Group Project #1: Impact of CAFE Standards on Fuel Use and GHG Emissions

Civil Systems Investment Planning and Pricing

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1. Executive Summary

The CAFE (Corporate Average Fuel Economy) standards were originally developed in the 1970s "as a response to the Arab Oil Embargo" to lessen the dependence on foreign fossil fuels.[1] Since then, CAFE standards have grown to become the standard to assess motor vehicle efficiency. One specific aspect of the CAFE standards is to set future standards and determine the impacts on manufacturers and the environment. In 2011, the Department of Transportation set the standard for CAFE at 54.5 MPG in 2025. In 2012, the CAFE standard was changed again to the footprint method, which establishes an MPG based on the size of the vehicle. In this report, we found that the estimated fuel amount saved in 2025, based on the 2011 CAFE standards, is 3,378 to 4,114 millions of gallons per year. Using the 2012 CAFE standards, we found that we saved 19,485 to 32,407 million gallons of fuel within 2025 when compared to 2011 CAFE estimate. By using the 2011 CAFE standards we will save an estimated $13,453 to $21,1334 million and with the 2012 CAFE standards, we will save an estimated $77,599 to $166,476 million in fuel savings in 2025 dollars.

The environmental impacts of CO2 emissions were also assessed by calculating the CO2 emissions for each method (2011 Estimate, CAFE Footprint Method, and Frozen Footprint Method). We found that the most CO2 emissions were reduced by following the 2011 estimate using CAFE standards, followed by the 2025 revised footprint method, and the 2025 footprint method. The cost of the emissions, measured through the social cost of carbon, were found, respectively, to be $6 to $37 billion, $7 to $51 billion, and $8 to $55 billion in 2019 dollars. These emissions are a large portion of the annual CO2 generated by the transportation sector in the US. Based on this, the group recommends the maintenance of the 2025 footprint method for its reduction in fuel consumed and consumer spending saved.

2. Background

The United States is a major source of CO2 emissions in the world, accounting for 15% of the global CO2 emissions.[2] Domestically, emissions have been increasing every year by 2% since 1990, with the transportation sector accounting for 29% of domestic greenhouse gas emissions (GhG).[3] It is evident that the CAFE standards offer a much needed way to lower CO2 emissions in the United States. As CO2 is continued to be released at high rates, the impact on the will be detrimental. According to NASA, the sea levels rise, precipitation patterns change, the intensity of hurricanes increase, and agricultural growth will be impacted.[4] These impacts will have economic consequences, according to the World Economic Forum the "global economy could lose 10% of its total economic value by 2050 due to climate change".[5] As a result, the US Department of Transportation has tasked us with creating a report on the CAFE standards below.

[1] (Nock, 2021, #)
[2] (Union of Concerned Scientist, 2020)
[3] (Environmental Protection Agency, 2021)
[4] (NASA, n.d.)
[5] (Marchant, 2021)

3. Assumptions

3.1. Assumptions for 4.1

In part 4.1, we assumed that by 2025 all cars on the road will meet the 54.5 mpg standard listed in the project objective provided in class. The cars on the road in 2011 are ⅔ passenger vehicles, ⅓ light trucks, and all conventional gasoline powered. It is assumed that each vehicle travels 15,000 miles per year[6] and the number of vehicles on the road equals the number of drivers.The CAFE standards we use are assumed to increase linearly after 2011. The price of gas increases each year at the rate of inflation and is assumed to be constant within that year. Gasoline prices from 2021 to 2025 follow a regression model. The average interest rate is constant from 2011 to 2025 and is based on the average rate from 2011 to 2020.

3.2 Assumptions for 4.3

In 4.3, similar assumptions were held from 4.1 such that each vehicle on the road drove 15,000 mile per year and that the number of vehicles on road is equal to the number of licenced drivers. More specific to 4.2, It is assumed that the top 50 most popular vehicles sold can be normalized to represent the entire population of cars on the road. Furthermore, the top 50 cars follow the exact CAFE standards of their footprint classification. This means that if the CAFE standard for SUVs is 40 MPG for instance, then all SUVs on the road at the time meet the 40 MPG requirement. Lastly it is assumed that CAFE standards increase annually at a rate of 1.5% until a new proposal by the NHTSA goes into effect in 2024 at which CAFE standards will increase at a rate of 8%[7].

4. Projected Impact of CAFE Standards for 2025

4.1 Methodology of Fuel Saved

To calculate the fuel saved by modifying the CAFE standards for 2025, we calculated the difference of estimated annual fuel consumed by motor vehicles between 2011 and 2025. First, we had to establish the upper and lower bounds of vehicles in the U.S. for 2011 and 2025. For the lower bound, we took the number of licensed drivers and multiplied it at the average rate of US population growth from 2009 to 2011.[8] This gave a lower bound range of 212 million to 189 million cars. To estimate the upper limit, we assumed the number of licensed drivers, and consequently cars, would increase at the rate of licensed drivers from 2009 to 2011.[9] This gave us a range of 212 million to 227 million cars. Dividing the range by the difference in years from 2011 to 2025, we find that we save 3,378 to 4,114 million gallons of fuel per year.

[6] (Environmental Protection Agency, 2011, 3)
[7] (National Highway Traffic Safety Administration (NHTSA), 2021)
[8] (The World Bank, 2021)
[9] (U.S. Department of Transportation, 2014)

	Fuel (mil. gal.)	Fuel (mil. gal.)
2011	1.10E+05	1.10E+05
2025	5.21E+04	6.24E+04
Fuel Saved Per Year	4114	3378

Table 1. Estimated Fuel Saved

4.2 Monetary Value of The Reduced Fuel Consumption

Taking into account the estimation of total gallons of fuel used (lower bound, upper bound and best guess). This was used to calculate the approximate monetary value of the reduced fuel consumption by knowing that the average price per gallon is $3.52, with a lower bound of $3.07 and higher bound of $3.96 [10] using the equation 1, and in order to calculate the value of money in 2025 as in the equation 2 of this total cost calculated in 2021, we used the inflation rate which was estimated as 1.75% according to US Inflation calculator[11].

$$Total\ Cost\ in\ a\ given\ year\ =\ Total\ gallons\ consumed\ in\ the\ year\ \ *\ \ Price\ per\ gallon$$

Equation.1 Total fuel consumption in 2025 base on 2018 fuel consumption

$$Cost\ \ of\ fuel\ usage\ (2025)\ =\ Cost\ \ in\ (2011)\ *\ (1\ +\ i)^{n}$$

i: Inflation rate, estimated as 1.75% N: 15 years from 2011 to 2025

Equation.2 Total fuel consumption in 2025 base on 2018 fuel consumption

4.3 Methodology of Fuel Saved Using Footprint Method

The footprint method is a method that accounts for the area of a vehicle accounting for distance between the wheels of said vehicle. In 2016 it has become evident that the previous estimate made for MY 2011 cars can be revised to account using the footprint method. To calculate the similar estimation of finding fuel savings, the fuel consumption in 2025 must be first calculated accounting for the footprint method. To use the footprint method, the classifications of the different sizes of vehicles and their respective emissions and fuel economy standards must be found first. Data with such information can be found on the NHTSA fact sheet[12]. We assumed the top 50 most sold vehicles this year and their respective footprint classifications can be normalized to represent the total population of vehicles on the road now and in 2025. To go about doing this,we first classify each of the top 50 vehicles sold to their respective footprint sizing category and assign each one a MPG value based on the footprint standards. The assumption here is that during this time these vehicles categorized follow the footprint Fuel economy standards exactly. With the list of 50 MPGs from the footprint standards,

[10] (U.S Energy Information Administration, 2012)
[11] (US Inflation Calculator, n.d.)
[12](National Highway Traffic Safety Administration (NHTSA), 2016)

the averages of those values are taken to get an average 2016 MPG value of 46.9 MPG. This of course falls short of the 54.5 MPG value required in 2025 but we must account for the incremental annual change of the average Fuel economy in the US. It is stated in a NHTSA regulations webpage that fuel economy standards increase at a rate of 1.5% annually with the proposal suggesting an 8% increase in 2024. Assuming these rates are constant, exact and are applied on every year, we can calculate the 2025 MPG using our 2016 value with a constant increase of 1.5% every year and a constant increase of 8% from 2024-2025. From this a MPG value of 60.8 MPG as the projected average in 2025. To give the estimation a range to account for any error, we change the assumption of an 8% increase in fuel economy projected to start in 2024 and start it in the year after its proposal in 2022. This assumption suggests rapid development and implementation of CAFE standards. With this assumption the average MPG in 2025 is 68.8 MPG. So with the calculation of the second fuel economy value there are now three values to use for the estimation: the minimum require average of 54.5 MPG to be used as a lower bound, 68.8 MPG representing aggressive implementation to be used as an upper bound and 60.8 MPG to act as an average. Using the MPG values, the total amount of fuel used by applying each of the three MPGs to the following equation.

$$Total\ Fuel\ Consumption\ =\ Total\ Population\ of\ Cars\ \times\ \frac{Miles\ Driven}{Car \cdot year} \times \frac{Gallon}{Miles}$$

Equation 3. Equation to determine total gallons of fuel based on MPG.

Since estimation requires fuel savings in 2025, there must be a case where the fuel standards are not met. A scenario in which fuel economy standards did not meet the 54.5 MPG average is a case to calculate fuel savings to. The most realistic case of this is when you apply the 1.5 % rate of increase to the CAFE standards. Assuming that the rate of change of CAFE standards remains constant at 1.5% since 2016, the projected CAFE standard at 2025 is set at 41.5 MPG as shown on the graph below.

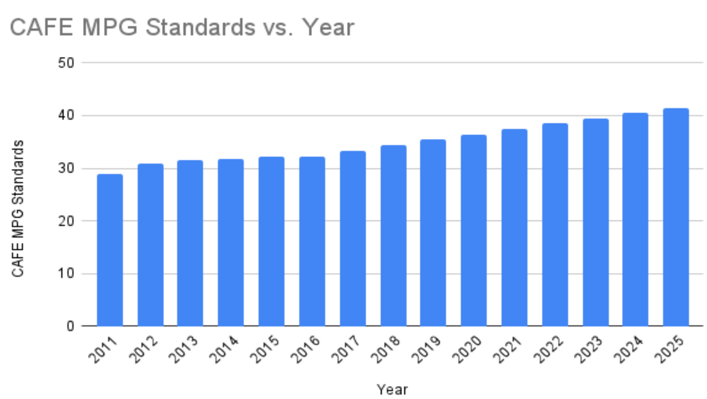


Figure 1. CAFE Standards reported by NHTSA with projected growth from 2018-2025.

Applying equation 1 to both the projected CAFE standard, 41.5 MPG, and required CAFE standard, 54.5 MPG, and taking the difference in the fuel amounts results in a value of

19,485 million gallons of fuel. Applying the same strategy but with the 68.8 MPG and 41.5 MPG results in a savings of 32,407 millions of gallons of fuel. This results in a range of fuel savings from 19,485 to 32,407 million gallons of fuel saved within a year in 2025. This means that billions of gallons of gas can potentially be saved in 2025 if we attempt to radically improve fuel economy standards of manufacturers. This in turn could result in higher priced vehicles which would slowly start to enter the US roadways.

Comparing this answer to the savings estimated in section 4.1, The fuel savings when using the footprint method are significantly higher than those in the previous estimation. While the fuel consumption values of 4.1 and 4.2 were very similar in magnitude and range, the methods of calculating savings were significantly different. Within the footprint method estimation, the 54.5 MPG is a minimum requirement in this estimation while it is a maximum in our previous estimation. Population of cars in the US is projected to only increase in the footprint method while decreasing in the calculation in 4.1. Additionally, after taking the difference in fuel amounts, the estimation in 4.1 includes dividing the number of years between 2011 and 2025 while this method does not. This is because with the footprint method calculation, average fuel economy standards must be calculated annually in order to determine the standards the subsequent year. Because this is done, the annual fuel savings can be determined by the difference between fuel amounts within a specific year using NHTSA's projected CAFE Standard vs our calculated requirements. The incentives of the footprint method is that large vehicle manufactures do not have to exactly meet the average fuel economy standards allowing time for development and implementation of technology in future model vehicles.

4.4 Methodology of Fuel Saved Using a Revised Footprint Method

In order to get the new projection for fuel consumption on an annual basis based on revised footprint method, 2018 fuel consumption should be projected from 2016 with the same calculation we used before in 4.2. However, in the revised footprint method, MPG Standard will be frozen in 2020, which means, the rate of an 8% increase to CAFE standards we assumed to take effect after 2021 will not be used in this process. In summary, the total cars number will be increasing at the constant rate 0.476% as mentioned in 4.1, miles per year per car should be constant at 15,000 and the MPG value will vary from 2018-2020 increasing at a rate of 1.5% similar to 4.2.

In order to get the lower bound, in this case. We make two assumptions: There is a constant CAFÉ standard, and linear relationship between car's number and total fuel consumption. Therefore, we use the Equation as follows:

$$Total\ fuel\ consumpiton(in\ 2025) = (1+i)^n * Total\ fuel\ consumpiton\ (in\ 2018)$$

Equation.4 Total fuel consumption in 2025 base on 2018 fuel consumption

In this equation, “i” means the increasing rate in a car's number, n means the years from 2018 to 2025. After we get the upper and lower bound, the average value is reasonable to be the expected value.

The range of 2025 fuel consumption is 68.2 to 70.3 billion gallons with revised method. In this case, it shows a revised footprint method will generate a greater value in consumption than the footprint method. That means the CAFE policy that freezing 2020 MPG will result in more money spent on fuel which, in the meantime, will generate more greenhouse emissions that will do harm to the environment.

4.5 Three methods to estimate carbon dioxide emissions

4.5.1 2011 Estimation Method

To start the estimation,we will estimate 2009 carbon emission from the previous year (2008) and also the real-world carbon emission in 2009.[13] This will allow us to set the upper and lower bounds of our estimations. Next we assume there is a linear function between annual emission and us this relationship to get each subsequent year's values. There are two cases to consider when looking at emissions, one with and without the CAFE policy. The CAFE will allow us to estimate a value in 2025 using CAFE standards. The second case, without CAFE policy, a real-world carbon emission from 2009-2011 will be needed to create a linear function and estimate the subsequent years using said function. In the second case, ⅔ of the total number of cars will be set to represent passenger cars while the remaining ⅓ represents light trucks. For the first case when is CAFE applied, the carbon emission in 2025 should be 359.63 million gram/mile in 2025 by using the equation below:

$$total\ carbon\ emission(in\ gram) = CAFE\ emission\ CO2\left(\frac{g}{miles}\right) * cars\ number\ in\ U.S. * averaga\ miles\ per\ year\ per\ car.$$

Equation 5. Total emissions of Carbon Dioxide from vehicle fuel consumption

The range of carbon emission policy in units of ton/mile without CAFE standards in 2011 is 391 ton/ mile when only the upper bound in previous year is used and 380 ton/mile when only the lower bound in previous year is used Using these two data points to move forward in the future, we will get the 2025 total carbon emission at the range of 229.54 ton/mile and 359.63 million ton/mile.

Based on EPA data, we will get the total carbon emission by using the conversion of 8.8 kg co2 per gallons of fuel consumed and dividing that by 54.5 miles per gallon[14] and convert kg

[13] (Environmental Protection Agency, 2020)
[14] (Environmental Protection Agency, 2010)

to gram to get to 163.3 grams/mile in 2025.Revised footprint method in 2025 with CAFE standards in 2025 results in 521.2 Megaton, in this case we assume the upper and lower bound should be around 5% because of the mathematical error for significant digits. Total carbon emission at 2025 without CAFE at the range 469.6 Megaton to 574.0 Megaton.

4.5.2 Footprint Method

This method was implemented similarly to the one from the previous section. In order to get the total grams of carbon emission in 2025, we keep the total cars change with constant carbon emission in grams/mile. Firstly, we convert MPG into grams/miles in each different car and then we will take an average of them each year. The rate among years has a range [0.015-0.05] for carbon emission. 141.1 ton/miles was calculated for 2011 years according to linear regression. Then we multiply grams/miles required in different years with that year's cars number.The upper bound comes from Equation 2. In this case, our upper and lower bound should be 612.04 megaton in 2025 and 774.73 megaton in 2025.

4.5.3 Revised foot print method in CO2

In this case, we will freeze carbon emission in 2020. In order to get the total gram carbon emission in grams in 2025, we keep the total cars changed with constant carbon emission in grams/mile. Similar to what we get in the previous question, the upper bound comes from Equation 2. In this case, our upper and lower bound should be 674.79 megaton in 2025 and 708.52 megaton in 2025, which is shown in Fig.1.

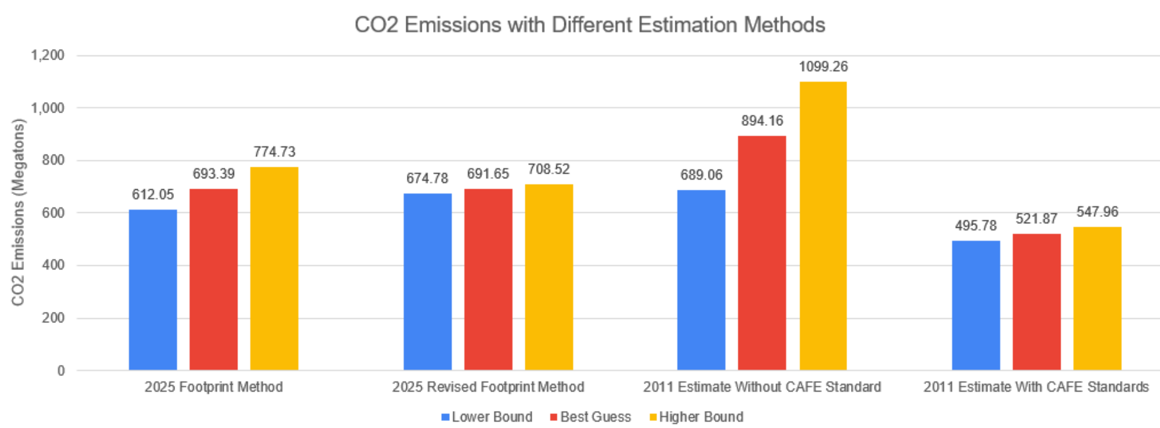


Fig.2 CO2 emission with different methods or different policies

4.5.4 Discussion and Results

In this table and figure, we summarize the lower and upper bound we get from the previous section. By comparing those different results with 2011 without the CAFE method, we could estimate the impact of each policy on CO2 emission in 2025. In this table, we use the exact value without CAFE, subtract by the exact value each case, and assume it is in the 10% range(which is from the maximum range for our three methods.)

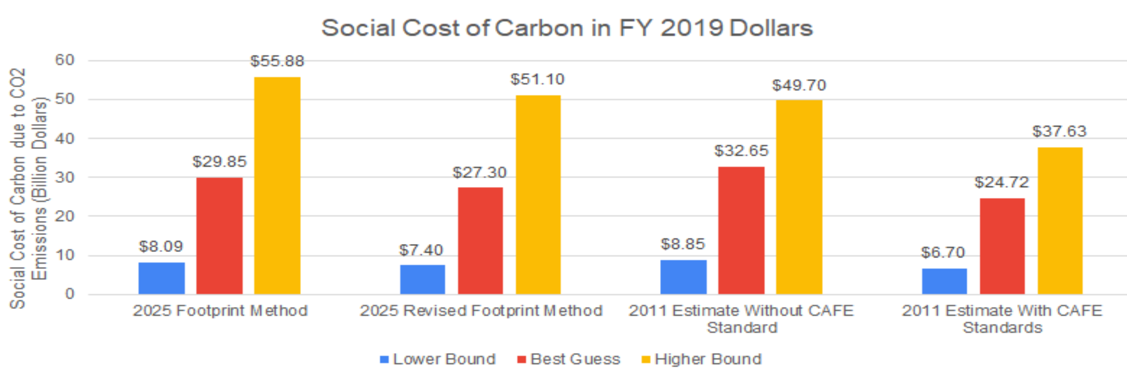
I think the best way to estimate the impact of CAFE is the revised footprint method. If we only consider the amount of money or carbon dioxide emissions we saved, 2011 estimation>foot print method=revised footprint method. However, 2011 estimates with CAFE standards get the lowest value compared to the case without CAFE standard,which is not accurate. Between the 2025 footprint method and 2025 revised footprint method, the revised footprint method is better because its upper and lower bound is more close(which means it's more accurate.)

CO2 Emission (Megaton) in 2025											
2011 estimation method with CAFÉ			foot print mechod with CAFÉ			revised foot print method with CAFÉ			without CAFÉ		
Lower	Upper	Exact	Lower	Upper	Exact	Lower	Upper	Exact	Lower	Upper	Exact
495.78	521.87	547.96	612.05	774.73	693.39	674.78	708.5	691.65	689.06	1099.26	894.16
CO2 we saved		346.2			200.77			202.51			

Table 3. CO2 Emission (Megatons) in 2025 in different methods with CAFE.

4.6 Comparing Monetized Effects for Cost of Emissions

In order to answer the senior leaders at the Environmental Protection Agency (EPA) request to assess the environmental impact of the CAFE standards at three different levels, which are the 2025 footprint method, the revised 2025 Footprint Method2011 CAFE standard.We used the Social cost of Carbon (SCC) which is an estimate measured in dollars of the economic damages that would result from emitting one additional ton of CO2 into the atmosphere[15]. Therefore, we converted the fuel consumption to the amount of CO2 it emits, we used the CO2 emotions and this way we calculated the environmental impact each one separately. To convert the CO2 emissions to a monetary value, we assumed the discount rates presented by the EPA (United States Environmental Protection Agency)[16] 2.5%, 3% and 5% to calculate our lower and higher bounds, being 3% our best guess. It is important to mention that the Social Cost of Carbon was expressed in 2007 dollars, therefore we converted it to 2019 dollars considering the cumulative price increase from 2007 to 2019 in dollars. The results for monetary value of environmental impacts across the three standards are shown in the following figures 3 and 4 depending on the estimation method and also on the discount rate. We realized that the results differ fairly by the influence of the discount rate chosen.



[15] (Rennert, 2019)
[16] (United States Environmental Protection Agency, n.d.)

Figure 3. Social Cost of Carbon in FY 2019 Dollars

From the comparison made in the previous figure we could identify that the method that saves the most fuel is the 2011 estimation.

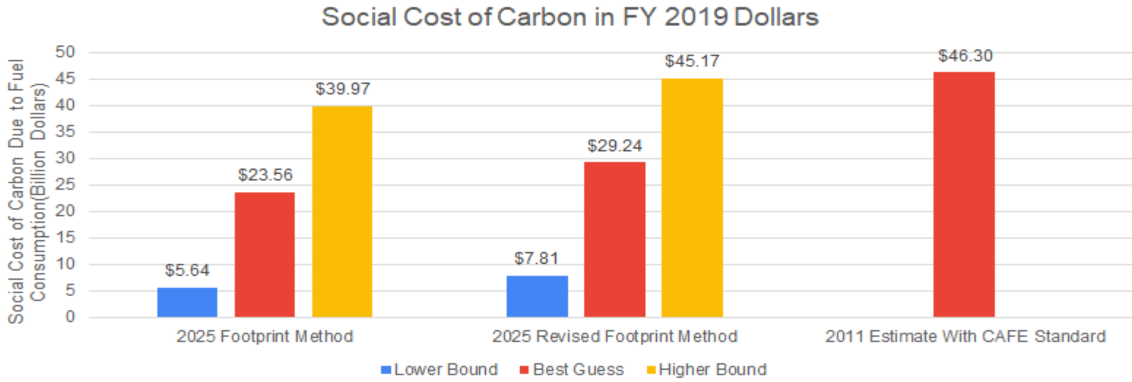


Figure 4. Social Cost of Carbon in FY 2019 Dollars

4.7 CAFE Savings Compared to Others

By comparing the reductions of CO2 in section 4.4 to the entire US CO2 emissions in 2019, we can ground the results in reality and assess their effect on the whole. In 2019, the U.S. emitted 5,255.8 Million Metric Tons (MMT) of CO2.[17] We can summarize the CO2 emissions for 2025 for each method compared to the total in table 4.

Method	CO2 Saved Lower (MT)	CO2 Saved Upper (MT)	CO2 Saved Lower Bound	CO2 Saved Upper Bound
Footprint 2025	116.2	226.7	2.21%	4.31%
Revised Footprint 2025	179.0	160.5	3.41%	3.05%
Non-CAFE Estimate 2011	193.3	551.1	3.68%	10.49%

Table 4. Estimated CO2 Saved Compared to Actual CO2 U.S. Emissions 2019

5. Policy Recommendation

Through our research we have been able to analyze various methods, based on this we recommend the 2025 footprint method. Though the best method calculated is the maintenance of the 2011 Estimate with CAFE standards, we believe that based on our experience this is incorrect. We believe our calculations and assumptions for the 2011 Estimate with CAFE standards are incorrect and require more analysis. The recommended 2025 footprint method shows a reduction in CO2 of 4.3% and a social cost savings of roughly $6 to $41 billion dollars in 2019.

[17] (Environmental Protection Agency, 2021)

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