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Induction of a Consumption Pattern for Ethanol and Gasoline in Brazil

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Abstract: Historically, carbon dioxide emissions from transport have been a globally discussed and analyzed problem. The adoption of flex fuel vehicles designed to run ethanol–gasoline blends is important to mitigate these emissions. The main purpose of this paper is to analyze the impact of the ethanol–gasoline price ratio on different vehicle models, and discuss the opportunities to increase ethanol consumption from this perspective. Our analysis shows that the use of a unique fuel economy ratio for all flex–fuel vehicles in the country significantly reduces the opportunity of some customers to purchase hydrous ethanol. The paper also discusses possible actions to provide adequate information that may increase the possibility of fuelling vehicles with a high-level ethanol blend.

Keywords: high ethanol blend; energy efficiency gap; flex fuel vehicles

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1. Introduction

Governments might improve the competitiveness of markets through regulations and incentives. In several sectors, regulations have acted in favor of making products safer, and restrictive environmental laws have forced changes in manufactured goods. For instance, there have been important technological advances in the automotive industry, where there is a large variety of vehicle models with many embedded technologies. In each new production cycle, technological innovations are embedded, enabling new experiences for all customers [1–3].

The continuous advance process in the automotive sector includes a large variety of technologies, such as intelligent vehicle technologies [4], automatic parking assistance systems [5], the incorporation of Internet of Things (IoT)-based technologies [6,7], and advanced brake control [8,9]. With regard to the vehicle propulsion system, flex fuel technology allows for an engine to run simultaneously with two different fuels, for example, hydrous ethanol (E100) or gasoline [10–13].

The current energy demand has led to alternatives to petroleum fuels being sought that can meet the needs of today's population. Given the latest [14] and current global economic crises, the demand for new alternative and renewable fuels is very high. Ethanol is currently considered to be the most suitable fuel for spark ignition engines [15] because, in addition to being renewable, it does not require any changes in the geometry of the engine [16], and has several physical and combustion properties somewhat similar to gasoline [14].

Some other advantages of ethanol over gasoline and other fossil fuel are the higher octane value and higher heat of vaporization, supplying a higher output from a given engine than that of gasoline [17–20]. In addition to being sustainable and promoting agriculture, ethanol produces fewer carbon emissions and less CO_2 during combustion [17]. Lower heating value and lower boiling point are among the disadvantages of ethanol. E100 is also more expensive to produce and it has less energy content than gasoline [17,21]. For instance, gasoline has a higher calorific value than that of E100 for the latent heat of evaporation, 44 and 26.9 MJ/kg, respectively [22]. Overall, biofuel technology is a measure to reduce greenhouse gas emissions [20] and it is strategic for many countries [23–27], but biofuel markets are largely influenced by both governmental policies and fossil fuel demand [28].

Although the use of alternative fuels has globally been promoted, and fuel blending mandates exist in 52 countries [29], the development and use of ethanol-powered flex fuel vehicles (FFVs) is concentrated in only four markets: the USA, Canada, Europe, and Brazil [30]. In addition, FFV not only stands as an alternative path towards reducing pollutant emissions, but also as a step in the transitional process to electric vehicles [26,27,31]. The United States is the largest ethanol producer in the world. The current E10 (10% ethanol blend) is projected to be constant in the U.S. up to 2030 [28]. The Environmental Protection Agency has also approved two other blends, E15 [32] and E85 [11]. As of 2021, E85, a gasoline–ethanol blend used in FFV containing from 51% to 83% ethanol, was sold in more than 3700 public gas stations in 42 states [33].

By 2030, Europe aims to increase the share of renewable energy in transport to 14% or more [34]. Sweden plays an important role in this goal because, by 2030, the government is committed to reduce greenhouse gas emissions from domestic transportation by 70% less than those in 2010 [35]. Since 2005, the Swedish Pump Act has required that large-enough stations with sales of over 1500 m^3 of petrol or diesel offer at least one type of renewable fuel [35,36]. Despite the share of renewable energy in the Swedish transport sector being 27.2% in 2017 [35], the ethanol market share has decreased since 2010 because of the introduction of diesel vehicles that met the criteria of being green, changes in the national rebate structure of FFV, and E85 blend being less economically attractive than gasoline [37]. On the other hand, France introduced E85 in 2007, and its sales volume has increased since then. The compatibility of a large fleet, the availability of over 19% of France largest filling stations, and government support, for instance, the rise of the renewable mandate for petrol grades and reduced fuel tax on E85, are the main reasons for the successful use of E85 in France [38].

Brazil is a well-established market for the consumption of biofuels, with a huge FFV fleet and available infrastructure to supply E100 all over the country [28]. In 2019, more than 90% of light vehicles sold in Brazil were FFVs [3]. E100 plays a strategic role in the Brazilian automotive sector. In this sense, Brazil has an important market share in the global production of biofuels, producing large volumes of bioethanol [3,39,40], which can ensure the maintenance of this technology. Brazil also has Renovabio, a program to foment the development of biofuel chains and reinforce the competitiveness of biofuels in Brazil, also fostering discussions about new technologies and the development of advanced biofuels [41]. Renovabio can be compared to the States' Renewable Fuel Standard, the California Low Carbon Fuel Standard, and the European Union's Renewable Energy Directive programs. An additional incentive for the development of this biofuel market was the Brazilian commitment assumed by Brazil at COP26, in Glasgow in 2021 [42]. Both consolidated E100 as a viable alternative to gasoline, and meeting decarbonization targets is highly dependent on investments and policies to promote the ethanol production chain in Brazil [43].

Regarding the decision-making process of choosing the fuel to be used in an FFV, previous studies showed the use of high-level ethanol blends as highly price-sensitive [44–46].

Anderson [47] evaluated the household preferences for E85 as an E10 substitute in Minnesota. He found that an increase of USD 0.10 per gallon in E85 price relative to E10 may lead to a 12–16% decrease in the consumption of E85. Liu and Greene [48] found that the price of gasoline E85 is a critical factor for the choice of E85. Pouliot and Babcock [49] estimated the consumption of 1 billion gallons of E85 in all US metro areas if the ethanol blend price was set to save drivers 20% on a cost-per-mile basis.

The biofuel availability is also important for fuel choice. The lack of adequate infrastructure reduces ethanol availability and consequently the FFV market [50]. The capacity constraints to supply E85 stations may be an issue to raise E85 fuel consumption in the U.S., as it requires the installation of new E85 pumps in strategic locations [49,51]. Lastly, concern with environmental issues impacting ethanol consumption is not unanimous among researchers. Salvo and Huse [52] presented that drivers with strong environmental attitudes or residing in sugarcane-growing states are more likely to choose ethanol in Brazil, while Andersson et al. [53] concluded that the quantity of drivers that choose ethanol on the basis of environmental and climate motives was small among the 1200 FFV owners surveyed in Sweden. However, since this small group comprised young people, climate issues and environmental beliefs may become more important in the future for Swedish drivers.

The publicized price–equivalence between E10 and E85 is 0.77 to be equivalent on a cost-per-mile basis in the U.S. [48]. The Brazilian ethanol–gasoline price threshold is widely presented as 0.7 for the general public and highlighted in the literature of the area [52,54,55]. This 0.7 threshold was also reported by the Ministry of Mines and Energy on its quarterly communication [56]. For instance, Bahia (Brazilian state) has Law no. 13444 (2015) that requires a mandatory and fully visible sign in all gas stations with information regarding the current price-equivalence between gasoline C (27% ethanol blend) and E100. This law also prescribes the following message in the sign: greater than 70%—better gasoline; less than 70%—better ethanol; equal to 70%—indifferent, assuming that all cars' fuel economy ratio for gasoline–ethanol are equal. Another example is the newest update in Tocantins State Law no. 3936 (updated in May 2022). This law requires that the fuel retailer inform customers of the price ratio between gasoline C and E100 currently in the pump without any additional statement about the better ratio option. The information sign with the ethanol–gasoline price ratio is widely used all around the country. Regardless, there is no federal law on this subject.

This study evaluates the impact of the widely publicized ethanol–gasoline threshold of 0.7 in Brazil for FFVs against the individual measured vehicle threshold in the customer's decision when they are filling up their car in the top three E100-consuming states in Brazil before the COVID-19 pandemic, namely, São Paulo, Minas Gerais, and Paraná. The novelty of this paper is to analyze the impact of the ethanol–gasoline price ratio on different vehicle models and discuss the opportunities to increase ethanol consumption from this perspective. The paper proceeds with a description of the used dataset, while the formulas and variables included in the analysis are defined. In Section 3, the results from the analysis are presented and discussed. Lastly, some concluding remarks are found in Section 4.

2. Materials and Methods

2.1. Fuel Economy Data

The Brazilian National Institute of Metrology Standardization and Industrial Quality (INMETRO) publicizes the data of all light vehicles approved in the Brazilian Labeling Program. Vehicle category, model, engine capacity, fuel economy, energy efficiency, and other information are examples of the available data. Figure 1 is the template of the National Energy Conservation Label (PBE) used in every approved vehicle of this program [57].

PBE was developed to reduce energy consumption in accordance with the goals of the National Energy Efficiency Plan, which aims to provide useful information that influences customer decisions, and promote product innovation and technological development [57]. The program also aims to mobilize Brazilian society to contribute to economic development and social well-being [58].

All vehicles' model fuel economy measurements are obtained in the laboratory in accordance with NBR 7024 standards, and using standard Brazilian fuels (gasoline C and E100) and pre-established driving cycles. All vehicles are tested according to this standard in a controlled condition, ensuring that all measurements can be replicated under the same conditions. It can be used as a comparison between different vehicle models within the same category. INMETRO adopted adjustment factors to approximate the values measured in the laboratory to those perceived by drivers in their real use [57].

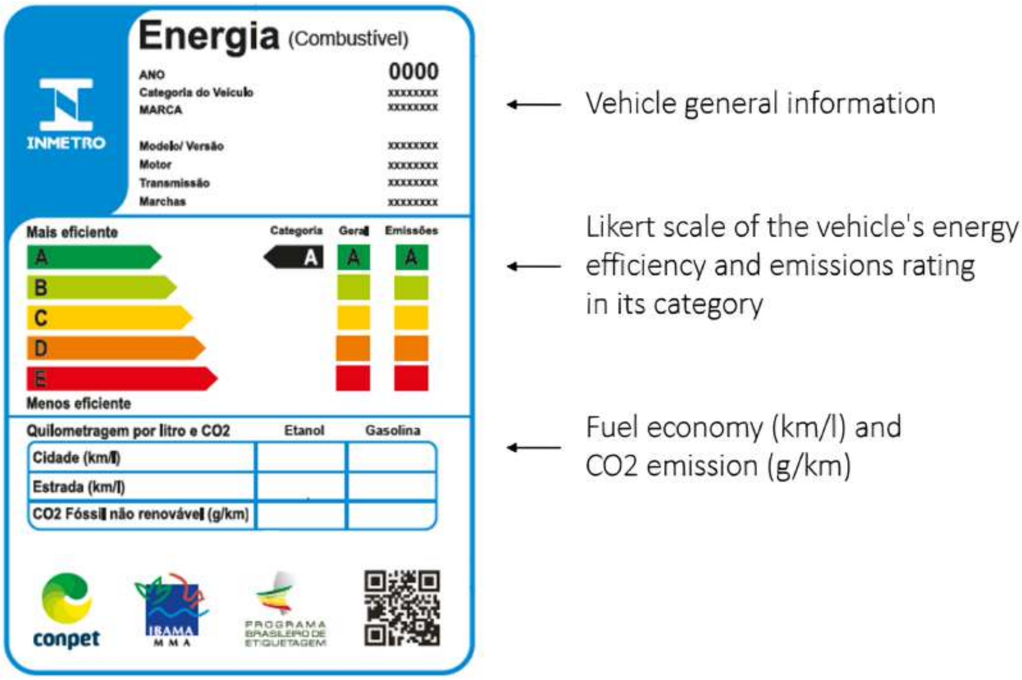

Figure 1. National Energy Conservation Label template with information explanation. Adapted from [57].

This study uses the 2019 Light Vehicles report, updated March 2022 [57]. Only flex–fuel car models were considered regardless of category or brand, totaling 298 evaluated vehicle models (Table 1). We did not use vehicle brands to present or discuss any part of the results.

Table 1. All vehicle models evaluated in this study split by category.

Vehicle Category	Quantity
Commercial	5
Compact	58
Extra large	2
Large off-road	2
Large	36
Medium	70
Minivan	5
Pickup	23
Compact pickup	14
Subcompact	17
Compact SUV	53
SUV—4 × 4 compact	2
Large SUV	9
SUV—4 × 4 large	2
Grand Total	**298**

2.2. Fuel Price Data

The historical series of fuel prices at distribution and retail markets (for instance, gasoline C, E100, diesel) segregated by state and city, both weekly and monthly, is available on the site of the Brazilian National Petroleum Agency [59]. This study uses the average weekly price of the state for gasoline C and E100 to calculate the weekly ethanol–gasoline price ratio (WEGPR) from January 2017 to December 2019 (157 weeks) in Brazilian reals (BRL) for the states of São Paulo, Minas Gerais, and Paraná (Figure 2 and Table S1). This time range was chosen because it was after the implementation of Petrobras' fossil fuel import price parity policy and before the COVID-19 outbreak.

Figure 2. WEGPR of the top three E100 consuming states in Brazil, namely, São Paulo, Minas Gerais, and Paraná from 2017 to 2019.

2.3. Method

First, we calculated the vehicle ethanol–gasoline economy ratio according to Equation (1), where VFER is the vehicle fuel economy ratio for each model, measured in km/L. This ratio was separately calculated considering the vehicle fuel economy available for the city and the highway .

$$\text{VFER} = \frac{\text{Ethanol fuel economy}}{\text{Gasoline fuel economy}} \tag{1}$$

Second, we performed descriptive statistical evaluations of the VFER calculations, and tested the data for normality with the goal of using the measures of central tendency and of dispersion or variation to calculate the weekly opportunity of using E100 in the largest fuel markets of the country.

Lastly, we calculated the weekly opportunity to fill up the car with E100 (WO–E100) according to Equation (2), and it was valid for each vehicle model.

$$\text{WO–E100} = \frac{\text{WEGPR}}{\text{VFER}} \tag{2}$$

For instance, the customer may fill up the car with gasoline if WO–E100 is greater than 1 considering the customer price-sensitive behavior; if the WO–E100 value is less than 1, it is better to fill up the car with E100. A WO–E100 value equal to 1 means that there is no economic difference in filling up with gasoline C or E100.

3. Results and Discussion

Initially, VFER data were tested for normality. On the basis of the p-value of <0.005 for a 95% significance level (Figures 3 and 4), we concluded that our data did not follow a normal distribution. On the basis of the normality test result, we used the median, quartile, and whisker extreme values for our evaluations.

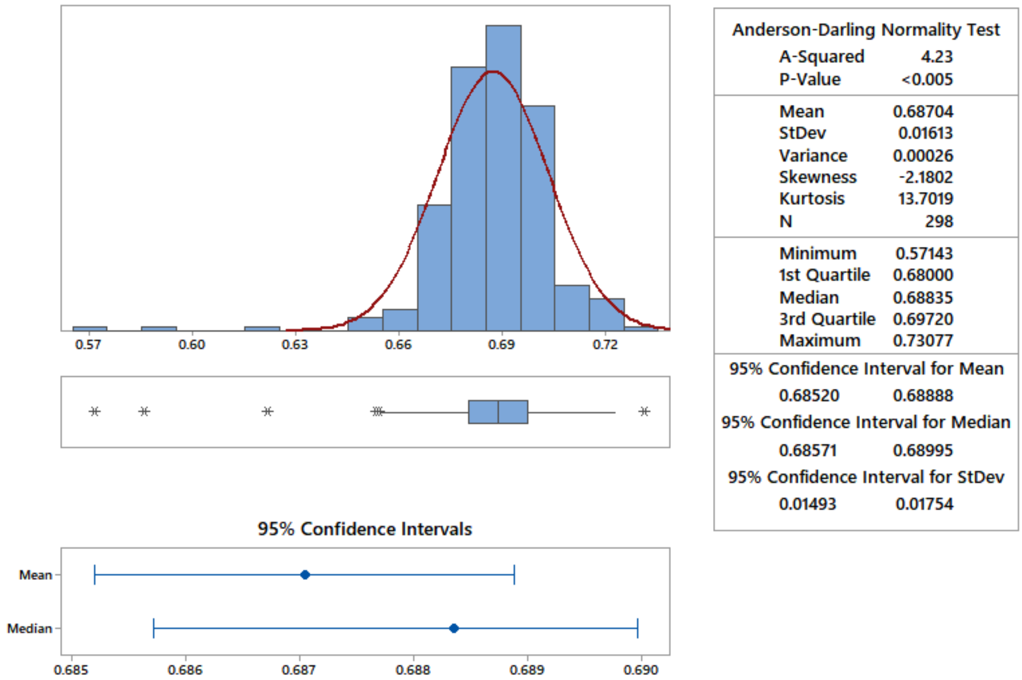

Figure 3. Descriptive statistics of $VFER_{city}$ calculations and test for normality. Red line line shows the distribution, Stars represent the outliers and bullets are the Mean or Median calculated values for the data.

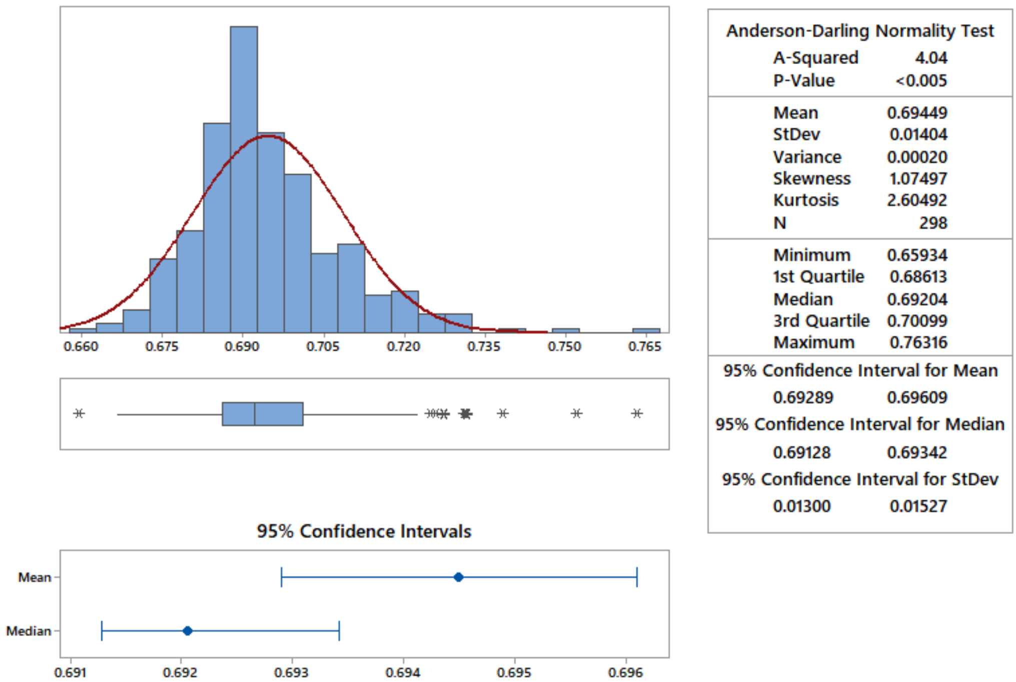

Figure 4. Descriptive statistics of $VFER_{highway}$ calculations and test for normality. Red line line shows the distribution, Stars represent the outliers and bullets are the Mean or Median calculated values for the data.

The calculated VFER median based on the NBR 7024 standard city cycle ($VFER_{city}$) was 0.688 (95% confidence interval (CI): 0.6857–0.6899) for the evaluated sample of 298 vehicles (Figure 3). The VFER median based on the highway cycle ($VFER_{highway}$) was 0.692 (95% CI: 0.6912–0.6934) (Figure 4). Despite being statistically different, the difference between the medians was only 0.004.

Table 2 shows the values of the median, quartile, and whisker extreme values for VFER $_{city}$ and VFER $_{highway}$ calculations. On the basis of the similarity of the city and highway values, we decided to use the following VFER numbers for WO–E100 evaluation: 0.66 (lower extreme average), 0.69 (median average) and 0.72 (upper extreme average) to compare with WO–E100 results for the 0.7 public threshold.

Table 2. Median, quartile, and whisker extreme values for VFER calculations.

	VFER$_{city}$	**VFER$_{highway}$**
Upper extreme	0.722	0.722
Q1	0.697	0.700
Median	0.688	0.692
Q3	0.680	0.686
Lower extreme	0.654	0.666

WO–E100 analysis shows a huge difference within the states for the evaluated lower and upper limits, 0.66 and 0.72, respectively (Figure 5). On the basis of only the price-sensitive customer behavior, a VFER of 0.66 creates the opportunity for the customer to fill up the car with E100 in 42.7% of the evaluated weeks in São Paulo. On the other hand, a VFER of 0.72 create the opportunity for the customer to buy E100 in 89.8% of the evaluated weeks in the same state. This is more than twice as many opportunities as those for the vehicle at the lower extreme, and 14% more opportunities to refuel it with E100 when compared with the 0.7 threshold. This result corroborates with that of Pacini et al. [54], who discusses how the 2% difference on the VFER heavily impacts the overall fuel competition.

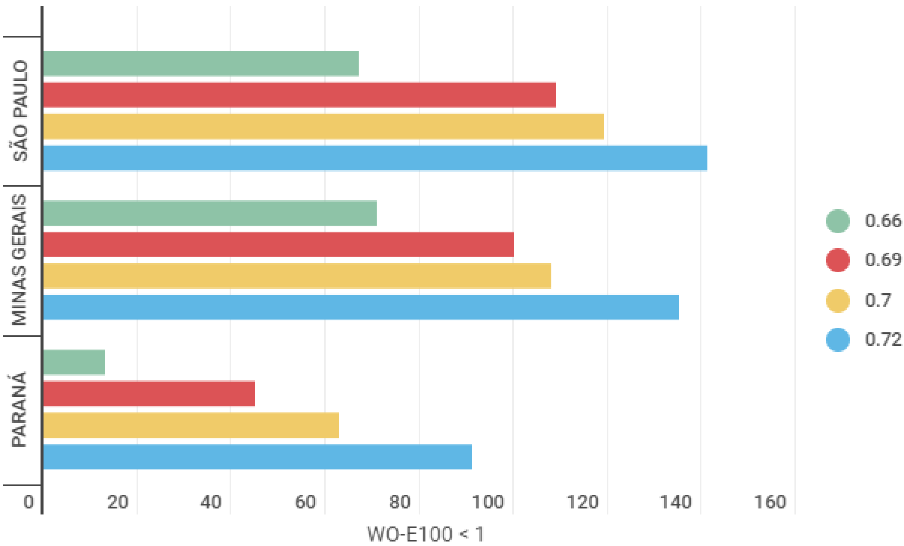

Figure 5. Count of WO–E100 of calculated values less than 1 for 157 weeks from January 2017 to December 2019. If WO–E100 value is less than 1, it is better to fill up the car with E100.

Our analysis also shows that a unique fuel economy ratio for the country is not a good solution to represent all vehicle models for any fuel market. The average price–equivalence between gasoline C and E100 in the literature lies between 0.70 [60] and 0.68 [54] for E100. Although seemingly insignificant, this 2% difference may have a huge overall impact on fuel competition [54] because the customer choice of renewable fuels is highly dependent on fuel economy thresholds [48,49,61,62], and the retail price is dependent on supply and demand factors [63]. The actual fuel economy ratio in Brazil lay between 0.722 and 0.654. For instance, drivers of vehicles whose VFER is 0.72 may have 62% more opportunities to fill up with E100 than those of a vehicle whose VFER is equal to 0.66 in Brazil. It is an average value based on the analyses of those three states during the period of 2017–2019 (Figure 5).

Regarding the information sign in the gas stations, our evaluation also shows that Bahia Law no. 13444 of 2015 requires that every gas station show inadequate information, generalizing the best ethanol–gasoline price ratio at 0.7. The inadequate information may be a potential cause for the energy efficiency gap, which is the name given to the gap between the theoretical potential and current level of energy efficiency [64]. Remedies to correct the energy efficiency gap may include taxes, subsidies, regulations, and programs to provide or enhance energy efficiency information on home appliances, buildings, machinery and vehicles [65]. The FFV energy-efficient gap was also highlighted as an issue by Salvo [55].

The inadequate ethanol–gasoline threshold information may be mitigated by the creation of a Brazilian federal law requiring all gas stations to report only the ethanol–gasoline price ratio, similar to law no. 3936 of the state of Tocantins. However, in the case of passenger vehicles, the effectiveness of these policies depends on whether or not customers value the benefits of fuel efficiency [66]. In addition to this law, the PBE should be used to present the measured VFER for each vehicle model on the fuel economy label area using discrete categories, similar to the Likert scale used with emissions and energy efficiency. Furthermore, the government should create a large public education campaign all over the country about the WO–E100 index, and its economical and social usage benefits when refueling the car.

4. Conclusions

This study presented the ethanol–gasoline threshold of 0.7 for FFV versus the measured VFER for each model in Brazil. Our analysis also shows that the information of a unique fuel economy ratio for all flex–fuel vehicles may undermine the ability of the customer to choose the best fuel when considering its price. In this context, the customer choice between ethanol and gasoline could benefit from having the actual fuel economy ratio information for any globally available model. For instance, Brazilian owners of vehicles whose VFER is 0.72 have 62% more WO–E100 opportunities to refuel the vehicle with E100 than those of a vehicle whose VFER is equal to 0.66. In this case, the government should broadly inform the customer all over the country about the gains from filling up their vehicle following the WO–E100 calculation.

There is a need for a multidisciplinary approach to mitigate the FFV energy-efficiency gap. First, the government could require all new FFVs to show the actual VFER in the cluster whenever the driver starts refueling. This VFER can be compared with ethanol–gasoline price ratio to support the price–sensitive decision of fill up with high-level ethanol blend. Each VFER may be different for the same vehicle model because it is based on the driving behavior plus city and highway fuel mileage measured from several blends of ethanol and gasoline. Second, the cluster could present the expected vehicle emissions for each fueling on the basis of the actual fuel blend in the tank, and compare it with both the calculated emissions of previous fueling and the best available biofuel in the country, such as E85 or E100. It may also impact the decision of drivers with strong environmental attitudes.

Third, the government (i.e, Brazilian Ministry of Mines and Energy) should propose a federal law requesting all stations to show the price–equivalence between gasoline and high ethanol blend in parallel to publicize the importance of knowing your own VFER. Lastly, the PBE may be used to show the expected measured VFER for each vehicle model as a strategy to reduce the energy-efficiency gap. It may increase the sales of vehicles that are more energy-efficient when using high-level ethanol blends. All these actions may be globally applied to increase the demand of ethanol.

These actions should take place simultaneously with a better understanding of the vehicle technologies and engine calibrations that allow for the increase in VFER values. It is necessary because more than 75% of the Brazilian vehicles models presented VFER values below the threshold of 0.7. Future developing models that forecast high ethanol blend sales should consider the VFER of the different models and its weight on the market on the basis of the actual vehicle fleet. We also expect to see evaluations of the impact of new technologies and a reduction in the energy-efficiency gap in the decision-making process of fueling FFV with high-ethanol blends.

Supplementary Materials: The following are available online at https://www.mdpi.com/article/10.3390/su14159047/s1, Table S1: Raw data, ratio and WO-E100.

Author Contributions: A.S.N.F. and H.S.: supervision, conceptualization, methodology, validation, formal analysis, investigation, data curation, writing—original draft, writing—review and editing, funding acquisition. T.B.M.: conceptualization, methodology, validation, formal analysis. R.G.O.d.S.: methodology, software, writing—original draft, validation, formal analysis. M.A.M.: methodology, software, writing—original draft, validation, formal analysis. J.G.A.C.: methodology, software, validation, formal analysis. P.A.L.: conceptualization, resources, project administration, writing—review and editing. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest: The authors declare no conflict of interest.

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