Renewable and Sustainable Energy Reviews 13 (2009) 2201–2204

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Bio-fuels production and the environmental indicators

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ARTICLE INFO

Article history:
Received 16 December 2008
Accepted 20 January 2009

Keywords:
Bio-fuels
Energy
Environmental indicators
GHG emissions

ABSTRACT

The paper evaluates the role of the bio-fuels production in the transportation sector in the world, for programs of greenhouse gases emissions reductions and sustainable environmental performance. Depending on the methodology used to account for the local pollutant emissions and the global greenhouse gases emissions during the production and consumption of both the fossil and bio-fuels, the results can show huge differences. If it is taken into account a life cycle inventory approach to compare the different fuel sources, these results can present controversies. A comparison study involving the American oil diesel and soybean diesel developed by the National Renewable Energy Laboratory presents CO_2 emissions for the bio-diesel which are almost 20% of the emissions for the oil diesel: 136 g CO_2/bhp-h for the bio-diesel from soybean and 633 g CO_2/bhp-h for the oil diesel [National Renewable Energy Laboratory—NREL/SR-580-24089]. Besides that, important local environmental impacts can also make a big difference. The water consumption in the soybean production is much larger in comparison with the water consumption for the diesel production [National Renewable Energy Laboratory—NREL/SR-580-24089]. Brazil has an important role to play in this scenario because of its large experience in bio-fuels production since the seventies, and the country has conditions to produce bio-fuels for attending great part of the world demand in a sustainable pathway.

Contents

1. Introduction

The world energy supply will demand a huge amount of natural resources and fuels, and this will result in a large amount of greenhouse gases emissions if the business as usual scenario is maintained. Therefore, it is important to verify the potential of the bio-fuels in this context in comparison with the fossil fuels environmental performance.

According to the IPCC WGIII AR4 [1], global primary energy use almost doubled from 5363 Mtoe (225 EJ; toe is tonne of oil equivalent) in 1970 to 11,223 Mtoe (470 EJ) in 2004. The average annual growth over this period was of 2.2%. According to IEA, the global total primary energy supply in 1973 was 6128 Mtoe, and in 2005 was 11,435 Mtoe and the global total final energy consumption in 1973 was 4700 Mtoe while in 2005 was 7912 Mtoe. These numbers correspond to around 15,661 $MtCO_2$ emitted in 1973 and 27,136 $MtCO_2$ emitted in 2005. IEA [2] estimates that the world primary energy consumption will increase around 123% from 2003 (7.3 billion toe) to 2030 (16.3 billion toe).

Although fossil fuels participation in the global energy use in 2004 – estimated as 81% – was smaller than 30 years ago – 86% – such difference was mainly due to the increase in the use of nuclear energy. Despite the substantial growth of non-traditional renewable forms of energy, especially wind power, over the last decade, the

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1364-0321/$ – see front matter
doi:10.1016/j.rser.2009.01.015

Table 1
World proved fossil fuel reserves.

Source	Reserves at the end of 2007 (physical units)	Time range for exhaustion of reserves
Oil	1,238 (billion barrels)	25-70 years
Natural Gas	177.36 (trillion cubic meters)	30–110 years
Coal	847,488.0 (million tonnes)	65–215 years

Source: BP Statistical Review of World Energy, June 2008; World Energy Council; Center for International Economics.

Table 2
World primary energy consumption by fuels in 2007 (million tones oil equivalent).

Fuel/year	Oil	Natural gas	Coal	Nuclear energy	Hydro electricity	Total
2006	3,910.9	2,558.3	3,041.7	634.9	697.2	10,843.0
2007	3,952.8	2,637.7	3,177.5	622.0	709.2	11,099.3
%	35.6	23.7	28.6	5.7	6.4	100.00

Source: BP Statistical Review of World Energy, June 2008.

share of renewable energy uses (including traditional biomass) in the primary energy mix has not changed compared with 1970 [3].

An important indicator that fossil fuels will be used in the world for a long time horizon is the increase of their foreseen reserves. The global fossil fuels confirmed reserves indicated huge numbers in 2007: around 1237.90 (billion barrels) for oil, 177.36 (trillion cubic meters) for natural gas and 847,488.0 (million tones) for coal. These reserves of global fossil fuels, expressed in energy units, are around 910 billion of TOE (tons of oil equivalent)—170 bi TOE for oil, 150 bi TOE for natural gas and 590 bi TOE for coal. Although the coal already participates with an important percentage in the global energy matrix, the world coal supply in 2005 was only 2.89 bi TOE, which is small compared to the large existent coal reserves of 590 bi TOE. [4] It is estimated an average lifetime of about 50 years for oil, 70 years for natural gas and 140 years for coal [5] (Table 1) and these numbers still do not include the Brazilian pre-salt crude oil reserves recently announced.

The contribution of different sources to the total primary energy consumed in the world in 2007 is presented in Table 2 [6]. It can be observed the huge participation of fossil fuels, around 87.9% (35.6% for oil; 23.7% for natural gas; 28.6% for coal), and it is foreseen an increase of this percentage in the future.

The Brazilian total energy supply from 1990 to 2005 shows an increase in the non-renewable sources participation, from 38% to 55%, and a decrease in the renewable energy participation, from 62% to 45%. According to the Brazilian Energy Balance, annually elaborated by the Ministry of Mines and Energy, the electricity supply in Brazil increased from 424.8 TWh in 2004 to 441.6 TWh in 2005, with an increased participation of hydro, coal, oil derivatives and biomass, and a decrease of natural gas, nuclear and energy importation. It is estimated a consumption of 600 TWh in Brazil for the year 2015, what represents a huge amount of energy increase for a decade [7]. This expansion may incorporate climate change mitigation and sustainable development actions, depending on the strategies established by the governments.

2. Potential of GHG emissions reductions by sectors

The IPCC WGIII, AR4 [3] [Fig. 1] presented some important conclusions regarding climate change mitigation opportunities for all sectors and all regions (subdivided as OECD, non-OECD and Economies In Transition). There are multiple mitigation options in the transport sector, but their effect may be counteracted by the growth in the sector. Improved vehicle efficiency measures, leading to fuel savings, have net benefits in most of the cases (at least for light-duty vehicles). However, there is not enough information to assess the mitigation potential for heavy-duty vehicles. Bio-fuels might play an important role in addressing GHG emissions in the transport sector, depending on their production pathway. Bio-fuels used as gasoline and diesel fuel additives/substitutes are projected to increase up to 3% of the total transport energy demand in the baseline in 2030. This may even increase more, to about 5–10%, depending on future oil and carbon prices, improvements in vehicle efficiency and the success of technologies which will utilize cellulose biomass.

Some pilot programs in Brazil are presented as examples of how the transport and energy sectors can assume great importance in the climate change mitigation options. It is very important to study

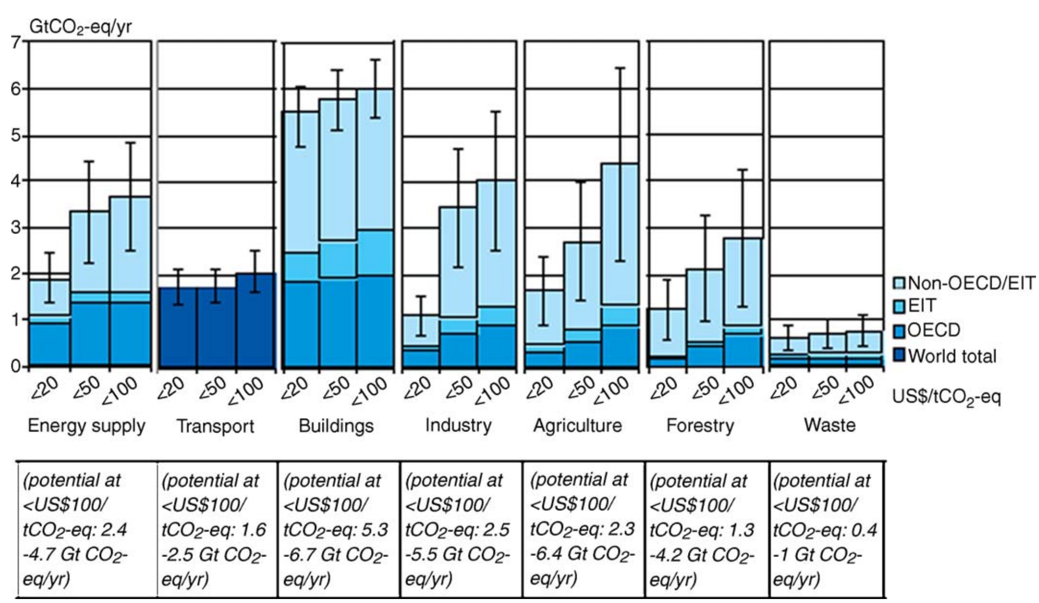

Fig. 1. . Estimated sectoral economic potential for global mitigation for different regions as a function of carbon price in 2030 from bottom-up studies, compared to the respective baselines assumed in the sector assessments. Source IPCC, 2007: Summary for Policymakers. In: Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.

the best way to insert alternative sources in the Brazilian energy matrix, by reducing the impact of human activities in such a way as to offer more sustainable options. The bio-fuels production can cause regional and cross-boarder conflicts due to the use of the soil, the water and the atmospheric pollution, both global and local [8].

3. Bio-fuels and GHG emissions reductions

Depending on the methodology used to account for the GHG emissions for comparison between fossil and renewable fuels, very different results may be obtained. Starting with the evaluation of the energy balance during the production of the biofuel, the energy output may be artificially increased if one takes into account all the byproducts, and this may be translated into artificially smaller GHG emissions. It is also known that the majority of the energy input is of fossil origin. Depending on the type of fertilizers and the fuels for the rural machinery and tractors, the GHG emissions associated with the production and use of corn oil ethanol, may be greater or smaller than the GHG emissions from the production and use of regular gasoline. "By using a worldwide agricultural model to estimate emissions from land-use change, we found that corn-based ethanol, instead of producing a 20% savings, nearly doubles greenhouse gas emissions over 30 years and increases greenhouse gases for 167 years. Bio-fuels from switch grass, if grown on U.S. corn lands, increase emissions by 50%". [9]. According to Fargione et al., [10] "bio-fuels are a potential low-carbon energy source, but whether bio-fuels offer carbon savings depends on how they are produced. Converting rainforests, peatlands, savannas, or grasslands to produce food-based bio-fuels in Brazil, Southeast Asia, and the United States creates a 'bio-fuel carbon debt' acting opposite to the greenhouse gas (GHG) reductions these bio-fuels provide by displacing fossil fuels. In contrast, bio-fuels made from waste biomass or from biomass grown on abandoned agricultural lands planted with perennials incur little or no carbon debt and offer immediate and sustained GHG advantages".

Some countries such as German and Sweden announced governmental policies for fossil fuel use reduction of 80% and 100%, respectively, for the next 20 years. Nevertheless, the world fleet is estimated to be between 700-800 million (at 2007) vehicles and is expected to increase to 2.1 billion in 2050. As a result of all that growing process, it is foreseen that 40% of the world energy will be consumed by the transportation sector in developing countries. Brazil has around 39 million vehicles being 21.5 million for light-duty vehicles and 17.5 for diesel vehicles (mostly medium and heavy-duty). The fuel sources for the light vehicles in Brazil can be seen in Table 3. Gasoline is responsible for 17 million, alcohol for 2 million, flex-fuel for 1.3 million, and NGV for 1.2 million.

As it was mentioned depending on the toll of analysis to compare bio and fossil fuels, the results can show controversies. For example, the life cycle inventory used by the National Renewable Energy Laboratory to compare oil diesel and soybean diesel presents CO_2 emissions for the bio-diesel which are about 20% of the emissions for the oil diesel: 136 g CO_2/bhp-h for the bio-diesel from soybean and 633 g CO_2/bhp-h for the oil Diesel. (NREL/SR-580-24089) [11].

Table 3
Number of light-duty vehicles by fuel sources in Brazil, 2005.

Gasoline	17 million
Alcohol	2 million
Flex-fuel	1.3 million
NGV	1.2 million
Total	21.5 million

Source: based on the Brazilian National Energy Balance, 2008.

The steps considered in the study were: soybean transportation, production and conversion processes, refining and combustion. It can be highlighted the big water consumption for the soybean production in comparison with the water consumption for the diesel production as a very important environmental indicator to be considered as well. It is estimated that 70% of the water in Brazil is used for irrigation processes in the agriculture sector.

4. Fossil and bio-fuels and local environmental impacts

There are also impacts due to the alcohol fueled engines and to the sugarcane burning on local air pollution, such as the emission of particulate matter (PM), carbon monoxide (CO), methane (CH_4) and oxides of nitrogen (NOx). It is estimated that the average vehicle miles traveled in Brazil is 16,000 km year^{-1}, and the average fuel consumption is 8 km l^{-1} for ethanol and 10 km l^{-1} for gasohol [12]. This difference in fuel consumption has to be taken into account in the evaluation of the environmental performance.

The substitution of gasoline by gasohol and ethanol as an alternative fuel significantly reduces impact as the air pollution in the urban area. Initially, lead additives were reduced as the amount of alcohol in the gasoline was increased and the first were completely eliminated in 1991. The aromatic hydrocarbons (such as benzene), which are particularly toxic, were also eliminated and the release of SO_2 (due to the low sulphur content of ethanol based fuels) was also reduced. Pure ethanol cars do not present sulphur emissions.

Another important environmental indicator in the ethanol combustion is related to the aldehydes emissions. The aldehydes emission factors for ethanol are higher when compared to gasoline or gasohol. The emission of aldehydes in new vehicles with ethanol engines may be 3.5 times greater than the emission for the new vehicles operating with pure gasoline. Nevertheless, the acetaldehyde from the use of ethanol is less aggressive to the environment and the human health than the formaldehyde found in gasoline.

The CO emission by vehicles with gasoline fueled engines is 1.16 times the emission of the ethanol engines. The use of new gasohol fueled automobiles incorporating technological innovations (canister, catalytic converter and electronic injection) according to the Brazilian legislation, contributes to lower the air pollutants emissions in urban areas. Both ethanol and gasohol engines provide some environmental benefits that can result in better human health and improved quality of life, as well as greenhouse gas benefits.

5. Conclusion

The work presents a discussion about the local and global environmental indicators for fossil and renewable fuels. The international debate involving the advantages and disadvantages of the world agricultural activities for fuel production versus food production is commented with focus on the energy scarcity and the worsening of global environmental problems. Depending on the methodology used to account for the local pollutant emissions and the global greenhouse gases emissions during the production and consumption of both the fossil and bio-fuels, the results can show huge differences.

The world energy matrix incorporates a majority use of fossil fuels, almost 90%, with the tendency for presenting the same scenario still for a long time. It is very important to emphasize the necessity for the development of new technologies to reduce the fuel and vehicle pollutants emissions, and to establish more strict standards and stronger policies to face the related environmental problems. Brazil has an important role to play in this scenario because of its large experience in bio-fuels production since the seventies, and the country has conditions to produce bio-fuels for attending great part of the world demand in a sustainable pathway.

References

[1] IPCC WGIII AR4 chapter I.
[2] IEA, Key World Energy Statistics, 2007.
[3] IPCC, 2007: Summary for Policymakers. In: Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, In: B. Metz, O.R. Davidson, P.R. Bosch, R. Dave, L.A. Meyer (Eds.), Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.
[4] World Energy Outlook, Focus on Brazil, 2006.
[5] IPCC, TAR, Synthesis Report, 2001.
[6] British Petroleum Statistical Review of World Energy, June 2008.
[7] Brazilian National Energy Balance, 2008.
[8] Muylaert de Araújo MS, Vasconcelos de Freitas MA. Acceptance of renewable energy innovation in Brazil—case study of wind energy. Renewable and Sustainable Energy Reviews 2006 [Available on line 30 October].
[9] Searchinger T, Heimlich R, Houghton RA, Dong F, Elobeid A, Fabiosa J, Tokgoz S, Hayes D, Tun-Hsiang Y. Use of U.S. croplands for biofuels increases greenhouse gases through emissions from land-use change. Science 2008;319(February 29 (5867)):1238–40.
[10] Fargione J, Hill J, Tilman D, Polasky S, Hawthorne P. Land Clearing and the Biofuel Carbon Debt. Published Online February 7, 2008 Science doi:10.1126/science.1152747.
[11] National Renewable Energy Laboratory—NREL/SR-580-24089.
[12] Ribeiro SK, Rosa LP. Activities implemented jointly and the use of fuel alcohol in Brazil for abating CO_2 emissions. Energy Policy 1997;26:103–11.