Influencing Flex Fuel Car Customers at the Gas Station

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ABSTRACT

The Flex Fuel car was presented by Volkswagen in Brazil in March 2003 to allow the customer to choose the fuel at the gas station and not at the dealer, and to use the wide available ethanol without the anxiety caused by its supply crisis occurred in the beginning of 1990ies. The customer answered positively and currently the technology is dominant.

Since the launching event, the question about the most advantageous fuel arose. An analysis with simplifying assumptions was the base of the known thumb rule that ethanol is the right choice if its price is lower than 70% of gasoline's. After 22 years, the Flex technology and its energetic efficiency have changed significantly. Additionally the role of ethanol changed from an alternative fuel to the strongest decarbonization measure for passenger cars in the country.

The thumb rule must therefore be reviewed and the environmental importance of this biofuel must be clearly informed to the customers. As a first step in this direction, an downloadable APP was created. This paper aims to present its methodology, limitations and the possible next steps in the direction to convince customers about their important role in the way to zero carbon emission.

OVERVIEW OF FUELS IN BRAZIL

OTTO FUELS IN BRAZIL - Ethanol was introduced as fuel in Brazil as an governmental answer to the oil crisis of the of 1970ies. With incentives, the production and distribution infrastructure were stablished and since the early 1980ies and the Otto fuel customers had since then two options at gas stations.

The first Otto fuel is a commercial gasoline type C (or gasohol), a mixture (Exx) of pure gasoline (also called "gasoline type A" or E0) with "xx" percent in volume of anhydrous ethanol, E100a, being the "xx" fixed by the government within limits defined by law. It is worthy to note that once the government change the "xx", all gas stations of the country must offer this new gasohol. Additionally the gasoline used for emission and consumption homologations is fixed in xx=22% and a "premium" gasoline specification is also allowed, where xx=25%.

The second Otto option is a commercial hydrous ethanol containing about 95% in volume of pure ethanol (the rest is practically water). It is also called in this text E100h (or E95H). This fuel is mostly produced in Brazil from the secular sugar cane plantations and, more recently, from corn that shares the same area with other crops, normally Soya. Table 1 summarizes the main characteristics of the Otto fuels in the country.

As a brief observation, it should be mentioned that Diesel fuel (that has its own mandates of BioDiesel mixing) is not allowed for passenger cars and light commercials in Brazil, with some exceptions defined by specific legislation. As Otto fuel, also the CNG (Compressed Natural Gas) is offered at specific gas stations, but the annual sales volume is much lower than gasoline (E27) and Ethanol (E100h)

CARBON INTENSITY – The legislation RenovaBio was established in Brazil in 2017 to incentivize BioFuel producers via the possibility to issue special carbon credit (CBio) in the Brazilian stock market [1]. To be eligible to issue the credits, the used biomass cannot come from areas deforested after June 2019. Producers must also comply with Brazilian environmental legislation - among other requirements, a percent of property must keep the native biome [2] and demonstrate it via the official Rural Environmental Registry (CAR) [3]. The customers for CBios are fuel distributor companies that become yearly, from government, a target for decarbonization [4].

According to RenovaBio, the quantity of CBio per liter of biofuel that a producer can issue in stock market is mathematically linked to the carbon intensity, IC, in $gCO_2e/MJ = (gCO_2e/l) / ED$), being ED the Energy Density in MegaJoule per liter (MJ/l) of biofuel, with the value also defined in the legislation. The nonrenewable CO_2e is measured by an authorized audit company, using a standardized calculation tool (RenovaCalc), from the plantation stage, throughout the production and distribution processes, up to the combustion. The result is subtracted from a fixed IC value for the fossil fuel that the biofuel replaces (for instance, ethanol replaces gasoline E0). Each 1ton of CO2e avoided allows the issuing of 1 CBio. The result of the production plant audit process is subject to public consultation (and contestation), so that most of producers values are known. An average IC value of most of the biofuels in Brazil can, this way, be derived [5]. The IC values for ethanol and gasoline are showed also in Table 1. Since Flex cars customers may freely mix gasoline and ethanol at gas station, it is necessary to calculate the IC for a mixture. This estimation are showed in References [6], [7].

Table 1. Otto Fuels for Flex Fuel vehicles in Brazil

Purpose →		Pure gasol. mix w/ E100a	Anhydrous mix w/ E0	Reference Homologation	Commercial Offered in Fuel Stations			
Properties[a]	Fuel → Name →	E0 "Tipo A"	E100a "Anidro"	E22 "Referência"	E25 "Premium"	E27 "Tipo C"	E100h "Hidratado"	E100p "Premium"
Ethanol content	%	0	≥99,3 m/m	22 v/v	25 v/v	27 v/v	92,5-94,6 m/m	95,5-96,5 m/m
Water content	%	0	≤0,7 m/m	0	0	0	≤7,5 m/m	≤4,5 m/m
Calculated Values[b]								
Stoich. Air/Fuel Ratio	–	14,57	8.94	13,26	13,09	12,97	8,42	8,64
TtW CO2 in Combustion	gCO2/l	2331	1501	2149	2124	2107	1441	1470
Energy Density Other	MJ/l	31,65	21,18	29,35[d]	29,03	28,82	20,32[d]	20,73
TtW CO_2 in Combustion	gCO_2/MJ	73,7	70,9	73,2	73,2	73,1	70,9	70,9
Carbon Intensity	gCO_2e/MJ	87,4[c]	26,93[c]	77,8	76,3	75,1	28,5[c]	Not available

/a/ Source: ANP (National Petroleum, Natural Gas and BioFuels Agency)
/b/ Estimation perfomed by the authors
/c/Source: RenovaBio and EPE (Empresa de Pesquisas Energéticas)
/d/Official values in Brazil, provided by INMETRO are slightly different: E22=28,99; E100h=20,09.

FLEX FUELS IN BRAZIL

The stablished ethanol infrastructure, the availability (low prices) of this fuel in the early 2000s and the advances of digital engine control units were crucial for the Volkswagen decision to innovate launching the Gol 1.6l Total Flex® in March 2003. The technology gave the customers the power to choose the fuel at gas station and not to be “married” with a single fuel, since the vehicle purchase, being less subjected to changes in taxation policies among Brazilian states, international prices (oil and sugar, for instance) and seasonal crop variations. Other OEMs, followed the trend and the Flex became the dominant technology for passenger cars and light commercials, being also the majority (>82%) of the current circulating fleet [8].

FLEX HOMOLOGATION – In Brazil, every Flex Fuel model must demonstrate by tests that pollutant emission standards are met for three fuels in US75 test cycle (in laboratory): reference gasoline (E22), hydrated ethanol (E100h) and a mixture with 50% vol. of these fuels (approximately an E61 with some water). The measurements of exhaust emissions (including aldehydes), need to be confirmed by RDE (Real Drive Emissions) tests. Additionally, the evaporative emission control, the ORVR (On-Board Refueling Vapor Recuperation) and OBD (On Board Diagnosis) systems have to be tested to guarantee they keep legal limits with any mixture in between the E22 and E100h. Until two years after start of production of the model, an experimental proof that the emission control systems work properly up to 160.000km is demanded by authorities. Also, while the model is being offered to the market, conformity emission tests are required for quality control [9].

This complex homologation (and process control) includes also the measurement of fuel consumption (C, in l/100km) and fuel economy (FE, in km/l) and energy consumption (CE, in MJ/km). For this, the vehicle being homologated need to perform not only the FTP75 (Urban, with 55% of weight in MJ/km or l/100km result), but also the Highway (Hwy) cycle (with 45% weight). The combined average (Urban, Hwy) follows the US CAFE (Corporate Average Fuel Economy) regulation for each of these fuels: E22 (Ref. Gasoline) and E100h (Hydrated ethanol). The part of the homologation process related to energy consumption measurement is summarized, for combustion Flex Fuel engine, in Figure 1. For Flex cars with hybrid powertrain, a similar process is followed, with variance in norms/ driving cycles.

The simple average between the combined average of E22 and E100h is the Energy Consumption value (CE) of the Flex Model and defines (according to vehicle categories) the color of the Energetic Efficiency label that need to be visual to the customers at the dealer. The label also includes the km/l values, separated for Urban and Hwy, for both fuels. These values, measured during homologation, are corrected in a standardized way to represent out of laboratory driving conditions: geography, weather, pavement, driving style, accessory use, etc [10].

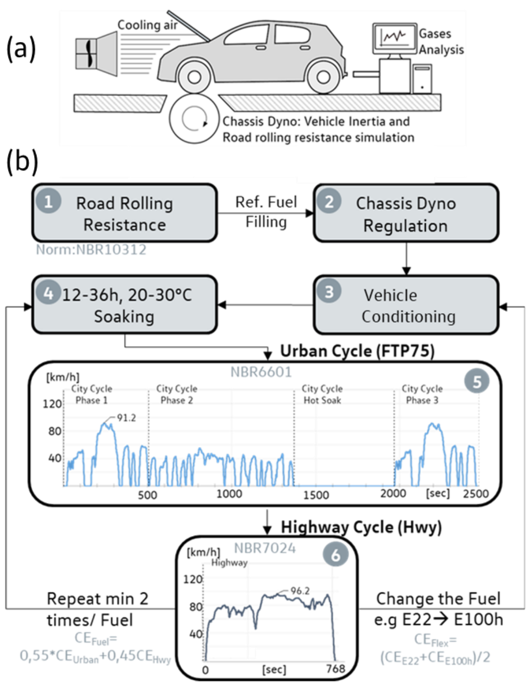

Figure 1: (a) Schematic Chassis Dyno (b) Homologation tests procedure for combustion Flex Fuel vehicle energy consumption. For Hybrid other norms and cycles are used.

The values of CE in MJ/km found in homologation process are also used to compose an year weighted average fleet energy consumption (CE_{fleet}, where the weight is the sales mix of every model in the year), that is required by government to be reported and compared with a limit defined by legislation (as function o average mass). The noncompliance leads to heavy penalties to the OEM [11].

The homologation process for flex vehicles defines also the Energy Parity (EP). This quantity is defined as the ratio between the measured (combined) CE with E22 and E100h [12]. Ratios above 1, indicate that the Flex vehicle is more efficient with E100h than with E22. Energy efficiency and CO_2e legislations take the EP into consideration to grant tax reduction, in order to incentivize the Flex vehicle projects to prioritize the choice of E100h by customers and contribute for mobility decarbonization

FUEL MIXTURE IDENTIFICATION – For a good quality combustion, any spark ignition engine, working in Otto, Miller or Atkinson cycles must be controlled (among other variables) in term of the Air/ Fuel ratio. In Brazil, practically all Flex vehicles count with an emission control system that includes the so called 3-way catalyst technology, which is high efficient for oxidizing and reduce pollutants only in case the Air/ Fuel ratio is kept, by the Engine Control Unit (ECU), around the stoichiometric ("Stoich") value of the gasoline/ ethanol mixture in use. Without a stoichiometric value identification, not only the 3-way catalyst wouldn't work properly, making the vehicle pollutant emission homologation impossible, but also the drivability would be seriously damaged with very frequent lack of power and misfiring occurrences. Additionally, incorrect spark timing could lead to fatal engine hardware damages, via knocking and/or auto ignition phenomena.

Equation (1) shows the calculated fuel mass to be injected in engine. It can also be used to describe, in a simplified way, the methodology used for fuel mixture (i.e. Stoich) identification.

$$\dot{m}_{fuel\_calc} = \frac{\dot{m}_{air}}{\lambda_{desired} \times \text{Stoich} \times K} \quad (1)$$

$\dot{m}_{fuel\_calc}$ is the ECU calculation for the fuel mass flow necessary to obtain, with the air mass flow entering the engine, $\dot{m}_{air}$, a mixture with the desired standardized air fuel ratio (also called desired lambda, $\lambda_{desired}$). $\dot{m}_{air}$ is controlled by a throttle valve whose position is a function of the torque required by the driver via accelerator pedal. It can be directly measured with an air mass sensor or calculated using the RPM, manifold air pressure and temperature signals together with calibrated parameters representing air density drop along engine intake ducts. "Stoich" is the current stoichiometric value of the fuel (before the next fuel recognition procedure is performed). K is a multiplier whose value is close to 1, if the learning procedure to determine a new fuel is "turned-off".

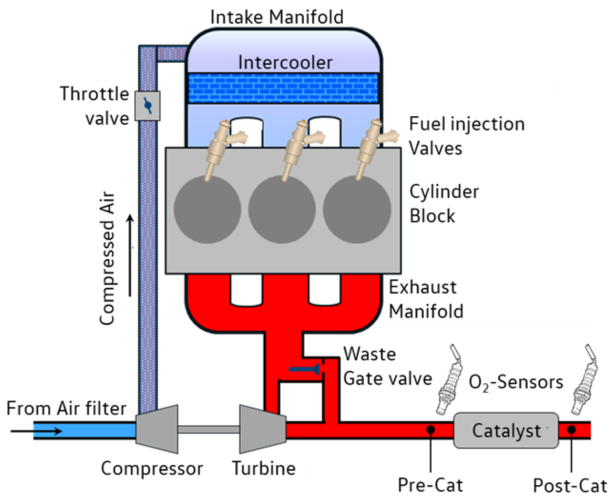

Figure 2: Schematic Direct Injection Turbo Charged Engine.

In this condition, an exhaust O_2-sensor, that present a voltage output function of Air/Fuel ratio, is used to make small corrections of the fuel mass injected, for instance to slightly compensation variation of parts geometry due to production tolerances. Figure 2 shows a schematic positioning of the O_2-sensor (pre-cat) in the exhaust system. The figure represent a direct injection turbo engine; the natural aspirated with manifold (and not in-cylinders) injection version have similar configuration, but without the compressor/ turbine/ waste gate set and intercooler. It is worthy to mention that due to OBD (On Board Diagnosis) legislation requirement, a second O_2-Sensor (Post-cat) is also used to verify the catalyst efficiency and the signal plausibility of the pre-cat sensor.

If the fuel learning procedure is activated, K value will increase or decrease stepwise from the unit, based on a sequence of the O_2-sensor readings, until a superior (or inferior) limit is reached. After overcoming one of these limits, the value of K is incorporated in the new "Stoich" value and the new fuel is known, as showed in Figure 3.

This procedure is executed while required conditions to allow the fuel recognition process are met. These conditions are several (not described in Figure 3), such as the variation of the tank fuel level sensor position, time to burn the old fuel present in the fuel line, stable running conditions, absence of diagnosis in O_2-sensor, absence of fuel vapor from blow-by system, among others [6].

This learning method depends only on already existing sensors in the car (low cost) being used normally for non turbo charged engines. One main disadvantage is that the engine burns an "incorrect" mixture for some seconds, until the new "Stoich" is defined. The Brazilian legislation allows this and also the disabling of the OBD system during learning process.

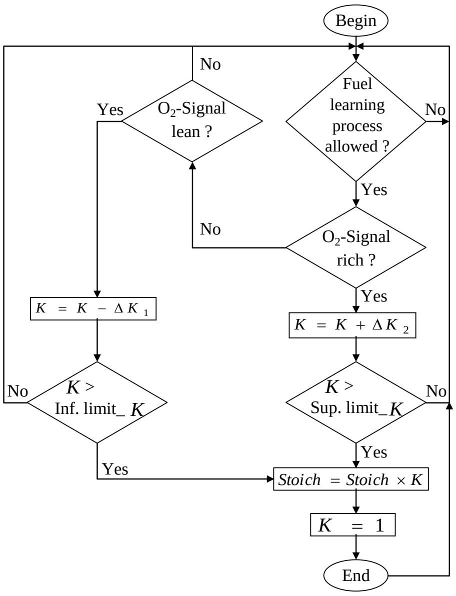

Figure 3: Simplified fuel identification flow chart [6]

For turbo charged engines, for safety reasons, the fuel recognition is normally performed primarily via a physical sensor ("ethanol sensor"), that is installed in the fuel line, upstream of (but close to) the engine fuel rail. Typically it comprises a cylindrical capacitor with two tubes, the inner and outer electrodes, flowing the fuel between the gaps, as showed in Figure 4. An AC voltage is applied to the electrodes. The variation of ethanol content in fuel mixture changes the relative permittivity of the fuel, leading to capacitance and output circuit frequency change. This is used by the ECU to define the ethanol content. Additionally, the permittivity varies with fuel temperature, which has to be measured in order to correct the sensor output signal accordingly [13].

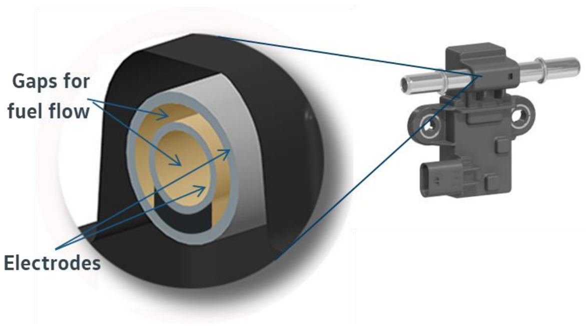

Figure 4: Schematic view of an ethanol sensor [14]

FUEL CONSUMPTION ESTIMATION - No matter the method, it is possible to estimate the stoichiometric value of the fuel present in the vehicle fuel tank. Thereby the ECU can use the integration of Equation (1) with respect to time to estimate the total mass of fuel (in grams) used by the engine from the start until shut down.

Alternatively, the consumed fuel estimation can be performed by time integration of the fuel injection pulses (given in milliseconds). In this case, it will be necessary to know the fuel injection valve characteristics (slope of the curve of fuel mass per pulse vs. injection time and the dependence of this curve on the battery voltage) and their variations with fuel mixtures physical parameters and with (estimated or measured) temperature.

FUEL CHOICE BASED ON PRICE

The most used criteria to select the fuel at gas station is the fuel price. Due to the lower (ca 29,4%) energy density of E100h in comparison with the commercial gasoline, E27 (Table 1), a direct comparison of fuel cost per liter ($Price_{Fuel}$) does not bring the correct conclusion. The cost per km should therefore be calculated based on available information of that type of model Equation (2).

$$(R\$/km)_{Fuel} = Price_{Fuel}[R\$/l]/FE_{Fuel}[km/l] \qquad (2)$$

The FE, fuel economy value, in km/l, can be taken from the labeling program (i.e. already corrected to adapt for customer out of laboratory condition, as mentioned above) in both urban (FTP75) and highway cycles. The customer reasoning to choose ethanol instead of gasoline (E27) is to obtain $R\$/km_{E100h}$ <= $R\$/km_{E27}$.

Alternatively, with simple algebraic manipulation of this inequality lead to the conclusion that the price per liter of E100h must fulfil the condition showed in Equation (3) to be financially cheaper (in R$/km) for the customer. In this expression, EDR is the ratio ED_{E100h}/ ED_{E27}.

$$\left(\frac{R\$}{l}\right)_{E100h} \leq EDR * EP * \left(\frac{R\$}{l}\right)_{E27} \qquad (3)$$

Equation (3) explains the simple thumb rule divulged since the launching event of the first flex car. At the time it was considered that EP (energy parity) was 1 (same energy consumption with ethanol and gasoline). The product EDR*EP, called later Advantage Factor [15], was around 70%, what is still used by customers: if the price of ethanol is less than 70% of the Gasoline price, it is worthy to choose ethanol. Nevertheless since engines and vehicles were developed trying to be favorable to ethanol (due to government incentives), in some cases the EP differ from unit. This difference is measured and divulged during vehicle homologation.

FUEL CHOICE BASED WELL TO WHEELS CO_2e EMISSIONS

CO_2e, is the adding of non-renewable CO_2 and other greenhouse gases (converted to a CO_2 via a standard scale) emitted [7]. The well to wheels CO_2e, or $WtWCO_2e$, is the non-renewable CO_2e emitted by the vehicle exhaust system added to the CO_2e generated during the process to produce the fuel or electrical energy and to make it available to the customers. Examples of calculation were given in Ref [6].

In Brazil, due to more recent legislations such as RenovaBio and Rota2030, the calculation became more direct and based on official and well documented values of fuel carbon intensity (in gCO_2e/MJ) and vehicle energy consumption, CE (in MJ/km), via equation (4).

$$WtWCO_2e_{Fuel}=IC_{Fuel}*CE_{Fuel} \qquad (4)$$

In this expression, the subscript “Fuel” will be one of the available commercial fuels: or E27 or E100h. The values for IC are stored for the use of the App. Since the customer are still in gas station, the cycle he or she will do after filling the tank is unknown. So, the CE values are those obtained for the homologation model to which the customer car is linked. This connection occurs via the VIN (Vehicle Identification Number) or chassis number.

Equations (2), (3) and (4) allows showing to the customer two criteria to influence his or her fuel choice: the financial and the environmental. The presentation of this information at the in-vehicle infotainment is showed in Figure 5. The fuel prices should be inserted into the application called “Abasteça Consciente” by the customer. It should be noticed that, in Brazil, the price per liter of every fuel offered in a gas station must be clearly presented to customer next to fuel pumps.

Figure 5: Financial and Ecological criteria for the Flex vehicle customer decision, E27 or E100h.

AVOIDED WELL TO WHEELS CO_2e EMISSIONS

The Avoided CO_2e is defined here as the mass of CO_2e avoided, in a certain driving cycle, due to type of fuel selected by the Flex car customer. It is the difference of the effective well to wheels CO_2e emitted during a driving cycle and the well to wheels CO_2e that would had been emitted, if the customer had chosen E27 (commercial gasoline) as fuel. It can be expressed by equation (5).

$$AvoidCO_2e=[IC_{Fuel}*CE_{Fuel}-IC_{E27}*CE_{E27}] * Dist \qquad (5)$$

Where “Dist” is the distance in km of the driving cycle. This expression is valid for any real cycle. Since the for Flex vehicles, fuels can be mixed, it is necessary to perform an estimation of the carbon intensity of every possible mixture of the commercial fuels, IC_{Fuel}. In turn, the CE_{Fuel} can be obtained via the fuel consumption estimation methods mentioned above and the knowledge of the energy density of the mixtures.

The Equation (6) is proposed to calculate $IC_{Fuel.}$ The assumption is that it can be assumed as an weighted average of the IC of the commercial fuels, being the weight the energy density, ED, multiplied by the percent in volume of that component in the mixture, %Vol.

$$IC_{Fuel}=[IC_{E100h}*ED_{E100h}*\%Vol_{E100h}+IC_{E27}*ED_{E27}*\%Vol_{E27}]/ [ED_{E100h}*\%Vol_{E100h}+ED_{E27}*\%Vol_{E27}] \qquad (6)$$

Observe that equation (6) can also be adapted to calculate IC of different types of gasohol, such as E22, E27, E30, E35, etc, where the values for the components E0, and anhydrous ethanol, E100a, are also known from RenovaBio legislation and showed in Table 1.

The method to estimate the energy density of mixtures is expressed in Equation (7). In this case, when the mixture involves E100h, small errors due to the well-known ethanol-water mixture volume contraction, that occurs due interaction of molecules of ethanol and water in such a way that they occupy less space together than they do separately.

$$ED_{Fuel} =ED_{E100h} * \%Vol_{E100h}+ED_{E27} * \%Vol_{E27} \qquad (7)$$

CE_{E27} ESTIMATION – An additional problem of equation (5) is how to estimate the energy consumption with gasoline E27, CE_{E27}, if the vehicle is not using this fuel in the real cycle. Note that, the only value available for CE_{E27}, is that of the homologation, where the car runs a special driving cycle, defined by norm. The proposed assumption to make the estimation is that the energy parity (EP) of the vehicle, which is also measured during the homologation, remains unchanged in any driving cycle. Also, it is assumed that the variation of the energy consumption with a mixture of fuels is linear. Figure 6 illustrate these assumptions.

In Figure 6, the unknown is the “A” value, while “C” and EP are known. A simple analysis of triangle similarity followed by algebraic manipulation leads to equation (8) that allows calculation of $A=CE_{E27}$ in the real driving cycle.

$$CE_{E27}= CE_{Fuel} / [1-(EP-1)*k / EP] \qquad (8)$$

$$k=(\%Vol_{Fuel} -\%Vol_{E27}) / (\%Vol_{E100h}-\%Vol_{E27})$$

Note that, in homologation, EP is measured with E22 (reference fuel) but assumed to be the as with E27 (commercial fuel).

Moreover, for the expression of “k”, $\%Vol_{Fuel}$ means the percentage of ethanol in fuel. So, for E27, the value would be 0,27. For E100, 1,00. This carries an small error, since the commercial fuel, E100h, contains around 5%vol. of water in its composition, what qualitatively might affect EP but in a negligible magnitude.

The CE_{E27} estimation via equation (8) allows the calculation of avoided CO_2e (“AvoidCO_2e”) due to the customer fuel selection via equation (5).

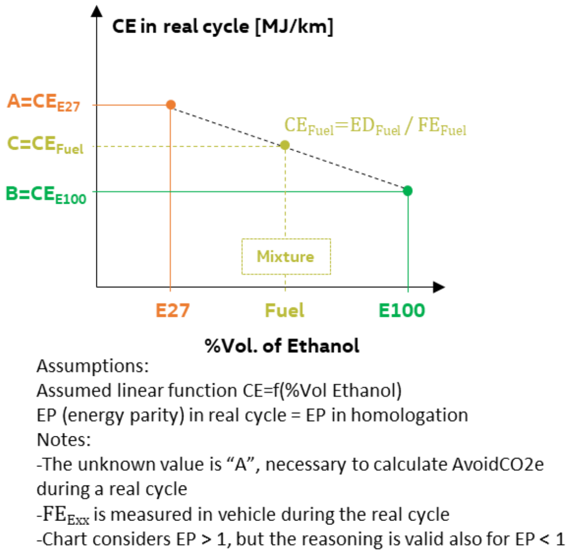

Figure 6: Assumptions for CE_{E27} calculation

ALTERNATIVE SCALE FOR AVOIDED CO_2e

The mass of avoided CO_2e calculated via Equation (5) can be expressed in kg, but the value have low significance for most of customers. A more ludic scale was therefore proposed to count the long term (that mean along several driving cycles) avoided CO_2e.

It is known that trees removes CO_2 from the air via leaves and water (H_2O) from the soil via root. The leaves contain the substance chlorophyll (green pigment) that, together with sunlight, is capable to break H_2O molecules allowing the combination (or synthesis) of the H_2 and CO_2 into glucose, a type of sugar. The sub product O_2 is released in atmosphere helping the respiration process of animals. The glucose serves as the primary energy source for the tree. This energy is used for various growth processes, including cell division and the formation of new tissues. This process allows to say that “trees are made of air”, as the internet video produced in order to explain young people the carbon cycle and its importance [16].

Therefore, in the proposed scale, the avoided CO_2e is converted into a number of standardized trees. This means the number of trees that would have to be planted (and cultivated to guarantee their growth) to remove the same mass of CO_2 from the air, as the amount avoided by the customer in his or her fuel selection.

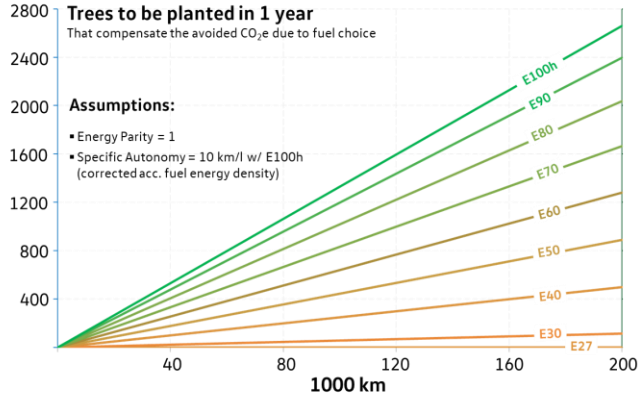

Figure 7: Alternative/ ludic Scale for the Avoided CO_2e due to fuel choice

Naturally this is a very rough estimation: The amount of CO_2 removed by a tree to grow depends on the species, soil and climate conditions along many years. The variation is therefore big. A deep simplification was possible using the work of Lacerda et al. (2009) [17]. According to the authors, a reasonable number is 7,14 tonCO_2e (that, for simplicity, was considered 7) per tree in 20 years. The research considered trees from the Atlantic Forest, in southeast Brazil, the region that concentrate the biggest number of vehicles in the country. The authors also mention that the growth curve of trees are not linear along the years (with inclination varying according to age). Nevertheless this linearity assumption was adopted to simplify the calculation. So, if 7 trees takes 1 tonCO_2 from air in 20 years, 140 trees would remove the same 1 tonCO_2 in one year. The scale is this way expressed in equation (9).

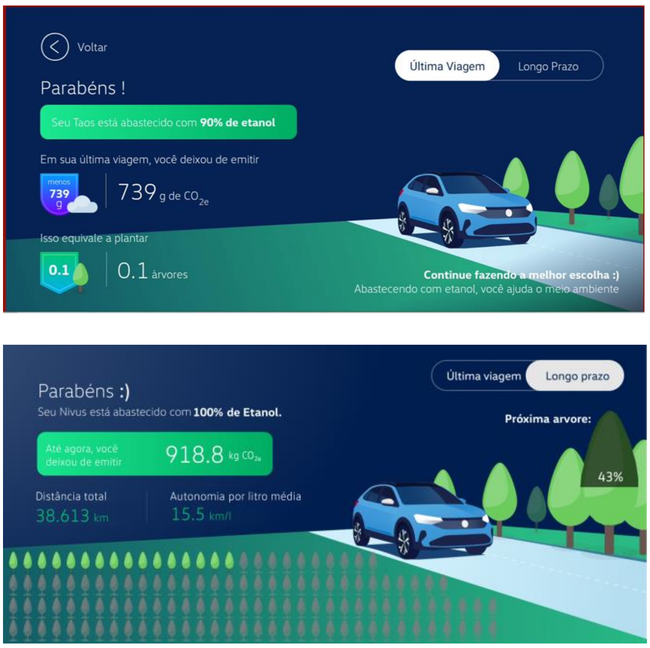

Figure 8: Alternative/ ludic scale showed at vehicle media center: Above: the last Driving Cycle; Below: long Term

$$Trees = AvoidCO_2e(ton)*140\ (tree/(ton.year)) \quad (9)$$

Figure 7 intends to give a sensibility of the required trees to compensate different fuels. As an example: if the customer choose always to drive with E100h (instead of E27), with a vehicle making 10km/l_{E100h}, along a life cycle of 200k km, it would be necessary to plant and raise for 1 year ca. 2660 trees (or 133 trees planted and raised for 20 years). This magnitude is quite big: Considering an OEM licensing, in one year, 350 thousand flex cars (as that of the example above), it would be necessary require 930 Million trees to be planted in a year. Considering, arbitrarily, 0,25m^2 of Area per tree, it would require a space with 2,4 times the São Paulo city area (1.512km^2) [19]. This makes the fuel choice a strong lever for decarbonization.

The AvoidCO_2e can be calculated for a single driving cycle or for the long term (i.e. several driving cycles). Both results are presented to customers in screens showed in Figure 8.

AUTOMOTIVE APPLICATION AT THE IVI (In-VEHICLE INFOTAINMENT)

The development and the implementation of the App was performed inside the laboratory of the Electronic and Connectivity department of Product Development Division in Volkswagen South America, São Bernardo do Campo. This Area is designed to be capable of promote vehicle connectivity and to develop tools, adapted to the market intended for the vehicle, in order to improve customer experience and/or to help the daily life inside the time he or she spend inside the vehicle.

The development software used for the App presented in this article was the Android Studio, based on Automotive Android sdk (software development kit).

The vehicle parameters are obtained from the vehicle CAN (Controller Area Network), in that the engine ECU broadcast it. The acquisition frame is around 500ms. In case the customer provides connectivity to the IVI, through cell phone routing, vehicle data is uploaded to a cloud to support App improvements.

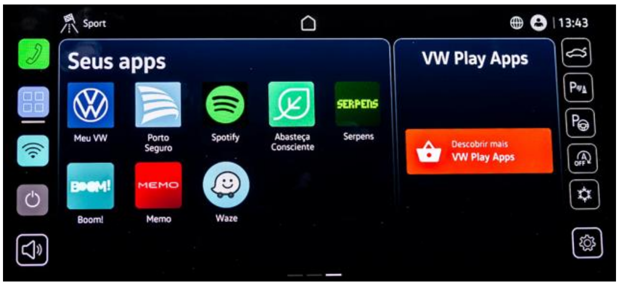

Figure 9: Presentation of the vehicle media center screen, showing the App "Abasteça Consciente" already downloaded

The App is left available for the customer at VW Play App store. It can be freely downloaded by accessing the app-store and searching for "Abasteça Consciente". It is offered for all customers with vehicles equipped with "VW Play" infotainment. Figure 9 shows the App already downloaded in the vehicle media center.

RESULTS AND NEXT STEPS

Since the App release in last Quarter of 2022, the number of downloads was 18.560. The amount of uploaded data (that occurs in case the customer provides connectivity via cell phone routing) was ca 0,8 TeraBytes. To increase these numbers, the idea is to have the App as a standard in the Infotainment, avoiding the necessity to download it. The next steps proposed for the App are linked to the opportunities of the connected cars, a trend in the Brazilian market.

The connected car opens the technical possibility to know the behavior of each customer and his or her response to incentives to select ethanol as fuel, instead of the gasoline E27. As can be concluded from Table 1, this represent a reduction of circa 70% in the Well to Wheels, non-renewable CO_2e released to air in each driving cycle. In the case all Flex vehicle customers could connected to a cloud and tracked, there would be the possibility to measure the percentage of ethanol being chosen at fuel stations by the customers.

This value (counted in energy basis) is called "ethanol usage factor" (EUF) and represent a big lever for the decarbonization in Brazil, as explained in [7]. An estimative of EUF was performed by Oliveira et al. (2024) [8]: For 2022, in Brazil, EUF=28%. This means that 28% of the energy of Otto fuels used by the Flex fleet came from E100h. Internal estimations led to the conclusion that, if the EUF could be increased by 10 percent points (it means more E100h usage) via influencing customer choice, the average life cycle (cradle to grave) CO_2e per vehicle could be reduced by ca. 5% for an OEM, with portfolio strongly based on Flex technology. As an example, for an annual Flex cars sales volume of 320.000 cars, this would represent ca. 450.000 tonCO_2e avoided, every year. To obtain a similar reduction via electrification, the company mix of battery electric cars (BEVs) would need to increase to more than 10%, a challenging task in Brazil, given market characteristics such as cost orientation, lack of charging infrastructure and the investments necessary to stablish it.

Another App improvement to be studied is the calculation method for the avoided CO_2e presented in this text (and active in the App). The method relies on the assumption that the vehicle energy parity, EP, is constant, no matter the geographic/ traffic conditions the customer has faced in the driving cycle. A more sophisticated model could be developed to consider the actual vehicle signals of rpm, loads and temperature along this driving cycle and, based on vehicle efficiency mapping (previously informed to the App), to make a more accurate estimation. The knowledge of vehicle efficiency map could also be used, via an adequate algorithm, to inform the customer a projection of the consumption, the cost and the CO_2e for a route that he or she are still intending to cover. A comparison between possible routes for the same destination could also be offered.

Furthermore, the App could be prepared to offer more than information to the customer, in order to influence her or his fuel decision. The possibility to calculate the avoided CO_2e in the long term opens the chance to study opportunities for gamification and other types of rewards, such as gathering points in a mileage program or even a direct cash back solution, via the administration of carbon credits to be issued based on the customer fuel decision. The viability of such credits requires deeper investigation, including how to deal with the imprecisions of the fuel identification system and about the regulation of carbon credit market.

The vehicle connection with fuel stations could also be a line of research. The fuel prices would be directly send to the vehicle to make the selection process even easier for the customer. This sophistication can be further improved in case the Carbon Intensity, IC, of the ethanol E100h, available in the gas station tanks, could be estimated and transmitted to the App inside the vehicle. The accumulation of avoided CO_2e (and thus the customer reward) would be, this way, higher in those fuel stations offering ethanol from suppliers with lower fuel footprint, i.e, lower IC. This could represent an additional incentive for the producers (together with RenovaBio) to improve their processes.

These initiatives, as mentioned above, can represent a significant reduction for the passenger car and light commercials CO_2e emission, with low investment and using the ethanol infrastructure already stablished country wide. Although not usually mentioned as decarbonization measure, infotainment technology with this purpose should be incentivized by companies, academic and also upcoming CO_2e legislations in the country.

AKNOWLEDGMENT

The authors would like to thank Guilherme Bendini for the valuable contribution to this work during his period in VWB/ Way to Zero Center.

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