LIFE-CYCLE ASSESSMENT OF THE ETHANOL PRODUCTION FROM MOLASSES

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ABSTRACT

The converting biomass to biofuels is a vital choice for the subjugation of alternative sources of energy and elimination of polluting gases due to the exhaustion of fossil fuels. As it is environmentally friendly, and available as a blend with gasoline for combustion engines, ethanol has emerged as a possible substitute. In the US, Brazil, China, and other nations, bioethanol is already used. It is possible to use agricultural waste, especially molasses, a by-product produced during the sugarcane refining process to reduce dependence on fossil fuels. The effects of the changing land-use on the development of the sugar cane have been reviewed in this report. In most situations, compared to conventional gasoline (CG), higher upstream effects of ethanol- based molasses appear to have an impact on its net life-cycle impact. Under the particular conditions considered, this results in a fuel blend that is less environmentally friendly than CG. The effect of ethanol-gasoline on efficiency and emission levels is analyzed in this report. In order to determine the environmental impacts of ethanol from sugar beet and sugarcane over its entire life cycle, we evaluated the life cycle assessment (LCA) of sugarcane and sugar beet ethanol. This study also analyzed the economic effects of bioethanol production and the ethanol net energy balance dependent on molasses.

Key words: Biofuels, Molasses, Ethanol, Sugarcane, Pakistan

INTRODUCTION

The primary advantage of an approach to the life cycle isthat all pressures can be compensated for the exploitation of raw materials through processing, usage and disposal. This method is useful for determining the efficiency of transport biofuels greenhouse gas (GHG) emissions based on a reasonable analogy with popular renewable resources, as it reflects the entire life cycle of biofuels rather than just combustion in engines (Silalertruksa and Gheewala, 2011). The fact that bio alcohols are carbon- containing makes them the carbon cycle intermediate materials (Zhao and Wang, 2020). Biofuels containingcarbon are proven to reduce carbon emissions significantly (Pechout, Dittrich and Vojtisek, 2014). Plants, seeds, plant fibers, sugarsand other natural materials may be used to produce biofuels. In many provinces of China, millions of ethanol- gasolines (E10) cars are still running (Zhao and Wang, 2020). Anhydrous bioethanol-gasoline, containing bioethanol, primarily made from maize, is also available in Chinese market (Zhao and Wang, 2020). By fermentation, ethanol is made from sugar, especially sugarcane and starch. By fermenting certain agricultural waste material, the biomass industry will generate extra ethanol (Prasad et al., 2007). Lignocellulose biomass is a potential explanation of ethanol that is not specifically associated with foodprocessing (Freudenberger, 2009). 2016 data shows that the global production of bioethanol amounted to 100.2 billion liters (WBA Global Bioenergy Statistics; 2017). The annual production of bioethanol is continuously rising and the global supply and demand for bioethanol is projected to rise to almost 134.5 billion liters by 2024. (OECD-FAO Agricultural Outlook, 2015).

The increased bioethanol consumption in Brazil is mainly due to the steady rise in the number of flexible fuel vehicles (FFVs) sold (Bušić *etal*., 2018). The USA and Brazil, accompanied by the European Union and China, are thus expected to remain the two major producers of bioethanol (OECD-FAO Agricultural Outlook 2015). Total life-cycle emission levels of molasses-based ethanol (MoE) are measured at 432.5 kg CO2eq m−3 ethanol, in Nepal. Prevented emissions are 76.6 percent while traditional gasoline is substituted by ethanol obtained from molasses (Khatiwada and Silveira, 2009). In order to be eligible as an alternative energy under RFS22, the life-cycle GHG status of a biofuel should be at least 20% smaller than that of the fossil fuel it substitutes, except for ethanol produced in some of the grandfathered refineries (Flugge *et al*., 2017). The Life Cycle Assessment (LCA) method is used to identify main elements of the MoE development cycle in which improvements are developed to achieve the quality of the environment. In particular, (i) the use of energy sources such as coal for the transformation of ethanol, (ii) the disposal of spent distillery in an anaerobic bath and (iii) the burning of cane waste for the production of sugar cane (Nguyen and Gheewala, 2008).

In 2009, Gopal and Kammen used upstream and processed life cycle results from Brazilian ethanol's GREET model to generate life cycle GHG emissions for ethanol derived from any conjunction of fresh sugarcane and molasses. They found that, with all other procedures and components similar to the standard Brazilian factory, ethanol generated with only molasses as feedstock had a GHG life-cycle rating of 15.1 gCO_2-eq MJ-1, that was substantially smaller than the actual California-GREET value of 26.6 gCO_2-eq MJ-1.
Replacing fossil fuels with sustainable bio alcohol fuels is one potential short-to-mid-term solution to the overdependence on fossil fuels (Gong *et al*., 2020). Muñoz, 2013, showed that, from a GHG perspective, a preferred alternative seems to be bio-based ethanol, but fossil-based ethanol is better when considering other effects, especially those associated with land use.

Sugarcane and Sugar Beet ethanol Life Cycle Assessment (LCA)

García *et al*., 2011 stated that the higher energy and lower emissions ratios found in Brazil compared to Mexico (Seabra and Macedo, 2011) were attributable to the lesser sugarcane transport distance and the lower quantity of areas of sugarcane burning to allow manual processing. Based on their analysis, Mexican emissions, across all modalities, were greater than those reported for Brazil (27.5 kgCO2e.GJethanol-1). The Mexican method with the largest proportion of renewable/fossil resources was also sugarcane-based ethanol that supplies surplus electricity with 4.8 GJethanol.GJfossil-1. The authors stated that the results were obtained using bagasse as the only source of fuel in the industrial process to satisfy electricity and steam requirements. While the sugarcane juice is being extracted from the stem, Sugarcane Bagasse (SB) is produced in great quantities. Consideration of fermentation the hemicellulose fraction as well as the cellulosic cell wall component is equally important for the economic development of SB ethanol (Antunes, 2014). Hemicellulose is roughly One-third of the available fraction of carbohydrate in SB (Canilha *et al*., 2012). Since there is 50-60% sugar in sugarcane molasses, this substance can theoretically be used as a feedstock for bioethanol. Other than sugar, amino acids and minerals, like magnesium (80-3900 mg.l-1), potassium (300-12000 mg.l-1) and calcium (150-2000 mg.l-1) are also found in sugarcane molasses (Basso, Thiago and Saul, 2011). The most widely used sucrose fermentation microorganism used in juice or molasses in the first wave of ethanol processing technology is Saccharomyces cerevisiae. This yeast is also used for the processing of 2G ethanol from the glucose solution produced by SBcellulosic percentage pretreatment (Canilha *et al*., 2012). The fraction of hemicellulose is high in residues of pentose, mostly xylose, which have not been fermented by *S. Cerevisiae*. *Scheffersomyces shehatae*, a xylose-fermenting yeast, has been considered a promising microorganism for the development of hemicellulose ethanol that provides high ethanol productivity. The use of xylose-metabolizing microorganisms in biorefineries would increase global yield of ethanol (Antunes, 2014). Another research claimed that the appropriate substrate for the development of fuel ethanol was decolored molasses. The report explained how adsorbent- column chromatography can effectively extract colorants from sugar beet or sugarcane molasses and produce biomass ethanol. As a result, the demand for colour and chemical oxygen in the subsequent waste water was found to have decreased by around 87 percent and 28 percent, respectively, relative to traditional molasses fermentation. The study showed that when adsorbent chromatography is carried out before the molasses fermentation, this method is the most reliable. In 2018, Demissie and Gheewala evaluated the effect of the production of ethanol from sugar cane molasses on the environment in Ethiopia between 2016 and 2017. Considering both midpoint and endpoint indicators, calculations were performed using the ReCiPe life cycle effect assessment process. The cultivation phase was shown to be the primary factor in Ethiopia to all the life-cycle effects of the production of ethanol from molasses, based on their study. The result shows that the cultivation phase contributed the most to climate change (54.5 percent), the formation of photochemical oxidants (80 percent) and the use of land (99 percent) due to fertilizer processing, cane burning and fertiliser decomposition and application. On the other hand, ethanol production made the largest contribution to the depletion of wealth (63 percent), terrestrial acidification (92 percent), terrestrial ecotoxicity (99 percent), marine eutrophication (92 percent) and ozone depletion (84.4 percent) due to the use of light fuel for ethanol plants.

The impact on efficiency and pollutant emissions of the ethanol-gasoline blend

Five separate models based on information obtained under the "U.S. Environmental Protection Agency Energy Policy Act" (EPAct) were used for the calculation of LA92 Phase 1 "particulate matter" (PM) emissions for "summer regular" (SR) gasoline with 0 percent, 10 percent and 15 percent ethanol by volume, respectively, (E0), (E10) and (E15). For E10 and E15, substantial decreases in PM were needed relative to E0 when aromatics were substituted with ethanol in order to retain the octane number. The linear combinations of EPAct fuels were balanced with SR E0 and E10 and findings show a 35% PM decrease for SR E10 compared to SR E0 (Clark *et al*., 2020). Topgul *et al*., 2006 examined the impact on performance and emissions of ethanol- gasoline (E0, E10, E20, E40, E60) and spark ignition. Blends with ethanol have also been established in order to allow the compaction to boost without any effect. The engine evaluations used eleven research blends ranging from 0 to 100 per cent of ethanol with an average of 10 per cent. CO emissions have declined as ethanol in fuel has increased. HC emissions reduced as the ethanol concentration of the fuel rose, but when E90 and E100 fuels were used, HC emissions improved exponentially. Muñoz, 2013 analyzed the controlled emissions of HC, CO and NOx from a two-stroke chainsaw engine utilizing coal, ethanol and ethanol- gasoline as a fuel. As the ethanol content increased, CO, NO and HC emissions decreased, but HC boosted when E85 and E100 were used. The addition of ethanol as opposed to methyl tertiary butyl ether (MTBE) was investigated by Schifter *et al*., 2005. The findings showed that for NOx with blends of 3 to 6 percent ethanol, CO emissions decreased, HC emissions boosted emissions were not statically significant.

In 2020, in a SI engine, Zhao and Wang researched the ability and emissions of E10. The results revealed that "Brake Thermal Efficiency" (BTE) improved with a high percentage of fuel blends compared to E10. The introduction of butanol altered the combustion behavior during exhaust gas recirculation (EGR) operation, namely prolonged ignition pauses, reduced knock number, rapid burning time and knock capacity. The “Brake-Specific Fuel Consumption” (BSFC) was boosted by butanol addition and decreased similarly to E10 when EGR was introduced. Hydrocarbon emissions from the blendsenhanced marginally with the raised EGR intensity, while emissions of CO declined. The butanol-E10 blends have shown comparable power output, compared to the baseline conditions, combustion stability andappropriate emissions have decreased marginally. The realization of a stable homogeneous liquid process is one of the main challenges in the efficient use of gasoline-alcohol fuel in a SI engine. The use of E60 as a fuel in a SI engine was investigated and Yüksel and Yüksel developed a carburetor to solve this problem in 2004. In that report, the ethanol-gasoline mixed using as a fuel was seen to minimize emissions of CO and HC by about 80 and 50 percent. In addition, considerable reductions in engine power were not observed.

Impact of the land use change for sugarcane production

Houghton, 2003 showed that about one third of the carbon emissions that have been released into the atmosphere since 1850 are due to changes in land use, while Dunn et al., 2013 reported that land-use change (LUC) GHG emissions apply less than previously thought to the total life cycle of biofuels (Dunn *et al*., 2013). Domestic and global product prices would increase in the US and other regions, and farmers would react by introducing new land into cultivation. Typically, providing new land into the development of commodities results in CO2 emissions, the emissions can be high if the previous land-use was natural grassland, forest or wetland. The above-mentioned domestic and foreign land impacts are alluded to as "absolute land-use change" and "indirect land-use change" (iLUC) (Fargione *et al*., 2008). The processing of molasses from food to fuel is a product of ILUC (T.Nguyen and E.Hermansen, 2012). With regard to the production area, there are wide varieties of GHG emissions, particularly when direct land-use change is included in boundaries of the system (Aoun and Gabrielle, 2017). Gabisa, Bessou, and Gheewala, 2019, evaluated the sustainability impact of ethanol production in Ethiopia using an LCA process. It has shown that the agricultural process certainly contributesto pollutant emissions. The authors recorded the Ethiopia's thermogenesis of sugar cane molasses-based ethanol production and argued that the involvement of cane trash burning was relevant for impact categories assessed and that the exclusion of pre-harvest cane trash burning greatly decreased global warming emissions, acidification, strato-spheric ozone, eutrophication and PM. Mechanical harvesting, on the other hand, has improved the impact of ecotoxicity, human toxicity and resource use to prevent the burning of pre-harvest cane waste.

Economic effectof bioethanol production

Despite technological and economic challenges, Low-cost feedstocks which do notinterfere with the food chain and feed are sustainable lignocellulosic raw materials, thereby encouraging sustainability (Bušić *et al*., 2018). The cost of processingbioethanol can be partly offset by reducing GHG emissions, ensuring the supply of energyand stimulating agricultural activities inrural regions (Balat and, Balat, 2009 and Festel *et al*., 2013). The main criticism of the allocation of co-products on a market value basis is that they do not have an impact on the environment (Gopal and Kammen, 2009). More of the economy depends on agriculture in developing countries such as Ethiopia, so that the economy supports the growth of the agricultural sector (Gabisa and Gheewala, 2019). The production of sugar in Ethiopia began around the 1950s with the cultivation of 35,000 ha and 12,500 tonnes of combined crushing capacity per day in four factories. The production of sugar has now been increased to 400,000 tonnes and the area of cultivation has been extended to 65,000 ha. Production of ethanol also rose from 7000 m3 to 20,000 m3 per day (Wondimu, 2010). Given these developments, with 750 PJ per year of bioenergy potential from various biomass resources, compared to other countries such as India, Thailand and Brazil, the contribution of the sector to the economy in

Ethiopia remains low (Gabisa and Gheewala, 2018). Around 40 percent of the global production of bioethanol comes from sugar beet and sugarcane, and the rest comes from starchcontaining feed stocks (Innovation driving sustainable biofuels, 010). Grains (mainly wheat) and sugar beet beets are the most suitable sustainable bioethanol raw materials in Europe. Bioethanol also was produced from surplus wine in France (Prieur and His, 2007). Raw material prices have a major influence on costs of bioethanol production and, based on the feedstock type, will account for 40-75 percent of the total cost (Li, Liu and Liu, 2004). The cost of processing sugarcane bioethanol is about 0.20-0.30 USD.L-1 in Brazil. Bioethanol derived from sugar beet and maize respectively achieved its lowest cost of production of 0.30 USD and 0.53 USD.L-1 in the US and the European Union (Balat and, Balat, 2009 and Festel *et al*., 2013). Depending on the feedstock expenses, the costs in China (cassava, sugarcane agasse or wheat) are 0.28-0.46 USD.L-1. In India, the manufacturing cost of bioethanol using raw materials containing sugar is around 0.44 USD.L-11, while, depending on the form of feedstock, it is 0.80-1.20 USD.L-1 from lignocellulosecontaining raw materials (Festel et al., 2013). After all, depending on the type of refining process, the cost of manufacturing gasoline (refining) (0.10-0.18 USD.L-1) is still lower (Plymouth, MA, USA: Volta Oil, 2018) and the cost of manufacturing bioethanol is only reasonable in Brazil.

Molasses based ethanol net energy balance

India's renewable energy program depends on the processing of ethanol from sugar cane molasses (Tsiropoulos *et al*., 2014). Compared with Brazil, Indian ethanol was proven to cause lower or equivalent GHG emission (0.09-0.64 kgCO2eq. kgethanolIN-1, 0.46-0.63 kg CO2eq.kgethanolBR-1), degradation of the ecosystem (2.5 PDF・m2・year. Kgethanoll N-1, 3.3 PDF・m2・yearly), human health effects 3.6・10-6 DALY.kgethanolIN-1, 4・10-6 DALY. kgethanolBR-1) and non-renewable energy usage (-0.3-6.3 MJ. kgethanolIN-1, 1-4 MJ. kgethanolBR-1) (Tsiropoulos et al., 2014). Khatiwada, S. Silveira, 2009, researched the total energy demands of sugarcane production, cane milling and ethanol conversion methods in order to investigate the MoE analysis of life cycle energy in Nepal. This has resulted in a negative “Net Energy Value” (NEV) (-13.05 MJ.L-1), a positive “Net Renewable Energy Value” (NREV) (18.36 MJ.L-1) and an energy yield proportion (7.47). The stronger average NREV and energy yield rate indicates that in order to create a minor fossil fuel, manufacturing of 1 L of MoE was required. However, Negative NEV suggested that total energy consumption (fossil and renewable) for the production of ethanol was higher than its final energy output. However, the renewables share amounts to 91.7 percent of overall energy needs. In determining the energy quantities and MoE yield ratio, the effect of increased molasses prices and decreased energy use on sugarcane milling and conversion of ethanol has been found to be important. Thailand's life cycle evaluation of cane molasses fuel ethanol (Nguyen and Gheewala, 2008) found that MoE absorbs less carbon energy in the form of E10 (5.3%), less petroleum (8.1%) & compared with CG, has a similar effect on acidification, over its life cycle.

CONCLUSION

It is also known that biofuels are one of the innovations that can reduce the effect of GHG on the transport sector. However, changes in land- use that may incorporate the creation of biofuel feed stocks and the resulting effects on the environment, including GHG emissions, are a possible drawback to biofuels. In the future, as limits on the use and dependency of petroleum become ever stricter, there could be tens of millions of ethanol-gasoline-fueled cars. Pure ethanol can be used, but engine design and fuel system modifications are required, although ethanol- gasoline blends do not contain low percentages of ethanol. Consequently, using ethanol-gasoline mixtures in SI engines is more beneficial than using ethanol only.

REFERENCES

Antunes, 2014. Bioethanol Production from Sugarcane Bagasse by a Novel Brazilian Pentose Fermenting Yeast UFMG-HM 52.2: Evaluation of Fermentation Medium. *International Journal of Chemical Engineering*, 2014, pp.1–8.

Aoun, W.B. and Gabrielle, B., 2017. Life Cycle Assessment and Land-Use Changes. *Life-Cycle Assessment of Biorefineries*, pp.221–231.

Balat M, and Balat H. 2009. Recent trends in global production and utilization of bio-ethanol fuel. Appl Energy; 86(11): 2273–82

Basso L C, Thiago O B, Saul N R. 2011. Ethanol production in Brazil: the industrial process and its impact on yeast fermentation. Biofuel production-recent developments and prospects, Brazil

Bušić, A. et al., 2018. Bioethanol Production from Renewable Raw Materials and its Separation and Purification: a Review. *Food Technology and Biotechnology*, 56(3).

Clark, N.N. et al., 2020. Quantification of gasoline-ethanol blend emissions effects. *Journal of the Air & Waste Management Association*, 71(1), pp.3–22.

Demissie, E., and Gheewala, S. 2018. Life cycle assessment of ethanol production from molasses in Ethiopia. Journal of Sustainable Energy & Environment 10: 1-7

Dunn, J.B., Mueller, S., Kwon, Hy. et al. 2013. Land-use change and greenhouse gas emissions from corn and cellulosic ethanol. Biotechnol Biofuels 6, 51

E.W. Gabisa, S.H. Gheewala, 2018. Potential of bio-energy production in Ethiopia based on available biomass residues, Biomass and Bioenergy. 11, 77–87

Elias W. Gabisa, Shabbir H. Gheewala 2019. International Journal of Engineering, Applied and Management Sciences Paradigms (IJEAM), Volume 54 Issue 1

European Biofuels Technology Platform. Strategic research agenda 2010 update: Innovation driving sustainable biofuels. Available from: http://www.biofuelstp.eu/srasdd/ SRA_2010_update_web.pdf

Fargione, J., J. Hill, D. Tilman, S. Polasky, and P. Hawthorne. 2008. “Land Clearing and the Biofuel Carbon Debt.” Science. Vol 319; 1235-1238

Festel G, Würmseher M, Rammer C, Boles E, Bellof M. 2013. Modelling production cost scenarios for biofuels and fossil fuels in Europe. Discussion paper No. 13–075. Mannheim, Germany: ZEW – Centre for European Economic Research; Available from: http://ftp.zew.de/pub/zew-docs/dp/dp13075.pdf

Flugge, M. Lewandrowski, J. Rosenfeld, J. Boland, C. Hendrickson, T. Jaglo, K. Kolansky, S.; Moffroid, K. and Pape, D., 2017. "A Life-Cycle Analysis of the Greenhouse Gas Emissions of Corn-Based Ethanol". Publications from USDA-ARS Faculty. 1617.

Freudenberger, R. 2009. Alcohol Fuel. New Society Publishers, Canada.

Gabisa, E.W., Bessou, C. & Gheewala, S.H., 2019. Life cycle environmental performance and energy balance of ethanol production based on sugarcane molasses in Ethiopia. *Journal of Cleaner Production*, 234, pp.43–53.

García, C.A. et al., 2011. Life-cycle greenhouse gas emissions and energy balances of sugarcane ethanol production in Mexico. *Applied Energy*, 88(6), pp.2088–2097.

Gong C.; Li Z.; Yi L.; Huang K.; Liu F. 2020. Research on the performance of a hydrogen/methanol dual-injection assisted spark-ignition engine using late-injection strategy for methanol. Fuel; 260

Gopal, A.R. & Kammen, D.M., 2009. Molasses for ethanol: the economic and environmental impacts of a new pathway for the lifecycle greenhouse gas analysis of sugarcane ethanol. *Environmental Research Letters*, 4(4), p.044005.

Houghton, R.A. 2003. Revised estimates of the annual net flux of carbon to the atmosphere from changes in land use and land management: 1850–2000. Tellus B, 55, 378–390

Khatiwada, D. & Silveira, S., 2011. Greenhouse gas balances of molasses-based ethanol in Nepal. *Journal of Cleaner Production*, 19(13), pp.1471–1485.

Khatiwada, D. & Silveira, S., 2009. Net energy balance of molasses-based ethanol: The caseof Nepal. *Renewable and Sustainable Energy Reviews*, 13(9), pp.2515–2524

Canilha, L., A. K. Chandel, T. S. S. Milessi, 2012. "Bioconversion of sugarcane biomass into ethanol. *Journal Biomedicine and Biotechnology*; 15

Li K, Liu S, Liu X. 2014. An overview of algae bioethanol production. Int J Energy Res. 38(8):965–77. https://doi.org/10.1002/er.3164

Muñoz, 2013. Life cycle assessment of bio-based ethanol produced from different agricultural feedstocks. *The Int. Journal of Life Cycle Assessment*, 19(1), pp.109–119.

Nguyen, and Gheewala, S., 2008. Life cycle assessment of fuel ethanol from cane molasses in Thailand. *The International Journal of Life Cycle Assessment*, 13(4), pp.301–311.

Nguyen, and Hermansen, J.E., 2012. System expansion for handling co-products in LCA of sugar cane bio-energy systems: GHG consequences of using molasses for ethanol production. *Applied Energy*, 89(1), pp.254–261

Nguyen, Thu Lan T., and Shabbir H. Gheewala. 2008. Life Cycle Assessment of Fuel Ethanol from Cane Molasses in Thailand. *The International Journal of Life Cycle Assessment*, vol. 13, no. 4, pp. 301–311., doi:10.1007/s11367-008-0011-2

OECD/Food and Agriculture Organization of the United Nations. OECD-FAO Agricultural Outlook2015. Paris, France: OECD Publishing; 2015

Pechout M.; Dittrich A.; Vojtisek M. 2014. Operation of an Ordinary PFI Engine on n-butanol and Iso-butanol and Their Blends with Gasoline. SAE Technical Paper; 2618

Prasad, S., Singh, A. & Joshi, H., 2007. Ethanol as an alternative fuel from agricultural, industrial and urban residues. *Resources, Conservation and Recycling*, 50(1), pp.1–39

Prieur-Vernat A, and His S, 2007. Biofuels worldwide. Panorama. Rueil-Malmaison, France: IFP-

Innovation Energy Environment

Schifter, I.; Díaz, L.; Lo´pez-Salinas, E. 2005. Hazardous Air Pollutants from Mobile Sources in the Metropolitan Area of Mexico City; J. Air & Waste Manage. Assoc, 55; 1289-1297.

Seabra, J.E. and Macedo, I.C., 2011. Comparative analysis for power generation and ethanol production from sugarcane residual biomass in Brazil. *Energy Policy*, 39(1), pp.421–428.

Silalertruksa, T. & Gheewala, S.H., 2011. The environmental and socio-economic impacts of bio-ethanol production in Thailand. *Energy Procedia*, 9, pp.35–43.

Topgul, T. Yucesu, H.S. C. inar, C. Koca, A. 2006. The Effects of Ethanol Gasoline Blends & Ignition Timing on Performance and Exhaust Emissions; Renew. Energy 31; 2534-42

Tsiropoulos, I. et al., 2014. Life cycle assessment of ethanol production in India in comparison to Brazil. *The International Journal of Life Cycle Assessment*, 19(5), pp.1049–1067.

Wondimu, G Ethiopian sugar corporation's profile, 2010. 1–22

World Bioenergy Association. WBA Global Bioenergy Statistics; 2017

Yüksel, Fikret & Yüksel, Bedri. 2004. The use of ethanol–gasoline blend as a fuel in an SI engine. Renewable Energy. 29. 1181-1191

Zhao, L. & Wang, D., 2020. Combined Effects of (E10) Blend and Exhaust Gas Recirculation on Performance & Pollutant Emissions. *ACS Omega*, 5(7), pp.3250–3257.