UNIVERSIDADE PAULISTA – UNIP

PROGRAMA DE PÓS-GRADUAÇÃO EM ENGENHARIA DE PRODUÇÃO

ESTUDO DE IMPACTO AMBIENTAL NO TRANSPORTE DE HORTIFRUTI E AVALIAÇÃO DA SUSTENTABILIDADE DE MOTORES A COMBUSTÃO INTERNA (CICLO OTTO)

Dissertação apresentada ao Programa de Pós-Graduação em Engenharia de Produção da Universidade Paulista – UNIP, para obtenção do título de Mestre em Engenharia de Produção.

GILSON TRISTÃO BASTOS DUARTE

SÃO PAULO

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Orientadora: Profa. Dra. Irenilza de Alencar Nääs.

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RESUMO

O conceito de impacto ambiental reflete o quanto determinadas ações afetam o meio ambiente. O transporte rural e urbano utilizando combustível líquido produz dióxido de carbono, que é um gás anisotrópico e induz o efeito estufa. É preciso estabelecer critérios que permitam indicar o comportamento futuro da logística de transporte, tanto rural, de alimentos dos centros produtores para os centros consumidores, como aquela de transporte urbano de passageiros. Desta forma, torna-se necessário traçar um plano estratégico para o desenvolvimento técnico de uma nova geração de motores de grande cilindrada para fins comerciais, que utilizem combustíveis fósseis de baixa octanagem e a necessidade da adição de combustíveis orgânicos a essa mistura, por diminuírem a emissão de poluentes. O objetivo desta dissertação foi estudar o impacto ambiental de motores em dois estudos de caso, o de transporte de produtos da região produtora para o centro de abastecimento, e avaliação da sustentabilidade de motores a combustão interna (ciclo Otto), utilizando combustíveis orgânicos. O primeiro estudo levantou dados de distâncias entre produtores rurais e um centro de distribuição localizado em Campinas, SP e avaliou o impacto ambiental do transporte de produtos. O segundo analisou os resultados da utilização de combustíveis orgânicos misturados a fósseis, utilizando um *powertrain* e sistemas de medição de emissão de gases. Os resultados indicaram que em um país continental como o Brasil, é inevitável o uso de transportes de longa distância para a distribuição de produtos, durante a entressafra. Também mostraram que mistura de combustíveis orgânicos diminui a emissão de poluentes em motores de ciclo Otto. O planejamento adequado de quantidades e distâncias ajuda a minimizar o impacto ambiental no transporte de mercadorias. Também se conseguiu identificar que o impacto ambiental de veículo de passageiros depende também de outras características do motor, como velocidade e lambda. Acredita-se que este estudo pode fornecer subsídio para tomadas de decisão em políticas de transporte no país.

Palavras chaves: impacto ambiental, logística, emissões, combustível alternativo.

ABSTRACT

The concept of environmental impact reflects the extent to which certain actions affect the environment. Rural and urban transport using liquid fuel produces carbon dioxide, which is an anisotropic gas and induces the greenhouse effect. It is necessary to establish criteria to indicate the future behavior of transport logistics, both rural, from food production centers to consumer centers, and urban passenger transport. Thus, it becomes necessary to draw up a strategic plan for the technical development of a new generation of large displacement engines for commercial purposes, which use low octane fossil fuels and the need to add organic fuels to this mixture, as they reduce the emission of pollutants. The objective of this dissertation was to study the environmental impact of engines in two case studies, that of transporting products from the producing region to the supply center and assessing the sustainability of internal combustion engines (Otto cycle) using organic fuels. The first study collected data on distances between rural producers and a distribution center located in Campinas, SP, and evaluated the environmental impact of product transportation. The second analyzed the results of using organic fuels mixed with fossils, using a powertrain and gas emission measurement systems. The results indicated that in a continental country like Brazil, the use of long-distance transportation for the distribution of products is inevitable, during the off-season. They also showed that mixing organic fuels reduces pollutant emissions in Otto cycle engines. Proper planning of the amount and distances helps to minimize the environmental impact of freight transport. It was also possible to identify that the environmental impact of the passenger vehicle also depends on other engine characteristics besides the fuel blend, such as speed and lambda. It is believed that this study can provide support for decision making in transport policies in the country.

Keywords: environmental impact, logistics, emissions, alternative fuel

CAPÍTULO I

1 CONSIDERAÇÕES INICIAIS

Ao partir do conceito de sustentabilidade, em que uma das premissas é buscar o desenvolvimento econômico e material, reduzindo a agressão ao meio ambiente, usando os recursos naturais de forma inteligente e racional, para que estes recursos se mantenham no futuro.

Com este estudo, buscou-se compatibilizar duas visões de sustentabilidade e de transporte. A primeira foi uma visão macro, na qual estudado o impacto ambiental de transporte utilizando caminhões a diesel, de legumes e frutas de várias regiões do país para um centro regional de abastecimento, verificou-se a possibilidade de melhorias logísticas. A segunda, estudou-se as emissões de gases de um motor do ciclo Otto, buscando um melhor entendimento do funcionamento de um motor à combustão, e o comportamento do mesmo com combustível fóssil (gasolina pura) e adotando gradativamente partes conhecidas de combustível orgânico (etanol), a 25%, 50%, 75% e 100%. E assim, observar alguns parâmetros inicialmente definidos no ensaio como temperaturas de pontos específicos, mas, principalmente, os níveis de emissões de gases, buscando uma mistura que resultasse em uma queima mais eficiente por um motor convencional, sem qualquer alteração técnica em relação aos motores hoje comercializados. E assim, demonstrar a possibilidade de se confirmar uma provável tendência futura, quanto ao tipo de motor e combustíveis utilizados nos veículos comerciais.

Esta dissertação de mestrado foi organizada em vários capítulos. O Capítulo I, trata da introdução, da justificativa, do objetivo e da metodologia resumida. Os resultados e a discussão são apresentados em trabalhos submetidos à publicação, de acordo com as normas das revistas a que foram submetidos. O Capítulo II expõe os resultados e as discussões sob a forma de dois artigos científicos, enquanto o Capítulo III encaminha as considerações gerais, contendo as conclusões e algumas recomendações para trabalhos futuros.

1.1 Introdução e Justificativa

O setor de transportes representa 20% de toda a energia utilizada no planeta e é responsável por 23% das emissões globais de CO_2 (IPCC, 2018). O transporte rodoviário e marítimo é dominado por motores de combustão interna (ciclo diesel) enquanto o transporte aéreo e dominado por motores a jato. Cerca de 96% de todos os automóveis de passageiros no Brasil, funcionam com motores de ignição comandada (ciclo OTTO) (OPEC, 2019). Estudos mostram que a tendência futura é a de que os automóveis de passageiros passem a utilizar energias renováveis, elétrica principalmente (EXXONMOBIL, 2019), e a rigidez no controle de emissões exigirá combustíveis mais puros, sem adição de nafta e demais subprodutos do refino. Sendo assim, as tendências tecnológicas terão um forte impacto na fabricação de combustíveis.

Figura 1- Composição de refino do óleo bruto (LARCO, 2019).

Logo, surge a necessidade de um desenvolvimento conjunto de novos combustíveis líquidos de baixa octanagem e motores de ignição comandada (permitem controle no ponto de ignição), para o setor de transportes de longa distância. Com isso, haverá um aumento na eficiência dos combustíveis de baixa octanagem, o que permitirá a utilização dos subprodutos do refino de petróleo (KALGHATGI, 2015).

O segmento de caminhões rodoviários transporta cerca de 60% de todos os produtos afretados no Brasil (WELLE, 2018). Caminhões a diesel rodam grandes distâncias das áreas de produção agrícola até os centros de distribuição de alimentos no país, e esses centros geralmente estão localizados em áreas metropolitanas.

A evolução da demanda de frete de mercadorias está intimamente associada ao PIB (Produto Interno Bruto) do país. O Banco Mundial examinou 33 países em diferentes estágios de desenvolvimento e sugeriu que as variações no PIB poderiam explicar quase 90% da diferença nos volumes de frete rodoviário de mercadorias (EDWARDS-JONES et al., 2008; MURATORI et al., 2017). A avaliação do transporte rodoviário de carga é um tanto desafiadora, devido a várias incertezas técnicas e econômicas (MELAINA e WEBSTER, 2011; ROTHWELL et al., 2016).

Em todo o mundo, existem várias iniciativas para reduzir o número de intermediários na cadeia de abastecimento alimentar e realocar geograficamente a produção e o consumo (EDWARDS-JONES et al., 2008; MARIOLA, 2008). Essas iniciativas compartilham a visão de atender aos diversos critérios de um sistema alimentar sustentável. Do ponto de vista econômico, a importância é colocada na redistribuição de mais valor para os agricultores, na reorganização dos fluxos econômicos e na redução do uso de recursos não renováveis. O desenvolvimento de cadeias ‘alimentares locais’ pretende ser mais ‘justo’, permitindo a renovação das relações entre a área metropolitana e a rural (DUPUIS e GOODMAN, 2005). No debate internacional sobre 'alimentos locais', os impactos ambientais considerados não se restringem às emissões de GEE. No entanto, as políticas de redução de carbono podem entregar potenciais compensações na questão geral de sustentabilidade ambiental, até que outros impactos sejam considerados (ROTHWELL et al., 2016)

A tendência de uso de combustíveis líquidos, derivados do petróleo, e a necessidade global de redução do nível de emissão de poluentes justificam a adição do etanol na gasolina pura. Assim, surgiu um motor que melhor se adaptou a essa mistura e consequentemente emitiu menos poluentes, o motor aspirado com a ignição. O etanol possui maior octanagem que permite a operação com maiores taxas de compressão sem entrar em autoignição e com maior eficiência (V.R.ROSO, 2019). Tecnicamente, esses motores permitem que sejam alterados os tempos de ignição (antecipar ou atrasar o ponto de ignição, quando necessário), a temperatura de operação (válvulas termostáticas eletrônicas) e a variação do tempo de injeção de combustível, conforme detectado pelas sondas lambda no escapamento e os sensores de pressão do coletor de admissão. No entanto, Barakat et al. (2016) observaram uma relação linear de baixa inclinação entre o consumo de combustível e a concentração de etanol. Outros autores (T. TOPGUL, 2006; R. CATALUNA ET AL., 2008; D. A. GUERRIERI ET AL., 1995) relataram um aumento acentuado no consumo de combustível usando a mistura etanol-gasolina. Cahyono e Bakar (2011) encontraram uma diminuição no torque e na potência do motor quando o etanol foi usado como combustível em contraste com a gasolina. No entanto, esses achados estão relacionados ao uso da mistura de etanol em motores convencionais de ignição a gasolina.

A aplicação de técnicas de mineração de dados em testes de misturas de combustíveis pode identificar informações com mais precisão por meio da aplicação de algoritmos. Recursos analíticos preditivos, mineração de dados e aprendizado de máquina podem ser usados para verificações precisas sobre o impacto ambiental de misturas de combustíveis fósseis e não fósseis, considerando o gerenciamento do crescimento de dados, integrando e analisando dados para obter insights válidos de tomada de decisão no uso de combustíveis (SHAH, 2012; RIBEIRO, 2013; FERREIRA, 2015; HABIB, 2015; JORGE, 2017).

Esta pesquisa se justifica pela escassez de informação científica no conceito de distribuição de alimentos do produtor para os centros consumidores, indiretamente pode ser visto como um estudo sobre a pegada de carbono desta operação. Por outro lado, também se avaliou o impacto ambiental do uso de combustíveis orgânicos, o que se justifica pela grande utilização no país de frota de veículos comerciais.

1.2 Objetivos

1.2.1 Objetivo Geral

Estudar o impacto ambiental de transporte sob duas vertentes, a visão macro de transporte em longas distâncias e a visão micro, do resultado de diferentes adições de etanol à gasolina.

1.2.2 Objetivos Específicos

- Estudar o impacto ambiental de transporte utilizando caminhões a diesel, de legumes e frutas de várias regiões do país para um centro regional de abastecimento.
- Avaliar as emissões de gases de um motor do ciclo Otto utilizando diversas misturas de etanol e gasolina. E, determinar a mistura ótima dos dois combustíveis para rendimento e emissões.

1.3 Metodologia Resumida

O primeiro estudo relata dados disponíveis no centro de distribuição de alimentos frescos (CEASA-Campinas, localizado a 22 ° 56 'de latitude sul, 46 ° 58' de longitude oeste e 300 m de altitude). A pesquisa enfocou o volume de alimentos transportados e a distância das áreas de produção em vários estados do país ao CEASA

O setor inclui o transporte do produto (alimentos frescos: frutas e legumes; mamão, tomate e batata) da área rural em vários estados diferentes para o centro de distribuição de alimentos da CEASA. O valor total transportado foi calculado considerando o número de viagens multiplicadas pela distância percorrida. A quantidade total de produto transportado foi encontrada no Relatório CEASA do centro de distribuição de produtos. Os dados são relativos à distribuição durante os anos de 2016 e 2017.

O Segundo estudo relata a pesquisa onde se utilizou de um conjunto *Powertrain* para o teste das misturas de combustíveis. O *Powertrain* trata-se de uma plataforma móvel, constituída de um motor de 1.598 cm^3, quatro cilindros em linha, oito válvulas, refrigeração por circuito de água sob pressão, com sistema de injeção eletrônica de combustível multiponto sequencial e um módulo gerenciador (marca Injepro®, modelo EFI-light v2) que permitiu controlar e acessar o mapa dos atuadores. A plataforma apresentava todos os sistemas de um veículo automotivo: sistema de alimentação de combustível e reservatório; sistema de arrefecimento com radiador e ventoinha; sistema elétrico (alternador e bateria) e de partida (motor de partida).

Os testes foram realizados com etanol (álcool anidro) e gasolina. As misturas utilizadas no teste de Powertrain foram: gasolina pura (E0), gasolina com 25% de etanol (E25), gasolina com 50% de etanol (E50), gasolina com 75% de etanol (E75) e etanol puro (E100). A gasolina padrão brasileira é comercializada com 27% de etanol (ANP N° 19, 2015; ANP Nº 9, 2017). Diante disso, a extração desse volume de etanol foi realizada em laboratório através da decantação e separação para fins de padronização antes do teste.

As metodologias detalhadas se encontram nos artigos, no Capítulo 2.

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CAPÍTULO II

2 RESULTADOS E DISCUSSÃO

Os Resultados e a discussão desta dissertação são apresentados na forma de artigos científicos

2.1 Artigo 1

Este artigo foi escrito nas normas da Revista Environmental Science and Pollution Research.

Impacto ambiental da distância de transporte rodoviário na distribuição de alimentos frescos: um estudo de caso no Brasil

Environmental impact of the on-road transportation distance in the fresh food distribution: A case-study in Brazil

Abstract

The pollutants' emissions from on-road transport is an important pressure on the climate change scenario, and most developing countries rely mostly on-road diesel transportation. The current study aimed to estimate the environmental impact of the distance from the production area of fresh food (papaya, potato, and tomato) to a fresh food distribution center located in Campinas, Sao Paulo, Brazil. The way each of the products were carried was assessed for calculating the total transported volume. The total amount carried was measured considering the number of trips multiplied by the distance traveled. An online calculator was used to allow the estimative of the amount of CO_2-eq, that is the GWP in 100 years. The highest CO_2 emission was identified in the potato transported from Paraná State to the distribution center, with a CO_2 emission of 3237 t/year (64% of contribution), followed by the papaya from Bahia State (2723 t/year, 42% of contribution), and the tomato from Sao Paulo State (625 t/year, 71% of contribution). However, when computing the Global Warming Impact (GWP), the highest value was found in the transport of potato from the Minas Gerais State (8

10^{-2} in 100 years) followed by the papaya from Rio Grande do Norte State (5 10^{-2} in 100 years) and the papaya from Bahia (3 10^{-2} in 100 years). The higher the amount of product transported by a trip the smaller the environmental impact in the long run. A proper strategy to reduce the environmental impact would be to have large freight volume when transporting food from vast distances within continental countries.

Keywords

Papaya; potato; tomato; freight; GHG emissions; Global Warming Potential

Introduction

The world transport sector represents nearly 20% of carbon dioxide (CO_2) emissions from fossil fuel combustion and around 15% of overall greenhouse gas (GHG) emissions (Forster at al., 2008; IFT, 2010; IEA, 2014). The pollutants' emissions from on-road transport cause severe pressure on climate change since the transportation within the supply chains is a crucial issue in the global carbon dioxide emissions (IEA, 2014; Dente and Tavasszy, 2018). The truck freight sector is a sole contributor to CO_2 emissions in large territorial countries such as Brazil that uses mainly diesel truck transportation. The on-road truck segment hauls about 60% of all freight in Brazil (Welle, 2018). Diesel on-road trucks travel vast distances from the agricultural production areas to the food distribution centers in the country, and those centers are usually located in metropolitan areas.

The evolution of goods' freight demand is closely associated with the country' GDP (Gross Domestic Product). The World Bank examined 33 countries at different development stages and suggested that the variations in GDP could explain nearly 90% of the difference in goods' road freight volumes (Edwards-Jones et al., 2008; Muratori et al., 2017). On-road freight transport assessment is somewhat challenging, due to several technical and economic uncertainties (Melaina and Webster, 2011; Rothwell et al., 2016).

Worldwide, there are various initiatives to both reduce the number of intermediaries in the food supply chain and geographically relocate production and consumption

(Edwards-Jones et al., 2008; Mariola, 2008). These initiatives share the vision of meeting the many criteria of a sustainable food system. From the economic viewpoint, the importance is placed on the redistribution of increased value for farmers, the re-arrangement of economic flows, and the reduction of the use of non-renewable resources. The development of 'local food' chains intends to be more 'just' and 'fair,' allowing renewal of the relations between the metropolitan and the rural area (DuPuis and Goodman, 2005). Within the 'local food' international debate, environmental impacts considered are not restricted to GHG emissions. However, carbon reduction policies may deliver potential trade-offs in the overall environmental sustainability issue, until other impacts are considered (Rothwell et al., 2016). Policy contexts need to consider how trade-offs will be assessed and managed as governments attempt to meet the agenda of emissions reductions (Melaina and Webster, 2011; Rothwell et al., 2016).

There are various ways of representing the environmental impact in the food chain scenario (Andersson and Ohlsson, 1998; Watkiss, 2005; Coley et al., 2009; Page et al., 2012; Ligterink et al., 2012; Nocera and Cavallaro, 2016; Caracciolo et al., 2017; Dente and Tavasszy, 2018). Although other GHG (N_x, NOx, HC, CO) emissions have been proposed to estimate environmental impact in food supply chains (Ligterink et al., 2012), carbon dioxide emission has been used to estimate the transportation impact in several developed countries, that have already established goal towards mitigation for climate change (Coley et al., 2009; Ligterink et al., 2012; Nocera and Cavallaro, 2016; Quiros et al., 2017; Ligterink, 2017; Dente and Tavasszy, 2018). Nocera and Cavallaro (2016) proposed an approach to creating simplified emission functions for road freight transport. The found results were compared to other emission models and showed the effectiveness of alternative emission mitigation strategies (Dente and Tavasszy, 2018). Such an analysis does not address the relative cost-effectiveness of different GHG reduction options, partly due to the significant uncertainties out to 2050 goals (IPCC, 2014). However, the combination of the aims and cost uncertainties leads to the adoption of a broad range of reduction options to raise the probability of meeting the cost-effectiveness goals (Nocera and Cavallaro, 2016). The other way of evaluating environmental impact is the use of Life Cycle Assessment (LCA) approach (Andersson and Ohlsson, 1998; Hall et al., 2014; Caracciolo et al., 2017). The LCA of two retail distribution networks (Carrefour and 7-11) was carried out by Wang et al. (2016), and the authors observed that the main impacts were in the use of fossil fuels, and the most significant factor was the distribution distance. The water footprint was also used to assess the environmental impact (Page et al., 2012), as well as the food miles concept (Watkiss, 2005), and the energy efficiency of food systems (Mundler and Rumpus, 2012).

Global warming potential (GWP) is a relative quantity of how much heat a greenhouse gas traps in the atmosphere (Quiros and Smith, 2017). It compares the quantity of heat trapped by a certain mass of the gas to the amount of heat caught by a similar mass of carbon dioxide. The GWP of an anisotropic gas indicates the amount of warming a gas causes over a given period (usually 100 years). GWP is equivalent to an index (GHG, 2011), which uses the CO_2 value of 1. The report by the Intergovernmental Panel on Climate Change (IPCC, 2014) estimates that greenhouse gas (GHG) emissions must be reduced within the range of 40–70% by 2050 from 2010 levels to avoid a greater than 2 °C increase in the global mean temperature. Such an aim might avoid the most severe climate change impacts. However, without a clear policy of mitigation actions to surpass the issues to large emerging economies, and large territorial countries (*i.e.*, China, Russia, India, and Brazil) that depend on on-road transportation is a great challenge (Melaina and Webster, 2011; Muratori et al., 2017; Dente and Travasszy, 2018).

The current study aimed to evaluate for the first time the environmental impact of the fresh food (papaya, potato, and tomato) transported by on-road diesel trucks from the different Brazilian States to the CEASA food distribution center located in Campinas, State of São Paulo, Brazil.

Methods

Selected boundaries for the analysis

The present study used data available from the fresh food distribution center (CEASA-Campinas, located at 22° 56' latitude South, 46° 58' longitude West, and 300 m of altitude). The research focused on the volume of food transported and distance from the production areas in several States of the country to the CEASA (Figure 1).

Figure 1. Map of Brazil with the country location in the South America, the States, and the average location of the food production area within the States, and the linear distance to the CEASA Food Center Distribution located in Campinas, São Paulo, Brazil.

The whole supply chain which connects the points of the food production and distribution center is quite a complicated scenario. Therefore, a sectoral analysis was established for the present study, as shown in the dotted line of Figure 2. The sector includes the transportation of the product (fresh food: fruits and tub; papaya, tomato, and potato) from the rural area in several different States to the CEASA food distribution center located in Campinas, São Paulo, Brazil. Data are relative to distribution during the years 2016 to 2017.

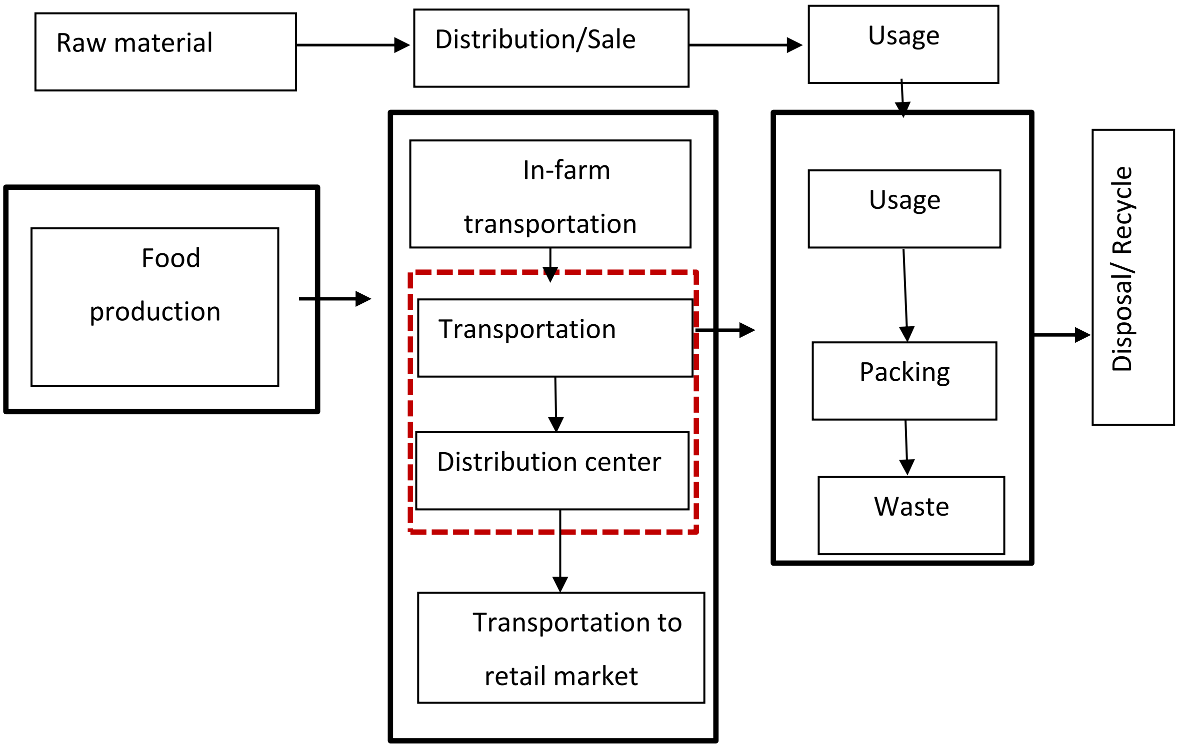

Figure 2– Schematic of the study system boundaries for the food transportation to the distribution center. The dotted red line is the object of the current study.

Three products were analyzed papaya, potato, and tomato. The distances of transportation were computed, and the CO_2 emissions were calculated using the online calculator (CFC, 2018).

Freight calculation

The volumetric capacity of the trucks was estimated. The most diesel on-road truck used has three measurements with lorry dimensions of 2.42 m width, 14.94 m length, and 2.73 m height. The volume the truck might carry is 98.29 m^3. The maximum freight capacity is 14 t. The size of each way the products are carried was estimated for calculating the total transported volume of the studied fruits and tub (papaya, potato, and tomato). Tomato and papaya are transported in boxes with the dimensions of 0.36 m of width, 0.55 m length, and 0.31 height (0.061 m^3). The boxes are put into the truck to complete the load.

It was considered that the boxes were placed inside the truck in the longitudinal position, as in this position the truck might reach the maximum weight possible with the more significant number of boxes. The total of boxes available was 1,512 boxes. However, the total capacity being 14 t, the truck might carry only 700 boxes. It was considered 20 kg of products per box (in the case of tomatoes and papaya). Potatoes are transported into bags of 50 kg. The total of bags carried was calculated considering a total of 280 bags per freight that will add up to 14 tons. In each load, the truck transports 14 t of products. The total amount carried was calculated considering the number of trips multiplied by the distance traveled. The total quantity of product transported was found in the CEASA Report of the products distribution center. Data are relative to distribution during the years 2016 and 2017. Table 1 shows the total distances of travel by the on-road diesel trucks to transport the total volume of each product from de production center to the CEASA food distribution center, Campinas, São Paulo State, Brazil.

Table 1. The product, the State the fruit or tub is produced, the amount of production in a year (t/year), the total distance traveled (total amount transported multiplied by the number of trips, km)

Product	**State**	**Quantity of product (10^4 t/year)**	**Total distance travelled (10^6 km)**
Papaya	Bahia	9.6	10.0
	Espirito Santo	7.8	6.0
	Rio Grande do Norte	4.0	8.0
Potato	Paraná	24.0	12.0
	Goiás	3.9	1.0
	Minas Gerais	3.0	0.9
	São Paulo	15.4	2.0
	Santa Catarina	2.7	2.0
	Rio Grande do Sul	0.8	0.6
Tomato	São Paulo	27.6	2.3
	Minas Gerais	2.0	0.9

Distance traveled = total amount transported multiplied by the number of trips within a year (km).

Global warming impact assessment

The values of the CO_2 equivalent (CO_2-eq) emissions were estimated adopting the 100-yr Global Warming Potential (GWP) values used by the Fourth Assessment Report (AR4) of the IPCC (Forster et al., 2007), and using the online calculator (CFC, 2018). The online calculator allows the user to enter the distance traveled and the average fuel consumption, and the result is the amount of CO_2-eq/year, that is the GWP in 100 years (Brander, 2012).

It was possible to estimate the GWP for each ton of product in a 100-year time, by combining the data which might impact the environment for the known period, which is the concept of GWP (Page et al., 2012). The scope of the total computation of the environmental impact is beyond the scope of the present study. The role of the transportation of food products might be expressed in GWP, as found in the current literature (Nocera and Cavallaro, 2016; Rothwell et al., 2016; Wang et al., 2016; Muratori et al., 2017).

Results and Discussion

The highest values of CO_2 emission were found in the potato that comes from Paraná State, with a CO_2 emission of 3237 t/year (64% of contribution), followed by the papaya from Bahia State (2723 t/year, 42% of contribution), and the tomato from São Paulo State (625 t/year, 71% of contribution) which was similar to those obtained by Quiros et al. (2017). The CO_2 emissions from the papaya transport were generally high from the various States. High values were also found for the potatoes transported from Goiás State (497 t/year), and the other observed values of CO_2 emission were somewhat smaller than the previously cited. The lowest amount observed in the present study was of the potatoes transported from the Rio Grande do Sul State.

Carbon dioxide emissions from on-road transportation have historically grown with a correlation to GDP, and there is a limited indication of near-term global decrease the freight demand from GDP. Over the 21st century, GHG emissions from truck transport are projected to grow faster than other sectors, with the size of growth reliant on the amount of a long-term association between freights and the use of carbon fuels. In climate change mitigation setups that apply a price to GHG emissions, mitigation of freight emissions is more restricted than for other demand sectors. In such scenarios, shifting to less-emitting transportation modes and technologies is projected to play a relatively small role in reducing freight emissions (Muratori et al., 2017). Nocera and Cavallaro (2016) studied several transportation ways in the Trans-Alpine region and the results the authors obtained of CO_2 emissions were close to those found in the present research when analyzing the on-road diesel trucks. Therefore, the calculator used in the present study might adequately forecast the potential environmental impact of the diesel on-road truck transportation. Naturally, there are other potential influences on the truck emission such as the driving behavior, road traffic congestion, and speed limits can all affect the emissions of a vehicle significantly (Ligterink, 2017).

Table 2. The product, the State the product comes from, the total distance traveled (km) and the calculated CO_2 emissions (t/yr).

Product	**State of the origin of the product**	**Total distance (km/year)**	**CO_2 emission (t/year)**	**CO_2 contribution (%)**
Papaya	Bahia	10396726	2723	42
	Espirito Santo	6264910	1641	25
	Rio Grande do Norte	8173971	2141	33
Total			6505	
Potato	Paraná	12357881	3237	64
	Goiás	1899469	497	10
	Minas Gerais	969601	254	5
	São Paulo	1805410	473	9
	Santa Catarina	1629230	426	8
	Rio Grande do Sul	654454	171	3
Total			5058	
Tomato	São Paulo	2386298	625	71
	Minas Gerais	991679	259	29
Total			884	

Shortening the distance between the production area and the distribution center might reduce the environmental damage. The transport companies may consider an alternative-fuel vehicle fleet to reduce the consumption of fossil fuels, as proposed by Dente and Travasszy (2018). In the study of the potential environmental impact of packaged beverages sold in two different distribution channels, Wang at al. (2016) conveyed information in an easily accessible way focusing on a general presentation of the distribution and sales systems and their environmental profiles rather than documenting the complete life cycle assessment methodology and calculation process. As to the traveled distances, Coley et al. (2009) suggest that when a customer drives a round-trip distance of more than 7 km to purchase organic vegetables, the carbon emissions are higher than the emissions from a system using cold storage. Such storage associated with the packing process, transport to a regional distribution center and final transport to customer’s doorstep used by large-scale vegetable suppliers is likely to have a smaller environmental impact. Consequently, some of the thoughts behind ‘local food’ concept might need to be reviewed (DuPuis and Goodman, 2005).

Concerning the environmental impact and the distance traveled, the results of the current study were not conclusive. The values of GWP/t of product varied (Figure 2), and were not necessarily proportional to the distance traveled, but the amount was inversely proportional to the quantity of product transported. However, it was clear that the potatoes from the State of São Paulo, where Campinas is located, produced a smaller environmental impact than the product from other States. Such results should reinforce the ‘local food’ concept. It might be possible that increasing the volume transported by freight the GWP is maintained within a low level by product where the distance is high, and the amount of transported product is also high, as shown in Figure 3 for potatoes transported from Paraná State. While the potatoes transported from Minas Gerais State, being in small amount generated a high GWP ($8\ 10^{-2}$ in 100 years). The higher the amount of product transported per freight the smaller the environmental impact in the long run.

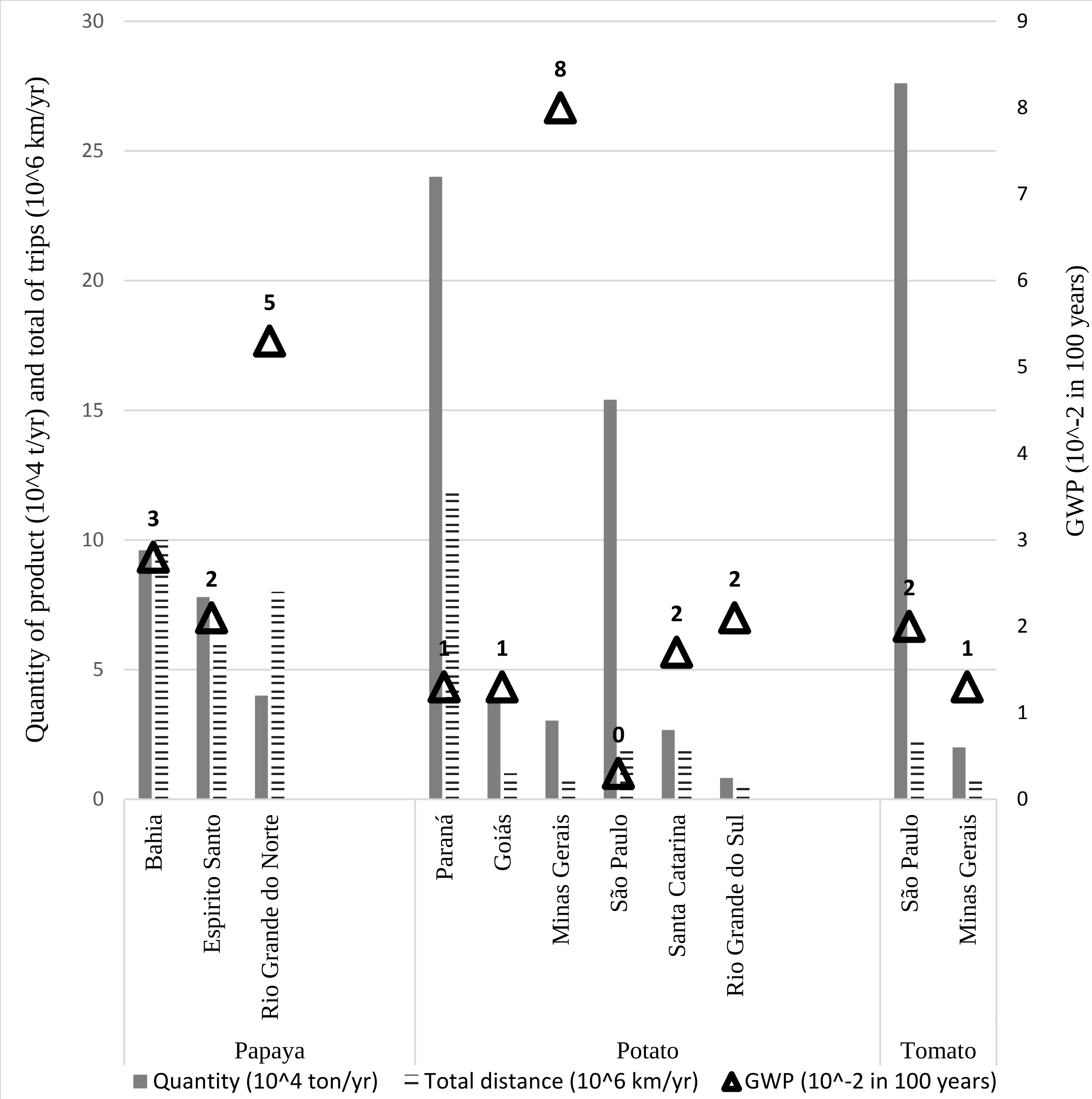

Figure 3 – Global warming potential (GWP/t of product) of the studied products due to the freight, from the production area to the distribution center.

Similar results were reached by Hall et al. (2014) when studying the life cycle of lettuce and chicken meat. Also, for resilient food supplies, physical supplies of land and water should be available for production, which was not the focus in the present research. Such evaluation (water and land use) is not always considered in the environmental assessments of transport policies, underestimating the potential environmental impact (Forster et al., 2007).

Knowing the product consumption potential in the region where the CEASA-Campinas is located, and the volume produced in a particular region it would be possible to develop a strategy that would meet the region's demand for the product with a smaller environmental impact. However, the interaction of the impacts of consumer choice and socio-economic systems highlights the inherent interdisciplinarity of food chain analysis (Edward-Jones et al., 2008). Different scales of production might influence the environmental impact at the local/global level. Morrow et al. (2010) examined different policies for reducing GHG emissions and oil consumption in the USA transportation sector under economy-wide CO_2 prices. According to the authors, all policy scenarios modeled fail to meet the goal of reducing GHG emissions by 14% below 2005 levels by 2020. Therefore, the mitigation of carbon emissions in large countries with great territorial distances is a theme of high complexity. Other studies in developed countries suggest that the energy efficiency of global food systems is higher due to the increased size and geographic location of producers, which increases the fuel use for transportation (Watkiss, 2005; Melaina and Webster, 2011; Rothwell et al., 2016; Muratori et al., 2017). With a rapidly expanding economy and growing transportation sector, China is also challenged to reduce transportation-related carbon emissions. As the transportation sector depends on crude oil, large territorial countries such as China, Brazil, and the USA rely on oil imports to support domestic demand. Interestingly, research on transportation-related carbon emissions from China and the United States are often dealing with strategies regarding energy security in addition to climate change (Morrow et al., 2010; Wang et al., 2007).

While the three-way catalyst, introduced around 1990, has reduced the emissions of gasoline urban vehicles to small levels, diesel engines used in truck transportation remain with large CO_2 potential emission. The fact that newer light-duty vehicles are not significantly cleaner than older ones reduces the effectiveness of local urban policy actions, like low-emission zones, to reduce the carbon emissions of traffic (Ligterink, 2017; Durbin et al., 2018). In the case of transportation from agricultural areas to the distributing and processing centers, diesel heavy trucks remain as an essential role in the environmental impact. The deterioration of industrial agriculture, the rising cost of refrigeration required for storage and transport, and the increased use of biofuels should change the energy balance back in favor of local foods (Mariola, 2007).

However, such a concept might not apply for large territorial countries with food production areas away from the distribution centers.

In the present study, we faced some questions that could not be answered such as the unbalanced issues of food transport and local food production. We understood that such a scenario is more complicated than the current literature points out (Edwards-Jones et al., 2008; Coley et al., 2009; Mundler and Rumpus, 2012). In a systematic review on the trends of carbon emissions in the transport sector, Tian et al. (2018) identified a lack of knowledge on how the application of renewable energy sources can help mitigate the overall GHG emissions from the transport sector. The authors encourage greater use of modeling to identify optimal pathways for reducing transportation-related carbon emissions that consider the environmental impact and relationships with food suppliers and other industrial sectors.

Conclusions

The Global Warming Impact (in 100 years) was estimated considering the on-road transportation of fresh food products within Brazilian territory to the distribution center in Campinas, Sao Paulo State. From the studied fresh food products, the highest environmental impact was found in the papaya transport from the Northeastern States to the CEASA in Campinas, São Paulo, followed by the potato and the tomato transport from several production areas in Brazil. The values of the CO_2 emission depend on the volume of transported product which is dependent on the consumers' demand.

The larger the volume of products transported by freight the lower the environmental impact in the long run. Such an effect is also related to the choice of food consumption in large metropolitan areas. The awareness of the consumer on the environmental impact might change the diet option; however, it is an option that might arrive after the embodiment of critical knowledge on the potential harm of climate change.

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2.2 Artigo 2

Este artigo foi escrito nas normas da Revista Fuel Processing Technology.

Classifying the Environmental Impact of a Spark Ignition Flex-Fuel Engine Using Ethanol - Gasoline Blends

Abstract

The present study aimed to classify the environmental impact of concentrations of gasoline and ethanol mixtures (pure gasoline, 25, 50, 75% ethanol blended to gasoline, and 100% ethanol) using a flex-fuel engine. The Powertrain used for testing the fuel blends was a mobile platform, consisting of a 1,598 cm^3 flex-fuel engine, four cylinders in line, eight valves, cooling by a water pressure circuit, with a sequential multipoint electronic fuel injection system and a management module that allowed to control and access the map of the actuators. We used the data mining approach to develop a classification model using the ethanol content in gasoline (0, 25, 50, 75, and 100% ethanol content), the engine rotational speed 900, 2000, and 3000 rpm and lambda (λ) as attributes. The classification target was the environmental impact concerning the CO_2 emission ('low,' 'average,' and 'high'). We used the Random forest algorithm to develop the models. The mean values showed that the carbon monoxide concentrations for all studied fuel content were above 0.5% of the volume. The classification models (accuracy 73%, κ =0.61) indicated that when the ethanol content in the blend is higher than 12.5%, the trend is that the environmental impact is 'high'; however, the general classification of the environmental impact depends also on the engine rotation, the air-fuel ratio, and λ.

Keywords: alternative fuel, ethanol, combustion, spark-ignition engine, flex-fuel engine.

1. Introduction

Non-fossil fuels are considered renewable since they are produced from a natural source (usually from plants). An example is ethanol (C_2H_5OH), a natural fuel produced from sugarcane that is considered an alternative source to fossil fuels [1-4. However, the advantages of fossil fuel, specifically liquid fuels, used on a large scale in automobiles have characteristics of high energy density and wide distribution in airports, ports, and roads. The mixture of the two fuels, gasoline, and ethanol, when properly combined, improves the general energy efficiency of the vehicles, the torque, and the engine power for application in flex-fuel technology [3,5,6], in addition to reducing emissions of greenhouse gases, carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (NO_2) when compared to pure gasoline 3,4,6-8]. However, the low ambient temperature might cause an increase in emissions [9], independent of the ethanol content (EC).

The trend towards the use of liquid fuels, derived from petroleum, and also the global need to reduce the level of pollutant emissions justify the addition of ethanol in pure gasoline. Thus, an engine emerged that best adapted to this mixture and consequently emitted less pollutants, the engine aspirated with the ignition. Ethanol has a higher-octane number that allows the operation with higher compression rates without entering auto-ignition and with greater efficiency [3]. Technically, these engines allow the ignition times to be changed (anticipate or delay the ignition point, when necessary), the operating temperature (electronic thermostatic valves), and the variation of the fuel injection time, as detected by the λ probes in the exhaust system and the pressure sensors of the intake manifold. However, Barakat et al. (2016) [10] observed a low slope linear relationship between fuel consumption and ethanol concentration. Other authors [11, 12, 13] reported a sharp rise in fuel consumption using the ethanol-gasoline blend. Cahyono and Bakar (2011) [14] found a decrease in engine torque and power when ethanol was used as a fuel in contrast to gasoline. However, those findings are related to the use of ethanol blend in conventional gasoline ignition engine. The ideal is to work with the mixture with ethanol, in engines with higher compression rates.

The International Energy Agency [4, 7] reports that CO_2 emissions from fuel combustion decreased by around 12% in the European Union, and 16% in the U.S.A. However, overall levels in the Americas showed little change, as large economies such as Brazil (+ 43%) and Mexico (+ 24%) increased emissions. Currently, Brazilian standard gasoline is sold with 27% ethanol in its composition (E27), according to the National Agency of Petroleum, Natural Gas, and Biofuels [15]. The use of ethanol blend can lead to better air quality in the cities in comparison, because it reduces CO emissions, despite increasing hydrocarbons (HC) in conventional engines [16].

The application of data mining techniques in tests of fuel blends can identify information more accurately through the application of algorithms. Predictive analytics, data mining and machine learning resources can be used for accurate checks on the environmental impact of fossil, and non-fossil fuel blends considering managing data growth, integrating and analyzing data to obtain valid decision-making insights in the use of fuels [17-21]. We did not find in current literature an algorithm to classify the environmental impact when using different blends of gasoline and ethanol in a flex-fuel engine. Therefore, the objective of the present study was to classify the environmental impact of gasoline and ethanol blends (pure gasoline, 25, 50, 75% ethanol blended with gasoline, and 100% ethanol) in a flex-fuel engine using the data mining approach.

2. Materials and Method

2.1 Powertrain test platform

The Powertrain (a Renault® flex-fuel engine) used was a mobile platform, consisting of a 1,598 cm^3 engine, four cylinders in line, eight valves, cooling by water pressure circuit, with sequential multipoint electronic fuel injection system and a management module (Injepro brand ®, model EFI-light v2) that allowed to control and access the actuators map.

Table 1. Technical specifications of the powertrain engine.

Volume	1.598 cm^3
Fuel system	Sequential Multipoint Electronic Injection
Cylinder displacement	80.5 mm
Number of cylinders	4
Compression ratio	9.5:1.0
Combustion chamber layout	Roof Shaped Pent
Upper piston geometry	Top piston crown on plate
Camshaft	2 - DOHC without VVT
Connecting rod length	137 mm
Diameter × stroke	79.0 × 81.4 mm
Geometric compression ratio	11.0: 1
Inlet valve opening (B-TDC)	10° (ref. 1 mm)
Inlet valve closure (A-BDC)	20° (ref. 1 mm)
Inlet valve diameter × lift	30 × 7.95 mm
Exhaust valve closure (B-BDC)	30° (ref. 1mm)
Exhaust valve closure (A-TDC)	0° (ref. 1mm)
Exhaust valve diameter × elevation	24 × 7,00 mm
Ignition order	1–3–4–2

The platform featured all the systems of an automotive vehicle with a fuel supply system and reservoir, cooling system with radiator and fan, electrical system (alternator and battery), and starter. The engine specifications are presented in Table 1.

The engine was instrumented with data acquisition systems (Fig. 1), composed of a system to acquire the test data. A system to control the engine registered the test data (Manager module, model EFI-light v2, InjePro®). An exhaust gas system was used to collect exhaust gas samples and analyze for the emission concentration (PC- Multi-Gas, Napro®, SP, Brasil).

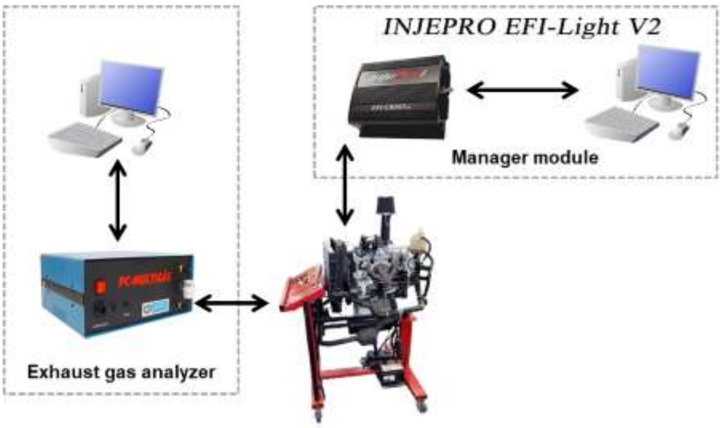

Fig. 1. Schematic diagram of the flex-fuel engine assembly and instrumentation.

The engine was warmed up before the tests started. It was brought to a condition of 924.4 mB of the indicated average effective pressure and subjected up to 900 rpm (low speed), 2000 rpm, and 3000 rpm to measure the concentration of gases (carbon monoxide (CO), carbon dioxide (CO_2), oxygen (O_2), hydrocarbon (HC), nitrogen oxide (NOx), corrected carbon monoxide (COc), corrected hydrocarbon (HCc = dilution factor × measured HC)), factor dilution (F-dilution), dilution, λ, and the air-fuel ratio.

2.2 Fuel blend testing

The tests were carried out using ethanol (anhydrous alcohol) and gasoline. The mixtures used in the Powertrain test were pure gasoline (E0), gasoline with 25% ethanol (E25), gasoline with 50% ethanol (E50), gasoline with 75% ethanol (E75) and pure ethanol (E100). Brazilian standard gasoline is sold with 27% ethanol [15, 22]. The extraction of this volume of ethanol was carried through decantation and separation for standardization purposes before the test. Before starting each data collection, we decontaminate the engine oil. The engine was started and running at idle (900 rpm), until the thermostatic valve opens (observed when the fan is running), when the 30 min count starts running at idle, and only then start testing.

The analyzer was maintained for an initial warm-up period, which consisted of 2 fan activation cycles to ensure the correct measurement of the gases. Within that period, the software reported that the equipment was heating up. Then, the equipment's leak test was verified by closing the gas capture probe and waiting for the instructions on the screen to start the tests. Before starting the measurement, the equipment performs a check to detect the presence of HC residues in the environment. This procedure aims to confirm that before measurements start, the indicated value is at its minimum. After the engine was already idling (900 rpm), it was expected 60 s, which was the estimated time to stabilize the gas reading and thus obtain a lesser variation in data collection. At the end of the 60 s cycle, a new cycle with a rotation of 2000 rpm and 3000 rpm later, was installed and maintained as the previous test, with data being collected using the same procedure as the initial one.

2.3 Data analysis

Data on gas concentrations (carbon monoxide (CO), carbon dioxide (CO_2), oxygen (O_2), hydrocarbon (HC), nitrogen oxide (NOx), corrected carbon monoxide (COc = dilution factor × measured CO), corrected hydrocarbon (HCc = dilution factor × measured HC)), dilution factor (F-dilution), dilution (dilution =CO,% + CO_2,%), λ and the air-fuel ratio were measured and collected in function of engine speed (900, 2000, and 3000 rpm) and fuel mixtures (gasoline and ethanol content: 0, 25, 50, 75, and 100% ethanol content). For each variable, the test was performed three times, each time lasting 30 s, to calculate the mean values (measurements were carried out within the time interval) of gas concentrations, F-dilution, dilution, λ, and the air-fuel.

Data pre-processing was performed in Excel spreadsheets for further processing in the data mining software RapidMiner Studio® v9 [23,24]. RapidMiner® is a data mining platform designed from elementary building blocks, called operators. Each operator performs a specific action on the data: loading and storing data, transforming data, or inference of a model in the data [25]. The data set of the tests in the powertrain was loaded, stored, transformed. After this data pre-processing, a predictive model was inferred through the processes of the operators (split data - 80% training data and 20% to develop the model; Random forest; apply model and performance) interconnecting their input and output ports (Fig. 2).

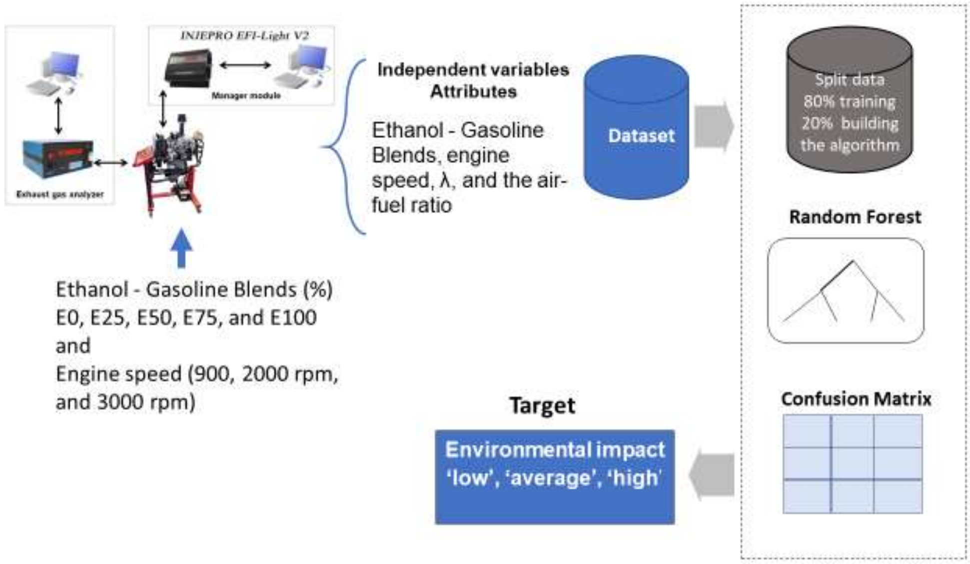

Fig. 2. The flow of the data mining process using the Random forest algorithm, illustrating the data processing steps and classification.

The attributes used to build the predictive model in data mining using the modeling classification were gasoline-ethanol mixture (0% ethanol, 20, 50, and 75% ethanol and 100% ethanol), the environmental impact (which was discretized in ordinal categorical data 'low', 'average' and 'high according to the values of CO_2 emission, Table 2), the engine speed 900 rpm, 2000 rpm, and 3000 rpm and the λ. When $\lambda = 1$, the mixture is stoichiometrically correct. When $\lambda < 1$, the mixture is rich, and $\lambda > 1$, the mixture is lean.

Table 2. Discretization of the environmental impact based on CO_2 emissions.

CO_2 emissions (%, vol)	Environmental impact
≤ 2.6	low
>2.6 and ≤ 8.5	average
>8.5	high

Discretization reduces and simplifies data, making learning faster, and the results more robust. After applying discretization, the data were treated as nominal data during the data mining process [26]. The use of classification algorithms based on Random forest (operator: random forest) was applied to generate rules for the prediction of the effect of the mixture of gasoline and ethanol on the environmental impact due to the air-fuel rotation, and λ. The model validation was parameterized using the operator split data with a percentage split of 80% for training and 20% for testing.

The percentage of correctly classified samples compared to the number of all examples is accuracy (Eq.1). The rate of true positives to all as positive predicted samples is the precision (Eq. 2). The recall is the ratio of precisely predicted positive observations to all observations in the target class (Eq. 3). The confusion matrix was calculated to find the prediction accuracy using the classifying performance. The kappa (κ) is a statistical coefficient of inter-rater reliability that is applied to evaluate the agreement between two appraisers. In this study, we assumed that the classification was appropriate when $\kappa \geq 0.6$.

$$\text{Accuracy} = (TP+TN)/(TP+FP+FN+TN) \quad (1)$$

$$\text{Precision} = TP/(TP+FP) \quad (2)$$

$$\text{Recall} = TP/(TP+FN) \quad (3)$$

Where TP = true positives, TN = true negatives, FP = false positives, and FN = false negatives.

3. Results

3.1 Gasses concentration

The results of the concentrations of CO, CO_2, O_2, HC, NOx, COc, HCc, F-dilution, dilution, λ and the air-fuel ratio as a function of fuel mixtures (E0, E25, E50, E75, and E100) and engine speed (900, 2000, and 3000 rpm) are shown in Tables 3 to 5.

Fuel tests without ethanol content (E0) showed average concentrations of 3.05% to 9.01% at 3000 rpm for CO concentration. The CO_2 concentrations were 2.43% when at low speed, 10.80% for 2000 rpm, and 4.63% for 3000 rpm. The O_2 concentrations were 15.07% for low speed, 3.10% for 2000 rpm, and 6.97% for 3000 rpm. HC ranged from 201.67 to 351.33 ppm vol. NOx showed values from 3.00 to 21.33 ppm vol. The COc concentration presented values from 3.33 to 10.43 ppm vol. The HCc concentration ranged from 2.99 to 7,321.33 ppm vol. The dilution factor varied between 1.10 and 36.20. The λ ranged from 1.06 to 2.00. The dilution was 5.49 to 13.78% vol, and the air-fuel ratio was 14.68 to 27.57 (Table 3).

Table 3. The concentration of CO, CO_2, O_2, HC, NOx, COc, HCc, F-dilution, dilution, λ, and the relationship air-fuel for pure gasoline.

E0											
Speed(rpm)	CO (% vol)	CO_2 (% vol)	O_2 (% vol)	HC (ppm vol)	NOx (ppm vol)	COc (% vol)	HCc (ppm vol)	F-dilution	Dilution (% vol)	λ	Air-fuel ratio
≤900	3.05	2.43	15.07	297.00	6.00	8.34	771.33	2.81	5.49	2.00	27.56
2000	2.99	10.80	3.10	201.67	3.00	3.33	2.99	1.10	13.78	1.06	14.68
3000	9.01	4.63	6.97	351.33	21.33	10.43	7321.33	36.20	13.66	1.10	15.10

rpm = rotations per minute. F-dilution = factor of dilution. Air-fuel ratio = relationship between the air and the fuel.

The fuel tests with a blend of 25% ethanol content (E25) showed an average concentration of CO from 2.92% to 13.48% vol. CO_2 concentrations ranged from 2.47% to 13.07% vol, and for O_2 concentration was from 0 to 15. 23% vol. Also, Hc results were from 88.33 ppm vol to 712.00 ppm vol, and NOx results were from 0 to 33.67 ppm vol. Results of COc concentrations were from 3.90% to 13.50% vol, and from 3.90 at 712.00 ppm vol for HCc, with dilution factor ranging from 0.74 to 2.62, dilution from 5.75 to 20.35, λ from 0.64 to 2.00 and air-fuel ratio ranged from 8.80 to 27.56 (Table 4). The fuel tests with a 50% ethanol (E50) blend showed an average CO concentration from 1.76% - 12.31% vol. Results of CO_2 concentration were from 3.13% - 10.70% vol, and for O_2, from 0.27% - 16.03% vol. HC concentration values ranged from 10.67 - 152.33 ppm vol, and from 0.00 - 6.33 ppm vol for NOx. Results of COc concentration were 5.39% - 12.30% vol, and HCc concentration varied from 31.33 to 152.67 ppm vol, with a dilution factor between 0.81 - 3.09. The dilution varied between 4.88 and 18.43, while the λ was 0.69 - 2.00. The variation of the air-fuel ratio was 6.25 - 18.02. Fuel tests with a mixture of 75% ethanol (E75) showed a CO average concentration of 1.97 - 12.06% vol, and CO_2 concentration from 2.97 – 7.97% vol. The results of O_2 were from 3.53 – 16.07% vol, and for HC results were from 84.00 – 241.33 ppm vol. Results of NOx concentration were from 0.00 – 3.67 ppm vol, and from 5.92% - 12.07% vol for COc. HCc concentrations found concentrations were from 183.33 – 245.00 ppm vol, with a dilution factor between 0.83 and 3.08. The dilution varied from 4.92 - 18.13% vol, the λ varied from 0.71 to 2.00, and the air-fuel ratio was 6.39 to 18.02 (Table 4).

Table 4. The concentrations of CO, CO_2, O_2, HC, NOx, COc, HCc, F-dilution, dilution, λ, and the air-fuel ratio for a blend with ethanol/gasoline blends (25, 50, and 75%).

	Speed (rpm)	CO (% vol)	CO_2 (% vol)	O_2 (% vol)	HC (ppm vol)	NOx (ppm vol)	COc (% vol)	HCc (ppm vol)	F-dilution	Dilution (% vol)	λ	Air-fuel ratio
E25	≤900	2.92	2.47	15.23	123.67	0.00	7.60	318.67	2.62	5.75	2.00	27.56
	2000	3.90	13.07	0.00	88.33	0.00	3.90	3.90	0.87	16.97	0.89	12.30
	3000	13.48	6.87	0.00	712.00	33.67	13.50	712.00	0.74	20.35	0.64	8.80
E50	≤900	1.76	3.13	16.03	10.67	0.00	5.39	31.33	3.09	4.88	2.00	18.02
	2000	7.74	10.70	0.27	152.33	0.00	7.74	152.67	0.81	18.43	0.77	6.98
	3000	12.31	5.83	3.30	145.00	6.33	12.30	145.00	0.83	18.16	0.69	6.25
E75	≤900	1.97	2.97	16.07	84.00	3.67	5.92	245.00	3.08	4.92	2.00	18.02
	2000	7.62	7.97	4.53	173.33	0.00	8.12	183.33	1.00	15.58	0.95	8.56
	3000	12.06	6.07	3.53	241.33	1.67	12.07	241.33	0.83	18.13	0.71	6.39

rpm = rotations per minute. F-dilution = factor of dilution. Air-fuel ratio = relationship between the air and the fuel

Fuel tests with 100% ethanol (E100) showed average CO concentration of 1.32 - 10.67% vol, from 3.93 - 10.90% vol for CO_2, and from 2.30 - 15.37% vol for O_2. The concentration of HC varied from 66.67 - 401.67 ppm vol, and for NOx was 0.00 ppm vol. COc concentration was from 3.74% - 10.66% vol and varied from 5.54 - 401.67 ppm vol for HCc, with a dilution factor between 0.84 and 2.88. The dilution varied from 5.26 - 17.91% vol, the λ varied from 0.72 - 2.00, and the air-fuel ratio was 6.48 to 18, 02 (Table 5).

Table 5. The concentrations of CO, CO_2, O_2, HC, NOx, COc, HCc, F-dilution, dilution, λ, and the air-fuel ratio for fuel with 100% ethanol.

E100											
Speed (rpm)	CO (% vol)	CO_2 (% vol)	O_2 (% vol)	HC (ppm vol)	NOx (ppm vol)	COc (% vol)	HCc (ppm vol)	F-diluição	Diluição (% vol)	λ	Air-fuel ratio
≤900	1.32	3.93	15.37	66.67	0.00	3.74	191.00	2.88	5.26	2.00	18.02
2000	5.54	10.90	2.20	105.33	0.00	5.54	5.54	0.91	16.45	0.91	8.16
3000	10.65	7.27	2.30	401.67	0.00	10.66	401.67	0.84	17.91	0.72	6.48

rpm = rotations per minute. F-dilution = factor of dilution. Air-fuel ratio = relationship between the air and the fuel

3.2 Random forest results

This operator generated a Random forest model, which is an assemblage of a certain number of Random trees. These trees are created on bootstrapped sub-sets of the input port. Each node of a tree signifies a splitting rule for one specific attribute. Only a subset of attributes is considered for the splitting rule selection. For classification, the rule is splitting values belonging to different classes. The building of new nodes is repeated until the stopping criteria are met. Each random tree generates a prediction for each input by following the branches of the tree following the splitting rules and evaluating the leaf. We used the minimal leaf size = 2. The model classification had an accuracy of 73% and κ =0.61.

We selected three trees for classifying the environmental impact. First, using the percentage of ethanol in the fuel blend and engine rotation (Figure 3). The second and third trees were selected by adding air-fuel and λ variables to the previous ones (Figures 4 and 5). Such trees represent the forecast of environmental impact due to the fuel blend. In the confusion matrix (Table 5), the accuracy of the model is presented (73%). The prediction for the ‘average’ environmental impact class was 90% (true average = 90%), the ‘high’ environmental impact classification precision was 70% (true high = 70%)and for ‘low’ impact it was 0% (true low = 0%). However, the model lacked in precision to classify the ‘low’ environmental impact (Table 6).

Table 6. Confusion matrix of the model for the classification of the environmental impact of ethanol and gasoline blends.

	True 'high'	True 'low'	True 'average'	Class precision (%)
Predicted 'high'	3	1	1	70
Predicted 'low'	0	0	0	0
Predicted 'average'	1	1	8	90
Class Recall (%)	70	0	90	Accuracy = 73%

The number of samples=45.

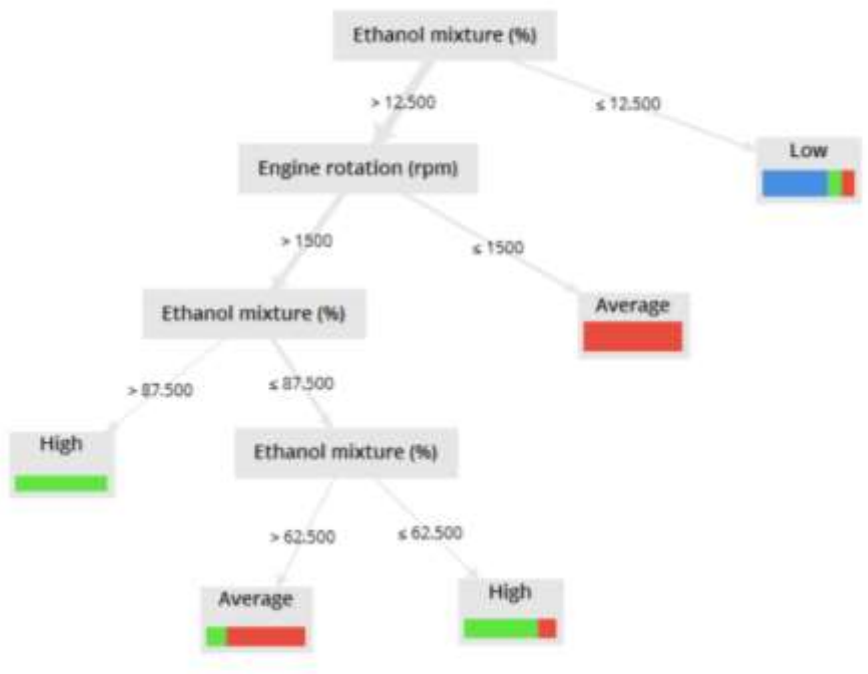

Fig. 3. The random tree for classifying the environmental impact of the ethanol and gasoline blend using the variables ethanol blend and engine rotation.

The 'if-then' rules are described as follows. If the percentage of the ethanol mixture is less than or equal to 12.5%, then the impact is 'low' (ratio of the total = 24% of the samples). If percentage of the ethanol content is higher than 12.5%, engine rotation needs to be checked. If the engine rotation is less than or equal to 1500 rpm, then the environmental impact is 'average' (ratio of the total = 28% of the samples). If the engine rotation is higher than 1500 rpm, another leaf needs to be checked, the ethanol blend. If the ethanol mixture is higher than 87.5%, then the environmental impact is 'high' (ratio of the total = 14% of the samples. If the ethanol mixture is less than or equal to 87.5%, then the environmental impact is 'average' (ratio of the total = 17% of the samples). If the ethanol mixture is less than 62.5%, then the environmental impact is ‘high’ (Fig. 3).

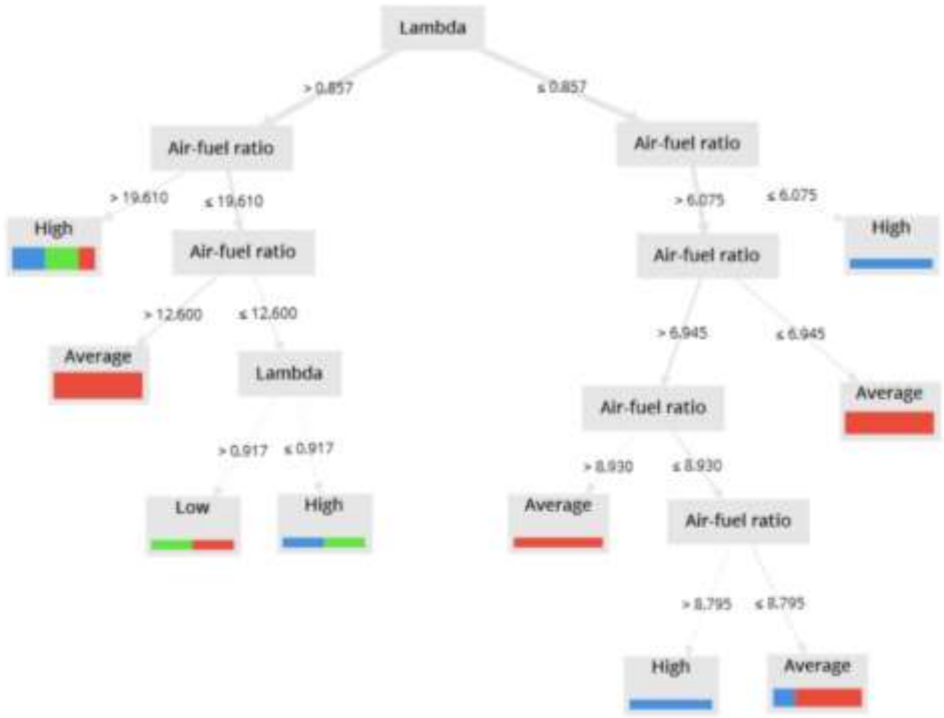

Fig. 4. The random tree for classifying the environmental impact of the ethanol and gasoline blend using the variables λ, and the air-fuel ratio.

The results of the decision tree using the λ and the air-fuel ratio is shown in Figure 4. If the λ is higher than 0.857, then one has to check the air-fuel ration. If the air-fuel ratio is higher than 19.61, then the impact is high (ratio of the total = 16% of the samples). If the air-fuel ratio is less or equal to 19.61, then one needs to recheck the air-fuel ratio. If the air-fuel ratio is higher than 12.6, then the environmental impact is ‘average’ (ratio of the total = 20% of the samples). If the air-fuel ratio is less than or equal to 12.6, then one has to check λ. If λ is higher than 0.917, then the environmental impact is ‘low’ (ratio of the total = 7% of the samples). If λ is less or equal to 0.917, then the environmental impact is ‘high’ (ratio of the total = 7% of the samples). If λ is less than or equal to 0.857, then the air-fuel ration needs to be checked. If the air-fuel ratio is less than or equal to 6.07, then the environmental impact is ‘high’ (ratio of the total = 7% of the samples). If the air-fuel ratio is higher than 6.07, then the air-fuel ration needs to be rechecked. If the air-fuel ratio is higher than 8.930, then the environmental impact is ‘average’ (ratio of the total = 7% of the samples). If the air-fuel ratio is higher than 8.795, then the environmental impact is ‘high’ (ratio of the total = 7% of the samples). If the air-fuel ratio is less than or equal to 8.795, then the environmental impact is ‘average (ratio of the total = 13% of the samples) (Fig. 4).

Fig. 5 presents the random tree for classifying the environmental impact of the ethanol and gasoline mixture using the gasoline blend, λ, engine rotation, and the air-fuel ratio.

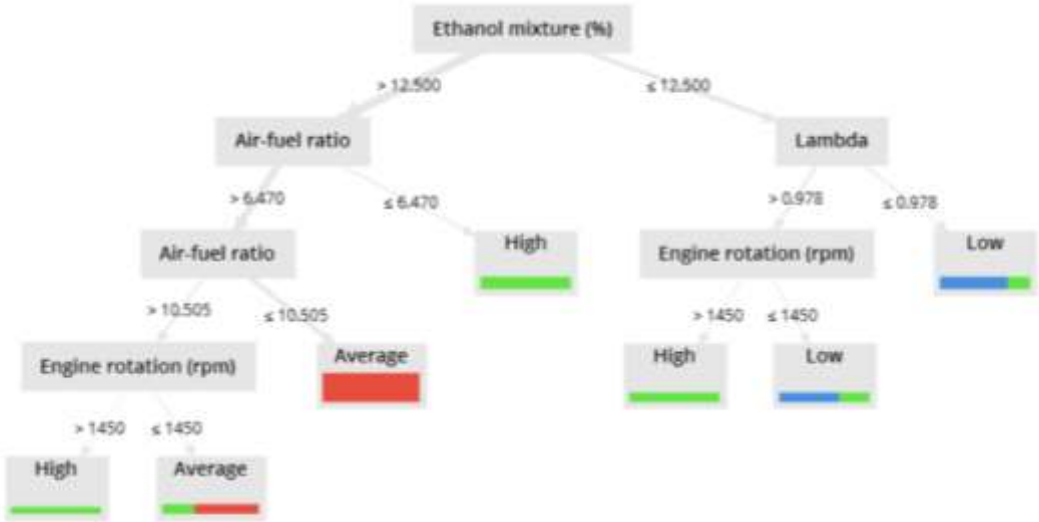

Fig. 5. The random tree for classifying the environmental impact of the ethanol and gasoline mixture using the gasoline blend, λ, engine rotation, and the air-fuel ratio.

If the ethanol mixture is higher than 12.5%, then one needs to check the air-fuel ratio. If the air-fuel ratio is less than or equal to 6.47, then the environmental impact is ‘high’ (ratio of the total = 14% of the samples). If the air-fuel ratio is higher than 6.47, then the air-fuel ratio needs to be rechecked. If the air-fuel ratio is less than or equal to 10.505, then the environmental impact is ‘average’(ratio of the total = 35% of the samples). If the air-fuel ratio is higher than 10.505, then one needs to check the engine rotation. If the engine rotation is higher than 1450, then the environmental impact is ‘high’ (ratio of the total = 7% of the samples). If the engine rotation is less than or equal to than 1450, then the environmental impact is ‘high’ (ratio of the total = 10% of the samples). If the ethanol mixture is less than or equal to 12.5, then on has to check λ. If λ less than or equal to 0.978, then the environmental impact is ‘low’ (ratio of the total = 14% of the samples). If λ is higher than 0.978, then the engine rotation needs to be checked. If the engine rotation is higher than 1450, then the environmental impact is ‘high’ (ratio of the total = 10% of the samples). If the engine rotation is less than or equal to 1450, then the environmental impact is 'low' (ratio of the total = 10% of the samples) (Figure 6).

4. Discussion

The use of ethanol, particularly in spark-ignition engines, is appealing due to its reasonably high octane and the fact that it is cleaner than gasoline. The results of the current showed that the CO concentrations for all fuel mixtures showed values above the reference of CONAMA (2019) [27], above 0.5% vol. However, HC, at 2000 rpm with a mixture of 25% and 50% EC, at low speed presented values within the emission limit [15,27]. Considering the HCc results, they also were within the acceptable limit (lower emissions) at 2000 rpm for E0, E25, E75 and E100, and at low speed in E50 mixtures and also in E75. The concentrations for CO_2 also showed values within the limit for all fuel mixtures at 2000 rpm [27]. We accept that the [27] reference is obtained from a vehicle using more complex anti-pollution devices than the model tested in the present study, such as direct injection, plasma ignition, and recirculation of exhaust gasses.

The Otto cycle engine is generally not ideal, since other gases that come from incomplete fuel ignition come out of the exhaust system. However, the ideal fuel ignition would be CO_2 + H_2O. When the combustion is ideal, all O_2 that enters the engine is used for ignition. The lower the concentration of this gas in the exhaust system, the closer the combustion is to the ideal [28]. The higher the concentration of CO_2 in the exhaust system, the better the combustion. The air-fuel ratio can also affect the CO_2 level. The lack of a rich mixture (O_2), the carbon combines with the oxygen in the burning generating CO (incomplete combustion). CO is considered a very toxic and reactive gas, so the lower the percentage, the better the combustion. HC also results from incomplete combustion, in fractionated parts of long chains of non-oxidized fuel. The lower the concentration of HC, the better the combustion of the mixture [3].

The fuel blends E25, E50, E75, and E100 had a dilution factor of less than 1 for 2000 rpm and 3000 rpm. However, in the test with pure gasoline, the dilution factor went from 36.20 to 3000 rpm. An increase in total hydrocarbon (HC) emissions was detected as the amount of ethanol in the fuel increased [8]. In the present study, the HCc indicated higher emissions for pure gasoline (E0) and with a mixture of 25% (E25) of ethanol in a rotation of 3000 rpm.

The addition of ethanol to gasoline can help to reduce pollutant gas emissions in ignition engines [29, 30]. The higher is the EC in the fuel mixture, the lower the environmental impact. In this study, mixtures with a higher percentage of ethanol had a lower environmental impact than mixtures with a lower EC that had a more significant environmental impact ('average' to 'high'). According to Schifter et al. (2018) [8], ethanol blended with gasoline in various concentrations is the most used alternative for positive-ignition engines, in order to incorporate non-fossil components and diversify energy input in transportation. However, most studies in current literature apply the gasoline-ethanol blend to design a gasoline engine. In flex-fuel engines, ethanol generates higher torque. Engines with alcohol need to have a higher compression ratio (useful volume, between the piston head and the head - fixed volume defined in the engine construction). If the ideal compression for the ignition is not reached, the burning of the fuel will not be perfect, generating high values of HC.

CO_2 emissions are an increasing trend with the addition of ethanol in gasoline design engines. The reason is attributing to the complete oxidation of carbon in the fuel. Higher volumetric efficiency can also be accounted for this unwarranted decrease. It is examined that higher latent heat of vaporization of ethanol is responsible for the increased production of CO_2 [31]. However, by rising the EC, the issue of increasing CO_2 can be reduced for slower engine speeds [32].

Knoll et al. (2009) [33] studied the performance and emissions of conventional vehicles (1999 to 2007) with up to 20% by volume of ethanol. The authors found that the increase in EC resulted in reductions in both total hydrocarbons, carbon monoxide, and increases in ethanol emissions and aldehydes. Fuels added to ethanol (E0, E10, E20, and E30) reduce CO, CO_2, and NO_X emissions without significant energy loss compared to gasoline in a four-cylinder spark-ignition engine [34]. The authors carried out combustion tests with gasoline and mixed with ethanol (50 and 85% v/v) in an engine with a maximum power of 15 kW, performed at eight different engine speeds, oscillating from 1500 to 5000 rpm, with increments of 500 rpm, the results showed that the addition of ethanol to gasoline implied a reduction in CO and HC emissions, in the whole engine speed range. The addition of ethanol increases the values of λ and makes combustion more complete, reducing gas emissions. Besides, the latent heat of vaporization of mixed fuels is higher than that of gasoline, providing greater efficiency to the engine's combustion process [35].

In low ethanol content (EC), the CO_2 emissions varied between blends, suggesting a dependence with C and H fuel contents. As the EC rises, the NOx emissions decrease, and the E-85 (or highest EC fuel) shows the lowest NOx emissions. Such an effect might be associated with temperature decline at the end of the compression stroke [2]. Suarez-Bertoa et al. (2015) [9] found an increase in CO_2 emissions in blends with high EC (E75 and E85) when compared to low EC (E5, E10, and E15). In the present study using a flex-fuel engine, the developed model indicated that low EC (<12.5%) associated with low engine rotation (<1450 rpm) leads to low environmental impact. On the other hand, high EC associated with either low or high engine speed tend to lead to average or high environmental impact, agreeing partially with previous studies [8,29].

The results of the study by Schirmer et al. (2017) [30] indicate that gas emissions using five λ values and six gasoline/ethanol blends indicate that rich mixtures ($\lambda < 1$) tend to produce higher concentrations of CO and HCs in exhaust gases. As λ increases, the higher quantity of oxygen in the air leads to smaller amounts of these gases being produced. However, it was observed that in lean mixtures, HC emissions tend to increase again because combustion may be incomplete. Tests with increasing EC in the fuel-alcohol blend showed that ethanol helps to reduce carbon emissions, possibly because of the oxygen contained in ethanol molecules, resulting in improved combustion and allowing more significant advantage to be taken of the fuel’s thermodynamic properties [2].

In a previous study, the addition of 40% ethanol to the unleaded gasoline gave the best results for the reduction of CO emissions by about 30% at 9:1 compression ratio [11]. The addition of 60% ethanol to the unleaded gasoline caused a decrease in CO emissions by about 20%. The addition of 60% ethanol to gasoline caused a 30% reduction in HC emissions at a high compression ratio [11]. Therefore, the emissions reduction is not only associated with the gasoline-ethanol content, but it also relies on other engine-related characteristics, as we found in the present study. We believe that it is possible to generate ‘If-Then’ rules that would help appropriate decisions by policymakers in reducing urban pollution in the long run.

5. Conclusions

We developed models to classify the environmental impact from a flex-fuel engine and different blends of gasoline-ethanol. The model forecast that the environmental impact is ‘low’ to ‘average’ when the fuel has a medium to a high percentage of ethanol blended considering rotation below 2000 rpm. On the other hand, for fuel mixtures with a low percentage of ethanol, the environmental impact depends on other characteristics of solicitation the engine.

Acknowledgments

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CAPÍTULO III

3 CONSIDERAÇÕES FINAIS

3.1 Conclusões

Através dos dois artigos que constituem este trabalho, observa-se que o Brasil, com sua vasta extensão territorial, apresenta uma logística de abastecimento muito peculiar e mesmo que se desenvolva um planejamento no intuito de aproximar os centros produtores de alimentos dos grandes centros consumidores, em alguns períodos da entressafra o abastecimento necessariamente será suprido por regiões produtoras mais distantes. Pois, no segmento de distribuição de alimentos, a palavra sazonalidade já não se aplica para justificar a escassez de algum produto. Já o artigo sobre eficiência energética de mistura de combustíveis (fóssil e renovável), deixa claro que a utilização de combustíveis renováveis, nas misturas combustíveis, se torna uma opção bem menos poluente.

Os resultados encontrados confirmam a tendência já comentada anteriormente, de que os veículos leves serão movidos com energias renováveis, já por sua vez, os veículos comerciais continuarão a utilizar combustíveis líquidos, pela concentração energética, pouco volume, rede de distribuição já existente e rapidez de abastecimento. O que implicará no desenvolvimento de motores alimentados com combustíveis de octanagem bem mais baixas do que os combustíveis atuais (utilizando os subprodutos do refino de petróleo), e a tendência de minimizar os efeitos poluentes desses combustíveis com a utilização de misturas destes com combustíveis provenientes de produtos orgânicos e renováveis, que são comprovadamente menos poluentes.

3.2 Recomendações de Trabalhos Futuros

Estudo de motores a combustão interna, ciclo OTTO, conceituais, de grandes cilindradas, com uma taxa de compressão mais adequada, com a clara finalidade de uso comercial, utilizando misturas de diesel e subprodutos do refino, mais combustíveis orgânicos, para atenuar a emissão de poluentes.

Estudo logístico de um programa de aproximação dos centros produtores de alimentos dos grandes centros consumidores