17,173	R 16,477
8	R 0	R 0	R 2,065	R 19,238	R 18,542
Vehicle lifetime	**-R 4,601**	**-R 5,297**	**R 36,503**	**R 31,902**	**R 31,206**

12 Unless otherwise noted, all costs and benefits are given in 2015 USD.

Table 5. Technology costs, benefits, and payback period for the average model year 2025 meeting the 120 g CO_2/km target under upper bound technology cost assumptions

Year of ownership	Vehicle cost: Cash purchase	Vehicle cost: 60-month loan purchase	Fuel savings	Cumulative operational savings: Cash purchase	Cumulative operational savings: 60-month loan purchase
1	-R 7,059	-R 1,863	R 3,985	-R 3,074	R 2,122
2	R 0	-R 1,740	R 3,674	R 600	R 4,055
3	R 0	-R 1,623	R 3,374	R 3,974	R 5,806
4	R 0	-R 1,510	R 3,085	R 7,058	R 7,381
5	R 0	-R 1,400	R 2,807	R 9,865	R 8,788
6	R 0	R 0	R 2,549	R 12,414	R 11,336
7	R 0	R 0	R 2,301	R 14,715	R 13,637
8	R 0	R 0	R 2,065	R 16,780	R 15,702
Vehicle lifetime	**-R 7,059**	**-R 8,137**	**R 36,503**	**R 29,444**	**R 28,366**

Table 6. Technology costs, benefits, and payback period for the average model year 2030 meeting the 95 g CO_2/km target under lower bound technology cost assumptions

Year of ownership	Vehicle cost: Cash purchase	Vehicle cost: 60-month loan purchase	Fuel savings	Cumulative operational savings: Cash purchase	Cumulative operational savings: 60-month loan purchase
1	-R 15,065	-R 3,972	R 9,830	-R 5,235	R 5,857
2	R 0	-R 3,711	R 9,091	R 3,856	R 11,238
3	R 0	-R 3,461	R 8,377	R 12,233	R 16,154
4	R 0	-R 3,219	R 7,685	R 19,919	R 20,620
5	R 0	-R 2,986	R 7,016	R 26,935	R 24,651
6	R 0	R 0	R 6,371	R 33,306	R 31,022
7	R 0	R 0	R 5,753	R 39,058	R 36,774
8	R 0	R 0	R 5,163	R 44,221	R 41,937
Vehicle lifetime	**-R 15,065**	**-R 17,349**	**R 90,925**	**R 75,860**	**R 73,576**

Table 7. Technology costs, benefits, and payback period for the average model year 2030 meeting the 95 g CO_2/km target under upper bound technology cost assumptions

Year of ownership	Vehicle cost: Cash purchase	Vehicle cost: 60-month loan purchase	Fuel savings	Cumulative operational savings: Cash purchase	Cumulative operational savings: 60-month loan purchase
1	-R 23,112	-R 6,100	R 9,830	-R 13,282	R 3,729
2	R 0	-R 5,699	R 9,091	-R 4,191	R 7,122
3	R 0	-R 5,314	R 8,377	R 4,186	R 10,185
4	R 0	-R 4,944	R 7,685	R 11,871	R 12,926
5	R 0	-R 4,585	R 7,016	R 18,888	R 15,357
6	R 0	R 0	R 6,371	R 25,259	R 21,728
7	R 0	R 0	R 5,753	R 31,011	R 27,481
8	R 0	R 0	R 5,163	R 36,174	R 32,644
Vehicle lifetime	**-R 23,112**	**-R 26,642**	**R 90,925**	**R 67,813**	**R 64,283**

ECONOMY-WIDE BENEFITS

Summing individual consumer benefits across the entire fleet leads to dramatic reductions in CO_2 emissions, as well as fuel savings (see Figure 4). Beginning in 2020, achieving a 120 g CO_2/km fleetwide average in 2025 represents a 3.4% annual improvement, while achieving a 95 g CO_2/km in 2030 represents a 4.0% annual improvement. Compared to business-as-usual (BAU) improvement of market driven 0.5% annual efficiency improvements, adopting a 120 g CO_2/km fleet average target by 2025 leads to annual total passenger car fleet fuel savings and CO_2 emission reductions of 7.4% by 2030. If this target is not updated, these annual savings increase to 13.3% by 2050. If the target is updated to 95 g CO_2/km by 2030, the improvement leads to an 11.9% annual emissions reduction by 2030. These annual emissions and fuel savings more than double to 27.8% by 2050, as compared to BAU.

These annual emissions equate to 0.8–1.3 billion liters less fuel burned by 2030, which reaches 2.5–4.1 billion liters saved by 2050. The annual fuel savings are worth R 13–20 billion by 2030, and balloon to annual savings of R 38–78 billion by 2050, as pictured in Figure 5.

Annual emissions and fuel savings are summarized in Table 8. Cumulatively, by 2050 annual fuel savings leads to total emission reductions between 82–159 million tons CO_2, and total monetary savings of R 0.6–1.2 trillion.

Summary and discussion

A summary of the cost analysis for meeting manufacturer average CO_2 emission standards for passenger vehicles in South Africa show several key results (see Table 9). Regardless of target and scenario, South African drivers would recoup the additional cost of efficiency technology within two to three years of vehicle ownership. Moreover, drivers who purchase new vehicles under credit loans start

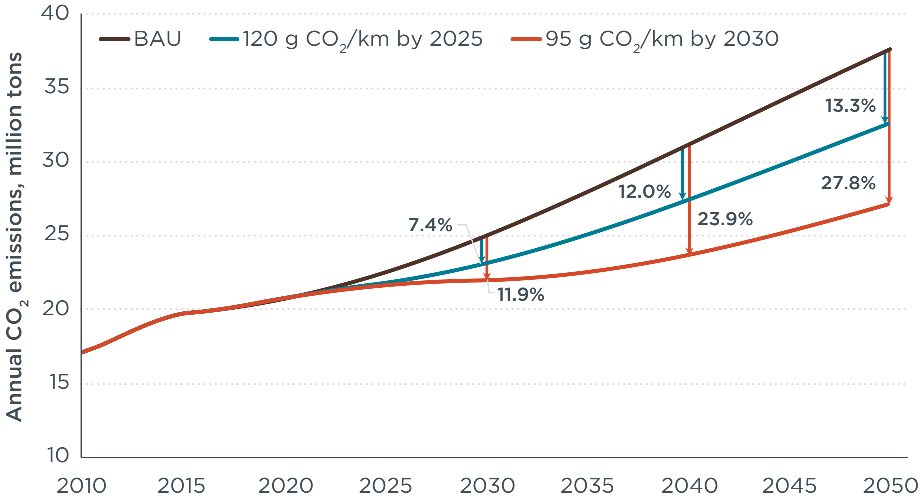

Figure 4. Annual emissions under business-as-usual (BAU) are 120 g CO_2/km by 2025 and 95 g CO_2/km by 2030 scenarios. Percent reduction in annual CO_2 emissions versus BAU shown for 2030, 2040, and 2050

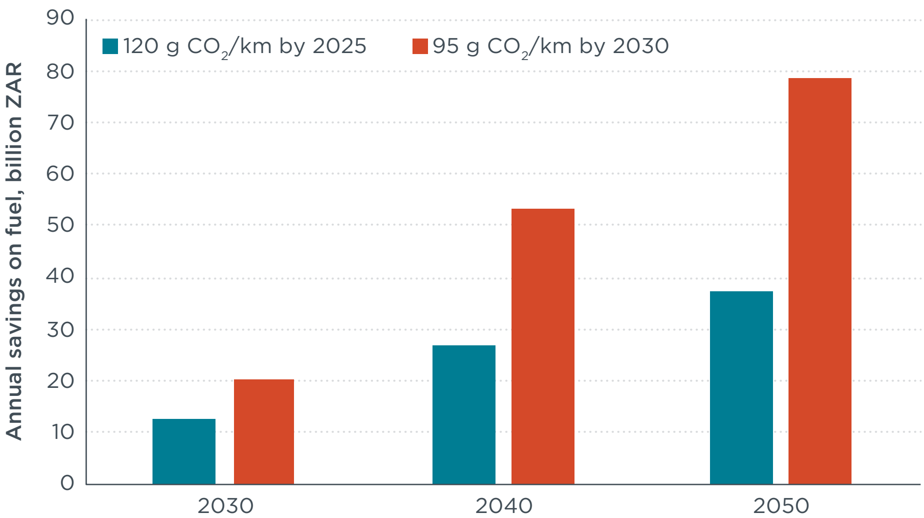

Figure 5. Annual fuel consumption under BAU, 120 g CO_2/km by 2025, and 95 g CO_2/km by 2030 scenarios (blue) and annual monetary savings on fuel versus BAU (red)

Table 8. Summary of annual CO_2 emissions and annual fuel consumption in key years

Scenario	Annual CO_2 emissions (million tons)			Annual fuel consumption (billion liters)		
	2030	2040	2050	2030	2040	2050
BAU	24.9	31.1	37.6	10.7	13.3	16.1
120 g CO_2/km by 2025	23.1	27.4	32.6	9.9	11.7	13.9
95 g CO_2/km by 2030	22.0	23.7	27.1	9.4	10.1	11.6
Reductions with respect to BAU						
120 g CO_2/km by 2025	1.8	3.7	5.0	0.8	1.6	2.1
95 g CO_2/km by 2030	3.0	7.4	10.4	1.3	3.2	4.5
% improvement with respect to BAU						
120 g CO_2/km by 2025	7.4%	12.0%	13.3%	7.4%	12.0%	13.3%
95 g CO_2/km by 2030	11.9%	23.9%	27.8%	11.9%	23.9%	27.8%

Table 9. Summary of key results of cost analysis (USD 1 = R 14.7)

Results	Target 120 g CO_2/km		Target 95 g CO_2/km	
	Lower bound	Upper bound	Lower bound	Upper bound
Cost to meet the standard	R 4,601 (USD 313)	R 7,059 (USD 480)	R 15,065 (USD 1,025)	R 23,112 (USD 1,572)
Lifetime fuel savings*	R 36,503 (USD 2,483)	R 36,503 (USD 2,483)	R 90,925 (USD 6,185)	R 90,925 (USD 6,185)
Cash purchase				
Payback period, cash purchase	2 years	2 years	2 years	3 years
Savings at fifth year, cash purchase	R 12,323 (USD 838)	R 9,865 (USD 670)	R 26,935 (USD 1,832)	R 18,888 (USD 1,285)
Net lifetime savings, cash purchase	R 31,902 (USD 2,170)	R 29,444 (USD 2,003)	R 75,860 (USD 5,161)	R 67,813 (USD 4,613)
60-month loan				
Payback period, 60-month loan	<1 year	<1 year	<1 year	<1 year
Savings at fifth year, 60-month loan	R 11,628 (USD 791)	R 8,788 (USD 598)	R 24,651 (USD 1,677)	R 15,357 (USD 1,045)
Net lifetime savings, 60-month loan	R 31,206 (USD 2,123)	R 28,366 (USD 1,930)	R 73,576 (USD 5,005)	R 64,283 (USD 4,373)

saving money during the first year of operation, as the costs are spread throughout the duration of the loan and fuel savings start accruing the moment the vehicle leaves the dealership. Lifetime savings are extremely positive for both targets, given the projected fuel price for South Africa, which reaches more than R 16 per liter by 2025, based on World Bank projections. The price of fuel at the station makes fuel-efficiency standards extremely beneficial to society given the short payback and strong savings over the years.

One caveat with the 95 g CO_2/km target, which is assumed in this analysis to apply for 2030, is that the cost and benefits are evaluated with respect to a baseline fleet from calendar year 2015. Lessons learned from the work by Lutsey et al. (2017) and Meszler et al. (2016) indicate that as new technologies enter the market, costs simultaneously drop. As a result, the cost projections for 2030 based on technology costs from 2017 applied to a 2015 fleet may be extremely conservative and produce even higher savings to consumers. It is recommended to reevaluate the cost and benefit for the 2030 target by 2023 or 2024, with an updated baseline fleet that better estimates the cost of the required technology improvement.

Although emissions, fuel, and monetary savings are substantial under both scenarios, 95 g CO_2/km achieves the biggest reductions as compared to BAU (see Figures 4 and 5). Compared to South Africa's Nationally Determined Contribution (NDC) of 398–614 Mt CO_2 by 2030 (NDC Partnership 2019), light-duty transportation could account for 4.1–6.3% of that annual total, if standards are not enacted. The 95 g CO_2/km standards could bring that share down by 12%, to just 3.5–5.5% of the NDC. Due to anticipated growth in vehicle sales, emissions are estimated to continue increasing after 2030, even under the 95 g CO_2/km by 2030 scenario. Additional phases of CO_2 standards and other supporting policy may be necessary through 2030 and beyond to reduce the sector's carbon footprint.

The results of this analysis show that although CO_2 emission standards would be a driving force to accelerate the adoption of efficiency technology, this type of policy is not enough to drive a transformation to zero-emission vehicles. Vehicle-efficiency standards act as one, but not the only, tool to reduce emissions from the light duty sector. Examples of additional policies that support standards and accelerate the adoption of EVs include electric vehicle sales mandates, fiscal incentives for zero- and low-emitting vehicles, disincentives for inefficient and polluting vehicles, and policies that contribute to modal shifting, such as from private to public transport (Slowik et al. 2019).

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