An assessment of energy balance from sugar-based ethanol for fuel-saving and climate policy – the case of an island economy

Riad Sultan*

Engineering Building,
Department of Economics and Statistics,
Faculty of Social Studies and Humanities,
University of Mauritius,
Reduit, Mauritius
E-mail: r.sultan@uom.ac.mu
*Corresponding author

Abdel Khoodaruth

Professor Sir Edouard Lim Fat Engineering Tower,
Mechanical and Production Engineering Department,
Faculty of Engineering,
University of Mauritius,
Reduit, Mauritius
E-mail: a.khoodaruth@uom.ac.mu

Abstract: The study assesses the efficiency of sugar-based ethanol production in Mauritius using the net energy balance and energy ratio. The findings indicate a positive net energy balance. For every one unit of fossil fuel used, the system returns more than six times in terms of renewable energy from ethanol. The fuel savings and other economic benefits which may be accrued to Mauritius are discussed. The sensitivity analysis shows that the fossil energy consumed in the production of fertilisers and in the transportation of feedstock to factory represents the main components which influence efficiency indicators. Greening the supply chain may enhance the efficiency and sustainability of bio-ethanol production systems. Green strategies may include the use of organic fertilisers, clean technology, and sustainable transportation and land use. The efficiency indicators can also be used to guide the CDM for sugar-based ethanol project.

Keywords: bio-energy; energy balance; energy ratio; sugar-based ethanol; fuel savings; sustainability; green economy; clean development mechanism; CDM; Mauritius.

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Biographical notes: Riad Sultan is a Lecturer in Economics at the University of Mauritius. He has wide experiences in socio-economic issues and policy-making, having served as the Research Executive of the Research Department of the National Economic and Social Council of Mauritius. He was involved with the African Peer Review Mechanism (APRM) project in Mauritius for the African Union. He has conducted research on areas such as green jobs assessment, green industry, economics of bio-ethanol, energy and ecosystem valuation in Mauritius. His research interests include climate change economics, fisheries, sustainable transport solutions and energy modelling.

Abdel Khoodaruth is a Lecturer in the Department of Mechanical and Production Engineering at the University of Mauritius. He read his first degree in Mechanical Engineering with a postgraduate degree in Project Management at the University of Mauritius. He has conducted research studies in the field of biofuel for electricity generation. He was previously working in the field of mechanical engineering in both the private and public sector and is also a Registered Professional Mechanical Engineer.

1 Introduction

Given that fossil-fuel consumption is a major cause of greenhouse gases (GHGs) in the world, policy-makers are seeking alternative sources of energy including solar, wind, hydraulic, geothermal and bio-energy as options to reduce GHGs and their associated environmental impacts (Garcia et al., 2011). Bio-ethanol produced by the fermentation and distillation of sugary or starchy is among the options to reduce the dependency on fossil fuel and to halt GHGs and global warming (Blottnitz and Curran, 2007; Balat and Balat, 2009; Nguyen et al., 2009; Gold and Seuring, 2011). According to Escobar et al. (2009), global production of ethanol might provide up to 7% of the global energy used in the transport sector by 2030. The carbon emission from biomass such as bio-ethanol is considered as neutral since biofuel combustion was previously sequestrated from the atmosphere during the growth of plants used as feedstocks (Demirbas, 2009; Goldemberg et al., 2008; Garcia et al., 2011).

In recent years, a debate has emerged on the potential of using bio-ethanol in the transport sector as an option for fossil fuel substitution and GHGs mitigation (Goldemberg et al., 2008; Silalertruksa and Gheewala, 2009). This has led to a growing interest in assessing the energy and environmental costs and benefits of ethanol production. According to Nguyen et al. (2009), energy is consumed in the production of biomass and in the conversion of feedstocks into ethanol. Thus, one of the indicators which may assist in the development of ethanol production system is energy balance (EB) which is defined as the difference between the energy content of ethanol and the total energy content of inputs consumed in the ethanol production system. Alternatively, the net energy balance (NEB) refers to the difference between ethanol energy content and non-renewable energy content of inputs in the production pathway. The NEB represents a refinement in assessing the performance of ethanol production system since it addresses the level of energy which is gained when the non-renewable fossil fuel energy is expended to produce renewable biofuel such as ethanol. A positive NEB is usually expected for sustainable biofuel development. However, estimates on NEB depend on the types of feedstocks used to produce ethanol which in turn depends on the climate and geographical characteristics of the country (Puppan, 2002), the transportation and land use planning (Chavanne and Frangi, 2011) and the ethanol conversion technology (Coelho et al., 2006). Energy ratio is defined as the ratio of energy content of ethanol over energy content of fossil fuel input and represents another indicator to evaluate ethanol's energy gain. It measures energy output from one unit of fossil fuel input into the production process (Gold and Seuring, 2011).

Sugar cane is one of the most widely used feedstock for ethanol (Coelho et al., 2006; Goldemberg et al., 2008; Garcia et al., 2011). Around 60% of ethanol comes from sugar cane (Demirbas, 2009). Sugar-base ethanol production system is well-developed in countries such as Brazil (Macedo, 1998; Coelho et al., 2006), Thailand (Nguyen et al., 2008), Nepal (Khatiwada and Silveira, 2009), and India (Prakash et al., 1998). Countries, such as Mauritius, whose geography is conducive to sugar cane cultivation, are also considering the option of producing bio-ethanol. Sugarcane has high photosynthesis efficiency and it can grow well in an intensive culture, reducing the competition with food crops. Due to characteristics of the sugar-based ethanol, the combustion emissions are less harmful than those from gasoline.

However, ethanol fuel policy decision depends on the energy indicators as defined above. The purpose of this study is to assess the energy balance, NEB and energy ratio of a sugar-based bio-ethanol production system for a small island economy, Mauritius, which produces sugar as its main agricultural products. Following the ACP-EU Sugar Protocol in the 1970s Mauritius benefitted a quota for sugar exportation at a guaranteed price to the EU market (Wellisz and Saw, 1994). Eventually, sugar exports contributed extensively to the Mauritian economic performance during the last decades or so. Such preferential treatment helped the island to create employment and to earn foreign exchange. However, in June 2005, the European Commission calls for severe reductions in EU sugar prices and an end to the current system of national quotas. Eventually, the sugar sector was reengineered to face the global challenge of export competitiveness. However, while economic competitiveness was a main criterion to re-define the Mauritian agricultural sector, the use of sugar cane as feedstock for biofuel is yet another option to be evaluated.

To date, no assessment for sugar-based ethanol production system in Mauritius has been published. This study therefore fills the gap by conducting a lifecycle-based assessment assuming ethanol is produced from sugar-cane, bagasse is used in ethanol conversion and the surplus bagasse is utilised to produce electricity which is sold as a product of the production system. The assessment estimates the amount of energy consumed in the agriculture and industrial phases, characterising biomass preparation and the conversion stage of ethanol production. By using the indicators such as EB, NEB and ER, this study contributes to the policy debate of using ethanol for substituting fossil fuel in the transport sector. While the use of ethanol will lead to a fall in gasoline, it also brings about an increase in energy which is consumed in its production phase. Thus, these indicators are used to estimate the amount of fuel saving which could be made if the sugar cane sector is directed towards ethanol production and the E-10 formula is implemented in the transport sector. The E-10 represents the combination of 10% ethanol with 90% gasoline. An evaluation of the fuel saving is essential to guide the E-10 bio-ethanol energy policy. The indicators can also be used in the context of CDM project which is further discussed in the study. The empirical results also show that bio-ethanol efficiency is also linked to the concept of the green economy as defined by the United Nations Development Programme (UNEP, 2011).

The paper is organised as follows: Section 2 provides a brief on the sugar cane sector in Mauritius. This is followed by an explanation of the conceptual framework and methodological issues in Section 3. Section 4 presents the empirical results for the energy indicators. Section 5 provides the discussion of the results and a sensitivity analysis is conducted based on simulating changes of inputs and other components in the production chain system. Section 6 concludes with policy implications.

2 Sugar cane sector in Mauritius

Sugar cane was introduced in Mauritius by the Dutch in 1639 given that the island's climate and land conditions make it suitable for the cultivation of sugar (Paturau, 1988; Ramkissoon, 1994). Economic activities for the last three centuries were based on producing and exporting sugar to Europe. By the mid-nineteenth century, Mauritius became one of Britain's major sugar-producing colonies such that in 1966, the Nobel Prize winner in Economics James Meade pointed out that 'Sugar is king in Mauritius', in his presidential address to the Royal Economic Society (Meade, 1967). In 1968, when Mauritius acceded to independence, the economy was highly dependent on sugarcane (Wellisz and Saw, 1994). In 1972, the sugar industry was the largest employer with 70,000 workers that is 36% of the population (CSO, 1975). Sugar exports amounted to around 45% of total exports and 94% of visible exports. In the same year, sugar represented one third of GNP.

In 1975, Mauritius benefited from the ACP-EU Sugar Protocol where it has a quota of 507,000 tonnes of sugar at a guaranteed price of export to the EU market (Wellisz and Saw, 1994). Through the Sugar Protocol and Special Preferential Sugar Agreement, the island received guaranteed prices at some 100%–200% above world market prices and guaranteed market share through quotas. At the time of the agreement of the Sugar Protocol, there was an accrued scarcity of sugar on the world market. In the mid-1980s, in line with the Sugar Protocol, the government introduces the Sugar Action plan which gave a boost to the sugar industry (Paturau, 1988). The stable revenues from sugar exports served in the diversification of the Mauritian economy (Table 1). Mauritius has diversified significantly the economy with the expansion of tourism, financial services and manufacturing industries (Zafar, 2011).

Table 1 Sectoral distribution of GDP in %, 1980–2010 (main sectors), Republic of Mauritius

	1980	*1990*	*2000*	*2010*
Agriculture	12.4	12.1	6.5	3.6
Manufacturing	15.2	23.6	22.5	18.5
Construction	7.6	6.9	5.3	6.9
Wholesale and retail, restaurants and hotels	14.2	16.7	17.5	17.5
Transport, storage and communication	11.3	10.7	12.7	9.6
Financing, insurance, real estate and business services	17.7	15.2	17.2	22.2
Others	21.6	14.8	18.3	21.7
Total	100	100	100	100

Source: National Accounts, Statistics Office, Mauritius, various issues. Others include mining and quarrying, electricity, gas and water, producers of government services and community, social and personal services

In June 2005, the European Commission published legislative proposals to reform the Common Market Organisation (CMO) for Sugar, which calls for severe reductions in EU sugar prices and an end to the current system of national quotas (Government of Mauritius, 2007). The change is the sugar sector is shown in Table 2. The Mauritian Government, in consultation and collaboration with stakeholders, devised a multi-annual adaptation strategy commonly known as the MAAS in the form of a ten year, 2006–2015, action plan. The objective of the MAAS is to ensure the commercial viability and sustainability of the sugar sector for it to continue fulfilling its multi-functional role in the Mauritian economy, but at a significant social cost. The strategy provides for a set of measures and projects aiming at improving the cost competitiveness of the sugar sector among other objectives. Ethanol production from sugar is one of the options for using sugar cane and the sustainability of this option is the focus of this sector.

Table 2 Agricultural sector in Mauritius

	2000	*2010*
Value added – agriculture, at basic prices in thousand Mauritian rupees ($US equivalent)	7,144 (275)	9,665 (311)
Of which: sugar cane in thousand Mauritian rupees ($US equivalent)	3,741 (143)	3,042 (98)
Share of agriculture in GDP at basic prices	6.8%	3.6%
Share of sugar cane in agriculture	52.4%	31.5%

Note: Figures in bracket represents $US equivalent calculated from official exchange rate (WBI, 2012).

Source: Digest of Agricultural Statistics, Statistics Office, Mauritius (CSO, 2010a)

3 Conceptual framework and methodological issues

Bio-energy production system generally consists of two process stages (Macedo et al., 1998; Nguyen et al., 2009). The first stage consists of the production of biomass and the second one is the pre-treatment and conversion of the biomass into energy products. Fossil fuel is consumed in these two process stages and hence, the efficiency of bio-ethanol production depends on fuel consumption of the operating components of these two stages. These two stages define the system boundary for the assessment. Following studies such as Ramjeawon (2004) and Silalertruksa and Gheewala (2009), the following operating units are included in the energy assessment:

- *The biomass production stage:* This stage includes sugar cane farming, manufacture of fertilisers and herbicides, transportation of fertilisers and herbicides to sugar cane field, and transportation of sugar cane to sugar factory. Sugarcane farming includes field preparation, plant cane farming, treatment and harvesting. Sugarcane is initially grown from short sections of cane (plant cane). For the couple of years the cane is cut and regrown (ratoon cane) before replanting with new cane stems. A cycle of sugarcane planting and harvesting is about 12 months.
- *The ethanol conversion stage*: The sub-system boundary includes sugar processing, electricity generation from bagasse and conversion of feedstock (sugar) to ethanol.

3.1 Biomass production stage: sugarcane cultivation and harvesting

3.1.1 Energy consumed in the production of fertilisers

The fertilisers which are used in cane cultivation include Nitrogen, Phosphorous and Potassium (NPK). Energy consumed in the production of NPK per tonne of sugar cane, E_f is estimated as follows:

$$E_f = \frac{f_k . f .}{y_c} \tag{1}$$

f fertilisers (NPK) used per hectare

f_k heat (energy) content (LHV) for producing NPK per kg in MJ

y_c tonne of sugar cane harvested per hectare.

3.1.2 Energy consumed in the production of herbicide

Herbicide is the second main input in cane cultivation. The estimated energy consumed in the production of herbicide follows the same method as fertilisers (NPK) and is shown as follows:

$$E_\eta = \frac{\eta_k . \eta}{y_c} \tag{2}$$

η amount of herbicide used per hectare

η_k heat (energy) content (LHV) per kg in MJ

y_c sugar cane yield per hectare.

3.1.3 Energy in transportation of fertilisers and herbicides

The transportation of fertilisers and herbicides from harbour to sugar cane field is a main activity which consumes fossil fuel (diesel) and this should form part of the energy analysis. However, the amount of fossil fuel used depends on the average distance travelled from harbour to sugar cane field and the amount of tonne which is transported per trip with the existing carrying capacity of the truck. The following equation is used to estimate the fossil fuel in the transportation.

$$ET_i = \frac{Tr.d..d_e.l_f}{c} \tag{3}$$

for $i = f$ for fertilisers and η for herbicides

Tr number of trips required

d amount of diesel consumed per km

de heat content of diesel

l_f average distance in km travelled per trip.

3.1.4 Energy used in irrigation

Irrigation is a mechanised process which uses electricity. The amount of electricity consumed, however, depends on the percentage of land irrigated. The formula takes into account the percentage of irrigated land.

$$E_x = \frac{x.x_p x_e}{y_s} \tag{4}$$

x amount of electricity consumed per hectare

x_p % of land irrigated

x_e heat content of one kWh of electricity.

3.1.5 Energy in the transportation of sugar-cane to factory

Energy consumed in the transportation of sugar-cane to factory depends on the number of trips, the load of trucks, and the average distance between the fields and the factory.

$$ET_c = \frac{Tr.d..d_e.l_f}{c} \tag{5}$$

3.2 Ethanol conversion stage

The second stage is the ethanol conversion. The sugarcane is first shredded using rotating knives and shredders to form small pieces. These are then compressed by rotating mills to produce sugarcane juice and bagasse as residue. The bagasse is used as fuel to produce steam in the boiler whereas the juice is fermented and rectified to produce hydrous ethanol. The latter are then dehydrated to produce anhydrous ethanol. It is estimated that 30 kWh per tonne of sugar cane (x_m) is needed to produce 86 L of anhydrous ethanol.

Thus, electricity is used in the conversion process and energy consumed in this process is calculated from the following formula:

$$E_m = x_m x_e \tag{6}$$

x_m electricity used per tonne of sugar cane.

Since bagasse is used for electricity generation, the last component is usually subtracted from the energy assessment and is treated as renewable energy credit (Nguyen et al., 2009). Bagasse is the most important industrial by-product from sugarcane (Coelho et al., 2006).

3.3 Energy efficiency indicators – energy balance, NEB, energy ratio

Equations (1) to (5) indicate the amount of fuel used in the preparation of feedstock and equation (6) represents energy in the conversion phase. Total energy consumed in the production phase is summarised as follows:

$$E_{mo} = E_f + E_\eta + ET_f + ET_\eta + E_x + ET_c \tag{7}$$

Since there are two products from sugar cane cultivation – ethanol and electricity, it is important to apportion the total energy used in the feedstock cultivation phase into these two products. The economic value is used as the apportionment rule.

It is important to distribute energy consumed in the biofuel production pathways between co-products. Since electricity is produced as co-product, the energy used up to the factory gate must be allocated between the two products (Hammerschlag, 2006; Wang et al., 2011; Nguyen and Hermansen, 2012). There are five potential methods to address multiple products of biofuel production pathways (Wang et al., 2011). The mass-based method refers to the mass output shares as the basis to allocate energy use. Since electricity does not have mass, the method would not allocate energy and emission to electricity generation. The energy-content-based method uses the energy output shares as the apportionment rule. However, since the use electricity and ethanol are meant to different sectors of the economy, this method is not chosen. The displacement method takes into consideration the products which are displaced by non-fuels products to estimate the energy use and emissions burdens of producing the otherwise displaced products. The process-purpose-based method estimates energy use and emissions of individual processes in a facility. This method is not appropriate when the processes lead to multiple products.

The market-value-based method, advocated by economists, uses the economic value of individual products to allocate energy use and emission among co-products. Accordingly, price is the best available indicator of how much of co-products are worth (Gopal and Kammen 2009). The other methods would not take the rise in prices into account unless the regulation is set based on the market value method. Based on studies such as Gopal and Kammen (2009), Nguyen and Hermansen (2012) and Khatiwada and Silveira (2011), the market-based method is used in this study.

Energy used in producing one litre of ethanol ($En_{ethanol}$) is calculated as follows:

$$En_{ethanol} = E_m + AR_{mo}\left[\frac{E_{mo}}{86}\right] \tag{8}$$

where $Ar_{mo}$is the proportion of energy allocated to sugar-based ethanol.

It is also assumed that one tonne of sugar cane can provide 86 litres of ethanol (Nguyen et al., 2009)

- Energy balance (EB) is calculated as follows:

  $$EB = EN_C - En_{ethanol} \tag{9}$$

  where EN_C is the energy content of 1 litre of ethanol.

- NEB is calculated as follows:

  $$NEB = EN_C - FEn_{ethanol} \tag{10}$$

  where $FEn_{ethanol}$ is the fossil energy consumed in producing ethanol following equation (8). It is calculated by taking only fossil fuel in equation (8).

- Energy ratio is estimated as follows:

  $$ER = \frac{EN_C}{FEn_{ethanol}} \tag{11}$$

4 Empirical findings

Data has been collected from various sources for the purpose of estimating the energy balance, NEB and energy ratio for the ethanol production system in Mauritius. The representative unit is 1 tonne of sugar cane and 1 litre of ethanol. Table 3 shows the main parameters which are used to define the system boundary. The representative rotation is taken from a cultivation with a seven-year plant cycle (Ramjawon, 2004). Table 4 gives the data source to estimate equations (1) to (7).

Table 3 Parameters for estimating NEB from ethanol production

Areas cultivated	62,100
Areas harvested in hectares	58,709
Tonnes of sugar cane cultivated	4,366,000
Tonnes of sugar produced	452,473
1 hectare	74.4 tonnes of sugar cane
1 tonne of sugar	9.64 tonnes of sugar cane
Functional unit	1 tonne of sugar cane, 1 litre of ethanol

Source: Digest of Agricultural Statistics, Digest of Energy statistics (CSO, 2010a)

Table 4 Data source for assessment of ethanol production system

Symbol	*Designation*	*Source*
f	Fertilisers (NPK) used per hectare	Ramjeawon (2004)
f_k	Heat (energy) content (LHV) for producing NPK per kg in MJ	IPCC (2007)
y_c	Tonne of sugar cane harvested per hectare	CSO (2010a)
η	Amount of herbicides used per hectare	Ramjeawon (2004)
η_k	Heat (energy) content (LHV) per kg in MJ	IPCC (2007)
y_c	Sugar cane yield per hectare	CSO (2010a)
Tr	Number of trips required	Calculated by authors
d	Amount of diesel consumed per km	Surveys
de	Heat content of diesel	IPCC (2007)
l_f	Average distance in km travelled per trip	Surveys
x	Amount of electricity consumed per hectare	Ramjeawon (2004)
x_p	% of land irrigated	CSO (2010a)
x_e	Heat content of one kWh of electricity	IPCC (2007)
x_m	Electricity used per tonne of sugar cane	Calculated by authors

Fertilisers, (f), include Nitrogen, Phosphorous and Potassium (NPK) and the amount used in one hectare of sugar cultivation in Mauritius are 138 kg, 50 kg and 175 kg respectively (Ramjawon 2004). Energy content for 1 NPK (f_k) is from the IPCC (2007). The amount of herbicides used per hectare of sugarcane (η) in Mauritius is 7.28 kg. The energy content (η_k) is taken from Ramjawon (2004, 2008).

All materials, fuels and other inputs (feedstocks) involved in the system are hauled by different transport facilities through different distances. The amount of diesel consumed per trip in the transportation of fertilisers and herbicides is 2.8 litre. The survey reveals that on average, distance travelled between harbour and the sugar cane field (l_f) is 55 km. The average distance between the fields and the factory is estimated at 15 km. The type of trucks which are used for fertilisers and sugar cane also differ. The two load factors have been taken into account to estimate the number of trips and eventually the amount of diesel consumed in the transportation stage. Data were collected through information exchange via personal interviews with officials from sugar factories, peer reviewed sources and educated assumptions and estimations. The heat content of diesel (*de*) is taken from IPCC (2007).

Given that not all cultivated land is irrigated, the energy consumed should reflect the proportion of land which is irrigated. In Mauritius, on average 25% of land is irrigated (x_p) and it is assumed that electricity is generated from fuel oil. Data were obtained from the Digest of Agricultural Statistics (CSO, 2010a) and from personal interviews with farmers in Mauritius.

Table 5 provides the energy consumed in the production process of ethanol. The distribution of energy among the different components is discussed in Section 5.

Table 5 Energy consumption for sugar-based ethanol in Mauritius

Energy consumption	MJ
Production of fertilisers	292.23
Production of herbicides	21.08
Transportation of fertilisers	1.96
Transportation of herbicides	0.04
Irrigation	2.7
Transportation of sugar cane to factory	59.12
Conversion of feedstock into ethanol	108
Total energy used (fossil + renewable energy)	485.01
Renewable energy credit	108
Total energy used (non-renewable)	377.01

Source: Authors' calculation from equations (1) to (14)

Given that there are two products from sugar cane, the economic-based method is used to calculate the apportionment ratio. With data on the price of ethanol and electricity sold to the grid, the economic value of the two products can be estimated. One tonne of sugar cane can provide 86l of ethanol, and the price of ethanol is taken to be Rs20 ($0.65 at exchange rate $US = Rs31). With an indicator of 125 kWh obtained from one tonne of sugar cane at a price of Rs3.9 ($US0.13) per kWh, the apportionment stands at 78% to ethanol. Based on the estimates, the amount of energy going to ethanol is 294.07 MJ per tonne of sugar cane and 3.42 MJ per litre. The study concludes the following energy indicators.

$$\text{Energy balance (EB)} = 21.2 - 4.04 = 16.80 \text{ MJ perlitre of ethanol}$$

$$\text{Net energy balance (NEB)} = 21.2 - 3.42 = 17.78 \text{ MJ per litre of ethanol}$$

Energy ratio (ER) = 6.19

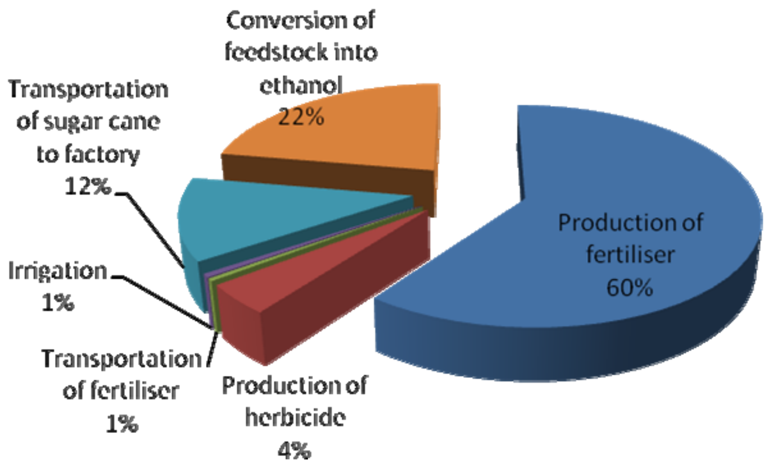
With an indication of energy balance, NEB and energy ratio, the following section provides a discussion of the results with a sensitivity analysis to show the main components which may impact on energy indicators.

5 Discussion

Figure 1 shows that 60% of total energy needed to produce ethanol is consumed by the production of fertilisers. This estimate can be compared with Ramjawon's (2004) life cycle assessment for sugar production which stands at 50%. Around 13% of total energy of the ethanol production system is used during the transportation phase of sugarcane from field to factory and that of fertilisers to the field. The production of fertilisers and transportation system therefore play a key role in determining the energy balance of ethanol. For a small island like Mauritius, the distance travelled depends on the size and location of the sugar factory. This component might be higher for countries producing feedstock and where the factory is located far from the sugar cane field. In fact, shorter distance is a must for sugar or ethanol to be economically viable. Consequently the transportation system may be the focus of policy consideration for raising the efficiency of ethanol production system.

The process to produce ethanol from sugar cane consumes about 22% of the total energy needed while irrigation uses only 1% of energy.

Figure 1 Energy balance (see online version for colours)



Source: Authors

5.1 Sensitivity analysis of energy indicators

Puppan (2002) concludes that the environmental life-cycle balance of ethanol is dependent on the agricultural climate conditions of the country. Energy efficiency varies strongly according to climate and production techniques. The Brazilian sugar cane yields around eight units bio-energy output from one unit fuel input into the production process (Goldemberg, 2008; Gold and Seuring, 2011). For the bio-ethanol energy system in Mauritius, the energy ratio is 6.19. An attempt is made in this section to analyse the sensitivity of the NEB and energy ratio following changes in the inputs used in the ethanol production chain.

Table 6 shows the changes in NEB and ER. The first row in Table 6 shows the effect of a fall in NPK used in sugar cane cultivation on NEB and ER. According to Macedo et al. (2008), Brazil uses 48 kg of Nitrogen per hectare; 117 kg of Phosphorous per hectare, and 125 kg Potassium per hectare. This makes 290 kg of NPK, around 20% fall compared to the Mauritian climate system. Applying the rate of NPK of Brazil in the present system analysis, *ceteris paribus*, the NET and ER will rise to 18.31 MJ and 7.33 respectively. The figure approaches the ER of Brazil as indicated by Gold and Seuring (2011).

Herbicides are used at the rate of 7.8 kg per hectare in Mauritius. In Nepal and Brazil, the rate is 1.65 kg per hectare and 2.2 kg per hectare respectively (Nguyen et al., 2008; Khatiwada and Silveira, 2009). A 20% decrease in herbicides would raise the NEB to 17.81 MJ. If the rate at which fertilisers are applied in Brazil is considered in the analysis, *ceteris paribus*, the NEB will increase to 17.91 MJ and ER to 6.45.

Table 6 Simulation on energy efficiency indicators

	Net energy balance	*Energy ratio*
Fertilisers and herbicides in sugar farming		
20% reduction in NPK	18.31	7.33
20% reduction in herbicides	17.81	6.26
Transportation of fertilisers and herbicides		
Average distance 100 km	17.76	6.15
Average distance –150 km	17.74	6.13
Transportation of sugar cane to factory		
Average distance 30 km	17.21	5.34
Average distance 60 km	16.15	4.19

Source: Authors

The transport stage is also a major determinant of energy efficiency of ethanol production system (Chavanne and Frangi, 2011). Table 6 shows the impact of changes in average distance of transportation of farm inputs to cane cultivation and the cane to factory. Ethanol distribution from the factory to the fuel dispensers is not accounted within the system boundary of this study. The calculated NEB and ER reflect the average distance travelled in Mauritius for the transportation of fertilisers and herbicides to cane field and for the transportation of feedstock to factory. If the average distances for the transportation of fertilisers and herbicides were 100 km and 150 km respectively, the change in NEB and ER as shown in Table 6 is marginal. However, the change in average distance of transporting sugar cane to factory to 30 km decreases the NEB to 17.21 MJ with an ER of 5.34. With an average of 60 km, the figures for NEB and ER decline to 16.15 MJ and 4.19 respectively. An important finding is that while the centralisation policy in the reengineering stage of the sugar sector in Mauritius has led to fewer sugar factories and reduced costs, this affects negatively efficiency indicators of ethanol production system. This aspect is important because policies and strategies geared towards competitiveness and those towards environmental sustainability may not be consistent. A holistic perspective taking into account the environmental, economic as well as the social issues is therefore essential in the development of ethanol from sugar.

5.2 Fuel saving potential and other benefits from sugar-based ethanol in Mauritius

Mauritius imported around 118,000 tons of gasoline, equivalent of 4,900 million MJ in 2010 (CSO, 2010b). With a policy of E10 (90% gasoline and 10% ethanol), the total amount of gasoline which may be substituted, stands at 490 million MJ or 15 million litres of gasoline. Given that 1 litre of ethanol has an energy content of 21.2 MJ, the fuel substitution policy (E-10) would lead to the consumption of 23 million litres of ethanol in the transport sector. To produce such level of ethanol, the ethanol production system utilises 3.42 MJ per litre, which implies a total energy content of 78.7 million MJ. Fuel saving is estimated at 411 million MJ. This takes into account the rise in diesel, fuel oil, electricity and other types of fossil fuels in the production phase of ethanol. If ethanol is blended with gasoline at a proportion of 10% by volume of fossil fuels for transportation, given a price of Rs25505 per tonne of gasoline, this could lead to saving of Rs 390 Million ($13 M) in terms of foreign currency.

A 100% use of an ethanol could be envisaged on a long term basis as in Brazil. This would replace totally the gasoline fuelled vehicles in Mauritius, the savings in terms of foreign currency would be Rs3000 million ($US100 million) and the rest of the production could be exported generating an additional revenue in foreign currency of an amount of Rs3600 million ($US120 million).

Moreover, given the current amount of land for agriculture, the total amount of ethanol that could be produced in Mauritius is 375 million litres (ML). At a price of Rs20 (US$0.67) per litre, the total revenue from the sale of ethanol is Rs7509 million (250 M$). This can compared to the revenue of Rs 6787 M (226 M$) for sugar exports. The production of feedstocks involves the same cost components as sugar production, with the ethanol conversion phase being the only component which would lead to difference in costs when producing ethanol. While such conversion costs are no available, economic reasoning does justify the production and exports of ethanol as alternative of sugar exports. Moreover, since the island is not using forest lands or is not converting food crops into ethanol feedstock, there are no opportunity costs in the assessment. It is also expected that converting sugar into ethanol will lead to a 25% increase of electricity generated. In Mauritius, excess electricity generated through bagasse is exported to the Central Electricity Board at a predetermined price. This would give an additional revenue of about Rs 335 M.

Options to reduce the use of fossil fuels in producing fertilisers or to shift from chemicals to organic fertilisers would contribute to lessening fossil fuel content of ethanol production processes. This conclusion can also be linked to the movement towards a ‘Green Economy’ which emphasises organic inputs rather than chemicals in the production of agricultural products. A green economy, according to the UNEP, is one that results in improved human well-being and social equity, while significantly reduces environmental risks and ecological scarcities (UNEP, 2011). The transition to the green economy necessitates the promotion of patterns of production that are resource and energy efficient, low carbon and low waste, non-polluting and safe (UNIDO, 2011). The production of fertilisers and herbicides provide an important avenue for intervention in terms of clean technologies which eventually may increase the efficiency of bio-ethanol production system.

Bio-ethanol can also be used to build the synergies for cooperation and technological transfer between North-South as well as South-South group of countries. Sustainable energy technology transfers in mitigating climate change from industrialisation countries to developing are formulated in Article 4.5 of the UNFCCC (Van der Gaast et al., 2009). Project cooperation between the two groups of countries takes place under the clean development mechanism (CDM) which officially became operational since 2000. CDM projects typically result in a transfer of GHG abatement technologies to developing countries in exchange for the GHG emission reduction credits. The rules governing the CDM were finalised in 2001, during the 7th Conference of the Kyoto parties. The contribution of the project to reduce emissions entails the issuing of certificates, certified emissions reductions (CERs), which can be traded internationally after proper validation of the project, and verification of the emissions reductions achieved (Silveira, 2005). The use of specific list of sustainable development criteria is important for selecting CDM projects. Given the positive aspect of sugar-based ethanol, the CDM scheme could then serve to attract part of the investments necessary to develop the ethanol project in Mauritius and implement the fuel substitution policies. The result can also be used to develop further sustainable criteria to form part of the norms of CDM projects.

6 Policy implications and conclusions

The study attempts to estimate three basic indicators to evaluate the efficiency of a sugar-based ethanol production system for Mauritius. The NEB is therefore positive since it uses only 3.42 MJ of fossil fuel to produce 21.2 MJ renewable energy. The energy ratio is estimated at 6.19, implying that for every one unit of fossil fuel consumed, the system returns more than six times in terms of renewable energy from ethanol.

A simulated exercise is undertaken to analyse the sensitivity of the efficiency indicators to changes in the characteristics of the production chain system. It is found that that the indicators are sensitive to the use of fertilisers and hence climatic conditions have a role to play in determining efficiency of ethanol production system. It is also observed that the transportation of sugar cane to factory is fuel intensive and affects efficiency indicators. Hence, land use and transport policy could be factors to take into account for future energy development. The strategy of centralisation in Mauritius has resulted in fewer sugar factories and lower cost of production but at the expense of an increase in average transportation distance between sugar cane field and the factory gate. This eventually leads to higher energy consumed and affects the energy balance of ethanol production. Hence, there may be inconsistencies between economic competitiveness and environmental sustainability unless a holistic perspective including the economic, environmental and social issues are taken into account. To enhance the efficiency of bio-ethanol production system, given the climate conditions, the supply chain management are emphasised. The use of organic fertilisers as proposed by the concept of a green economy and other clean agricultural practices can be an important strategy to enhance energy efficiency of bio-ethanol production system. Greener inputs are therefore consistent with ethanol development.

The energy indicators can consequently be used to estimate potential fuel savings. The analysis concludes that fuel saving when the E-10 policy is implemented is estimated at 411 million MJ, taking into account the rise in diesel, fuel oil, electricity and other types of fossil fuels in the production phase of ethanol. Mauritius can make other economic benefit such as saving on gasoline imports and foreign exchange which may improve the balance of payments in favour of the island. The excess ethanol can also be exported and with the rising of its price in the world – significant gains from trade can be achieved.

The finding of this paper opens important opportunities for Mauritius to participate in the Kyoto Protocol's Clean Development Mechanism. As discussed previously, the indicators derived in this study can be used in the design of criteria and norms for the transfer of technology and may assist in ethanol development project at an international level.

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