Energy footprint of locally produced bioethanol in Kenya

Working Paper

April 2013

Prepared for the PISCES Consortium by the University of Edinburgh

Although this research is funded by DFID, the views expressed in this report are entirely those of the authors and do not necessarily represent DFID's own policies or views. Any discussion of their content should therefore be addressed to the authors and not to DFID.

Author: Ebelechukwu Chiatula
Reviewers: Colin Pritchard (University of Edinburgh)
Editors: Mattia Vianello (Practical Action Consulting)
Main image: Beryl cooks a simple meal of rice, it takes her only 20 minutes on this Bioethanol Stove (J.Oliver/ Practical Action)

Acknowledgements:

Special thanks to Bilha Eshton, Nelson Gwaya, John Kapolon and Tameezan wa Gathui

List Of Acronyms

GDP	Gross Domestic Product
GHG	Green House Gas
HDI	Human Development Index
LCA	Life Cycle Assessment
MDG	Millennium Development Goal
SSA	Sub Saharan Africa

Abstract

The aim of this study was to conduct a lifecycle analysis of the direct and indirect energy inputs and outputs flowing through a bioethanol pathway in Kenya, using the life cycle energy assessment technique and energy performance indicators. The study was performed in western Kenya, and data was obtained from Mumias Sugar Company and Spectre International ethanol distillery. Fertilizers made up the largest share of energy inputs, while industrial chemicals were the lowest. Indirect inputs had a larger impact on the energy balance because of co-generation of electricity and steam by bagasse and biogas.
The energy ratio of the system was 1.5 MJ of ethanol produced per MJ of net energy inputs. The total energy consumed in the system was 13.6 MJ of inputs per litre of ethanol produced. The primary energy ratio which takes into account only the primary energy use is much higher, at about 4.2 MJ of ethanol produced per MJ of fossil inputs.
The wider implications of the findings are discussed, and suggestions made as to how to improve the results of this assessment. The significance of biofuel assessments to decision making is also discussed.

Contents

Table of Figures

Energy and Development

Energy evidently has a relationship with development; and although this relationship is not clearly understood, there is some correlation between them. The development community has recognised that providing modern energy services is fundamental in ensuring poverty reduction and sustainable human development. Although the Millennium Development Goals (MDG) do not address energy directly, some of the MDG indicators acknowledge issues relating to energy security and its importance to human development, eg:

MDG # 7.1 Proportion of land area covered by forest
MDG # 7.2 CO2 emissions, total, per capita and per $1 GDP

Traditional biomass is used by up to 50% of the global population and by over 60% of the population in Sub Saharan Africa (AGECC, 2010)(1), though it is has several disadvantages. Yet about 70% of the food we eat needs to be cooked before eating, and in most households cooking is the most energy consuming activity (PPEO, 2010)(5).

Figure 1, illustrates the relationship between the human development index (HDI) and energy consumption of selected countries. This shows that some countries with low HDI also have low energy consumption; some of these countries are in SSA and Asia. However, as the HDI rises, energy consumption varies more between countries.

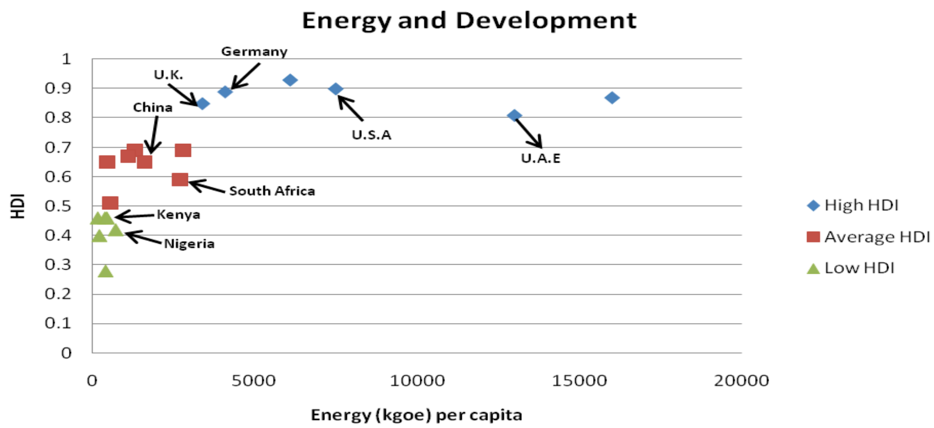

Figure 1: Relationship between Energy consumption kilograms of oil equivalent (kgoe)[3] and HDI

Source: Energy consumption (World Bank, 2008: http://data.worldbank.org/indicator/EG.USE.PCAP.KG.OE/countries)

HDI statistics (UNDP, 2010: http://hdrstats.undp.org/en/indicators/49806.html)

If funding priorities are focused on clean energy, on recent widespread innovations in energy technology and on supporting market systems, then achieving the energy goals will increase the chances of attaining the MDGs, However, there are several barriers to achieving these energy goals including technological, institutional, cultural and socio-economic barriers.

3 Energy use refers to use of primary energy before transformation to other end-use fuels, which is equal to indigenous production plus imports and stock changes, minus exports and fuels supplied to ships and aircraft engaged in international transport (World Bank, 2010).

Household Energy and the MDGs

Two popular traditional fuel sources for household use are firewood and charcoal. In 2008, these contributed about one-tenth of the global energy supply (Sims et al 2010 (9)). Wood combustion is assumed to be responsible for about 23% of global emissions of black carbon (Bond 2010, in PPEO, 2010 (5)) and collection of wood for fuel accounts for almost 50% of all removed wood (Dubois et al 2010 (10) and PPEO, 2010 (5)); but about 3 billion people rely on biomass for basic energy services. In Kenya, for example, it is estimated that about 60% of its population rely on biomass (predominantly wood and charcoal), but the demand is about 2.5 times the available sustainable supply (PPEO, 2010(5)). Statistics show that, modern energy is unevenly available across regions.

It is common cultural practice that predominantly women and children are in charge of preparing family meals; this makes them also responsible for gathering or purchasing the fuel used. Gathering firewood requires an average of 4-6 hours per day for households in remote locations, leaving less time in the day to do other activities. For children this means that school related activities are decreased (PPEO, 2010(5)). Due to the close relationship energy services have with other MDGs, it would be difficult to achieve the MDGs without addressing the issue of energy poverty (Modi et al 2006 (11)).

Demerits of Traditional Cooking Fuel Sources

Health Risks

People who depend on biomass are exposed to the possible danger of physical harm (burns and fires) and health related issues as a result of indoor air pollution. This has resulted in high mortality, especially for women and children who lack adequate access to health care (UNDP/WHO, 2009 (12)). Also, the inefficient technology used for cooking means that more biomass is used than required, depleting the wood resources. The environmental and health consequences to immediate communities and wider society of the continued use of biomass indoors and in inefficient arrangements are grave.

Institutional Issues

Rural households suffer the most from poor energy services (PPEO, 2010(5)) and the rural community has a higher concentration of people without access to modern energy services. However, so far there has been no extensive research into the energy system of the rural communities or to what extent the national efforts on improving energy access affect their lives (PPEO, 2010(5)). The lack of institutional support experienced by most traditional fuel users makes it difficult to harness or to access knowledge that can help improve their energy security.

Environmental Issues

There are several factors putting pressure on the biomass resources available, but climate change and environmental degradation could have high impacts on people with poor energy access since they lack the capacity to adapt (Chum et al 2011 (14)). But education on sustainable harvesting and improved cooking technology could help build their adaptive capacity (PPEO, 2010(5)).

Economic and Social Issues

Traditional biomass is only about 30% efficient with current technology (Sims et al 2010 (15)).Traditional biomass does not provide adequate lighting or mechanical power, and these two energy services are paramount for achieving better socio-economic status in a community (PPEO, 2010(5)). Lighting could provide additional hours after dark for hospitals, schools and business, boosting the local economy and providing social comfort. Mechanical power is needed on both a large and small scale for production; rural and small scale businesses will need large amounts of wood resources. The unavailability of affordable efficient mechanical power cripples the effort of developing local economies and, this directly affects the poverty levels (PPEO, 2012 (5)). Despite these disadvantages, it has been reported that many people still prefer to use wood-fuel for cooking, because feedstock supply is cheap and accessible, and the technology (i.e. the pots and cook stoves) is easily produced locally (Murren et al 2006 (13)).

In this study, an energy impact assessment is conducted on bioethanol household fuel produced to combat the issues of overexploitation of wood fuels, and indoor air pollution. Other impact assessment categories include greenhouse gases, biodiversity and land-use change. One popular criterion of assessment is the primary energy demand (Fritsche et al 2010 (16)). Primary energy demand is a measure of the amount of primary non-renewable energy (3) consumed for every unit of bioenergy produced (Fritsche et al 2010 (16)). This implies that the less primary energy is needed to produce biofuel, the better.

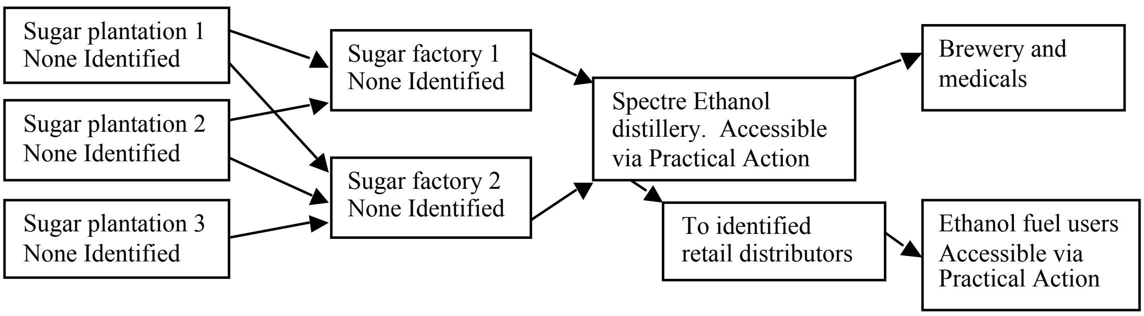

Figure 2: Bioethanol pathways traced in this study

- The global energy system has biomass and renewables as part of the mix, but together they satisfy only around 13% of global energy demand (1).
- Biomass is used by about half the world's population at the household level, especially for cooking and lighting (2).
- Energy consumption per unit of GDP is expected to grow within the next few decades, especially in developing countries (3).
- Brazil has developed an economicall y successful biofuel industry, which however still has problems regarding competition with food and destruction of significant ecosystems and biodiversity (4).
- The energy industry is under threat from inconsistent and unstable supply/price of fossil fuels, peak oil, pressure to decrease GHG emissions. Biofuels offer an opportunity to make the system more robust.

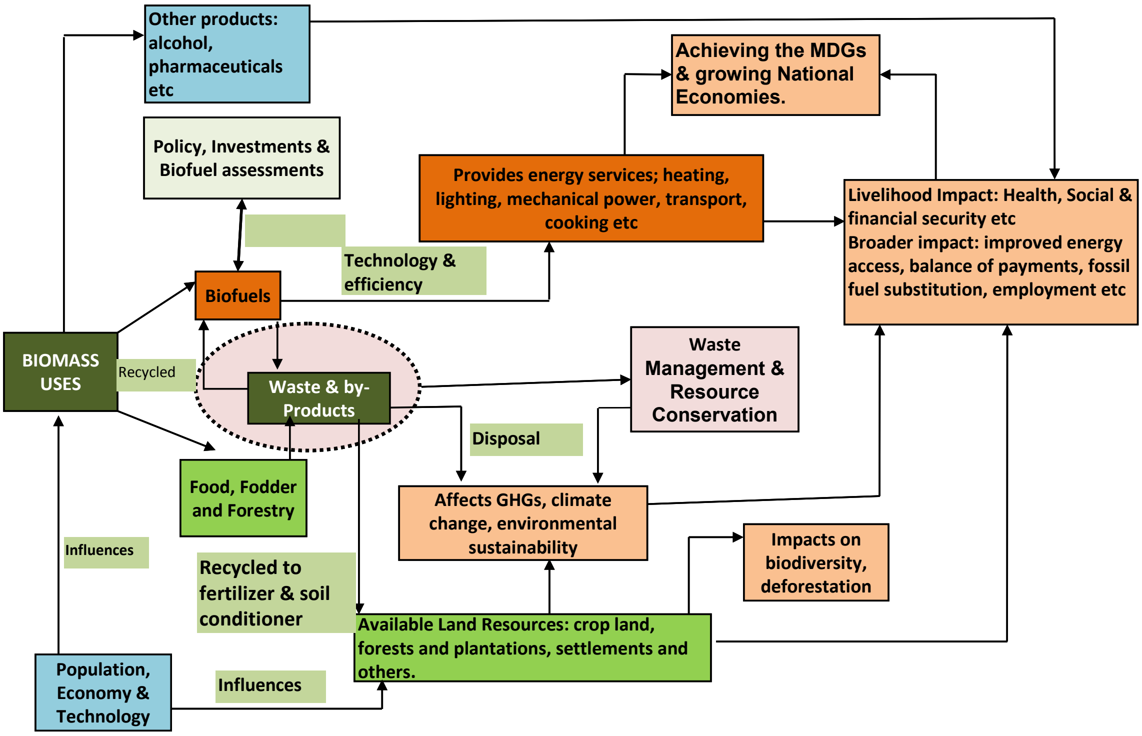

Figure 3: Concept loop diagram: Relationship between biofuels, energy services & human development

Source: Adapted from Utria 2004. "Ethanol and Gel fuel: Clean Renewable Cooking Fuels for Poverty Alleviation in Africa", Energy for Sustainable Development, volume 8, No. 3, pp 107-115.

Biofuel for Cooking in Kenya

- Biofuels derived from waste molasses could replace wood fuels and could result in:
  i. a decrease in deforestation rates
  ii. improved health and social conditions (by reduction in indoor air pollution)
  iii. preventing the use of food crops and croplands for direct energy production
  iv. a waste management strategy for the sugar industry
  v. enhanced economic or business opportunities; and much more (5).
- The molasses from one tonne of sugar through this pathway is estimated to yield about 7 litres of ethanol.
- Production of ethanol however itself consumes energy; so is it worthwhile to use this extra energy to produce a clean fuel, ethanol?
- Used exclusively for fermentation, one tonne of sugar could yield 70-95 litres of ethanol (6);
- The energy cost of producing ethanol by either means is critically dependent on the way in which the energy costs of agricultural inputs are assigned to each starting material (sugar, molasses). Two suggested methods of allocation are:
  1. Tonnage basis (the fermentable solids content of molasses is around 10% of sugar production)
  2. Value basis (alternative uses of molasses as e.g. animal feed currently have very low value, so on this basis most energy costs will be attributed to sugar production).
- In the tables that follow we have used tonnage of sucrose as the basis. (Rosenchien and Hall 1991(7)). On this basis, 13.2% of the total net energy in the farming and sugar processing (molasses generation) phases is attributed to the ethanol produced; while in fermenting and distilling ethanol, 85% of the energy is allocated to ethanol production (there are losses due to system inefficiencies and conversion to co-products.)

- Note that the requirements for ethanol as a cooking fuel (which may contain some water) are less stringent than those for ethanol for blending as a transport fuel (for which purpose it must be dehydrated at a substantial additional energy cost). Cooking ethanol and ethanol motor fuel should be regarded – and priced – as separate products

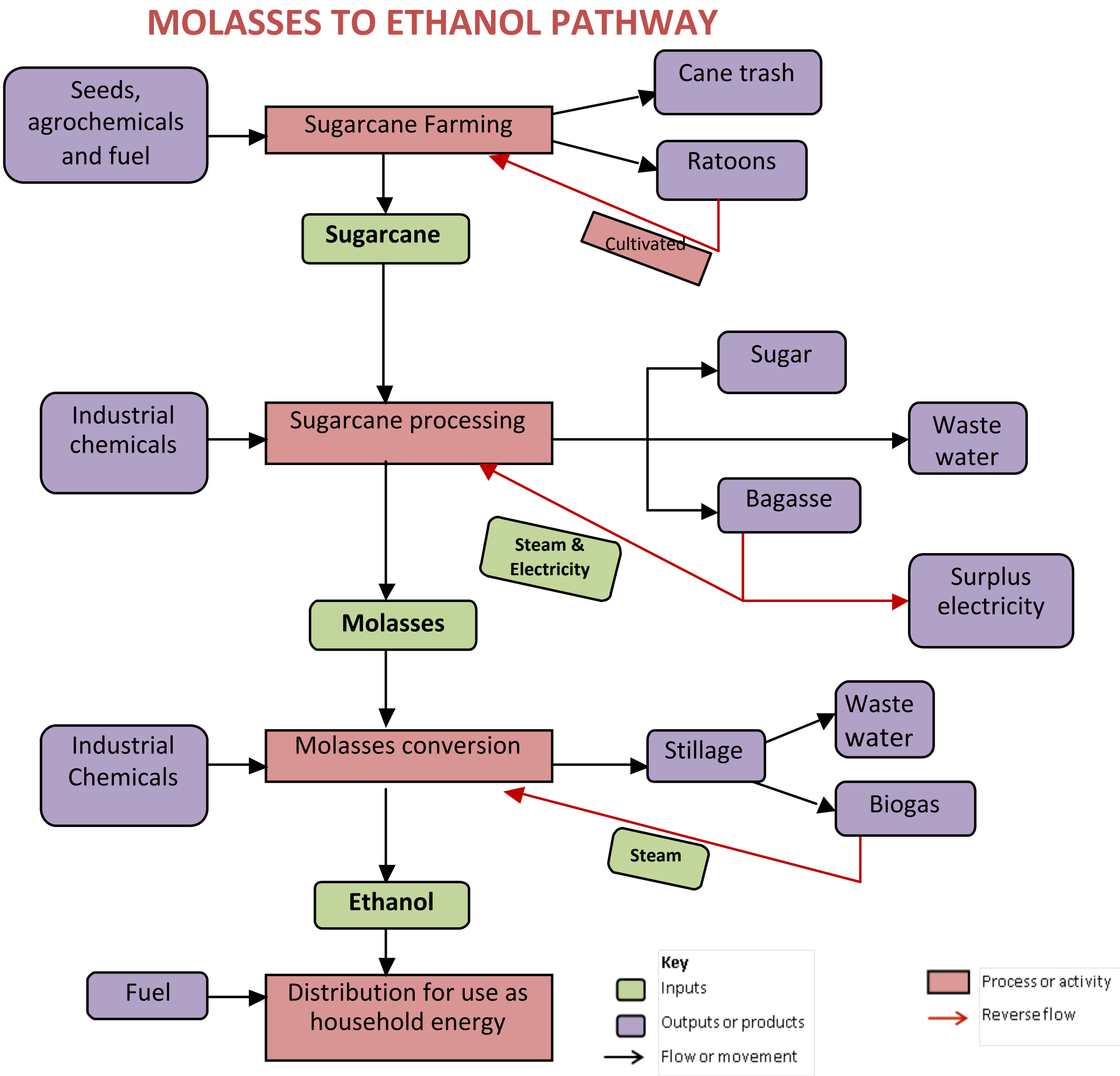

Figure 4: Cradle to Grave of Molasses to Ethanol Biofuel Pathway

Source: Gwara, and Murabwa, 2011, Personal Communication

Spectre International:

Left: Ethanol rectification and dehydration columns

Above: Effluent treatment ponds

Figure 5: Spectre International

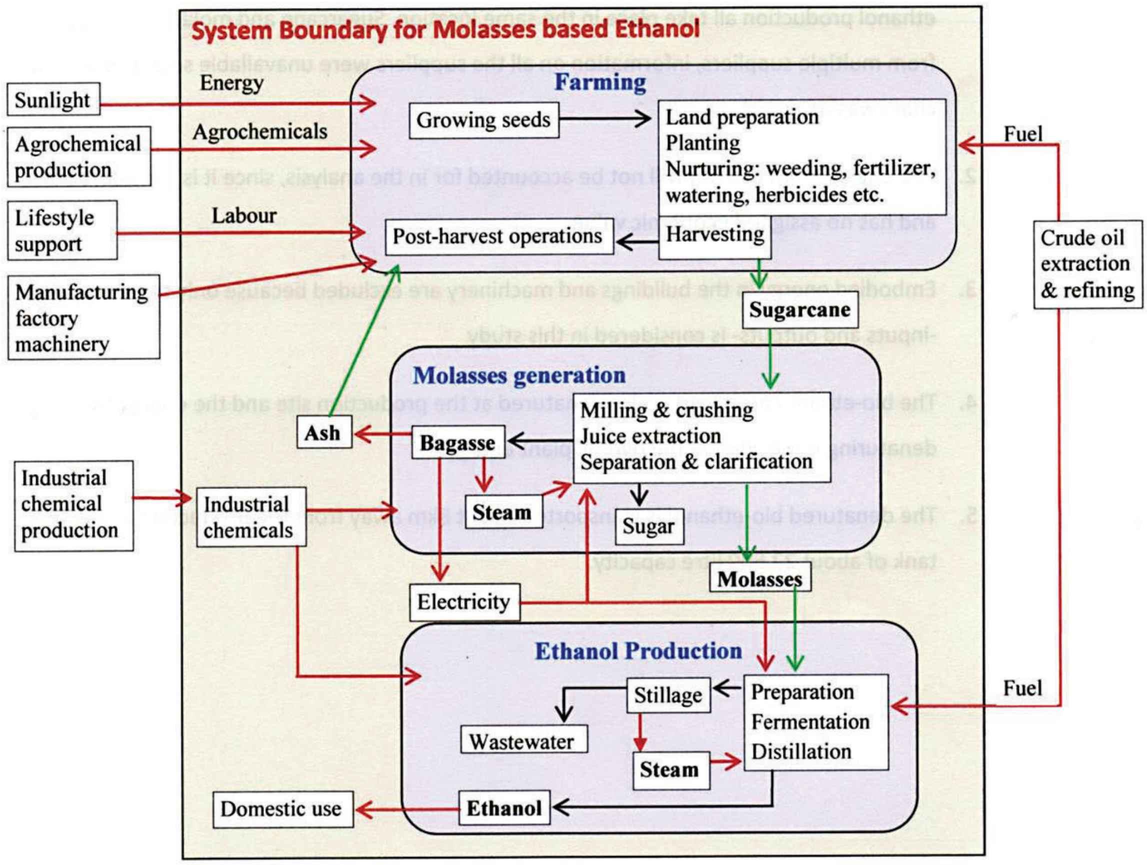

Figure 6: System boundary for Molasses-based Ethanol

Source: Gwara, and Murabwa, 2011, Personal Communication

Methodology: The ISO 14040 guide on life-cycle assessment was used to analyse the value chain; and previous authors' techniques for energy performance were adopted for analysing ethanol.

- The data used for the study were taken from the Government of Kenya 2009 databank.
- All the material and direct energy inputs and outputs were evaluated then converted to the functional unit of Megajoules per litre (MJ/L) of ethanol at 95.6% v/v.

Units are MJ per litre of 95.6% ethanol

Item (allocated on a sucrose content basis)	Input	Output	Contribution	
Sugarcane cultivation (86.2%)				
Fertiliser		4.9		
Agrochemicals		0.7		
Diesel		1.5		
Seedlings		0.2		
Total energy demand		**7.3**		
Net energy consumed		7.3		**7.3**
Sugarcane processing for molasses generation (13.2%)				
Electricity and steam		41.3		
Electricity export			64.9	kWh/te attributed to sugarcane
Chemicals for effluent treatment				
Fuelwood for startup		0.5		
Bagasse used (0.6%)			52.3	
Total energy demand		**41.3**		
Net energy consumed		0		**0**
Ethanol fermentation & distillation (85%)				Stillage accounts for the balance 15%
Electricity		3.4		
Chemicals for effluent treatment		0.2		
Heavy fuel oil for steam generation		2.9		50% HFO, 50% biogas
Biogas for steam generation		2.9		
Biogas generated			2.9	
Total energy demand		**9.4**		
Net energy consumed		6.5		**6.5**
Overall net energy consumed				**13.8 MJ/L ethanol**
Attributable energy if molasses is considered a waste byproduct of sugar				**6.5 M J/L ethanol**
Fuel value of ethanol				**20.6 MJ/L ethanol**

Table 1: Energy use in growing sugar and converting molasses to ethanol

Basis: tonnage of sucrose

Source: Gwara, and Murabwa, 2011, Personal Communication

Notes to Table 1:

- The percentages given in parentheses are the proportion of inputs/outputs attributable to the ethanol product
- Agricultural inputs in sugar-growing have major energy implications.
- Bagasse is used as fuel for steam raising and power generation: surplus power is exported - but not credited to ethanol.
- Molasses fermentation to ethanol, and ethanol distillation, are evaluated as offsite operations: the effective net energy use in these steps is the electricity and fuel oil used.

Analysis

- Cultivation of sugarcane contributed the largest share of energy demand, followed by the ethanol conversion phase; the sub-unit with the least demand was molasses generation.
- The multiple requirements for energy inputs imply that ethanol production is energy-intensive.
- The Energy Ratio is 1.5 MJ of ethanol for every MJ of inputs, and total energy gains are about 7MJ/L of ethanol.

Limitations of this energy analysis

A full Life Cycle Assessment (LCA) would include the energy used in producing the capital goods used in the production, distribution and use of ethanol - for example in the manufacture of the process plant and vehicles, containers and cookers; and in creating and maintaining the plantation roads. Of course many of these inputs will be required no matter what the fuel source may be; and although these will make a significant contribution to the total energy invested in bringing ethanol to households, we have insufficient data to make a realistic estimate.

However the greatest impact on the overall energy efficiency is the efficiency with which fuel is used in the cooking: is the flame fully controllable? Are cooking pots lidded or stacked? Are hayboxes used for slow cooking?

Furthermore, in order to fully model the environmental consequences of an increased bioenergy demand caused by a major sugar/molasses to ethanol programme, it would be necessary to use a methodology that has been developed to assess the worldwide land use changes occurring as a response to the dedication of existing agricultural land to energy crops. Such land use changes are also referred to as "indirect land use changes" and have a greenhouse gas implication that must be included in the LCA if there is to be a complete carbon balance.

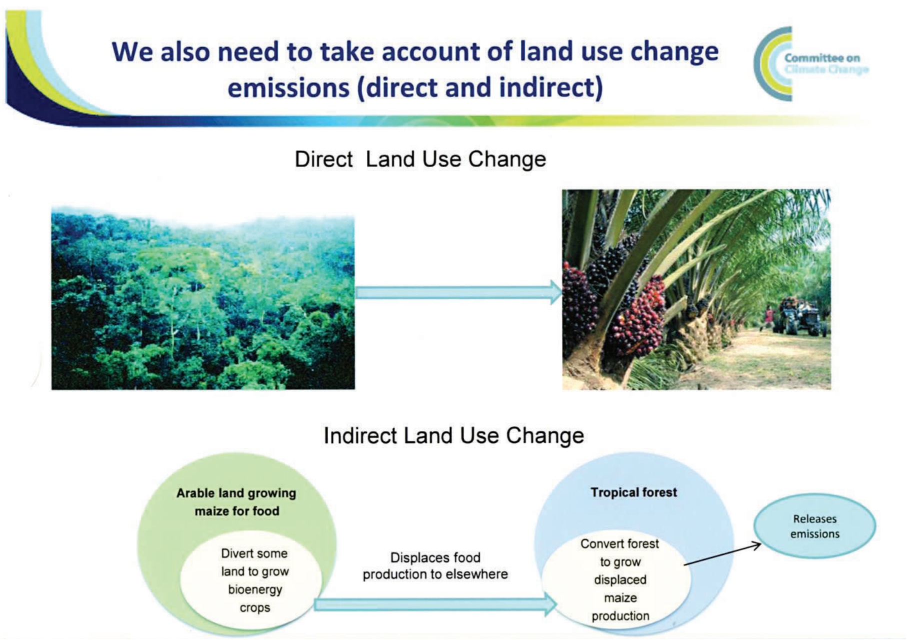

Figure 7: Land use change and GHG emissions
Source: Bioenergy Review, UK Committee on Climate Change, 2011

Conclusions

- The energy assessment of biofuels exposes gaps and added benefits that may not otherwise be readily identified; and this allows informed decisions to be made on biofuel development.
- Though the energy analysis was favourable (fuel value of ethanol is 1.5 times that of the net energy inputs), there is scope for improvement: for example optimising the biogas use for steam, electricity and fertiliser rather than just for steam, thereby decreasing the need for fertiliser imports; and energy recovery in distillation.
- A more detailed assessment should consider other impacts such as import substitution, indirect land use change, social impacts, GHGs, ecosystem services, water use; and particularly the efficiency of the cookstoves and cooking systems in use.

Appendix: Comparison with ethanol production from molasses in Thailand (8)

- The energy value added in this study is more than twice as high than in Thailand (molasses to ethanol pathway), though the energy ratio is not much higher; but the system boundaries and the activities of Kenya's case and Thailand's case are slightly different:
- In particular, the major source of energy for processing plant activities in Kenya is from bagasse, while that in Thailand was from both fossil and non-fossil fuels.
- Co-generation of electricity and steam from bagasse and biogas favours the Kenyan energy analysis positively.
- Fertiliser inputs, technical efficiency and degree of farm mechanisation all have a major impact on the results of energy analysis in this study.

References

1- 4 AGECC report, 2010. The Secretary General's Advisory Group on Energy and Climate Change.
5. Poor People's Energy Outlook, 2010. Practical Action.
6. Kaplinsky, R. 1987. Cane sugar: The Small Scale Processing option. London, IT Publications 1989.
7. Rosenchein, A.D. and Hall, D.O. 1991. Energy Analysis of Ethanol Production from Sugarcane in Zimbabwe. Biomass and Bioenergy, 1 (4): 241- 246.
8. Nguyen T. T., Gheewala S. H., Garivait W., 2008. Full chain energy analysis of fuel ethanol from cane molasses in Thailand. Applied Energy (2008) 85, 722-734.
9. Sims, R., P. Mercado, W. Krewitt, G. Bhuyan, D. Flynn, H. Holttinen, G. Jannuzzi, S. Khennas, Y. Liu, M. O'Malley, L. J. Nilsson, J. Ogden, K. Ogimoto, H. Outhred, Ø. Ulleberg, F. van Hulle, 2011. Integration of Renewable Energy into Present and Future Energy Systems. In IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation [O. Edenhofer, R. Pichs-Madruga, Y. Sokona, K. Seyboth, P. Matschoss, S. Kadner, T. Zwickel, P. Eickemeier, G. Hansen, S. Schlömer, C. von Stechow (eds)], Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.
10. Dubois O., Bogdanski A., Jamieson C., and Krell R., 2010. Making Integrated Food-Energy Systems (IFES) Work for People and Climate. Food and Agricultural Organisation of the United Nations Rome.
11. Modi, V., S. McDade, D. Lallement, and J. Saghir. 2006. Energy and the Millennium Development Goals. New York: Energy Sector Management Assistance Programme, United Nations Development Programme, UN Millennium Project, and World Bank.
12. UNDP/WHO 2009: The Energy Access Situation in Developing Countries. A Review on the Least Developed Countries and Sub-Saharan Africa. Available from: http://www.undp.org/energy. Accessed: 7/5/2011.
14. Chum, H., A. Faaij, J. Moreira, G. Berndes, P. Dhamija, H. Dong, B. Gabrielle, A. Goss Eng, W. Lucht, M. Mapako, O. Masera Cerutti, T. McIntyre, T. Minowa, K. Pingoud, 2011. Bioenergy: In IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation (Ref 9).
15. Sims, R., P. Mercado, W. Krewitt, G. Bhuyan, D. Flynn, H. Holttinen, G. Jannuzzi, S. Khennas, Y. Liu, M. O'Malley, L. J. Nilsson, J. Ogden, K. Ogimoto, H. Outhred, Ø. Ulleberg, F. van Hulle, 2011. Integration of Renewable Energy into Present and Future Energy Systems. In IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation (Ref 9).
16. Fritsche U. R, Klaus J. H., Wiegeman K., Herrera R., Bernd Franke, Susanne Köppen, Guido Reinhardt, Veronika Dornburg, André Faaij, Edward Smeets. 2010. Bioenergy Environmental Impact Analysis (BIAS): Analytical Framework. FAO: Food and Agricultural Organisation of the United Nations Rome.

Policy Innovation Systems for Clean Energy Security (PISCES)

Through action research, the PISCES project is contributing to innovation and providing new policy-relevant knowledge on bio-energy - leading to better practices and widening energy access to the rural poor in East Africa and South Asia. It is the energy Research Programme Consortium funded by the UK's DFID, whose members include ACTS (lead), Kenya; PAC-UK, Eastern Africa, and Sri Lanka; the University of Dar es Salaam, Tanzania; M.S. Swaminathan Research Foundation, India; and the University of Edinburgh, UK. For more information contact project manager Bernard O. Muok at b.muok@acts.or.ke and visit www.pisces.or.ke

The University of Edinburgh

The University of Edinburgh works with PISCES through two of its research institutes: the Institute for Energy Systems (IES), and the Centre of African Studies (CAS). IES has a long involvement with energy and environment related projects in developing countries. It has active awards in renewable energy research totalling £17m+; co-hosts the UK Energy Research Centre; and conducts road-mapping on R&D requirements for future energy technologies. CAS is an internationally recognised centre of excellence in research on Africa, and has a history of working with DFID. Visit: www.see.ed.ac.uk/research/IES/ and www.cas.ed.ac.uk

Practical Action Consulting (PAC)

Practical Action Consulting is the dynamic consulting arm of international development and technology charity Practical Action. Sharing over 40 years of international expertise, Practical Action Consulting provides independent and professional consulting in the use of technology for poverty reduction to governments, NGOs, aid agencies & the private sector.

www.practicalaction.org/consulting