Bio-fuel as a case to discuss sustainable development

Morris Thompson

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Biology Education Centre, Uppsala University, and Department of Urban and Rural Development, Swedish University of Agriculture, Ultuna, Uppsala
Supervisor: Professor Torbjorn Rydberg
Abstract

Since the first prophesy of peak oil by M Hubbert in the 1950s many developed nations have been searching to establish energy systems based upon renewable energy such as bio-energy. The push towards using energy crops to fulfill the global endeavors to establish a renewable energy system has provoked debates around the possible pending crisis; regarding the battle between land available for food production for human and animal consumption and land to make fuel. This “pending crisis” has put into motion the wheels of scientific and political discourse thus far (FAO- right to food discourse).

Before the start of this open and public discourse, the nation of Sweden has thrown out the gauntlet so to speak, to the future of sustainable energy use. The government has since, 2005 committed the nation to be virtually fossil fuel free by 2020.

Central to the discourse is the need to evaluate the benefits versus the cost of using bio-energy crop to make bio-fuel. This means a need for in-depth evaluation; hence the need for a tool that can perform a complete evaluation of the impact, without discounting any part of the production process. The environmentalist, and researcher, H T Odum devised one such tool that could evaluate as close as possible the energy process. This evaluation would take in consideration, the entire input of energy in creating the input source, to the point of getting an output supply of energy from the source in question.

This methodology is known as EMERGY analysis and this will be explored in-depth in the course of this dissertation. This is to provide a platform upon which the push towards bio-energy sufficiency can be carefully be explored.

Keywords: Energy, fuel, Net Energy Analysis, Emergy, Exergy, Sustainable, Sweden
Acknowledgments

“A wise man will hear and increase learning, and a man of understanding will attain wise counsel” The Book of Proverbs 1: 5 (NKJV).

It is most fitting I start off my acknowledgements using the wise word of Solomon, who encourage he whom is of understanding and desires to increase in learning to do so by the attainment of wise counsel. Hence I who sought and continue to seek wisdom and understanding, must say THANK YOU, to the following counsel below; who have made possible the two years Swedish journey of life’s learning.

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1. Introduction

In March 2007 the International forum on bio-fuel met in Brussels to promote compatibility standard worldwide. Standards which are supposedly to promote bio-fuel use worldwide and helping exporters and importers avoid adverse trade implications. With this push towards making the bio-fuel the fuel of choice as inferred on the US department of government website “America cannot sustain the level of bio-fuels production needed to meet our future energy requirements if we do not expand our ethanol production beyond food stocks like corn. We must move to the next level.”

Similarly the European Union policy on bio-energy pushes for a 20% share of energy consumption in the European Union (EU) to come from renewable energy; with 50% of this 20% of renewable energy accounted for by bio-fuel by 2020. This is to fit in the renewable energy policy of the EU Policy. The question to be asked is what is the next level beyond food stocks like corn and will it ever be sustainable?

Caution from the Food and Agriculture Organization (FAO) has been encouraging. Where a call of caution was made to remind policy makers not throw caution to the wind, in the pursuit of a new “global” energy source; instead for consideration to be given to important parameters in the search for a bio-fuel source. The FAO outlined in a study entitled, “The right to food and the impact of liquid bio-fuel” the following to be considered carefully:
1. Impact of price increases; 2. Land concentration and evictions; 3. Harmful structural transformation of agriculture and land holding; 4. Competition for water; 5. Environmental harm.

Similarly in a 2008 briefing paper the Overseas Development Institute outlined the impact that bio-fuel will have on developing countries and encourage the European to revise their policies towards poorer nation.

It is in view of what seems to be the mad rush towards a bio-fuel “sufficient” world this research paper is written, to bring about contemplation as encouraged by the FAO study; to look at the true impact of the increase conversion to bio-fuel use; to introduce the methodology call Emergy in understanding the true cost to making bio-fuel, fuel of choice (replacing fossil fuel in the transport sector especially) for Sweden.

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1 Tripartite Task Force 2007
2 Ibid
3 US Department of Energy 2009 (page 1)
4 Kraemer and Schlegel 2007 (page1)
5 Ibid
6 Office of Government Commerce 2009
1.1. Problem Statement
This research endeavors to provide answer/s to the problem statement- That sustainable bio-energy from energy crops is a farce if the true costs to the society (holistically); for developed societies such as Sweden, are taken in consideration.

In light of the above problem statement this paper proposes a hypothesis stating that- Presently, if the true energy cost of bio-energy from energy crops are counted, then it cannot be sustainable as defined in chapter 2 of the Brundtland report: Our common future.

1.2. Boundary of research
Because of the time involved for this research, a representative sample will be used. Hence Sweden will be used as representative of the EU; since all the countries of the European Union are expected to adopt the same document to their energy policy and Sweden has started to do so.

1.3. Aim of this dissertation
Aim of this research is to:

1. Explore the common methodologies use to evaluate the sustainability of bio-ethanol, such as: Life cycle assessment, Exergy, Net energy analysis.

2. Explore the broad system tool call emergy so as to provide an indepth understanding and relevance in energy analysis.

3. Look at the application of emergy analysis to bio-ethanol production, to test the sustainability; by using two cases, 1. Chinese and 2. Italian, bio-ethanol production plant. Choice of these two cases are only because their emergy analysis data are readily available and because they are international.

4. Use the relevant data for Sweden along with the two global cases to extrapolate or induce implications for Sweden.

5. Answer the questions: I. Can bio-ethanol, be a suitable substitute for fossil fuels in the Swedish economy, especially the transport sector? II. What would be the true cost to the Swedish society, to replace fossil fuel with bio-ethanol in the economy? By answering these questions, support for the hypothesis will be provided.

1.4. Importance of research
This paper intends to provoke policy makers, scholars and the like that are involved in making energy policies for Sweden to rethink the present plan; in the push for the 2020

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7Brundtland report 1987
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energy target. And equally intends to provoke other global energy policy makers to ponder any push towards substituting fossil with bio-fuels.

Equally this research intends to contribute towards the discourse in the public sphere calling for a debate on the push towards a bio-energy dependency world using [among other things] energy crops. A similar debate suggested by the FAO- “There is an urgent need for a forum in which the socially and environmentally sustainable criteria for bio-fuel production can be debated, formulated and adopted”8. This is so that, there can be extensive discourse to address the entire implications or costs of using energy crops for bio-fuel in our societies.

1.5. Thesis outline

This research endeavors to provide answers to the questions posed above; as a result the author opted to structure the paper as outlined below.

From Chapter 1.7 of the thesis, the background regarding the issues of bio-ethanol is explored. In similar light the methodology of emergy is explored. Emergy will be the central tool used in case analysis and from which induction will be made. Sweden and Bio-fuel, background to the decision to use bio-ethanol is explored in chapter 2. The incentives for bio-ethanol production process is thus explored, with background given of the “what and how” of bio-ethanol normal production in Sweden. Chapter 2 also involves the exploration of the pros and cons of bio-ethanol. This is done similarly for 3 of the most common and relevant analytical tool; the methods are critiqued respect to bio-ethanol evaluation. The three methods used are Life cycle analysis, Exergy analysis, and Net energy analysis.

Chapter 3 gives the reader an in-depth background to what the emergy perspective is and in the process revealing the “anatomical” parts or the various aspects involved in emergy and emergy analysis.

Chapter 4 is an inductive stage where data from two previous emergy analyses done on bio-ethanol are looked at; the two cases are from China and Italy. These data are complemented by relevant data for Sweden, to allow an analysis to be made.

In chapter 5 the theory of path dependency is introduce to embolden the arguments in the prior chapters; while Chapter 6 provides the conclusive remarks with implications and recommendations.

The approach of the author of this paper is to move away from conventional thinking and embrace a broader, in-depth view of analysis, like Daniel Berquist9 in his successful PHD paper. The author wishes to convey the understanding that it was intentional in the style in which this paper is written. Therefore there is a small departure at the end from conventional scientific writing to include and discuss a new theory at the end of the

8 FAO 2008 (page 50)
9 Bergquist 2008 (Page 16)
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conventional “Discussion” and also conduct semi-discussions while the cases results were presented. The purpose for this is not a sign of rebelliousness but an attempt to reinforce and integrate sections of the paper thus being holistic.

1.6. Important definitions

For clarity of conventional words which will be used throughout this research paper, it’s important that a couple of words are defined, as to the context in which they are used throughout this paper.

Fuel- the term is used in its classical sense of the world which is a substance that can be consumed or transformed to provide energy\textsuperscript{10}. It is a definition which concurs with or adheres to by the “Swedish oil commission”\textsuperscript{11}, which presently provides the directive regarding the sustainable energy future of Sweden. The Swedish oil commission in one of their objectives- “Through more efficient use of fuel and new fuels, consumption of oil in road transport shall be reduced by 40-50 per cent”. This thus alludes to the adherence of the classical definition of fuel and does not go beyond the provision of capability to do mechanical work. Hence the perspective of fuel used in this paper is that of the narrow systems perspective (that will be defined later) or the classical view where it is basically seen as the primary energy source.

Energy- The classical definition refers to energy as capacity to perform work; with the capacity to perform work in one of two convertible mechanical forms, kinetic or potential\textsuperscript{12}. Kinetic energy refers to the energy expressed by an object, body, particle, etc, due to its motion as alluded to by Odum in the book, “Environment, Power and society”\textsuperscript{13}. While potential energy is that energy a body possesses due to its state of position to another body, particle/s, etc or as Odum calls it, available energy\textsuperscript{14}. Hence potential energy is the available energy a body possesses due to its position.

As pointed out above they are both inter-convertible when work is done. When converted from one form to the other, heat is lost in the process, due to the resistance to that must be overcome; example a ball coming to stop at the top of a slope; a ball moving from the top of the slope to the bottom. In the former case the ball possess potential energy, in the latter it possess kinetic energy concurred by Odum\textsuperscript{15}.

Energy is measured in units of: the calorie, the joule, the British thermal unit (Btu), and the erg. The flow of energy is call power, and this is measured in time units such as calories per day, watts (joules per second), or horsepower=10.688 kilocalories/minute; 1 Btu=0.252 kcal;

\textsuperscript{10} Princeton word netweb dictionary 2009
\textsuperscript{11} Commission on Oil Independence 2006
\textsuperscript{12} API energy 2009
\textsuperscript{13} Odum 2007 (Page 42)
\textsuperscript{14} Ibid page 33
\textsuperscript{15} Ibid page 37
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1 kcal = 4.186 joules\textsuperscript{16}. Similarly the perspective of energy use in this paper is that of classical view, or what the author of this paper calls the narrow system perspective.

1.7. Background to the problem

In 2005 the Government of Sweden appointed a commission to draw up a comprehensive program to reduce Sweden oil dependence\textsuperscript{17}. In June 2006 the commission presented a “detail” plan to achieve oil independence, proposing the route of using bio-fuels mostly to replace fossil fuel\textsuperscript{18}.

It is an idea that Jack Santa Barbara questioned in the American context, in a special report for the International Forum on ‘Globalization and the Institute for Policy Studies’; whether the large scale domestic production of corn based ethanol (bio-ethanol) was going to provide an energy independence from fossil fuel, as the American government desires\textsuperscript{19}. Jack Barbara made the point that, by the end of 2006 there were 110 ethanol plants in the U.S., (many still undergoing expansion) 73 under construction and an additional 200 bio-fuel plant in the planning stage. Jack Barbara pointed out that this was a significant investment of taxpayer dollar\textsuperscript{20}; most of this money available in the form of subsidies and start up investment\textsuperscript{21}. This highlights the already significant investment already underway at such small scale.

Like the FAO Jack Barbara pointed out there are reasons to question whether ethanol or any combination of agro-fuel can provide the benefits extolled by the various supporters\textsuperscript{22}. To this end Jack Barbara asked eight basic questions about bio-fuel: 1. Does ethanol production actually results in significantly more energy available to do work than energy required in producing it? 2. What impact does the use of corn for ethanol has on the supply and cost of food? 3. Is there sufficient water available to produce ethanol on a large scale? 4. What is the impact of ethanol production on soil fertility? 5. What is the impact of ethanol production on forests? 6. Does ethanol reduce greenhouse gas emissions and other pollutants? 7. What is the impact of ethanol production on the poor and on the indigenous peoples? 8. Does ethanol production make economic sense?

Jack Barbara proposed the above questions as to provoke a balance debate regarding the sustainability of bio-fuel using energy crops. Not only did the questions, questioned the environmental impact, but also impact on the economy of food and energy production. He thus expands the debate taking a holistic view instead of single vision debate focusing on carbon dioxide emission.

\textsuperscript{16} Ibid page 32
\textsuperscript{17} Commission on Oil Independence 2006 (Page 2)
\textsuperscript{18} Ibid page 14
\textsuperscript{19} Barbara 2007
\textsuperscript{20} Ibid page 4
\textsuperscript{21} Ibid
\textsuperscript{22} Ibid
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It’s a similar argument that Matthias Fawer of the Sarasin group put forward in their annual sustainable report. Dr. Fawer presented the balance view and debate that should take place regarding bio-fuel pointing out the risk and opportunity that must be investigated. The opportunities being: Reduced dependency on fossil fuels, Reduction of greenhouse gas emissions, Reduction of air pollution, Improved fuel quality, No new logistics and infrastructure required, Supportive of local agriculture. On the other hand he asked that the risk be checked as well, pointing out the following risks: 1. Environmental impact of vast tracts of mono-culture, 2. Mounting pressure for rainforest clearance, 3. Crops in competition with the food and animal feed industry, 4. Critical working and social conditions in Third World and developing countries, 5. Use of genetically modified energy crops, 6. Lack of sales markets for by-products.

Four of the risks pointed out by Dr. Fawer, are very similar to those outlined by Jack Barbara in his report. The FAO report the “Right to food and the impact of liquid bio-fuel” outlined similar arguments to be consider regarding bio-fuel. In its report the FAO argues that States and non-governmental organization should consider the following risk before “plunging” full fledge or making policy commitment to investing in bio-energy projects from energy crops:

1. Impact of Price increases (due to market pressure on the demand for energy crops), 2. Land concentration and eviction (due to investors taking up land to invest in planting bio-fuel crops); 3. The harmful structural transformation of Agriculture and land holdings; 4. The impact on women; 5. Competition for water, 6. Environmental harm. This again, supports the need to look at bio-fuel from energy crop, at both end of the spectrum.

From all three reports it is clear that research is necessary to answer questions raised by the three reports highlighted above.

The main question that should be answered regarding the push to use energy crop for bio-fuel is- Is ethanol a sustainable substitute for petroleum based gasoline? In order to answer this question, one must answer the question of the net energy balance of the energy crop used for bio-fuel. Jack Barbara made the point that any desirable energy source should produce more energy than it took to produce it. This should be a fundamental and very important point in pushing for a new energy source to replace the fossil fuel. In a more mathematical approach J. Barbara define what is net energy (Net energy is the amount of energy that is left after the input energy is subtracted from the output energy). This is critical and central to understanding the energy function of the ideal energy source. Using the example of oil production, J Barbara made the example of what the input energy should be. In this case input energy would include: Items for the cost of drilling process, construction and transportation of the drilling rigs, the manufacture of all materials used in the drilling process. Hence the net energy would be the amount of energy extra or surplus

23 FAO 2008 (page17)
24 Ibid. page 17-23
25 Barbara 2007 (Page.5)
26 Ibid. page5
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energy available beyond the energy used to produce it\textsuperscript{27}. When this definition is taken in consideration then uncertainty arises according to J Barbara\textsuperscript{28} about the net energy of say, the corn to ethanol process, where it is unsure if it negative or positive. This point will be developed further in this paper.

Another argument put forward regarding the question of the bio-energy ethanol being a viable substitute is, what is the limits to the energy crop (corn) production? That is how much ethanol can be produced from the amount of corn grown? Can the energy need using bio-fuel of the United States be met without compromising the food security of the nation? (ibid. 5)

J Barbara provided statistics to provoke the thinking process by looking at the amount of corn crop being converted to ethanol. By this coming to the conclusion that even if all the current corn production were to be used for ethanol, it would only replace 16 percent of U.S. gasoline use\textsuperscript{29}. This thus highlights the limitation of using ethanol as the substitute to fossil fuel.

After addressing all the risk to be considered in pursuing bio-energy efficiency using energy crops J Barbara highlight the following parameters or framework which should be considered in the pursuit of the ideal energy source.

1. The ecological sustainable of the energy system must be ecologically friendly. According to J Barbara our energy system should be friendly to the environment and allow the ecology to bequeath to the next generation intact\textsuperscript{30}.

2. J. Barbara then made the point that energy system chosen must be accessible by all, should this energy system be scaled up globally (pointing to the social justice aspect of such energy system) it must offer access to scare resources by all\textsuperscript{31}.

3. Finally Barbara concluded with the point that such an energy system while satisfying the first two parameters should do such effectively; providing the highest level of net energy\textsuperscript{32}.

Jack Barbara issued a similar call as the UN (FAO), requesting a new paradigm to be found\textsuperscript{33} in looking at “sustainable criteria for bio-fuel production”\textsuperscript{34}.

It is this new paradigm or methodology which we now introduce in brief, in exploring the sustainability of bio-fuel from energy crops. Jack Barbara quoted Albert Einstein in reference

\textsuperscript{27} Ibid. page5  
\textsuperscript{28} Ibid. page5  
\textsuperscript{29} Ibid. page5  
\textsuperscript{30} Ibid. page23  
\textsuperscript{31} Ibid. page23  
\textsuperscript{32} Ibid. page23  
\textsuperscript{33} Ibid. 2007 (page 23)  
\textsuperscript{34} FAO. 2008. (page 50)
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for the need for new tool of assessment- “We can’t solve problems by using the same kind of thinking we used when we created them”\textsuperscript{35}. One such new paradigm or tool of investigating the sustainability of these crops is called Emergy. Emergy is a method used to evaluate the work previously done to make a product or service\textsuperscript{36}; Odum points out that Emergy is actually a measure of the energy in the past which differentiate from energy available to do work now Odum describes it as energy memory.

One might ask- “What it is, that this new methodology call Emergy has over the other methodologies that is popularly used to evaluate environmental impact and the cost to the environment?” Well the answer to this is summed up in comparative form in a paper presented at a Con-account conference in Prague in 2008. According to Juan Lui et al\textsuperscript{37} the merit and criticism of the known environment evaluation method versus that of the new methodology Emergy; summary is as follow and be discussed in-depth further in the paper.

1. Ecological footprint

- Academic background: Measure the land use to produce the food and absorb the waste.
- Merit: Simple and can be easily understood.
- Criticism: Single indicator that result in weak analysis; Aggregated calculation on consumption.

2. Life cycle assessment (LCA)

- Academic background: Environmental impact of a product [or service] throughout its entire life cycle.
- Merit: Easily accepted concept
- Criticism: Uncertainty of the methodology of all processes as linear.

3. Exergy

- Academic background: Second law of thermodynamics, which state that the entropy (breakdown of an isolated system not in equilibrium will continue until it reaches a maximum value at equilibrium\textsuperscript{38}.
- Merit: Precise calculation and universally accepted
- Criticism: Calculations do not take in account the ecological and social factors

\textsuperscript{35} Ibid. page 9
\textsuperscript{36} Odum 1998 (page 3)
\textsuperscript{37} Liu et al 2008 (page6)
\textsuperscript{38} All about Science 2009
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4. Emergy

- Academic background: Most energy and material on earth originated from solar energy
- Merit: Extend research boundary to include all the cumulative of energy and material impacting the system in question
- Criticism: Complicated methodology and calculations.

Because the Emergy methodology is such an in-depth methodology for analysis as identified by researchers Juan Lui et al\(^\text{39}\), this research proposal poses the use of such as the methodology to look at the impact or cost of bio-fuel using energy crops such as corn. This will thus attempt to provide that in-depth discourse as call for by the UN\(^\text{40}\).

1.8. Methodology

The intention of this research was never to look for one particular scientific method to find answers to questions posed at the start of this paper. Instead the author of this paper adopted the approach promoted by Johansson (2004)\(^\text{41}\) quoting Michael Quinn Patton (1990), “Rather than believing that one must choose to align with one paradigm or the other, I advocate a paradigm of choices. A paradigm of choices rejects methodological orthodoxy in favor of methodological appropriateness”.

With choosing to use appropriateness over orthodoxy the author of this dissertation chose the following approach of a deductive case study approach in finding answers to the posed questions and hypothesis.

A deductive case study methodology according to Johansson (2004)\(^\text{42}\) has as its ideal, the scientific experiment. It assume of an object being studied that has a reality independent of us; a reality capable of being investigated. It has as its starting point a hypothesis that highlights what rules apply in a given case. There can also be two competing mutually exclusive hypotheses; in other words, if one is true, the other is false.

To qualify the hypothesis or correct hypothesis, evidence is sought to bring verification. The path of the research involves searching for evidence which either verifies or falsifies the expected consequences of the hypotheses or as Johansson puts it “The hypotheses lead the investigations: they indicate what facts are relevant”. Accordingly facts are validated through a process of triangulation, using both quantitative and qualitative approach.

\(^{39}\) Ibid. Page 6
\(^{40}\) FAO 2008 (Page 50)
\(^{41}\) Johansson 2004 (Page 31).
\(^{42}\) Ibid
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Triangulation is taken to be more in its natural science sense, than social science which refer more study of human behavior from different perspective. In this paper it is the use of several location markers to pinpoint a single spot or objective as concur by Louis Cohen et al.\(^{43}\)

Qualitative research- According to Van Maanen (1983) quoted in S H. Iorio\(^{44}\); is a research/analysis which seeks to decide, translate, thus coming to terms with meaning and not frequency, ambiguous, discrete, replicable and clearly defined. Instead Fitch\(^{45}\) said it is about description, analysis and explanation.

Quantitative research- According to Daniel Riffe et al\(^{46}\); in quantitative research, the process involves statistical procedures, and tools that summarize data so that patterns may be efficiently illuminated\(^{47}\). This thus indicates a different emphasis than in a qualitative research; here an emphasis is on discrete and frequency and numbers. Daniel Riffe et al\(^{48}\) concur by stating that quantitative research is about describing a sample population, learning the frequency of occurrences, so as to assess what is typical or unusual\(^{49}\). In this dissertation data from emergy analysis will be used to provide that pattern according to Daniel Riffe et al\(^{50}\) highlighted above.

To provide depth to the literature and data review (qualitative research) deduction will be done using two previously done emergy analysis to deduce information for a third and similar situation. This is because the carrying out of an emergy analysis for bio-ethanol use in Sweden is outside the context of this thesis (because time and study/research required).

The emergy analysis has five main steps as highlighted by the United States Protection Agency Environment (EPA)\(^{51}\): 1. This involves the completion of a systems diagram which is a construction of a diagram representing all interactions between human and natural components of the system identified as relevant; 2. Involves translating this knowledge into aggregated form on a diagram addressing the system in question. This thus involve gathering data from government sources; 3. Involve descriptions pathways in the aggregated diagram, where they transferred to emergy analysis table with quantitative calculations, evaluate the pathways; 4. Then there is the gathering of raw data for analysis along with conversion factors to convert raw data into emergy units; 5. Finally after raw data has been converted into emergy units, indices are calculated from subsets of the data. This section provides a macroscopic picture of the emergy and dollar flow in the system account.

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Footnotes:

\(^{43}\) Cohen et al 2003 (Page 112)

\(^{44}\) Qualitative research in Journalism: Taking it to the streets. Lorio and Mahwah 2004 (p.178)

\(^{45}\) Fitch 2-38 Win 1994 (p32)

\(^{46}\) Daniel et al1998 (page 178)

\(^{47}\) Ibid.page151

\(^{48}\) Ibid

\(^{49}\) Ibid

\(^{50}\) Ibid

\(^{51}\) EPA 2009 (page 2.1-2.2)
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1.8.1. Emergy

H.T Odum made the argument that calories of different kind are not equal. Expounding he made the point that it takes different amount of sunlight (either directly or indirectly) to produce different type of matters. Example it takes 1000 kilocalories of sunlight to make a kilocalorie of spatially dispersed organic matter; it takes 40,000 kilocalorie of coal; 170,000 kilocalories to make a kilocalorie of electrical power, and 10 million or more for a kilocalorie of human activity.\(^{52}\)

Emergy is defined as the available energy used to make another kind of energy, or it is the energy that is required transforming a package of energy into another kind or used up in the transformation process. Odum define it to be “the available energy of one kind previously used up directly and indirectly to make a product or service”.\(^{55}\)

1.8.2. Transformity

As mentioned up above, Odum pointed out that Joules of one kind is not the same as Joules of another kind. Thus to treat with energy of different kind, a transformation factor is needed or as Odum pointed out, “relate all forms of energy in a series”. Thus a transformity is used, which is defined as the Joules of one form previously required either directly or indirectly in order to generate one calorie of another type of energy.\(^{56}\)

The units of transformity are the emergy equivalent of energy, the emjoules per joules, or the emcalorie per calorie e.g. as pointed out Odum, the solar transformity of electric power is 1.7 E5 solar emcalories/calorie which is the emergy/energy.\(^{57}\)

1.8.3. Emdollar

As the system of humanity and the environment is based upon a system of money our appreciation of the value of the new energy concept (emergy) must be expressed in an economic equivalent. This is economic equivalent of the emergy or the money circulation with a buying power supplied by a certain quantity of emergy.\(^{59}\)

The emdollar is significant as it is like the emergy which provides the true energy value of a system. The emdollar is an indication of what part of the total economic power that a resource is contributing to the economy, as highlighted by H T. Odum. Hence the emdollar is just the economic equivalent of the true economic value or contribution of a resource in question or discussion.\(^{60}\)

\(^{52}\) Odum 1998 (page 2)  
\(^{53}\) Ibid.2  
\(^{54}\) Odum 2007(page.69)  
\(^{55}\) Ibid  
\(^{56}\) Ibid.page73  
\(^{57}\) Ibid  
\(^{58}\) Ibid.page252  
\(^{59}\) Odum 1998 (page 2)  
\(^{60}\) Odum 2007 (page 256)
1.9. Potential outcome of work and Importance

This dissertation might lend support to other papers out there inviting the Swedish government to consider all issues respect to production and use of bio-energy, in pursuit of the 2020 goal.

It is hoped that at the completion of this thesis, evidence will be presented to qualify the call by the UN (FAO) among other international authority that has called for expansion of the debate around bio-fuel.

This dissertation endeavors to provide evidence to add further doubt on the popular belief purported by governments such as the United States, European Union, South Africa among others; that bio-energy from energy crop is green and sustainable energy. But importantly this dissertation hopes to use the Swedish analysis as model for consideration for the European Union and the rest of the world when energy policies are drafted.

To provide further evidence that the old methodologies being used to judge the absolute sustainability of a system aren’t as effective and there is need for further application of the methodology call Emergy; which gives an in-depth analysis.

And finally but not least, provide a body of work which can add to the constructive discourse around bio-energy or bio-fuel. This hopefully will enhance the present perspective and provoke careful thought among energy policy makers.

2. Classical Analyses of Bio-ethanol

In order to discuss ethanol in Sweden it would be important to discuss the basic processes through which bio-ethanol is normally produced in Sweden. The below figure 1 is a representation of the basic aspects of the production system for ethanol.
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Figure 1: The basic Production process of bio-ethanol. Source\textsuperscript{62}

The ethanol production process in diagram above, in detail involves\textsuperscript{63}: 1 Grinding: Wheat is taken to the plant by a truck where it is unloaded into an inlet funnel. Wheat is conveyed and transported further for cleaning and temporary storing. Milling is done in a hammer mill, where the whole grain is ground to flour.

2) Starch conversion: Slurry is made from the wheat flour after which enzymes are added. The starch in the grain (approximately 60% of the content) is then converted to a sugar solution, called mash.

3) Fermentation: Ordinary bakery yeast is added to the mash/sugar solution and the sugar is converted to ethanol and carbon dioxide.

4) Distillation and purification: Ethanol is separated from the mash by distillation and finally a complete removal of water is made in a molecular sieve after which water-free ethanol is obtained.

5) Fodder drying: The alcohol free mash, or stillage, is dried. The stillage, which is rich in protein and thereby a high-value animal feed, is dried with steam. The dried product is finally turned into pellets.

Important to note that all the processes above require the input of energy, in other-words the production bio-ethanol requires energy input.

The Norrköping plant, Sweden, uses wheat as the main feed stock. With approximately

\textsuperscript{62} U.S Department of Energy 2009
\textsuperscript{63} Grahn 2004 (page 10)
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135,000 tonnes of wheat is needed for the production of 50 million litres of ethanol (ibid); in Mid-Sweden this means that 25,000 hectares are needed (Agroetanol 2004).

2.1. The Swedish fuel choice for transportation

In order to understand the choice of the use of bio-ethanol as the choice fuel to replace fossil; it is important to understand why Sweden chose bio-ethanol.

The Swedish research on alternative liquid fuel is divided into two phases, according to Maria Grahn in a research paper titled "Why ethanol is given emphasis over methanol in Sweden?"\(^{64}\) In Phase 1, research was organized (in the 70s and 80s) and centered on a number of projects. These projects involve gasification process for producing methanol from wood, peat and coal.

In the second phase, in the 90s, of the Swedish research, the research was organized around a large number of projects focused on ethanol production\(^{65}\).

Phase 1- The Suez canal crisis of the 1956 is believed to have provided the impetus for the Swedish research in alternate fuel to replace fossil. This period saw the restriction in the use of the motor vehicle according to Mari Grahn quoting Zacchi & Vallander (2001)\(^{66}\). The 1973 oil crisis provided further impetus for the formation of the OED [OED is an acronym for oljeersättningsdelegationen (Free translation - Commission of oil substituting)] and so in 1979 the Swedish minister of energy commissioned the OED. The OED suggested the introduction of 15% blend of methanol in gasoline and the building of a combine heat plant\(^{67}\). This plan was for methanol to substitute 10% of gasoline and diesel during the 80s\(^{68}\). Accordingly this resulted in most of the research for an alternate fuel in Sweden being organized around a number of different projects; these include testing different raw material such as peat, wood, and coal. This included conversion methods such liquefaction and gasification, with focus on the gasification method for producing methanol, as concurred by Zacchi & Vallander\(^{69}\).

Phase 2- In the 1990s the focus of alternate energy research focused on ethanol. This started with the development of a 1994 ethanol project by “The Foundation of Swedish Ethanol Development” (in Swedish: Stiftelsen Svensk Etanolutveckling, SSEU, from 1999, BioAlcohol Fuel Foundation, BAFF\(^{70}\). Then in 1998 the group Agroetanol got permission to erect an ethanol plant in Norrköping, with the intended purpose of producing ethanol fuel for 5% gasoline blend.

\(^{64}\) Ibid. page 8
\(^{65}\) Ibid
\(^{66}\) Ibid. page 5
\(^{67}\) Ibid
\(^{68}\) Energimagasinet (1981) No 2, Page 31-32
\(^{69}\) Guido & Vallander (2001)
\(^{70}\) Grahn 2004 (Page 17)
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With the establishment of the Swedish ethanol program in 1993, this saw increase funding from the Swedish government. Support came in line of a general trend, where the established programs instead of providing funding for individual projects; instead had a more comprehensive form of interests which makes it easier to choose specific issues on which to focus and exclude others\(^\text{71}\). Since then Grahn continues, ethanol has remained the main option for Swedish renewable energy for motor fuel, (ibid) concurred by (Zacchi&Vallander, 2001).

Current use and development of ethanol fuel in Sweden; at this stage, it is best to go to Table 1, presented below which provides a more in-depth picture of the state of ethanol use and development in Sweden. As will be seen there is an overwhelming support for and use of the renewable fuel, bio-ethanol.

**Table 1: 2009 production, and feedstock of bio-ethanol in Sweden. Source\(^\text{72}\)**

<table>
<thead>
<tr>
<th>Company</th>
<th>Area and Product</th>
<th>Product capacity and year</th>
<th>Feedstock</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lantmännen, Agroetanol AB, Norrköping (operational)</td>
<td>-ethanol -animal feed -carbon dioxide</td>
<td>57 million liters</td>
<td>Cereal</td>
</tr>
<tr>
<td>Lantmännen, new plant (start production October 2008)</td>
<td>-ethanol</td>
<td>150 million liters</td>
<td>Cereal</td>
</tr>
<tr>
<td>SEKAB/Domsjö Fabriker AB, Örnsköldsvik</td>
<td>-paper pulp -etanol -steam</td>
<td>18 million liters</td>
<td>Wood rawmaterial (sulphite)</td>
</tr>
<tr>
<td>SEKAB E-Technology, Örnsköldsvik</td>
<td>-research/pilot Plant</td>
<td>2 million liters</td>
<td>Wood rawmaterial</td>
</tr>
<tr>
<td>Nordisk Etanolproduktion AB, Karlshamn (planning phase, start production 2011)</td>
<td>-ethanol</td>
<td>135 million liters</td>
<td>Wheat</td>
</tr>
<tr>
<td>Lantmännen Lantbruk/Sala Heby</td>
<td>-ethanol</td>
<td>44 million liters</td>
<td>Wheat</td>
</tr>
</tbody>
</table>

\(^{71}\) Ibid.page6

\(^{72}\) GAIN Report Number: SW8006, Date: 6/4/2008 (Page 7-8)
Bio-fuel as a case to discuss sustainable development

The funding provided by the Swedish government for bio-ethanol has grown since the mid 80s, before then (1975-85) the Swedish government funding was for different liquefaction and gasification projects, with central focus on both Methanol and Ethanol\(^{73}\). However since 1985 the Swedish government has dropped support for methanol. The reason for the lost of support is believe to be based upon the conclusion that the production of bio-methanol could not compete economically with methanol produced from natural gas as pointed out by Zacchi&Vallander, 2001 quoted by Grahn\(^{74}\).

The following table 2, gives an indication of the present support from the Swedish government [for research and development] ethanol experiences, versus other alternate fuel development.

**Table 2: showing the money allotted to research on renewable energy between the years 1998-2004.**

*Source*\(^{75}\)

<table>
<thead>
<tr>
<th>Program</th>
<th>Type of Fuel</th>
<th>Support period</th>
<th>Governmental support</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ethanol production from wood</td>
<td>Ethanol</td>
<td>1998-2004 (7yr)</td>
<td>210 MSEK (30 MSEK/yr)</td>
</tr>
<tr>
<td>Alternative transportation fuels</td>
<td>Primarily possible fuels from the syngas (H2 and CO) produced by gasification of wood, i.e. Methanol, FT-diesel*, DME** and hydrogen</td>
<td>2002-2006 (4yr)</td>
<td>56 MSEK (14 MSEK/yr)</td>
</tr>
</tbody>
</table>

One thing that is immediately obvious from the table above is that the Swedish government has given and is giving far more support for ethanol research than any other alternate renewable energy. However the question still remains unanswered as to why ethanol has

\(^{73}\) Ibid.page7  
\(^{74}\) Ibid.page 7  
\(^{75}\) Ibid.page16
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become the renewable fuel of choice since the 1970s. To answer this we turn to Johanna H. Ulmanen et al\textsuperscript{76} whose research “Biofuel developments in Sweden and the Netherlands: Protection and socio-technical change in a long-term perspective”, explores the dynamics of the choice.

Johanna H. Ulmanen et al\textsuperscript{77} alluded to the point that preferential treatment was and is given to ethanol as the renewable energy of choice because of political decisions and not so much scientific outcome. Expounding further Johanna H. Ulmanen et al pointed out that initial attempt to convert sugar beet plant into alcohol plant failed because the cost was too high and dissuasive. However through powerful lobby groups (such as the ethanol lobby group) lobby funds were secured\textsuperscript{78}.

With the money secured by the ethanol lobby group, the Federation of Swedish farmers and the industrial group, Alfa Laval built an ethanol plant based on wheat in Lidköping in south Sweden for a trial period, 1984-1987\textsuperscript{79}. After the end of the trial period negotiation went on for further funding, but money proposed weren’t enough; until 1988 when the Swedish government and the EU stepped in. The new assistance gave farmers tax exemption to produce up to 50,000 m$^3$ per year.

### 2.2. The reason for the choice of bio-ethanol

At the same time a farmer’s organization in the north of Sweden [which laid the foundation for Swedish Ethanol Development (SSEU)] worked with regional authority and local municipalities to explore the possibility of producing and using wood ethanol\textsuperscript{80}. With links to the Swedish political party, the Centre party; SSEU was able to acquire funding for scaling up their ongoing ethanol bus project\textsuperscript{81}. However the question regarding the choice of ethanol as the bio-fuel of choice is still unanswered.

Maria Grahn in a research paper titled “Why is ethanol given emphasis over methanol in Sweden?” attempted to provide an answer to the above question. To make ethanol the renewable fuel of choice in Sweden; the final decision was really a political compromise. A decision made in a compromise on the 15 January 1991 (NU40:1990/91, p40)\textsuperscript{82}, between three (3) of the political parties of Sweden: Center party, Social democratic party, and the liberal party.

\textsuperscript{76} Ulmanen et al 2009 page1406–1417
\textsuperscript{77} Ibid. Page 1408
\textsuperscript{78} Ibid. Page 1408-1409
\textsuperscript{79} Ibid. page 1408-1409
\textsuperscript{80} Ibid. page 1408-1409
\textsuperscript{81} Ibid
\textsuperscript{82} Grahn 2004 (page16)
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In 1990 preliminary negotiations started between the three (3) parties of Sweden with the intended aim of drawing up sustainable energy guidelines. In this agreement the year 2010 represented the final year to phase out the use of nuclear power stations in Sweden. However this phase out is dependent upon a renewable energy source become large and cheap enough, so that the phase out of using nuclear energy won’t affect Swedish industries and welfare (ibid).

In this nuclear phase out the green center party was the party most against the use of nuclear energy. The centre party was invited in the negotiations regarding sustainable energy policies because the ruling party had to bridge any existing political dissonance. And being the party that has historically advocated for the Swedish farmers, the centre party used their given political leverage to negotiate in the interest of the farmers.\[^{83}\]

In the “three party agreement” there is a lot of support for energy efficiencies; renewable energy projects, and importantly in this case for ethanol production\[^{84}\]. The support for ethanol could be followed from the Swedish agriculture policy of spring 1990, in the bill-1989/90:146. In this bill (1989/90:146) the present agriculture policy resulted in deregulation of arable land. This thus allowed lands that were previously paid to be placed in fallowed to be used for wheat production for energy purposes. The agreement in this 1990 agricultural policy saw money once used to pay farmers to put land in fallow to be used to build an ethanol plant\[^{85}\]. It was through this deal that the ethanol plant built by Agroetanol on Hänelö, 10 km from the centre of Norrköping. This agreement was taken in consideration in the three (3) party agreements of 1991\[^{86}\]. This decision/agreement was further backed up by a 2002 memorandum which restated that 230,000 hectares of land is available for planting energy crops\[^{87}\].

The table 3 below gives an outline as to the financial support that was agreed to in the 1991 three party agreement on sustainable energy production in Sweden.

\[^{83}\] Ibid
\[^{84}\] Ibid
\[^{85}\] Ibid
\[^{86}\] Ibid.page 17
\[^{87}\] Ibid
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Table 3: Government support for bio-ethanol decided from the three (3) parties agreement of 1991. Source

<table>
<thead>
<tr>
<th>Program</th>
<th>Support Period</th>
<th>Government Support</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy efficiency and energy efficient technology</td>
<td>5 yrs</td>
<td>150 MSEK (30 MSEK/yr)</td>
</tr>
<tr>
<td>Support to the National Board for Consumer Policies to produce energy declarations</td>
<td>1 yr</td>
<td>5 MSEK</td>
</tr>
<tr>
<td>Biomass (excl. peat) fuelled heat and power plants:</td>
<td>5 yrs</td>
<td>Approx 1000 MSEK (200 MSEK/yr)</td>
</tr>
<tr>
<td>4000 SEK/kW installed effect for plants ordered after Feb 20, 1991</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1500 SEK/kW to restore plants built July 1990-Feb 1991</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1000 SEK/kW to restore plants built 1985-June 1990</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Small wind power plants</td>
<td>5 yrs</td>
<td>250 MSEK (50 MSEK/yr)</td>
</tr>
<tr>
<td>Solar panels</td>
<td>5 yrs</td>
<td>50 MSEK (10 MSEK/yr)</td>
</tr>
<tr>
<td>Ethanol production</td>
<td>No stated time limit</td>
<td>356 MSEK/yr</td>
</tr>
</tbody>
</table>

2.3. Sweden, energy, and support for renewable energy

According to the Swedish Ministry of enterprise, energy and communications, the production of electricity in Sweden is almost fossil fuel free. In a document titled- “Making Sweden an oil-free society” by 2020, the commission on oil independence, 21 June 2006, pointed out the route to such; underscoring three objectives are:

- Through more efficient use of fuel and new fuels, consumption of oil in road transport shall be reduced by 40-50 per cent.
- In principle no oil shall be used for heating residential and commercial buildings
- Industry shall reduce its consumption of oil by 25-40 per cent

The above objectives it intend to accomplish by 2020, according to the said government document.

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88 NU40:1990/91, page3-4
89 Sweden Ministry of Enterprise 2009
90 Commission on Oil Independence 2006 (page 4)
91 Ibid
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The document went on to point out that the above ambition is not new, but one that existed a very long time now in Sweden. Thus pointing out that in the last decade Sweden has reduced its oil dependence, for heating homes and commercial building, by 70 percent\textsuperscript{92}. This success has been achieved in part due to the replacement of district heating plants once dependent on oil with those using bio-fuel\textsuperscript{93}. The transport sector is another area in which the government highlighted, where they going to make changes; by reducing the dependence of this sector by 40-50 percent. This target set for transportation is also set for machines in the industrial sector as well\textsuperscript{94}.

Figure 2 shows a histogram of the various energy sources in the economy, showing the contribution of different energy source to different sectors of the economy. The total of energy supply in Sweden in 2004 was 647 Terra-Watt hours (TWh) with oil accounting for 32 percent and bio-fuel, peat, etc accounting for 17 percent\textsuperscript{95}.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure2.png}
\caption{Total energy supplied in Sweden in 2004. Source\textsuperscript{96}}
\end{figure}

In figure 3 below gives a breakdown of the end user distribution of the total energy produce is given, showing the industries which use most of the energy generated in Sweden. It also gives a breakdown of the energy sources that contribute to the end users energy “consumption”. Note the vast contribution to the domestic transport sector that oil still make to the sector.

\textsuperscript{92} Ibid
\textsuperscript{93} Ibid.page5
\textsuperscript{94} Ibid.page19
\textsuperscript{95} Ibid. page 9
\textsuperscript{96} Ibid. Page 9
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Figure 3: Histogram showing the end user distribution of the different energy sector in Sweden. Source\textsuperscript{97}

Table 4 below gives a more comprehensive picture of the energy generated by oil. The consumption by the different sector is given in percentage and Terra-Watt hours.

Table 4: \textit{Percentage use of oil among the different sectors in Sweden in 2004. Source}\textsuperscript{98}

<table>
<thead>
<tr>
<th>Sector</th>
<th>Oil use</th>
<th>Area of use of oil</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transport sector</td>
<td>97 percent</td>
<td>95 TWh</td>
</tr>
<tr>
<td>Agriculture, Forestry, Fisheries</td>
<td>70</td>
<td>7 TWh</td>
</tr>
<tr>
<td>Building sector</td>
<td>67</td>
<td>2 TWh</td>
</tr>
<tr>
<td>Residential and commercial buildings</td>
<td>11</td>
<td>10 TWh</td>
</tr>
</tbody>
</table>

\textsuperscript{97} Ibid. Page 10

\textsuperscript{98} Ibid.page10
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<table>
<thead>
<tr>
<th>Industry</th>
<th>18 TWh</th>
<th>Heating and processing energy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Production of district heating</td>
<td>4 TWh</td>
<td>Peak load, etc</td>
</tr>
<tr>
<td>Service sector</td>
<td>3 TWh</td>
<td>Heating and motor operation, etc</td>
</tr>
<tr>
<td>Production of electricity</td>
<td>3 TWh</td>
<td>Power in industry and district heating plants</td>
</tr>
</tbody>
</table>

The Commission on Oil Independence\(^99\) gave five reasons to support the argument for Sweden to become oil independent:

- To reduce Sweden’s climate impact;
- Securing the supply of Sweden’s energy in the long term;
- For Sweden to become a leader in the development of technology for the efficient use and sustainable use of energy;
- To strengthen Sweden’s economic competitiveness;
- To use and develop the energy from the field and forest of Sweden; what is termed Sweden’s “green gold”.

It important to note that the last reason for Sweden to become oil independent points to the development and use of the natural resource of Sweden in the form of the land and the forest; thus emphasizing the use of bio-energy.

Not only is the drive, for Sweden to become oil independent, driven by internal drive, but also an external drive from without; in the form of the European Union (EU). In the EU policy document on energy, Commission’s green paper A European Strategy for Sustainable, Competitive and Secure Energy on 8 March 2006\(^{100}\):

- A cut of a minimum of 20% in greenhouse gas emissions from all primary energy sources by 2020 compared to 1990 levels.
- 50% cut in carbon emissions from primary energy sources by 2050, compared to 1990 levels.
- A target of minimum of 10% for the use of bio-fuels by 2020.

\(^99\) Ibid.page 11
\(^{100}\) Commission of the European Communities 2007
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- That the energy supply and generation activities of energy companies should be 'unbundled' from their distribution networks to further increase market competition.
- Improvement in energy relations with the EU's neighbors, including Russia.
- The development of a European Strategic Energy Technology Plan to develop technologies in areas including renewable energy, energy conservation, low-energy buildings, 4th generation nuclear power, clean coal and carbon capture.
- Developing an Africa-Europe Energy partnership, to help Africa 'leap-frog' to low-carbon technologies and to help develop the continent as a sustainable energy supplier.

Upon comparison it can be seen that the mandated targets set out by the European Union and the nation of Sweden are very comparable, if not same as concurred by the Swedish government website. Sweden’s targets are just laid out in a more comprehensive form regarding the types of renewable energies that will be used. Example of this involves setting a target to reduce the use of fossil fuel by 40-50 percent for transportation, thus replacing with renewable energy use in transportation. Importantly Sweden has taken bold steps to increase the use of the renewable energy from bio-ethanol. According to the Global Agriculture Information Network, in 2007 bio-ethanol was the most common bio-fuel in Sweden, comprising 90% liquid bio-fuel.

One of the driving forces so to speak behind the growth in the bio-fuel industry in Sweden is a set of legislations that promote the use of bio-fuel through tax relieves. As the report pointed out if the tax relieves are taken away then the bio-fuels would be non-competitive compare to fossil fuels. As can be seen from the Table 5 below that the bio-fuels are only competitive because there is zero tax on them.

Other policies of the Swedish government which support bio-fuel are (ibid. Page 5):

- Access to environment-friendly fuels throughout the country. Since April 2006, all major fuel stations in Sweden are required to sell at least one type of bio-fuel.
- The Swedish government has introduced a cash bonus of Swedish Krona (SEK) 10,000 (USD 1,665) to private individuals who buy new “green” or environmentally friendly classified cars. The program is scheduled to run from April 1, 2007 until 31 December 2009.
- Free parking for green cars.

101 Sweden Ministry of the Environment 2009
102 Commission on Oil Independence 2006 (page 4)
103 USDA Foreign Agricultural Service GAIN Report 2008 (page 6)
104 Ibid. page 4
Bio-fuel as a case to discuss sustainable development

- As of August 2007, there is a permanent congestion charge in Stockholm which has had a positive impact on the environment. Green cars are exempt from this charge.

- A tax for light-duty vehicles based on carbon dioxide emissions instead of weight was introduced in 2006. It is aimed at motivating car buyers to choose fuel-efficient vehicles.

- As of 2007, at least 85% of all cars purchased by government authorities and 25% of emergency services vehicles have to be environmentally friendly.

- The Continuous expansion of biogas stations.

<table>
<thead>
<tr>
<th>Energy source</th>
<th>Energy Tax</th>
<th>Carbon dioxide</th>
<th>Sulfur Tax</th>
<th>Total Carbon dioxide and Energy Tax</th>
<th>VAT</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional Gas (SEK/liter)</td>
<td>2.95</td>
<td>2.34</td>
<td>0</td>
<td>5.29</td>
<td>1.23</td>
<td>6.61</td>
</tr>
<tr>
<td>Diesel Oil (Sek/Liter)</td>
<td>1.23</td>
<td>2.88</td>
<td>0</td>
<td>0.411</td>
<td>0.47</td>
<td>4.58</td>
</tr>
<tr>
<td>Ethanol/RME</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

All the above mentioned policies are policies which would have been charted under the Swedish Government Bill 2005/06:154. The bill states that the country of Sweden energy policy is to obtain all its energy from renewable energy sources. This bill is written and preceded by the electricity certificate system, which was introduced in 2003. This certificate was introduced to encourage producers and suppliers of electricity to turn to supplying green electricity or electricity from renewable energy in essence that is efficient and affordable. This stems from the “vision” document that influenced the wording of the bill which reads, “The vision in [of] Sweden is that the country will obtain all its energy from renewable energy sources in the long term.”

Another policy which supports the growth of bio-fuel in Sweden is the financial and technical support that comes from the EU for farmers that farm bio-fuel feedstock. This support

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105 ibid.page4
106 Sweden Ministry of Sustainable Development 2005
107 Government of Sweden 2005
108 ibid.page1
109 Ibid. Page 1
comes from or under the Common Agriculture Policy (CAP), the MacSharry reform of 1992\textsuperscript{110}. Under the 1992 reform there was a set aside scheme in the arable sector, which allows the control of the sector and the surpluses from the sector. Equally this introduced an early retirement scheme; an agri-environment scheme and afforestation scheme introduce to reduce production capacity and improve the structure of farming\textsuperscript{111}.

Under the 2003 CAP reform, crops which were once eligible for direct payment if farmed on set aside land only, are now available for payment (subsidy) no matter what land the crops are farmed on\textsuperscript{112}. With the set aside scheme being integrated in the new single market scheme, energy crops can be cultivated on set aside land as long as the use of the biomass is guaranteed for use by a contract or by the farmer\textsuperscript{113}.

Agreement has been reached with the common market organization on sugar; where sugar beet grown for bio-ethanol will be exempted from quotas while the commission pursues making it qualify for both subsidies for non-food on set aside land and energy crop subsidies\textsuperscript{114}. Equally important a special aid was introduce in 2003, with “€45 per ha is available, with a maximum guaranteed area of 1.5 million hectares as the budgetary ceiling”.

It was noted in the EU report on bio-fuel\textsuperscript{115} that most of the bio-fuel produced presently is produced from food crops. The commission noted the global concern about this, as bio-fuel competes with crops for food and raw material for other industries. The commission promised to continue monitoring the demand of bio-fuel demand and its impact on food and raw material demand in the future\textsuperscript{116}.

2.4. Types of liquid bio-fuel produced in Sweden

Bio-ethanol is the most common liquid bio-fuel produced in Sweden (90% of the total produced in Sweden). 80% of the bio-ethanol produced is from cereal, while the other 20% is from wood fermentation, from sulphite liquor which is a by-product of the paper pulp production\textsuperscript{117}. The cereal base ethanol is an additive to use in gasoline as mandated by the government where a 5% ethanol must be added to the gasoline\textsuperscript{118}. Then there is bio-ethanol from sulphite wood pulp; this is mostly used in 85% ethanol gasoline E85\textsuperscript{119}

The company Agro-ethanol is one of the largest ethanol producers in Sweden presently, producing up to 57 million liters annually. Its production of ethanol comes from wheat which

\textsuperscript{110} Trinity College Dublin 2009  
\textsuperscript{111} Ibid  
\textsuperscript{112} COMMISSION OF THE EUROPEAN COMMUNITIES 2006  
\textsuperscript{113} Ibid.page12  
\textsuperscript{114} Ibid.page12  
\textsuperscript{115} Ibid  
\textsuperscript{116} Ibid.page13  
\textsuperscript{117} USDA Foreign Agricultural Service GAIN Report 2008  
\textsuperscript{118} Ibid. page 13  
\textsuperscript{119} Ibid. page 13
accounts for two thirds production and the rest from barley and rye. All materials use in the ethanol production is grown in neighboring communities\footnote{Ibid. page 6}.

Cellulosic ethanol, which is ethanol from cellulose of wood, etc., is responsible for 20\% of the bio-ethanol produced in Sweden\footnote{Ibid. page 7}. The company SEKAB is the largest producer of cellulosic ethanol in Sweden, most of which is produced for E85 fuel (gasoline blend of 85\%ethanol and 15\%gasoline to give a flexi fuel [ibid. Page.6]). SEKAB has an operating capacity of 18 million liters presently which should be increase with recent investment of SEK 33.8 million (USD 5.6 million) from the Swedish energy agency\footnote{Ibid.page7}.

In May 2008 SEKAB refer to their imported ethanol from Brazilian sugar cane, which is used in bus and heavy vehicle, as verified sustainable ethanol. Verified sustainable ethanol according to SEKAB and progressive Brazilian producers is quality assured from environmental, climate, and social perspective. They developed criteria that follow the entire life cycle of the product from the sugarcane field to the use in car. These criteria seem to be in line with those of the criteria still being drafted by the UN, EU, ILO, and a number of NGOs in ongoing negotiations\footnote{Ibid} and concurred by the SEKAB press release of 26 May 2008\footnote{SEKAB Press release 2008}. The author of this paper will address the issue of verified sustainable ethanol later in this paper.

2.5. Bio-ethanol and popular analysis of sustainability

Bio-ethanol, according to the energy system research unit (ESRU) at the University of Strathclyde\footnote{Energy systems research unit, University of Strathclyde 2009}, is ethanol produced from the fermentation of sugar as concurred by SEKAB\footnote{SEKAB 2009}; it can also be processed by combining ethylene with steam\footnote{Energy systems research unit, University of Strathclyde 2009}. However the main source of producing bio-ethanol comes from energy crops. These are crops grown specifically to produce bio-ethanol, and include: corn, maize and wheat crops, waste straw, willow and popular trees, sawdust, reed canary grass, cord grasses, Jerusalem artichoke, myscanthus and sorghum plants\footnote{Ibid}.

ESRU (ibid) describe ethanol to be the same as ethyl alcohol that is a clear colorless liquid with chemical structure C2H5OH. It is biodegradable, having a low toxicity and causes little environmental toxicity when spilt. Ethanol is a high octane fuel, and when burn it produces carbon dioxide and water. Because of the high octane nature of ethanol it has been used to replace lead in petrol. By this addition to petrol, ethanol allows it to burn efficiently and completely. E10 is the most common blend is 10\% ethanol and 90\% petrol of fuel used in
vehicles in\textsuperscript{129}. Vehicle engines require no modifications to run on E10 and vehicle warranties are unaffected also. Only flexible fuel vehicles can run on up to 85% ethanol and 15% petrol blends (E85)\textsuperscript{130}. According to SEKAB\textsuperscript{131} the E85 is normally used in Sweden in only some heavy vehicles such as bus and Lorries use the E85 blend.

Ethanol provides a purer exhaust when it is burned in an engine because it does not produce or leave behind sulphur, sulphur compound, or cyclic compounds such as benzene. After combustion in an engine, no soot is found, only small amount of acetic acid and formaldehyde is produced\textsuperscript{132}.

2.5.1. Energy input in bio-ethanol production

The calculations of energy inputs are based on primary energy inputs only; that is, all energy flows are calculated based on inputs in unconverted state. This includes energy input such as diesel in cultivation (equivalent to about 37% of the total energy input), commercial fertilizers (approximately 41%), seed, pesticides, the manufacture and maintenance of field machinery, field transport by tractors etc (all together add up to approximately 22%). Figures based on current farming practices in Sweden\textsuperscript{133}.

In the processing of to raw material into ethanol, energy is used in the form of heat, steam and electricity, as well as all transportation operations concerned with feedstock and by-products (transported on average by trucks, 50 km), are included. Of the total primary energy input in the ethanol production, approximately 90% represents heat and steam and 10% electricity. The energy invested in farm buildings, roads and conversion plants is negligible compared to the net energy flows in the production systems, and is therefore not included in the evaluation. Grain harvest (wheat) corresponds to 7.5 tonnes/ha (15% water content) and straw harvest 5 tonnes/ha (15% water content), representing average yields in northern Europe. Because of ecological restrictions a significant amount of the straw is believe to be left in the field (approximately 3–4 tonnes/ha), maintaining the content of soil carbon and preserving the humus level (based on experiences from long-term Swedish field trials)\textsuperscript{134}. Please see the figure 4 below which gives a diagrammatic breakdown of the energy flow for the production of bio-ethanol in Sweden.

\textsuperscript{129} SEKAB 2009
\textsuperscript{130} Energy systems research unit, University of Strathclyde 2009
\textsuperscript{131} SEKAB 2009
\textsuperscript{132} Ibid
\textsuperscript{133} Börjesson 2009 (Page 589-590)
\textsuperscript{134} Ibid
Bio-fuel as a case to discuss sustainable development

**2.5.2. Green House Gas emission during cultivation of energy crop**

Greenhouse gas (GHG) emissions in the cultivation of energy crops are accounted for from carbon dioxide from tractors, fertilizer manufacture, etc. and nitrous oxide from arable land and from the manufacture of nitrogenous fertilizer. Often emissions of nitrous oxide are more than that of the emissions of carbon dioxide (see Table 6 below). However there is much uncertainty about how much nitrous oxide is emitted from arable land, and such emissions may vary widely depending on local conditions.\(^\text{136}\)

**Table 6: Emissions of greenhouse gases in the case of grain cultivation, expressed as kg of CO\(_2\)-equiv./GJ of harvested grain.\(^a\) Source\(^\text{137}\)**

<table>
<thead>
<tr>
<th>Cultivation system</th>
<th>CO(_2) fossil fuels(^b)</th>
<th>N(_2)O(^c) land(^d)</th>
<th>N(_2)O N fertiliser manufact.(^d)</th>
<th>Total</th>
<th>CO(_2) change of land-use(^e)</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wheat – grain</td>
<td>10</td>
<td>9.2</td>
<td>5.7 (1.5)</td>
<td>25</td>
<td>0</td>
<td>25</td>
</tr>
<tr>
<td>- cultivation on “normal” arable land</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- cultivation on grass-covered mineral soil</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- cultivation on grass-covered peat soil</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\(^\text{135}\) Börjesson and Tufvesson 2009 (Page 590)
\(^\text{136}\) Ibid
\(^\text{137}\) Ibid. page 590
Bio-fuel as a case to discuss sustainable development

a Average for northern Europe, which corresponds to cultivation in southern Sweden\textsuperscript{138}. Excluding straw harvest.
b Emissions from tractors, manufacture of fertilisers, etc. Including a small quantity of methane emissions.
c Biogenic emissions from land based on the IPCC model\textsuperscript{139}. The input of commercial nitrogen fertiliser is 150 kg N/ha and year.
d Based on source\textsuperscript{140} and source\textsuperscript{141}. Values in brackets relate to emissions from manufacture with catalytic nitrous oxide gas cleaning.
e In the case of straw harvest, the binding of land-based carbon is assumed to fall by 150 kg C/ha and year, and in the case of cultivation of annual crops on grass-covered mineral soil and peat soil, the losses of soil carbon are estimated to amount to 500 kg C/ha and 7000 kg C/ha and year, respectively\textsuperscript{142}. Figure 5 below is a summary of the derivative of the label “good” and “bad” ethanol. According to Börjesson (2009)\textsuperscript{143}, this figure should be viewed as a sensitivity analysis of the GHG emission of a well defined bio-fuel production system. There can be variation depending on the systems allocation methods, assumed technology, boundaries, alternative landscape use, etc. Figure 5 below provides an outline as to what is the good ethanol or the bad ethanol.

In its simplicity the figure indicates that if fossil fuel alternative produces less GHG than it does, then it is good ethanol; however it produces equal or more GHG than fossil, it is bad ethanol\textsuperscript{144}.

\textsuperscript{138} Börjesson and Tufvesson 2009
\textsuperscript{139} IPCC 2006 [chapter 11]
\textsuperscript{140} Jenssen and Kongshaug 2003
\textsuperscript{141} Davis and Haglund 1999
\textsuperscript{142} Börjesson 1999 (page. 137–154)
\textsuperscript{143} Börjesson 2009 (Page 592)
\textsuperscript{144} Ibid. page 592
Figure 5: Emissions of GHG from grain-based ethanol production, taking into account various systems and calculation methods and in comparison with petrol. The various examples may be viewed as an illustration of the scale from “good” ethanol to “bad” ethanol (see the text for more explanation) Source 145.

According to Börjesson (2009) 146, the current production of Swedish ethanol from wheat can be seen as “good” ethanol, reducing GHG emissions by some 80% compared to petrol; Ethanol based on sugarcane from Brazil leads to a reduction, on average of 85%; while ethanol from maize in the USA responsible for a reduction of only 20% on average.

The reason for the above is that fossil coal accounts, on average, for 25% of the fuel used in ethanol plants in the US, and natural gas for the remaining 75% quoting Börjesson quoting M. Wang et al 147. Because of this Börjesson (2009) 148 believes there is a potential for improvement of current ethanol production systems (especially in the US, but also worldwide) thus leading to improved GHG benefits.

2.5.3. The criticism of bio-ethanol

The criticism of bio-ethanol can be summed up in the pros and cons by Joint compilation of Political Capital and Green Capital 149 as seen below.

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145 Ibid. page 592
146 Ibid. page 592
147 Wang et al 2007 (page 2)
148 Börjesson 2009 (page 594)
Pros and cons of Bio-ethanol

**Pros**
- reduces emission of greenhouse gases
- particularly advantageous in public transport
- substitutes fossil fuels to some extent
- fosters energy independence
- creates new jobs
- has moderate impact on food price hike: over the last years, the price of non-raw material rice increased, whereas the price of raw material sugar decreased
- guarantees the livelihood of farmers even after the reform of Common Agricultural Policy (CAP)
- is profitable for motorists even if the energy content of ethanol is less than that of traditional fuels
- improves fuel quality as an additive
- knocks down fossil fuel prices

**Cons**
- reduces the amount of available food, raises food prices
- will reduce emission of greenhouse gases only in certain cases, now increases its amount
- use of biofuels is favourable for those with a car; they would not be encouraged to switch to public transport
- shortage of available farm lands, import dependency prevails
- changes in demand-supply balance may lead to restructuring of farm lands, basically to destruction of forests
- reduces biodiversity due to extensive farming and intensive fertilization
- problematic positive energy balance as it needs fossil fuel, too
- its sustainability is difficult to predict as it depends on the energy source used for production
- high water demand of industry; inadequate technology produces wastewater
- upsets the life of local communities
- renewed dependence between undeveloped agrarian and developed countries
- first-generation fuel lobby may strengthen to the extent where technology gets stuck and stops developing into a second or third generation technology

A few of the above important pro and cons (critique) of bio-fuel will be discussed below further. Using the energy crop sugar cane which is lauded by many as the ideal crop for bio-ethanol production according to Alfred E. Hartemink and alluded to by Macedo

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150 Ibid
151 Hartemink 2008 (page 41)
152 Macedo 1998 (page 77-81)
2.5.4. The Cons of Bio-fuel

Emission of Greenhouse gases- According to Alfred E. Hartemink\textsuperscript{153}, the cultivation of sugar cane affects the balance of carbon dioxide (CO2) and other greenhouse gases. Other greenhouse gases are emitted when: 1. Pre-harvest burning of the sugarcane cause release of methane but also when stillage is applied to soil as conditioner and when fertilizer and bagasse is burned; 2. Oxides of Nitrogen are also emitted from the soil.

Hartemink pointed out further that the growing of sugar cane does fixes atmospheric CO2 however there is emission from fossil fuel used in field operation, transport, production of agrochemicals used, irrigation, and that used by the processing plant. The carbon benefit is realized when fossil fuel used in the processing plant is substituted for by bagasse from the sugar cane, as pointed out by Macedo, 1998\textsuperscript{154}.

Soil organic carbon- Under the cultivation of sugar cane the organic carbon (C) declines over time; however the decline varies for different soil types and also depends on the original carbon level of the soil type. The preparation of some soil for the growing of sugar cane can cause significant release of CO2, example the everglades land of Florida, when drained for sugar cane cultivation\textsuperscript{155}.

Impact on soil- erosion experienced after the harvest

Because of the heavy machinery employed in the modern system of sugarcane/crop production soil compaction is normally a problem. Also the frequent application of inorganic fertilizer contribute to this problem by decreasing the soil aggregate stability of some soil, decreasing the bulk density and reducing water infiltration, concurred by Graham et al., 2002a and Mills and Fey, 2003 quoted by Alfred E. Hartemink 2008\textsuperscript{156}.

With the lowering of the soil aggregate stability this predisposes the soil to erosion\textsuperscript{157}, which normally see loss of 505 Mg soil ha\textsuperscript{-1} year\textsuperscript{-1} with soil cultivated under sugarcane; where the greatest loss is experienced after harvest. This of course is due to the fact that the periodic harvesting remove most vegetation from the field as concurred by Hartemink, 2005b, quoted by Alfred E. Hartemink 2008\textsuperscript{158}. This, thus point to the fact the practice of sugarcane cultivation might not be the best for maintaining soil integrity. Hartemink (2008), however remind us that the land is normally covered by sugar cane throughout most of the year and thus maintain a balance\textsuperscript{159}. Hartemink quoted Wood (1991), who expressed that there is a growing concern regarding the erosional effects of sugarcane cultivation and that is why green harvesting is advocated as the best option. The advantages experienced by

\textsuperscript{153} Hartemink 2008 (page165)
\textsuperscript{154} Ibid. page 41
\textsuperscript{155} Ibid. page 41
\textsuperscript{156} Ibid.page163
\textsuperscript{157} Ibid
\textsuperscript{158} Ibid
\textsuperscript{159} Ibid
green harvesting with sugarcane, is that it reduces soil temperature, increased soil fertility and soil organic matter, and improved soil structure"\textsuperscript{160}.

Impact on water and air- Because sugarcane requires a lot of water, it is normally grown in areas with high rainfall, or where irrigation is efficient and effective, an argument concurred by Hartemink\textsuperscript{161}. Because of this natural need for water, its implication is very important for water balance and availability (for domestic use).

Vallis et al., 1996, quoted by Hartemink\textsuperscript{162} pointed out that because of the high water input in the growing of the sugarcane, there is also increase leaching of nutrient from the soil which call for the input of nitrogen fertilizers\textsuperscript{163}. He went on further to point out that with only 20%-50% of fertilizer recovered there is growing concerned for the rising NO3 levels in groundwater, especially in environmentally sensitive areas\textsuperscript{164}. There is also the concern for nitrogen loss aerially through the sugarcane leaves and via de-nitrification and ammoniacal loss from nitrogen fertilizers, as this is a greenhouse gas\textsuperscript{165}.

\subsection*{2.5.5. The pros of bio-fuel}

According to the preliminary outcome from the conference on bio-fuel\textsuperscript{166}, bio-fuel offers a number of pros:

1. A new energy paradigm

That is, it offers a new energy alternative to fossil fuel of which bio-fuel is surely a part of. Since bio-fuel “can be associated with income generation, job creation, rural development, greenhouse gases emissions reductions, and increased access to energy”. Thus highlighting the importance of bio-fuel as a new opportunity or blue chip as the stock investor would say.

The conference on bio-fuels went on to point out that bio-fuel is at a pivotal juncture or intersection of public policies such as that of: social, agricultural, economic, environmental, energy and technology.

\subsubsection*{2.5.5.1. Bio-fuels and energy security}

With the concentration of the energy supply in the form of fossil fuel in the hands of a few people this adds impetus to the need to resolve this imbalance. In resolving the imbalance global energy security would be address as alluded to by the international bio-fuel conference paper\textsuperscript{167}. The paper pointed out that, this forces the decentralization of control of the energy supply in the form of bio-fuel; it could be produced in at least 100 countries, as
well as reduce the unequal access to energy. It can also play an important role in diversifying the global and national energy mixes.

### 2.5.5.2. Bio-fuel and Climate change

With climate change believed to be the greatest challenge ever faced by mankind; it will require a revolutionary way in which energy is used in the society or economy. Bio-fuel is believed to be an integral part of this revolution. With very low-carbon options for reducing emissions in the transport sector: bio-fuels are one of the few options for large-scale use, at affordable cost.

### 2.5.5.3. Bio-fuel and innovation

With investment in bio-fuel, the developing countries stand to benefit greatly from the growing of the different feedstock, given a lot are located in the tropical region of the world. This is of course because a number of developing countries lie in the warmer region of the world, or where part of the country lies in the tropical region.

It is assumed they will benefit from capacity building since innovation is an inherent component of the bio-fuels. This is assuming that investors (developed countries) will not use the developing countries to produce the bio-fuel feedstock, but will instead invest in processing plants, and skills development.

### 2.5.5.4. Bio-fuels and international trade

With the establishment of a global market for bio-fuel and bio-fuel classified as an environmental good (within the WTO FRAMEWORK) it is believed it will address challenges such as sustainable development, energy security, and climate change.

### 2.5.5.5. Bio-fuels and international cooperation

Developing countries stand to benefit from a regional approach for bio-fuel. In Africa, for example, a regional approach may be a condition to achieve economies of scale therefore making bio-fuels a competitive alternative. Because Brazil has been at the forefront of bio-fuel production, it can then become International Center of Excellence. In this way, Brazil could serve to stimulate the exchange of ideas and knowledge, especially among developing countries.

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168 Ibid. page 2
169 Ibid. page 2
170 Ibid. page 2
171 Ibid. page 2
172 Ibid. page 2
173 Ibid. page 3
2.5.6. Common evaluation tools for bio-fuels

One of the tools used to assess the environmental and energy impact of a product or service is the life cycle assessment (LCA)\textsuperscript{174}. According to Energy systems research Unit at the University of Strathclyde, a life cycle assessment is a quantitative technique used to approximate the environmental impact of a product or service from the cradle to the grave\textsuperscript{175}. This assessment take into consideration any product or services that may be required to facilitate its use or production\textsuperscript{176}. This thus point to the depth or breadth that a LCA tries to span in its assessment or consideration of a product. As concurred by the United States Environmental Protection Agency (EPA); a LCA is a cradle to grave methodology of assessing industrial processes. The EPA went on to point out that this cradle to the grave process takes in consideration the gathering of the material from the earth, the creation of the product, and the return of the material back to the earth\textsuperscript{177} [when the product is disposed of]. The EPA expounded further that the LCA allows for the cumulative environmental impact of all stages of a process, since all stages are interdependent. By doing this the EPA points out that it allows for the true environmental trade of the creation of a product or process\textsuperscript{178}.

The diagram below in figure 6 is taken from the US government EPA website, and it is an outlay of what an average LCA looks like diagrammatically.
Bio-fuel as a case to discuss sustainable development

**Figure 6:** Possible Life cycle assessment stages (LCA) (Source EPA 1993)

A LCA is conducted by:

1. By compiling an inventory of all material and energy used and environmental releases.

2. Evaluation of potential environmental impact from inputs and environmental releases such as Sulphur dioxide (SO2), Nitrogen Oxide (NO), hot waste water into a stream, etc.

3. Interpreting the results to help decision makers make more informed decisions.

According to the Energy systems research Unit at the University of Strathclyde, key advantage in using a LCA is that it offers a direct and fair comparison between products and services; regarding environmental impact and energy use\(^{179}\).

The EPA makes the point that a LCA is a detail process, which is systematic. A LCA consist of four phases: 1. Scope definition, 2. inventory analysis, 3. impact assessment; 4. Interpretation of results\(^{180}\).

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\(^{179}\) Energy systems research unit, University of Strathclyde 2009

\(^{180}\) EPA 2006
Bio-fuel as a case to discuss sustainable development

1. **Goal Definition and Scoping** – Is a Definition and description of the product, process or activity. This establishes the context in which the assessment is to be made and identity of the boundaries as well as the environmental effects.

2. **Inventory Analysis** – This involves the identification and quantification of energy, water and materials usage and then the environmental releases in forms such as: air emissions, solid waste disposal, waste water discharges.

3. **Impact Assessment** - Assess the potential human and ecological impact of energy, water, and material usage as well as the environmental releases identified above in the inventory analysis.

4. **Interpretation** – This is the evaluation of the results from the inventory analysis and impact assessment to help select the preferred product, process or service with a clear understanding that some uncertainty and assumptions was used to generate the results.

The following is a synopsis of a LCA for bio-ethanol (sugarcane as feedstock) done by Lin Luo et al of the Institute of Environmental Sciences (CML), Leiden University. The functional unit in this case is according to Luo, is defined as power to the wheel for driving a mid-size car for a distance of 1 kilometer.

2.5.6.1. **The system boundary**

This includes all the processes, which are included within the boundary of the fuel systems; including those for capital goods and wastes management. Base case and future case are shown in Figs. 7 and 8, respectively.

2.5.6.2. **Impact assessment**

The focus of this study was on the following impact categories:

- **Abiotic depletion potential (ADP)** - ADP refers to the consumption of fossil fuel, raw mineral material; this is based on the world’s geological extractable reserves.

- **Greenhouse gas (GHG) emissions** - The release of a number of gases known to cause the greenhouse effect (trap heat in atmosphere) through natural or human activities. These gases include among others: Carbon Dioxide (CO2), Methane (CH4), Nitrous Oxide (N2O), fluorinated gases (Hydrofluorocarbons, perfluorocarbons, and sulfur hexafluoride).

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181 Life cycle assessment and life cycle costing of bio-ethanol from sugarcane in Brazil-Luo et al 2009 (page.1613–1619)
182 ibid.page2
183 ibid.page5
184 BLOCK et al 2009 (page 3)
185 EPA 2009
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- **Ozone layer depletion (ODP)** - expresses the potential of a gas to destroy ozone. CFC11 is used as reference component.\(^\text{186}\)

- **Photochemical oxidation (POCP)** - means a relative amount of photochemical ozone concentration contributed by various NMHC (Non-methyl hydrocarbon).\(^\text{187}\)

- **Human toxicity (HTP & ETP)** - The human toxicity potential gives the impact on human health of components emitted to the atmosphere or discharged in surface water.\(^\text{188}\)

- **Acidification (AP)** - According to the UK’s Air pollution information systems (APIS) acidification is a natural process by which nutrient bases such calcium, magnesium and potassium are lost through the process of leaching and are replaced by acidic elements such as hydrogen and aluminum. Acidification however is commonly associated with atmospheric pollution arising from anthropogenically derived sulphur (S) and nitrogen (N) as NOx or ammonia. Anthropogenically or man-made derived pollutant deposition can increase the rates of acidification, which may then exceed the natural neutralizing capacity of soils.\(^\text{189}\)

- **Eutrophication (EP)** - University of Manitoba institute of fisheries classify eutrophication into two (2), natural and manmade or anthropogenic.\(^\text{190}\) As a natural process eutrophication is defined as the process by which lakes gradually age and become more productive; which normally takes thousands of years to progress. The anthropogenic eutrophication involves the cultural processes of human which accelerate the aging process and result in excessive plant nutrients in these water bodies.\(^\text{191}\)

Figure 3 below provide a graphical display of the impact assessment. In this impact assessment a comparison is given using the impact of other derivative of the bio-ethanol and fuel mixed with different percentages of bio-ethanol.

2.5.6.3. **Critique of LCA**

While the LCA claims to be an impact assessment it never really live up to such, since a LCA gives a quantitative assessment of pollutants release in the environment and not a quality of the impact on the environment. The afore-said is an argument concur with by Weidema (2008),\(^\text{192}\) who stated that a LCA is too often presented and perceived as an excessively, quantitative technique at the expense of the many results, obtained from qualitative studies. This is also the case for the, description given in the ISO standards, although there isn’t an explicit required quantification. Hence it never normally show or measure the impact say using bio-ethanol versus fossil fuel will have on the energy economy.

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186 ibid.page2
187 XIAO and ZHU- 2004 (Page 4)
188 188 BLOCK et al 2009 (page 3)
189 Air pollution information system 2009
190 Institute of Fisheries University of Manitoba 2009
191 Ibid
192 Weidema 2008 (Page 2)
Alluding to the single “vision” or narrow systems perspective of the LCA Weidema argues that more often than not, the data are presented as single values not giving any indication of uncertainty or data quality\(^{193}\).

See Appendix 1 and 2 which gives a diagrammatic representation of a LCA for bio-ethanol production in Brazil using sugar cane as the energy crop. Figure A represents the base case as in the time the LCA was done which would be 2005\(^{194}\), and the future case as in Figure B. The future case represents an economic method of allocating investment from the time the plant is established to when it becomes profitable. In this case the future case is 10 years from 2005\(^{195}\).

**2.5.6.4. Discussing the results for the LCA of bio-ethanol**

The comparative results of the LCA for all the fuel alternatives in the base and the future case are shown in Appendix 3. The LCA results show that in the base case the levels of ADP and GHG emissions were drastically decreased when gasoline was replaced by ethanol fuels, 83% and 81%, respectively. This decrease in emission was believed to be due to the replacement of fossil resources by renewable biological resources.

ADP decreases even more in the future case decreases even more (87%); GHG emissions however decreased, much less (24%) than in the base case. The reason for the significant decrease in GHG emissions is that the growth of sugarcane takes up a large amount of CO2, counter-acted only partly by N2O-emissions from agriculture\(^{196}\). Of course this can be explained by the C4 chlorophyll structure of the photosynthetic mechanism of sugarcane compare to a number of other plants that have a C3 structure\(^{197}\).

The other impact categories, applying ethanol fuels cause a larger environmental impact: The agricultural process contributes largely to human and eco-toxicity; acidification and eutrophication; Ozone layer depletion is much lower for ethanol from sugarcane because it is mainly caused by the methane emission from crude oil production onshore; The POCP level is not significantly changed in both cases. When gasoline is replaced by ethanol fuels, emissions causing photochemical oxidation (POCP) from natural gas production and crude oil exploitation decrease, however the emissions from storing of the ethanol, or fermentation, or treating the co-product bagasse and electricity generation from the ethanol increases POCP\(^{198}\).

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\(^{193}\) Ibid. page 2  
\(^{194}\) Luo et al 2009 (Page 1615)  
\(^{195}\) Ibid. page 1618  
\(^{196}\) Ibid. page 6  
\(^{197}\) Sengbusch 2003  
\(^{198}\) Ibid.page6
2.5.7. Life cycle costing (LCC)

According to the Office of Government Commerce, of the British government\textsuperscript{199}, life cycle costing or whole life costing is a technique used to establish the total cost of ownership. The British government website points out that it is a structured approach that addresses all the elements of this cost and can be used to produce a spend profile over its entire lifespan. In other words this gives a complete financial cost of the product (bio-ethanol in this case) over its projected lifespan.

Lin Luo et al\textsuperscript{200} did a life cycle costing for the bio-ethanol as well as the LCA, the results are presented below in table\textsuperscript{7-10}.

2.5.7.1. LCC calculations

The cost calculations were done base on 2005 data. Here the gasoline production cost was taken as 0.59$/kg. Ethanol however performed better with a cost of 0.30$/kg in the base year (year from which the costing was done) and 0.26/kg in the future year. They included all the cost for a 1 kilometer drive using different alternative fuel in the table below.

<table>
<thead>
<tr>
<th>Case</th>
<th>Gasoline</th>
<th>E10</th>
<th>E85</th>
<th>Ethanol</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base case</td>
<td>0.0393</td>
<td>0.0388</td>
<td>0.0313</td>
<td>0.0294</td>
<td>$/km</td>
</tr>
<tr>
<td>Future case</td>
<td>0.0393</td>
<td>0.0385</td>
<td>0.0282</td>
<td>0.0254</td>
<td>$/km</td>
</tr>
</tbody>
</table>

It was concluded by Lin Luo et al\textsuperscript{202} that it was cheaper to drive with ethanol than with gasoline or other alternate fuel as can be seen from the table 7 above, 0.0393 and 0.0393 for gasoline compare with 0.0294 and 0.0254 and for ethanol. In this case they pointed out that the future case is more economical, as no extra electricity is produced but 2.4 times as much ethanol as the base case.

The other tables 8 to 10 below present the different scenario of the price of the fuel varying to see how it affects the price of driving the same vehicle. Lin Luo et al (2009)\textsuperscript{203} concluded that in the entire different scenario given below as can easily be observed from the tables below, it is far cheaper in both the base case and future case to drive using ethanol. They

\textsuperscript{199} Office of Government Commerce (UK) 2009
\textsuperscript{200} Luo et al 2009 (page 1613–1619)
\textsuperscript{201} Ibid. page 1618
\textsuperscript{202} Ibid.page1618
\textsuperscript{203} Ibid. Page 1619
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reason that due to implementation of advanced process technology in the future case, production costs of ethanol has been brought down significantly\(^{204}\).

Table 8: Costs of 1 km driving with double crude oil price. Source\(^{205}\)

<table>
<thead>
<tr>
<th>Case</th>
<th>Gasoline</th>
<th>E10</th>
<th>E85</th>
<th>Ethanol</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base case</td>
<td>0.0816</td>
<td>0.0784</td>
<td>0.0402</td>
<td>0.0294</td>
<td>$/km</td>
</tr>
<tr>
<td>Future case</td>
<td>0.0816</td>
<td>0.0781</td>
<td>0.0370</td>
<td>0.0294</td>
<td>$/km</td>
</tr>
</tbody>
</table>

Table 9: Kilometer driving with double sugarcane price. Source\(^{206}\)

<table>
<thead>
<tr>
<th>Case</th>
<th>Gasoline</th>
<th>E10</th>
<th>E85</th>
<th>Ethanol</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base case</td>
<td>0.0393</td>
<td>0.0403</td>
<td>0.0483</td>
<td>0.0511</td>
<td>$/km</td>
</tr>
<tr>
<td>Future case</td>
<td>0.0393</td>
<td>0.0395</td>
<td>0.0388</td>
<td>0.0390</td>
<td>$/km</td>
</tr>
</tbody>
</table>

Table 10: Costs of 1 km driving with double both prices. Source\(^{207}\)

<table>
<thead>
<tr>
<th>Case</th>
<th>Gasoline</th>
<th>E10</th>
<th>E85</th>
<th>Ethanol</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base case</td>
<td>0.0816</td>
<td>0.0799</td>
<td>0.0572</td>
<td>0.0511</td>
<td>$/km</td>
</tr>
<tr>
<td>Future case</td>
<td>0.0816</td>
<td>0.0790</td>
<td>0.0472</td>
<td>0.0383</td>
<td>$/km</td>
</tr>
</tbody>
</table>

2.5.8. Exergy

Another method of evaluating bio-ethanol is using the method call exergy. According to Odum exergy, this is the amount of available (potential) energy capable of doing useful work\(^{208}\). Hence this method is evaluation of the energy that is classified as exergy, has the capacity to do work.

Zanderighi (2008)\(^{209}\) carried out an exergy analysis for bio-ethanol. The evaluation was done using the Exergy return / Exergy input ratio or EROI- this is a measure of the efficiency in

\(^{204}\) Ibid. page 1618  
\(^{205}\) Ibid. page 1618  
\(^{206}\) Ibid. page 1618  
\(^{207}\) Ibid. page 1618  
\(^{208}\) Odum 2007 (page 68)  
\(^{209}\) Zanderighi L. 2008 (page 4)
storing energy. Because of the scope of this paper, only the necessary information from this study will be added so as to prevent undue complications.

EROI can be evaluated easily as follow: Exergy return is evaluated from the process flow sheet and for the exergy input, “all production steps from the land until the industrial plant must be considered”\textsuperscript{210}. Zanderighi (2008)\textsuperscript{211} pointed out that while it is difficult to evaluate the exergy for inputs not related to material balance, examples of this include: human work, machinery, buildings, supporting structures depreciation. In this case the author pointed out that the time and space for these not easily defined inputs, time and space must be defined properly.

Zanderighi (2008)\textsuperscript{212} however gave two special formulas for to calculate the EROI for two difficult to calculate (exergy) inputs: 1. Labor- $\text{ExW} = \text{n Exin}/\text{ntot}$, where $\text{n}$ the number of work hours on analysis. ntot is the total amount of work-hours annually and Exin is the exergy influx to the society per year; see Table\textsuperscript{11} below.

A method for the evaluation of the exergy of all investments evaluated on the basis of the monetary investment, can be done as follow: $\text{ExC} = \text{C Exin}/\text{Cref}$ C in the capital depreciation, or the monetary flux, and $(\text{Ex}/\text{Cref})$ is the monetary measurement of the exergy.

\begin{table}[h]
\centering
\begin{tabular}{|l|c|c|c|c|l|}
\hline
\textbf{AGRICULTURAL PRODUCTION} & \textbf{AGRIC} & \textbf{INDUSTRIAL} & \textbf{EXERGY IN} & \textbf{EXERGY OUT} & \textbf{EROI} & \textbf{ETHANOL (l/Ha)} \\
\hline
MAIS & 28+/−2 & 13+/−0.2 & 41+/−3 & 52+/−1 & 1.3 & 3100 \\
WHEAT & 22+/−2 & 8+/−0.2 & 30+/−2 & 31+/−1 & 1 & 2050 \\
BARLEY & 15+/−2 & 8+/−0.2 & 23+/−2 & 31+/−1 & 1.3 & 2050 \\
SUGARBEET & 28+/−3 & 12+/−0.2 & 50+/−2 & 48+/−4 & 0.96 & 4500 \\
\hline
\end{tabular}
\caption{The table below is a comparative table of the exergy value for bioethanol using different feedstocks. \textit{Source: Table extracted from “Table 3 - EROI of different agricultural production in the Italian system”}}
\end{table}

The shortcoming of this type of analysis is that it does not take in consideration externalities such as labor, capital, information, environmental effect in its analysis; it’s an argument.

\textsuperscript{210} ibid. page 4
\textsuperscript{211} Zanderighi L. 2008 (page 4)
\textsuperscript{212} ibid.page4
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concur by Sciubba and Ulgiati (2005)\textsuperscript{213}. Though the expert would quickly point out that such shortcoming is solved by the extended version of exergy analysis that is, extended exergy analysis (EEA). The EEA still comes up short, as it does not include externalities such as the effects of non-commercial fluxes like rain, solar irradiation, wind, deep heat etc\textsuperscript{214}. By ignoring these aforementioned externalities, EEA assume that these aren’t relevant in the creation or production of the bio-ethanol.

E. Sciubba and S. Ulgiati, posit that, the EEA is best suited when constructing a production function\textsuperscript{215} or a summary of the processes converging, all factors into a particular commodity production\textsuperscript{216}. In this case it is good for considering all the major production factors involved in the production of bio-ethanol.

\textbf{2.5.9. Net energy analysis}

Net energy is the energy output or balance after the total energy used to produce the product is subtracted, as alluded to by David Morris and Irshad Ahmed\textsuperscript{217}. In their research paper Morris and Ahmed explored the energy feasibility or the net energy balance of using a certain quantity (bushel) of corn to produce ethanol. They used three methods to estimate the net energy balance from the given quantity of ethanol from the bushel of corn\textsuperscript{218}.

Morris and Ahmed outlined three (3) fundamental questions important in arriving at the answer as to whether bio-ethanol from feedstock, corn, has net energy. The three used were: 1. How much energy is used to grow the raw material? 2. How much energy is used to manufacture the ethanol? 3. How do we allocate the energy used in steps one and two between ethanol and the other co-products produced from the raw material?\textsuperscript{219}

Three methodologies were explored in this net energy analysis: 1. Include taking the energy of the ethanol from the corn and the direct energy value of the co-products to estimate the energy credit. Example 21\% protein feed has a calorie content of 16388 BTUs (British Thermal Units) per pound or 1 054 – 1 060 J (joules) or 2.931 \times 10^{-4} \text{ kWh} (kilowatt hours) or 252 – 253 cal (calories, or "little calories").

2. The researchers found the problem with this method is that it places a fuel value on a food value, and hence undermines the true value of the product\textsuperscript{220}. This method involves the assignment of energy value to co-products based on their market value. This involves adding

\textsuperscript{213} Sciubba and Ulgiati 2005 (page 1986)
\textsuperscript{214} Ibid
\textsuperscript{215} Ibid
\textsuperscript{216} Samuelson 1972 (p.174)
\textsuperscript{217} Morris and Ahmed 1992 (Page 1)
\textsuperscript{218} Ibid. page 5
\textsuperscript{219} Ibid. page 2
\textsuperscript{220} Morris and Ahmed 1992 (page.6)
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up the market value of the product and co-products (in dollars) from corn and applying energy credit based on market value\textsuperscript{221}. Example of such can be seen in table 12 below.

Table 12: Showing direct energy methodology values for corn oil and co-product wet milling (BTU/Gallon of ethanol)\textsuperscript{222}.

<table>
<thead>
<tr>
<th>Products</th>
<th>Amount Produce (pounds)</th>
<th>Market Value (dollar per pound)</th>
<th>Total Value (dollars)</th>
<th>Energy Allocation (BTUs per gallon ethanol)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corn Oil (1)</td>
<td>1.6</td>
<td>0.35</td>
<td>0.58</td>
<td>8.164</td>
</tr>
<tr>
<td>21% Gluten Feed</td>
<td>13.5</td>
<td>0.05</td>
<td>0.68</td>
<td>9.914</td>
</tr>
<tr>
<td>60% Gluten Meal</td>
<td>2.6</td>
<td>0.12</td>
<td>0.31</td>
<td>4,914</td>
</tr>
<tr>
<td>Carbon Dioxide</td>
<td>17.0</td>
<td>0.04</td>
<td>0.66</td>
<td>9,914</td>
</tr>
<tr>
<td>Total Co-Products</td>
<td>34.7</td>
<td>-</td>
<td>2.23</td>
<td>32,511</td>
</tr>
<tr>
<td>Ethanol</td>
<td>16.5</td>
<td>-</td>
<td>2.97</td>
<td>43,300</td>
</tr>
<tr>
<td>Total Products</td>
<td>51.2</td>
<td>-</td>
<td>5.20</td>
<td>75,811</td>
</tr>
</tbody>
</table>

Ledger to understanding Table 12 figures above: 1. The market values for corn oil presumed in the table is for refined oil. With crude corn oil having a market value of 27 cents per pound. 2. The 21% protein feed includes 1.0 to 1.5 pounds of germ meal that is produced during the extraction of corn. 3. Average ethanol yield is 2.56 gallons per bushel, with 6.6 pounds to the gallon. A gallon of ethanol was sold for $1.20. Source: Corn refiners Association, Washington DC. National Corn growers Association, Saint Louis, Mo 1982.

3. This method involves a method call the replacement method. This involves determine the nearest competitor to corn products and then calculate energy requirement to raise the feedstock and then process it into that product. Example 1 pounds of corn take 1.6 pounds soybean oil to replace it. The energy required to raise the soybeans and extract the oil comes to 10616 BTUs; 13.5 pounds of 21% corn protein feed is 13.45 pounds of barley. The energy required for growing the barley and drying it is 1,336BTU per pound, which equal 7,047BTUs per gallon of ethanol equivalent; the replacement value for carbon dioxide would be base on the energy intensity value of the fermentation process that produces it as a by-product. The table 13 below provides a comparison of the replacement method along the prior two mentioned methodologies.

\textsuperscript{221} ibid. page 6
\textsuperscript{222} ibid. page 6
Bio-fuel as a case to discuss sustainable development

Table 13: Showing Co-Product energy credit methodology values for corn wet milling (BTU/Gallon of ethanol).

<table>
<thead>
<tr>
<th>Method</th>
<th>Corn Oil</th>
<th>60% Gluten Meal</th>
<th>21% Protein Feed</th>
<th>Carbon dioxide</th>
<th>Total Co-Products</th>
</tr>
</thead>
<tbody>
<tr>
<td>Market Energy Value</td>
<td>8164</td>
<td>4.519</td>
<td>9.914</td>
<td>9.914</td>
<td>32.511</td>
</tr>
<tr>
<td>Replacement Value (1)</td>
<td>10.616</td>
<td>2.827</td>
<td>7.047</td>
<td>4.460</td>
<td>24.950</td>
</tr>
</tbody>
</table>


The conclusions arrived at by the researchers are:

1. When the average efficiency corn farm and an average efficiency ethanol plant is assumed; then the total energy used in growing corn and processing it into ethanol and other products is 75, 811 BTU; There are 76,000 BTU’s per gallon and the replacement energy value for the co-products is 24,950 BTUs. With energy output of 100, 950 BTUs, then the net energy is 25,139 BTUs. This gives an energy output-input ratio of 1.33:1

2. The best existing operation of such kind, presently gives a net energy gain of over 50,000 BTUs, giving a ratio of 1.87:1

3. If the state of the art practices and mechanisms are observed then this ratio would be 2.2:1.

The researchers concluded that yes ethanol made from even corn is feasible, as it provide net energy. They however went on to say according to the data that comes from using cellulosic crops, it would be better than the using other feed stocks; it gives a ratio of 2.45 to 1. While the net energy analysis looks at input in the production of the product or service; it only counts the fuel in the production process. For the labor involve in the production process it counts the caloric value of the worker consume; the fuel used to produce the food and the fuel purchased with the wages are taken in consideration.

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\[223\text{ ibid. page 8}\]
\[224\text{ ibid. page 8}\]
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The market value is a poor method in assigning energy value, as it is based on how people perceive the value of the products, goods or service. It assigns value to the various aspects of the goods separately, as if the production of say wool of a sheep is independent in the meat of the sheep. In the case of bio-ethanol it would be assuming that the corn oil in the corn can develop independently of the gluten or protein or other corn kernel co-product.

The shortcoming of the replacement value of the net energy is just like that of direct valuation, where it ignores the unique make up of the product. The unique quality, circumstances required to produce that specific crop. It also ignores that while 1.6 pounds of soya bean replace 1 pound of corn. In essence the net energy analysis is totally quantitative in nature and ignores the qualitative aspect of the kernel that also influences the final product. Hence the disregard for environmental service involved in the production process of corn to energy; these are critiques concurred with in the comparative table “Detailed dialog comparison of EMA and EA (based on Brown and Herendeen, 1996)” of emergy and energy analysis Robert A. Herendeen

2.5.9 Process Analysis

This is a type of energy analysis, where a particular product or object or service is first identified then the process which produces the energy is examined for energy used. The goods and service/s, directly and directly, that were required are identified. With a compilation of such list, the fuels or the direct energy input is tallied. The non-energy goods and services input are further examined to determine the energy and non-energy goods and services input. The process continues until the input energy in a process is identified as negligible; see diagram below of figure 7.

C W. Bullard et al point out that a large number of terms never normally get computed and as result the analysis is terminated at a point where the input is believe to add negligible energy. While in the second stage of the analysis only the most significant inputs are considered, only a subset is further broken down into its components of fuel and non-energy goods.

The performance of a process analysis requires access to extensive data for the production. The shortcomings are however: 1. Factors of production that cannot be calculated in fuel used to produce it aren’t taken. Example of the aforesaid is a steel pipe, only the fuel used in creating the steel pipe in the manufacturing process is taken in consideration and not the labor that was engaged in the process. 2. In a process analysis a fuel cannot be attributed to

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225 Herendeen 2004 (page 229-230)
226 Bullard et al 1978 (page269)
227 Ibid. page 270
228 Ibid. page 269
229 Ibid. page 270
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labor a non-fuel product according to process analysis. 3. “Energy extracted from the earth does not appear in” process analysis and only energy inputs purchased are involved\(^{230}\).

![Diagram of process analysis stages]

*Figure 7:* the successive stages in a process analysis. Source\(^{231}\)

### 2.6.0 Energy Input-Output analysis (I-O)

This is an approach used regularly in economics analysis. It is a tool introduced by Leontief (1941). It was adapted by Herendeen and Bullard (1974) to analyze energy and labor intensities\(^{232}\).

The process involves a disaggregation into major sectors; this involves working out the energy entering one sector and leaving another. From this process an energy intensity factor

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\(^{230}\) Ibid. page 272  
\(^{231}\) Ibid. Page271  
\(^{232}\) Ibid. page 274
(Btu/\$) can be calculated by working out the dollar flow between the industries and energy consumed in the process\textsuperscript{233}.

However there is a lot of uncertainty associated with I-O analysis, these involve: 1. As the price of goods change over time and inflation, the price level will change, though product quantity remains the same. This is not accounted for by the I-O analysis. 2. The change in technology over time is another source of uncertainty. This change influence the energy use and dollar flow, as more new technology often increase the efficiency of energy use. 3. Each product manufactured within a sector has a unique energy coefficient (that is the energy required in its production process) however in the analysis, products in the same sector are grouped and given the same energy coefficient, though each product in a sector may differ in the actual energy needed in its production process (energy can be more or less needed)\textsuperscript{234}.

The critique of I-O analysis is that, this type of analysis only takes in accounts the fuel processes and not non-fuel processes or processes requiring the input of fuel. Example of processes not accounted for, are environment free services, since these are difficult to estimate or attribute a fuel “cost”. I-O analysis is a fuel summation and ignores energy required to produce capital used by each sectors\textsuperscript{235}, hence energy used in the production of say a building is ignored in such analysis. The shortcoming here is ignoring the fact that it takes energy to produce capital, and they don’t just appear in the midst of the earth without the input of energies.

\textbf{2.6.1 Methodologies in summary}

What all the above measurements or methodologies have in common is the deficiency of a broad systems perspective, which would provides a much wider panorama so to speak; to the true cost and impact of bio-ethanol of Sweden switching over to bio-ethanol as the main fuel in the transport sector and wider economy. This will be discussed below, first by outlining the two perspectives that are normally applied to the use and analysis of resources use.

All the above perspectives could be modeled according to the diagram below in figure 8 where the evaluation is seen as a measure of the input and output, as represented in the diagram below.

\textsuperscript{233} ibid. page 274-276
\textsuperscript{234} ibid. page 277-279
\textsuperscript{235} ibid.page279
3. Emergy an in-depth look and its application

3.1. Perspectives

The receiver base perspective, according to Daniel Bergquist\textsuperscript{236} quoting Simonsson (2004) is a system constructed by humans. The receiver base perspective of nature reflects on the perceived values a system offers to humans. This thus make the argument that the receiver base perspective of nature is based upon a platform of what one can get from a system, or what one can derive from the aspect of nature in question. Thus it would be what one can get from the river, the sea, the forest, etc.

Bergquist quoting Brown et al (2000)\textsuperscript{237} pointed out, the willingness to pay approach, as an example of the receiver base perspective which is a common perspective in economic science. Expounding on Brown (2000), Bergquist argue that it is a perspective based upon how one is willing to pay for the resource or service from and of the environment\textsuperscript{238}. The problem with this approach is that it totally conceals the level and the depth of human dependence on nature\textsuperscript{239}. When resources and services are paid for, it would seem as if the value is time set, and value set; in other words your dependence is base on how much you value it in time and space. This valuing system, however promotes an imbalance in global trade, quoting Hornborg (2001)\textsuperscript{240}.

One problem pointed out in the aforementioned thesis about the receiver base perspective, is that they don’t appropriately account for the free services and products that human

\textsuperscript{236} Bergquist 2008 (page.87)
\textsuperscript{237} Ibid.page87
\textsuperscript{238} Ibid.page88
\textsuperscript{239} Ibid. page 88
\textsuperscript{240} Ibid.page88
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economic system receives from the environment\textsuperscript{241}. Hence the value of services offered by the environment is never taken in consideration, as they are often times seen as free and difficult to value. With the receiver base perspective the value is normally placed on the resource or service according ones feelings.

The donor base perspective is the second perspective. The donor perspective accounts for the environmental contribution to a system regardless of the value perceived by human users; in this case whether it is perceived to have energy of mechanical activity, monetary, etc\textsuperscript{242}.

This (Emergy) provides a way of estimating the value of monetary and non-monetary resources, services and products on equal terms\textsuperscript{243}. Quoting Brown and Ulgiati, Bergquist (2004b) made the point that this type of perspective is an attempt to treat human and environmental contribution to a system on equal term\textsuperscript{244}. In other words this is an attempt to account for or give a value to those free services that are not easily valued by humans.

### 3.2. System Perspective

To understand the above perspective it’s important to take an in-depth look at perspective call the systems perspective.

The system perspective according to Odum and Odum represents a window of attention that is used to isolate a subsystem the greater whole, or the universe around it\textsuperscript{245}. By doing this the Odums point out, that “we identify the parts and processes and the sources of inflows across the imaginary boundary”\textsuperscript{246}; in other words we create a way of looking at the world. The window or way of viewing the world allows us to look at its components and how they interact together. Shu-Li Huang et al\textsuperscript{247} in reference to system (urban) see it as the sum that is greater than its parts. It is a view or situation that reflects a far-from equilibrium situation, as there is a development of spatial hierarchical order among the central places. This allows for the maintenance and then transformation “by means of interaction, fluctuation and dissipation of incoming energy sources”\textsuperscript{248}. This indicates a measure of inter-dependence, which allows for the growth and development of “system”, or environment, or resource, etc in question.

Huang et al\textsuperscript{249} stated a critical aspect about a system whether it be simple or complex is its ability to self organize its internal structure. Where self organize systems are complex in two

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\textsuperscript{241} Ibid. page 88
\textsuperscript{242} Ibid
\textsuperscript{243} Ibid
\textsuperscript{244} Ibid
\textsuperscript{245} Odum and Odum2001 (page 61)
\textsuperscript{246} Ibid
\textsuperscript{247} Shu-Li et al 2007 (page 497)
\textsuperscript{248} Ibid
\textsuperscript{249} Ibid. page 497
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ways: 1. their parts are too numerous in order to establish their casual relations and 2. Their parts and components are interconnected in a network of feedback loops, and thus make it possible to describe the system using differential equations\textsuperscript{250}.

Inherent to these system are the notion of self organization, as it speaks to the fact that external forces acting on the system do not alone determines the behavior of the system but triggers an internal and independent process. It is through this independent process that the system reorganizes itself in a spontaneous manner, concurred by Huang et al\textsuperscript{251}.

Odum and Odum describe the idea of a complex system by using symbols\textsuperscript{252}, some of these will be seen below in figure 9. As will be seen there are symbols for energy source, producers, consumers, storage. A Producer in this case is responsible for assimilating and storing energy usually in an organic form; the consumer uses the store organic matter to fuel their work, and the storage receives and stores the energy until it is used by the consumer, or dissipated into the environment\textsuperscript{253}. Figure 10 is a representation of this complex system using the system symbols according to Odum\textsuperscript{254}.

\textsuperscript{250} Ibid. page 497
\textsuperscript{251} Ibid. page 497
\textsuperscript{252} Odum and Odum. 2001 (page 62)
\textsuperscript{253} Ibid. page 62-63
\textsuperscript{254} Ibid. page 62
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Figure 9: Symbols used in Emergy systems perspective. Taken from S. E. Jorgensen and E Mueller (editors), Lewis Publishers Boca Raton, Florida. Handbook of Ecosystem Theories and Management (2000. Page283) H.T. Odum, M.T. Brown and S. Ulgiati.

Figure 10: The complex system model- Diagram for the calculation of indices. Symbols are explained in Fig. 2. R, N, and F indicate, respectively renewable, non-renewable and purchased emergy flows into a process. Eout is the exergy content of the output (Y) (F+N)/R is the total emergy assigned to the output as a measure of the environmental support needed (seJ). Finally, TrY/Eout is the transformity of the output (seJ/J). Source: 255

Difficulty that long existed, with: 1. Conventional energy analysis being unable to account and provide information about its potential impact or appropriate use; 2. The language of energy, has not been easily translated in the currency of human exchange 256. In the former case Lefroy and Rydberg made reference to the inability of the present energy analysis to give a complete picture of the impact of the energy used by any system. As they pointed out; in the latter case the same analysis does not provide a straightforward and in-depth way of calculating the human and environment exchange; in terms of energy. It was for these two

255 Sciubba and Ulgiati 2005 (page 1958)
256 Lefroy and Rydberg 2003 (page 196)
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reasons, pointed out above, Lefroy and Rydberg, expounded further that emergy analysis was developed\textsuperscript{257}.

3.3. Emergy the broad system perspective

Emergy, according to Odum is the memory of energy of the past\textsuperscript{258}, a definition that Lefroy and Rydberg concur with, when they state that, emergy is a measure of the total energy used in the past in making a product or service\textsuperscript{259}. Hence this represents the quantitative measure of the energy content of the past that goes into the construction of a resource, product, or service. The other aspect to this analysis is that it recognizes that not all qualities of energies are the same or as Lefroy and Rydberg alluded to that, energetics recognizes different qualities or forms of energies.

The above is an argument Bergquist, made substantively (using the work of Odum) in his work when he argued that, the emergy concept is predicated on the concept of different energy being unequal to their contribution processes of geobio-sphere; because of having different exergy contents\textsuperscript{260}. This highlights the difference in the energy contribution by different types or kind of energy to all forms of environmental processes. Bergquist gave the example of several joules of plankton is required to produce 1 Joule of energy in a fish; while several Joules of fish meal is required to produce 1 Joule in a shrimp; while several Joules of shrimp meal is required to produce a Joule in humans. Concluding he pointed out that, what all energy has in common is that all these require the input of other forms of energy to be produced (ibid). It is this which creates what Odum would refer to as the hierarchy of energy.

3.4. Transformity

The measure of how much emergy that is used in an energy transformation process and the energy content in the final product/s or service is referred to as transformity\textsuperscript{261}. Odum see transformity as “the calories of available energy of one form previously required directly and indirectly to generate one calorie of another form of energy”\textsuperscript{262}. Because of this solar transformity is usually expressed in solar emjoules per Joules of the output flow\textsuperscript{263}. This thus indicates that it is a factor or quotient in relating different types of energy to each other. The units of transformity are emjoules per joule, or emcalories per calorie. Example the solar

\textsuperscript{257} Ibid. page 197
\textsuperscript{258} Odum 2007 (page 69)
\textsuperscript{259} Lefroy and Rydberg 2003 (page 197)
\textsuperscript{260} Ibid. Page. 91
\textsuperscript{261} Bergquist 2008 (page 92)
\textsuperscript{262} Odum2007 (page 73)
\textsuperscript{263} Bergquist 2008 (page 92)
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Transformity of electric power is $1.7 \times 10^5$ solar emcalories/calorie\textsuperscript{264}. Odum in his work gave a basic outline of the measurement of transformity, which is reproduced below\textsuperscript{265}.

Solar Transformity = $\frac{\text{Solar Emergy/Time}}{\text{Energy/Time}}$

Solar transformity = $\frac{\text{Solar empower}}{\text{Power}}$

Solar emcalorie/Calories = Solar emjoules/Joule

Odum alluded to the point that as you move up an ecosystem chain the energy decreases at each step; hence the solar transformity increases along each step up the ladder so to speak, concurred by Odum\textsuperscript{266}. He alluded to transformity as a measure of the position that each kind of energy is in the ecosystem hierarchy\textsuperscript{267}. Example of this transformity and relation is seen in table 14 below.

Table 14: Is a table of the transformities relationship as the hierarchy increases from sunlight to species formation (source: A Prosperous way down)\textsuperscript{268}

<table>
<thead>
<tr>
<th>Item</th>
<th>Solar Emcalories per calorie</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sunlight energy</td>
<td>1</td>
</tr>
<tr>
<td>Wind energy</td>
<td>1,500</td>
</tr>
<tr>
<td>Organic matter, wood, soil</td>
<td>4,400</td>
</tr>
<tr>
<td>Potential of elevated rainwater</td>
<td>10,000</td>
</tr>
<tr>
<td>Chemical energy of rainwater</td>
<td>18,000</td>
</tr>
<tr>
<td>Mechanical energy</td>
<td>20,000</td>
</tr>
<tr>
<td>Large river energy</td>
<td>40,000</td>
</tr>
<tr>
<td>Fossil fuels</td>
<td>50,000</td>
</tr>
<tr>
<td>Food</td>
<td>100,000</td>
</tr>
<tr>
<td>Electric power</td>
<td>170,000</td>
</tr>
<tr>
<td>Protein foods</td>
<td>1,000,000</td>
</tr>
<tr>
<td>Human services</td>
<td>100,000,000</td>
</tr>
<tr>
<td>Information</td>
<td>$1 \times 10^{11}$</td>
</tr>
<tr>
<td>Species formation</td>
<td>$1 \times 10^{15}$</td>
</tr>
</tbody>
</table>

By observation of the table above it can be seen that as you descend down the table the solar energy input increases. This highlights that the more complex the product, resource, or service become the more transformity is associated with this. Transformity also provides a connection between the lower and higher energy level of the hierarchy\textsuperscript{269}.

\textsuperscript{264}Ibid. page 73
\textsuperscript{265}Ibid. page 73
\textsuperscript{266}Odum 2007 (page 73)
\textsuperscript{267}Ibid
\textsuperscript{268}Odum and Odum 2001 (page 69)
\textsuperscript{269}Odum 1998 (page 3)
3.5. **The significance of Emergy**

When the energy flow is multiplied by the transformity then an emergy flow is obtained\(^{270}\), or the measure of the flow emergy is obtained. The emergy used within a year by a nation thus account for their annual empower; this is the flow of emergy per unit time and is normally referred to as its’ empower\(^{271}\). This thus gives a measure of the true measure of energy necessary as support for an ecosystem or a nation, from one lower level of the hierarchy to upper level.

3.6. **Feedback and Reinforcement**

According to Odum, when you incorporate material (resource) into another product it carries with it, emergy of that material; it’s the same when the material is released as the emergy goes with it\(^{272}\). Hence the memory of the energy used in the creating the material goes with it, wherever the material goes. This understanding is fundamental as it will become important when bio-ethanol is discussed in this system view of emergy. Also when material is dispersed or broken down throughout the environment, its concentration decreases. Not only it loses concentration, it loses emergy and transformity (ibid).

After the process of transformation has taken place, some of the energy is fed back to reinforce the process that is responsible for the transformation concurred by Odum and Odum\(^{273}\). To paint the picture clearly the analogy of the pollinating bee is used to “paint” the picture much more clearly. In this example the feedback occurs as a process of reinforcement when say a bee feeding on the nectar from a flower, also pollinate flowers. In this way it increases the available flower that can produce nectar. In other words the process of (positive) feedback increases the existence of a product; process or services. Processes of nature eventually will develop and displace other processes that does not reinforce\(^{274}\).

3.7. **Energy hierarchy and organization**

“When many units of one kind [energy] combine to support another kind of unit that feeds back control”\(^{275}\) this is known as hierarchy. The hierarchy of energy can also be seen as the “interdependent relationship between the higher and lower level units”\(^{276}\). It can be describe as a relationship\(^{277}\) in many units at a lower level contribute to fewer units at a

\(^{270}\) Odum and Odum 2001 (page 69)  
\(^{271}\) Ibid \(^{272}\) Odum 1998 (page 5)  
\(^{273}\) Odum and Odum 2001 (page 64)  
\(^{274}\) Ibid \(^{275}\) Odum 2007 (page 65)  
\(^{276}\) Bergquist 2008 (page 91)  
\(^{277}\) Ibid. Page 284
higher level\textsuperscript{278}. The best way to understand this is to think of the structure of a pyramid, with many bricks or blocks at the lower level; the higher up you go the less the number of blocks or bricks become.

Odum et al\textsuperscript{279} postulated that since energy is in everything (from the cell to information) and having an energy transformation process then most things forms a hierarchical series. This hierarchal nature thus sees time and space increases along each transformation. Moving up this hierarchy, as energy passes along; some is passed on but most of it is lost or degraded moving up the hierarchy. This lost due to the second (2\textsuperscript{nd}) thermodynamic law, which points out the desire for everything to come in energy equilibrium with its environment. Hence because of this there is an increase in entropy of the endeavor of this process. Please consult the figure 11 below, it is a breakdown of the principle of energy hierarchy and transformation.

\textsuperscript{278} Ibid
\textsuperscript{279} Odum et al 2000 (page 284)
It is noted that as convergence takes place in the energy hierarchy, through a series of transformation, the final product will end up with available energy content lower than the initial resource, product, or service that was started out with; an argument alluded to by Odum et al.\textsuperscript{280} It is important to note that the final product is far more valuable than the first they pointed, as a lot of resources; energy went into making this product (ibid). To understand the energy process in this hierarchy concept, please take a look at figure 12 below. In this case, down to up means left to right.

\textsuperscript{280} Ibid
3.8. Self organization

In 1922 Lotka used energy law to produce a rational for the Darwin’s concept of natural selection, by stating that the maximization of flow of energy for useful purposes was the criterion for natural selection\(^{281}\). Hence the act of natural selection is a process of reinforcing the most efficient energy path, process, or system. Odum argue it to be a manifestation of systems that are able to adjust their load and operate at the peak of power efficiency\(^{282}\). During their process of selecting the most efficient path, these systems reinforce themselves, and choose paths with the “optimum load for maximum output”.

By reinforcing their path and processes, production is increased Bergquist pointed out\(^{283}\). This process he noted is call autocalytic system design, autopoesis or simply self-organization\(^{284}\). Lokta quoted by Odum also pointed that this process of reinforcement is a very important process in material recycling process. As he explains it, material recycled back down the hierarchy are kept at lower energy level so that material recycled back into the chain lower down depends on, only external energy source as a limiting factor.

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\(^{281}\) Odum 2007 (page 37-38)
\(^{282}\) Ibid. page 37
\(^{283}\) Bergquist 2008 (page 93)
\(^{284}\) Ibid. page93
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Odum noted that a few researchers such as Lekota saw self organization as a system of selecting the best design for maximum energy usage or self maximizing of energy flow\(^{285}\). In a self maximizing energy flow the typical system design is normally a web like, please see the system design diagram figure 12 above and below in figure 13, noticed the web-like structure the interconnectedness where energy is feedback along different recycling path. Or it could be said that the typical path is a system designed for energy flow and transformation processes\(^{286}\).

![Figure 13: An emergy systems diagram of the standard production consumption model. Reinforcement is shown by the dotted lines, where material is recycled back to the producer. Source\(^{287}\)](image)

As the process reinforce itself it makes one energy path more prominent, as it self-organize. Here lower quality energy and smaller quantity energy is fed back to the system in the form of recycle material; hence this amplifies the production process. Example of this can be seen by looking at our ecosystem, where large animals control large amount of organism through their various actions such as: placing of waste products; the ways of eating, and control of pollination, seeding, and reproduction\(^{288}\). The by-products of materials released from each unit also recycle back in the production thus contribute to the reinforcement of a production path hence self-organization.

When the process of trial and error process for system evolution or transformation is going on for a long time a point is reached, of “most energy use”\(^{289}\). In other words as evolution of a hierarchical energy process goes through cycles to achieve its most efficient path, eventually it will reach a state where energy use is most efficient. This is so because of a

\(^{285}\) Odum 1988 (page 1133)

\(^{286}\) Ibid. page1133

\(^{287}\) Ibid. page 1133.

\(^{288}\) Ibid. page 1133

\(^{289}\) Bergquist 2008 (page 93)
reinforcement of the correct processes by the ecosystem. This reinforcement process occurs through feedback to increase the efficiency and productivity of the ecosystem\textsuperscript{290}.

Brown et al (2004) use the metaphor of the Maxwell demon\textsuperscript{291} to explain why natural system is designed to use energy hierarchy. Because there isn’t enough energy in molecules to support a system’s process of transformation; however in self-organization many different energy types, or energy of many molecule converges to support few molecules, or system of higher energy hierarchy concurred by Brown et al\textsuperscript{292}.

The importance of self-organization is that it is an environmental principle locked into the ecosystem which provides an insight into how the ecosystem works\textsuperscript{293} and thus is a blueprint to be followed for manmade energy systems. But importantly self-organization addresses the concept which Bergquist pointed out in his work, that an energy source must provide a net contribution of energy to the larger energy system in which it is embedded. Or it should provide more energy to the system than it cost to extract and process it as available energy\textsuperscript{294}. As pointed out above this is what is called the net energy or better net emergy, and it is this perspective which the discussion of bio-ethanol now turns.

### 3.9. Net emergy

Earlier net energy was discussed above, according to Odum it is the energy flow that is above and beyond what is required to extract and process that energy\textsuperscript{295}; importantly where the output, input and feedback energy are expressed in the same energy equivalent.

As we have already identified above the use of emergy in this paper addresses the broader systems view regarding energy. Thus identifying the energy used to make the energy instead of just available for mechanical work, that is exergy, the energy available to do useful work or mechanical work, as concurred by Odum\textsuperscript{296}. Instead this paper is looking at the total energy involved in a given packed of energy.

The net emergy yield is the emergy yield minus the emergy from the economy used to process the product with fossil fuel seen as an example of a product which has a high net emergy\textsuperscript{297}. Thus resource or products with net emergy yield are able to use the net emergy to support other sector of the economy.

\textsuperscript{290} Ibid
\textsuperscript{291} Brillouin 1962 (page351)
\textsuperscript{292} Brown 2004 (page 17-28)
\textsuperscript{293} Bergquist 2008 (page 94)
\textsuperscript{294} Ibid
\textsuperscript{295} Odum 1975 (page 8)
\textsuperscript{296} Odum 2007 (page 68)
\textsuperscript{297} Odum and Odum 2001 (Page 98)
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The emergy yield ratio (Yield Emergy/Feedback emergy) is believed to be a good measure of a product to the economy. Odum alluded to a similar point that a source with a high net emergy yield ratio or net emergy yield is qualified to be a good primary energy source. Thus the less emergy goes into processing an emergy [energy] source for usage the more its emergy content will be.

In a society not all energy source need to have a net emergy yield, however it is important that society has at least one primary net emergy yield source. This is important so that the primary emergy yield source can offset the lack of net emergy or low emergy of all the secondary sources. Or these secondary low net emergy sources can be empowered by the use of the primary source so as to expand or maximize the system’s total emergy base.

3.10. Economic significance of net emergy yield

As pointed out earlier not all source need to be a net emergy producer. In economics terms this can be interpreted as not all sector of the economy need to be a primary emergy producer, or net yielder. They can use the main energy sources and make their contribution to the economy. Where the resources, goods, services among other input from the main economy are used to produced other goods services in the economy. Important is that the net balance of the energy, emergy, yield must be positive and not negative as insinuated by Odum. Example of primary energy sector of the economy working with secondary, involves the equipment for solar water heater is built using fossil fuel. Though there is no net emergy contribution, it offsets this by providing heated water and using no fossil fuel to do this directly.

3.11. Cases and Discussion

This paper now turns its attention for the emergy results for an analysis (done in China and Italy) of bio-ethanol using the energy source wheat and corn. A brief background to the analysis will be given and then the results. This analysis results will then be discussed for implications for Sweden.

3.11.1. Brief background

An emergy analysis was conducted on two bio-energy plant producing bio-ethanol; one in China and one in Italy, with wheat and corn as source material respectively. The following are the results for the two emergy analysis.

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298 Odum 2007 (Page 205-206)
299 Ibid. page 207
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As highlighted above it is a process of triangulation that will be used to induce or gather relevant pointers or information that could be used as guidelines for Sweden. Hence the information from China, Italy and other available information from Sweden will be used to provide discussion information in this case.

3.11.2. The bio-ethanol production in China and Italy

The bio-ethanol plant in China studied is located in the city Nanyang city of Henan Province. The total fixed capital investments were US$1x10^7 in the year 2001. The plant has a production capacity of on a yearly basis of 7.18x10^5 ton of wheat, obtained from about 167,000 ha of plantation lands. The plant has a milling capacity of the plant is about 2000 ton of wheat/day; the average production ratio is 0.28 ton alcohol/ton of wheat; the average productivity of wheat in the area is 4300 kg/ha, so that alcohol productivity per ha is around 1.20 ton/ha; the alcohol produced is concentrated up to 99.5% and the total alcohol production could therefore reach 2x10^5 ton/yr.

Co or by-products such as filter cake and vinasse are used as fertilizers, in order to decrease the need for fossil-based chemical fertilizers. Table 15 and 16 gives a picture of the technical performance of the wheat to ethanol conversion process, with main conversion and economic parameters. Due to the large variety of water sources used (ground water, river water, stored rain water) as well as due to the variety of irrigation regimes of wheat production (depending on season and wheat cultivar), water was not accounted for in our tables.

The Italian bio-ethanol plant had a similar set up as that in China, except corn was used instead of wheat see Table 17 below. Giampietro and Ulgiati (2005), who accounted for energy credit due to the use of distillation residues as animal feedstock. With indirect energy saving, increased by 26%, the output/input energy ratio of bio-ethanol that is. Giampietro and Ulgiati had concerns of the 26% energy credit applicability. Therefore slightly decreasing the energy ratio calculated in the Italian case.

Results- The bio-ethanol production process includes: wheat cropping, transport to factory, wheat to alcohol conversion, mixture with gasoline and finally delivery to the gas station.

The first step involves the conversion of the raw data to energy and emergy flows. Flows are then grouped according to their characteristics: locally renewable input, locally nonrenewable input, materials and services from economy, and products. The total energy invested directly and indirectly into the agricultural step is equal to 2.38x10^4 MJ/ha. About
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5.5 kJ are needed per gram of grain produced, which translates into an output/input energy ratio of 2.5 for wheat grain.\(^\text{304}\)

The diagram in figure 14 below represents the emergy system perspective of bio-ethanol production process with wheat as the energy crop.

![Emergy diagram](image)

**Figure 14:** Emergy systems diagram of bioethanol production using wheat (after Brown and Ulgiati, 2004) showing the main inputs to and steps of the process. Dashed lines represents the inflow of money from bioethanol sale and the outflow of money for the purchase of goods and services. Source: \(^\text{305}\)

The following are the data in Table 15 are the results of the different aspect of the analysis of bio-ethanol production according to X. Dong et al.\(^\text{306}\).

First step involves an energy analysis of all the processes involved in the production, so a transformation of the data can be done. This is important so that all data can be in equivalent.
### 3.11.3. Cases: Chinese and Italian bio-ethanol emergy results

Table 15: *Energy analysis of wheat production in China (1 ha; reference years: 2002–2004). Source*

<table>
<thead>
<tr>
<th>Item</th>
<th>Raw amount</th>
<th>Unit</th>
<th>Energy equivalent (J/unit)</th>
<th>Ref. of energy equivalents</th>
<th>Energy flows (J/ha/yr)</th>
<th>% of total energy use</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seeds(^a)</td>
<td>1.25E+05</td>
<td>g/ha/yr</td>
<td>5.53E+03</td>
<td>This work</td>
<td>6.91E+08</td>
<td>2.90</td>
</tr>
<tr>
<td>Nitrogen fertilizer, N(^b)</td>
<td>1.80E+05</td>
<td>g/ha/yr</td>
<td>7.33E+04</td>
<td>Ulgiati (2001)</td>
<td>1.32E+10</td>
<td>55.40</td>
</tr>
<tr>
<td>Phosphate fertilizer, P(_2)O(_5)(^c)</td>
<td>7.50E+04</td>
<td>g/ha/yr</td>
<td>1.34E+04</td>
<td>Ulgiati (2001)</td>
<td>1.00E+09</td>
<td>4.22</td>
</tr>
<tr>
<td>Potash fertilizer, K(_2)O(^d)</td>
<td>6.00E+04</td>
<td>g/ha/yr</td>
<td>9.21E+03</td>
<td>Ulgiati (2001)</td>
<td>5.53E+08</td>
<td>2.32</td>
</tr>
<tr>
<td>Herbicides(^e)</td>
<td>1.11E+04</td>
<td>g/ha/yr</td>
<td>5.99E+04</td>
<td>Ulgiati (2001)</td>
<td>6.66E+08</td>
<td>2.80</td>
</tr>
<tr>
<td>Steel for agricultural machinery(^f)</td>
<td>7.30E+03</td>
<td>g/ha/yr</td>
<td>8.00E+04</td>
<td>Ulgiati (2001)</td>
<td>5.84E+08</td>
<td>2.45</td>
</tr>
<tr>
<td>Fuel for machinery (diesel)(^g)</td>
<td>1.38E+05</td>
<td>g/ha/yr</td>
<td>5.15E+04</td>
<td>Ulgiati (2001)</td>
<td>7.12E+09</td>
<td>29.90</td>
</tr>
<tr>
<td>Wheat harvested(^b)</td>
<td>4.30E+06</td>
<td>g/ha/yr</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total energy invested(^i)</td>
<td></td>
<td>J/ha/yr</td>
<td></td>
<td></td>
<td>2.38E+10</td>
<td>100.00</td>
</tr>
<tr>
<td>Energy equivalent of wheat</td>
<td></td>
<td>J/g</td>
<td>5.53E+03</td>
<td>This work</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Output/input energy of wheat production</td>
<td></td>
<td>J/J</td>
<td>2.496</td>
<td>This work</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\(^a\) Seeds used, 125 kg/ha/yr (Xiong and Zhang, 1996).

\(^b\) Nitrogen (N), 1.80E+05 g/ha/yr (Chen and Zhang, 2006).

\(^c\) Phosphate (P\(_2\)O\(_5\)), 7.50E+04 g/ha/yr (Chen and Zhang, 2006).

\(^d\) Ibid (page 3887)
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- Potash (K₂O), 6.00E+04 g/ha/yr (Chen and Zhang, 2006).
- Herbicides, 1.11E+04 g/ha/yr (Feng et al., 2002).
- Equipment and machinery. Total machinery weight: 7300 kg, mainly steel, allocated to 100 ha farmland for 10 years=7.30E+03 g/ha/yr (personal on-field investigation of the authors).
- Fuel for machinery=138.2 kg/ha/yr (Li and Lu, 2005).
- Wheat harvested, 4.30E+03 kg/ha/yr (Li and Lu, 2005).
- Energy content of wheat, 1.38E+04 J/g (Pimentel (1980)).

Table 16: Energy analysis of ethanol production from wheat (industrial phase). Source

<table>
<thead>
<tr>
<th>Item</th>
<th>Raw amount</th>
<th>Unit</th>
<th>Energy equivalent (J/unit)</th>
<th>Ref. of energy equivalents</th>
<th>Energy flows (J/ha/yr)</th>
<th>% of total energy use</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wheat from agricultural phase⁹</td>
<td>4.30E+06</td>
<td>g/ha/yr</td>
<td>5.53E+03</td>
<td>Ulgiati (2001)</td>
<td>2.38E+10</td>
<td>72.47</td>
</tr>
<tr>
<td>Water for alcohol production⁸</td>
<td>2.40E+07</td>
<td>g/ha/yr</td>
<td>5.99E+00</td>
<td>After Boustead and Hancock (1979)</td>
<td>1.43E+08</td>
<td>0.44</td>
</tr>
<tr>
<td>Sulfuric acid⁸</td>
<td>5.29E+04</td>
<td>g/ha/yr</td>
<td>6.28E+03</td>
<td>After Boustead and Hancock (1979)</td>
<td>3.32E+08</td>
<td>1.01</td>
</tr>
<tr>
<td>C₆H₆⁹</td>
<td>3.00E+03</td>
<td>g/ha/yr</td>
<td>5.15E+04</td>
<td>Ulgiati (2001)</td>
<td>1.54E+08</td>
<td>0.47</td>
</tr>
<tr>
<td>Sodium hydroxide⁸</td>
<td>2.00E+03</td>
<td>g/ha/yr</td>
<td>6.28E+03</td>
<td>After Boustead and Hancock (1979)</td>
<td>1.26E+07</td>
<td>0.04</td>
</tr>
<tr>
<td>Lubricants⁹</td>
<td>2.00E+03</td>
<td>g/ha/yr</td>
<td>8.37E+04</td>
<td>After Boustead and Hancock (1979)</td>
<td>1.67E+08</td>
<td>0.51</td>
</tr>
</tbody>
</table>

³⁰⁸ Ibid. Page 3888
## Bio-fuel as a case to discuss sustainable development

<table>
<thead>
<tr>
<th>Item</th>
<th>Raw amount</th>
<th>Unit</th>
<th>Energy equivalent (J/unit)</th>
<th>Ref. of energy equivalents</th>
<th>Energy flows (J/ha/yr)</th>
<th>% of total energy use</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity</td>
<td>1.42E+09</td>
<td>J/ha/yr</td>
<td>3.00E+00</td>
<td>Hancock (1979)</td>
<td>4.27E+09</td>
<td>13.01</td>
</tr>
<tr>
<td>Equipment (assumed mainly steel and iron)</td>
<td>7.80E+03</td>
<td>g/ha/yr</td>
<td>8.00E+04</td>
<td>After Boustead and Hancock (1979)</td>
<td>6.24E+08</td>
<td>1.90</td>
</tr>
<tr>
<td>Fuel for transportation (diesel)</td>
<td>6.48E+04</td>
<td>g/ha/yr</td>
<td>5.15E+04</td>
<td>After Boustead and Hancock (1979)</td>
<td>3.34E+09</td>
<td>10.16</td>
</tr>
<tr>
<td>Mass of ethanol produced</td>
<td>1.20E+06</td>
<td>g/ha/yr</td>
<td></td>
<td>Ulgiati (2001)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total energy investment</td>
<td></td>
<td>J/ha/yr</td>
<td></td>
<td>Ulgiati (2001)</td>
<td>3.28E+10</td>
<td>100.00</td>
</tr>
<tr>
<td>Energy equivalent of ethanol</td>
<td></td>
<td>J/g</td>
<td>2.74E+04</td>
<td>Ulgiati (2001)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Output/input energy ratio</td>
<td></td>
<td></td>
<td>1.09</td>
<td>Ulgiati (2001)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\[a\] Wheat used, 4.30E+06 g/ha/yr (Li and Lu, 2005).

\[b\] Process water: production of 1 ton of ethanol from wheat requires 20 ton water and 3.59 ton of wheat according to Li et al. (2007). Water used=23.96 ton water.
needed = 2.40E+07 g/ha/yr.

Chemicals: 1 ton of ethanol from wheat requires 50 kg of chemicals (44.16 kg sulfuric acid, 2.5 kg C₆H₆, 1.67 kg sodium hydroxide and 1.67 kg lubricants). Therefore, sulfuric acid used, 5.29E+04 g H₂SO₄/ha/yr, after Li et al. (2007); C₆H₆ used, 3.00E+03 g C₆H₆/ha/yr, after Li et al. (2007); sodium hydroxide used, 2.00E+03 g NaOH/ha/yr, after Li et al. (2007).

Electricity: Total used = 1.42E+09 J/ha/yr, after Li et al. (2007).

Lube oils used, 2.00E+03 g lube/ha/yr, after Li et al. (2007).

Equipment (mainly steel and iron): equipment allocated yearly to 1 ha ethanol production:
7.8 kg/ha/yr. Estimate includes processing machinery 0.44 kg/ha/yr, washing machinery 0.41 kg/ha/yr; boiler 1.5 kg/ha/yr, distillery stainless steel 0.37 kg/ha/yr; distillery steel 1.95 kg/ha/yr, other 3.03 kg/ha/yr. (personal on-field investigation of the authors) = 7.80E+03 g/ha/yr.

Transport: average distance from wheat production site to factory, 204 km; average distance from factory to market place, 50 km; transport truck maximum load, 8 ton/trip; consumption of diesel, 0.35 L/km; total mass of diesel for transport of produced ethanol, 6.48E+04 g/ha/yr.

Ethanol produced: 1.2 ton EtOH/ha = 1.20E+06 g/ha/yr, after Li et al. (2007); HHV of ethanol, 2.98E+04 J/g, after Wyman et al. (1993, p. 870); total energy of ethanol produced, 3.57E+10 J/ha/yr.

Table 17 below gives an in-depth comparison of the energy and emergy analysis of bio-ethanol using wheat and corn respectively as the energy crop crops.

**Table 17:** Energy and emergy performance indicators of wheat and ethanol production in China compared with corn and ethanol in Italy. Source 309

<table>
<thead>
<tr>
<th>Units</th>
<th>Wheat</th>
<th>Corn</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy and mass flows</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total commercial energy invested for grain production</td>
<td>J/ha/yr</td>
<td>2.38E+10</td>
</tr>
<tr>
<td>Total commercial energy invested for bioethanol production</td>
<td>J/ha/yr</td>
<td>3.28E+10</td>
</tr>
<tr>
<td>Grain produced</td>
<td>g/ha/yr</td>
<td>4.30E+06</td>
</tr>
</tbody>
</table>

309 (ibid. Page 3889).
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<table>
<thead>
<tr>
<th></th>
<th>Units</th>
<th>Wheat</th>
<th>Corn</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ethanol produced</td>
<td>g/ha/yr</td>
<td>1.20E+06</td>
<td>1.96E+06</td>
</tr>
<tr>
<td>Energy content of bioethanol produced</td>
<td>J/ha/yr</td>
<td>3.57E+10</td>
<td>5.84E+10</td>
</tr>
<tr>
<td>Net energy yield of bioethanol (energy of ethanol−energy invested)</td>
<td>J/ha/yr</td>
<td>2.89E+09</td>
<td>9.15E+09</td>
</tr>
<tr>
<td>Emergy flows</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Locally renewable inputs, $R_1$ (without double counting), agricultural phase</td>
<td>seJ/ha/yr</td>
<td>9.36E+14</td>
<td>9.35E+14</td>
</tr>
<tr>
<td>Locally nonrenewable inputs, $N$</td>
<td>seJ/ha/yr</td>
<td>9.71E+14</td>
<td>4.01E+14</td>
</tr>
<tr>
<td>% renewable of purchased inputs to agricultural phase, $%R_{F_1}$, without services</td>
<td>seJ/ha/yr</td>
<td>1.63E+10</td>
<td>4.68E+13</td>
</tr>
<tr>
<td>% nonrenewable of purchased inputs to agricultural phase, $%N_{F_1}$, without services</td>
<td>seJ/ha/yr</td>
<td>2.79E+15</td>
<td>3.21E+15</td>
</tr>
<tr>
<td>% renewable of labor and services related to agricultural phase, $%R_{S_1}$</td>
<td>seJ/ha/yr</td>
<td>8.19E+14</td>
<td>1.97E+14</td>
</tr>
<tr>
<td>% nonrenewable of labor and services related to agricultural phase, $%N_{S_1}$</td>
<td>seJ/ha/yr</td>
<td>2.33E+15</td>
<td>3.09E+15</td>
</tr>
<tr>
<td>Total eMergy inputs to agricultural phase, $Y_1=(R_1+N+%R_{F_1}+%N_{F_1}+%R_{S_1}+%N_{S_1})$</td>
<td>seJ/ha/yr</td>
<td>7.85E+15</td>
<td>7.88E+15</td>
</tr>
<tr>
<td>% renewable of purchased inputs to industrial phase, $%R_{F_2}$, without services</td>
<td>seJ/ha/yr</td>
<td>4.08E+12</td>
<td>2.14E+12</td>
</tr>
<tr>
<td>% nonrenewable of purchased inputs to industrial phase,</td>
<td>seJ/ha/yr</td>
<td>1.28E+</td>
<td>2.05E+</td>
</tr>
</tbody>
</table>
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<table>
<thead>
<tr>
<th></th>
<th>Units</th>
<th>Wheat</th>
<th>Corn</th>
</tr>
</thead>
<tbody>
<tr>
<td>%(N_{F2}), without services</td>
<td>yr</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td>% renewable of labor and services related to industrial phase,</td>
<td>seJ/ha/yr</td>
<td>2.02E+14</td>
<td>6.49E+13</td>
</tr>
<tr>
<td>%(R_{S2})</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>% nonrenewable of labor and services related to industrial</td>
<td>seJ/ha/yr</td>
<td>5.76E+14</td>
<td>1.02E+15</td>
</tr>
<tr>
<td>phase, %(N_{S2})</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total eMergy inputs to industrial phase, (Y_2=(%R_{F2}+%N_{F2}+%R_{S2}+%N_{S2}))</td>
<td>seJ/ha/yr</td>
<td>2.06E+15</td>
<td>3.14E+15</td>
</tr>
<tr>
<td>Total eMergy input to process, (Y=(Y_1+Y_2))</td>
<td>seJ/ha/yr</td>
<td>9.91E+15</td>
<td>1.10E+16</td>
</tr>
</tbody>
</table>

**Grain production**

<table>
<thead>
<tr>
<th></th>
<th>J/g</th>
<th>5.53E+03</th>
<th>3.84E+03</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy cost of grain</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Output/input energy ratio of grain</td>
<td></td>
<td>2.50</td>
<td>3.82</td>
</tr>
<tr>
<td>Transformity of grain, with labor and services</td>
<td>seJ/J</td>
<td>1.32E+05</td>
<td>9.92E+04</td>
</tr>
<tr>
<td>Transformity of grain without labor and services</td>
<td>seJ/J</td>
<td>7.91E+04</td>
<td>6.96E+04</td>
</tr>
<tr>
<td>Specific eMergy of grain with labor and services</td>
<td>seJ/g</td>
<td>1.82E+09</td>
<td>1.45E+09</td>
</tr>
<tr>
<td>Specific eMergy of grain without labor and services</td>
<td>seJ/g</td>
<td>1.09E+09</td>
<td>1.02E+09</td>
</tr>
<tr>
<td>Emergy yield ratio of grain =(Y_1/(%R_{F1}+%N_{F1}+%R_{S1}+%N_{S1})) (with L and S)</td>
<td></td>
<td>1.32</td>
<td>1.20</td>
</tr>
</tbody>
</table>
Bio-fuel as a case to discuss sustainable development

<table>
<thead>
<tr>
<th></th>
<th>Units</th>
<th>Wheat</th>
<th>Corn</th>
</tr>
</thead>
<tbody>
<tr>
<td>ELR of grain = (N + %N_{F_1} + %N_{S_1}/(R_1 + %R_{F_1} + %R_{S_1})) (with L and S)</td>
<td></td>
<td>3.47</td>
<td>5.68</td>
</tr>
<tr>
<td>Empower density of grain (Y_1/\text{area}) (with L and S)</td>
<td>seJ/m²</td>
<td>7.85E+11</td>
<td>7.88E+11</td>
</tr>
<tr>
<td>EYR/ELR of grain</td>
<td></td>
<td>0.38</td>
<td>0.21</td>
</tr>
</tbody>
</table>

**Ethanol production**

<table>
<thead>
<tr>
<th></th>
<th>J/g</th>
<th>2.74E+04</th>
<th>2.51E+04</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy cost of ethanol</td>
<td></td>
<td>1.09</td>
<td>1.19</td>
</tr>
<tr>
<td>Output/input energy ratio</td>
<td></td>
<td>1.24</td>
<td>1.14</td>
</tr>
<tr>
<td>Transformity of ethanol, with labor and services</td>
<td>seJ/J</td>
<td>2.77E+05</td>
<td>1.89E+05</td>
</tr>
<tr>
<td>Transformity of ethanol, without labor and services</td>
<td>seJ/J</td>
<td>1.67E+05</td>
<td>1.24E+05</td>
</tr>
<tr>
<td>Specific eMergy of ethanol, with labor and services</td>
<td>seJ/g</td>
<td>8.26E+09</td>
<td>5.46E+09</td>
</tr>
<tr>
<td>Specific eMergy of ethanol, without labor and services</td>
<td>seJ/g</td>
<td>4.98E+09</td>
<td>3.56E+09</td>
</tr>
<tr>
<td>EYR of bioethanol = (Y/(%R_{F_1} + %N_{F_1} + %R_{S_1} + %N_{S_1} + %R_{F_2} + %N_{F_2} + %R_{S_2} + %N_{S_2})) (with L and S)</td>
<td></td>
<td>1.24</td>
<td>1.14</td>
</tr>
<tr>
<td>ELR of bioethanol = ((N + %N_{F_1} + %N_{S_1} + %N_{F_2} + %N_{S_2})/(R_1 + %R_{F_1} + %R_{S_1} + %R_{F_2} + %R_{S_2})) (with L and S)</td>
<td></td>
<td>4.05</td>
<td>7.84</td>
</tr>
</tbody>
</table>
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<table>
<thead>
<tr>
<th></th>
<th>Units</th>
<th>Wheat</th>
<th>Corn</th>
</tr>
</thead>
<tbody>
<tr>
<td>% Renewable=1/(1+ELR) (with L and S)</td>
<td></td>
<td>19.81%</td>
<td>11.31%</td>
</tr>
<tr>
<td>Empower density=(Y/area) (with L and S)</td>
<td>seJ/m²</td>
<td>9.91E+11</td>
<td>1.10E+12</td>
</tr>
<tr>
<td>EYR/ELR (with L and S)</td>
<td></td>
<td>0.31</td>
<td>0.15</td>
</tr>
</tbody>
</table>

### 3.11.4. The significance of results

Figure 18 below is a blueprint so to speak of the so-called emergy signature\(^{\text{310}}\) of the whole process outlined above. Figure 18 is a bar diagram representing the relative size of the different categories of input flows. The results above of the embodied energy analysis in Table 15 highlights nitrogen fertilizer, fuel and electricity as the main input to the process, based on the heat content of each input, as previously discussed\(^{\text{311}}\). Xiaobin Dong et al quoted Brown and Ulgiati (2004) who pointed out that, complex systems aren’t driven by heat supply alone, but also by a mix of environmental services, fuels, minerals, goods, labor, information, and all items with characteristics other than heat content. Fig. 15 below is an indicator of services (a measure of the indirect labor invested to make and supply goods and resources) has the largest emergy input (slightly less than 30%) with energy (fuels and electricity) being the second largest input in emergy terms, thus totaling approximately 15%. Nitrogen fertilizer ranks third around 11%. Other input flows such as herbicides and process chemicals (even if supplied in smaller amounts) are not negligible in emergy terms, due to their resulting higher transformity. Finally, several flows normally disregarded in embodied energy analyses, such as rain, topsoil used up and direct labor each account for about 9% of total emergy investment\(^{\text{312}}\).

\(^{\text{310}}\) Odum 2007 (page 148)

\(^{\text{311}}\) Dong et al 2008 (page 3886)

\(^{\text{312}}\) Ibid
Figure 15: Emergy signature of the wheat to bioethanol conversion process, indicating the percentage of each emergy input to the process, including environmental services, soil loss as well as direct and indirect labor. Source 313.

The results of emergy analysis above indicate that there is a difference in accounting for embodied energy and emergy. The analysis indicates that all input flows are accounted for within the emergy procedure, not only commercial energy flows of fossil fuels and fossil-equivalent energies. The calculated transformities and specific emergies also take into account (a) free environmental services (solar radiation, rain, wind, deep heat), (b) locally available, slowly renewable flows (topsoil, ground water) and finally (c) labor, human services and information (know-how, education) from the economic system 314.

However for embodied energy environmental services and unmonied input flows are not included in embodied energy evaluations. Emergy figures aren’t defined and calculated, in the actual energy content of each energy flow, but instead to the environmental work that was performed by nature in order to make and supply that service or product. This gives a measure of the importance of the service and product from a donor-side perspective and the difficulty in replacing it, when it is used up. It is important to highlight that the yield per hectare of wheat production in the Chinese case is about 60% of corn production 315.

According to Dong et al (2008) 316 the significance of the difference in the two fuel analysis is realized when the emergy analysis and synthesis approach is observed. When all costs

313 Ibid. Page 3889
314 Ibid. Page 3888
315 Ibid. Page 3888
316 Ibid. Page 3890
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(environmental services, energy, materials and labor) are accounted for and converted into solar equivalent units, the transformity obtained is $1.32 \times 10^5 \text{seJ}/\text{J}$ for bio-ethanol from wheat, however higher than that from corn in Italy ($9.92 \times 10^4 \text{seJ}/\text{J}$). When these values, are compared to the transformity of fossil fuels (example diesel used in the process, $1.11 \times 10^5 \text{seJ}/\text{J}$, Table 18), it's shows that bio-ethanol in the investigated cases demands a similar or higher amount of environmental support than fossil fuels (coal, $6.71 \times 10^4 \text{seJ}/\text{J}$; natural gas, $8.05 \times 10^4 \text{seJ}/\text{J}$; crude oil, $9.07 \times 10^4 \text{seJ}/\text{J}$). Because transformities are efficiency measures on the space and time scales of the biosphere, this result simply means that, nature has been more efficient at making fossil fuel than man work of cropping and converting cereals. The EYR, is a measure of the process ability to exploit the locally available resources is very low (1.24 for wheat ethanol and 1.14 for corn ethanol). The problem here is that, from the point of view of exploitation of local resources, the EYR of extraction of mineral and fossil resources is much higher$^{318}$.

The conclusion according to Dong et al (2008) means that the cropping for fuel provides an emergy return and a contribution to the economy that is lower than mining or extracting nonrenewable resources, if available in the country. Therefore, the assumed advantage of cropping for fuel is not a real one, due to the low exploitation of local resources (imported nonrenewable resources are simply converted into bio-fuel). This however, only provides part of the picture, from the point of view of the alternative “local-imported” $^{319}$.

Importantly also is that the tables above show that the demand for bio-energy production is much more than the narrow systems view (input and output model) indicates. The emergy perspective shows that the demand and requirement is much broader, and of greater requirement. This can be seen from the total embodied energy and emergy for the production of bio-ethanol using wheat or corn. It’s a case of the difference between the receiver base perspective (embodied energy in this case) and donor base perspective (emergy perspective in this case).

$^{317}$ Odum 1996 (page 370)
$^{318}$ Ibid. Chapter 3 to 7
$^{319}$ Ibid. Page. 3890
4. Discussion on the significance of the result for Sweden

Sweden is a Baltic state in the European Union as can be seen in figure 16 above. Some basic geography statistic of Sweden are as follow:

Total area \( 449,964 \text{ km}^2 \),
\( (173,731 \text{ sq.miles}) \)

Population 2009: \( 9,269,986 \)

Figure 16: A Map of the Baltic States showing the country of Sweden. Source

Sweden is a Baltic state in the European Union as can be seen in figure 16 above. Some basic geography statistic of Sweden are as follow:

Total area \( 449,964 \text{ km}^2 \),
\( (173,731 \text{ sq.miles}) \)

Population 2009: \( 9,269,986 \)

---

320 Map of Sweden2009.29th.04
321 Geography of Sweden2009
322 Statistics Sweden 2009
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Table 18 and 19 below gives a breakdown of the Sweden agricultural land holding, and the type and amount of agricultural land. These agricultural lands are critical to the any success of the Oil commission proposal as bio-energy crops will require the use of land.

Table 18: Refers to holdings with more than 2.0 hectares of arable land, or with large animal stocks, or with at least 2 500 square metres of open land for horticultural production, or with at least 200 square metres of greenhouse space for horticultural production. Source Ministry of Agriculture, Sweden 2008\textsuperscript{323}.

<table>
<thead>
<tr>
<th>Type of farming</th>
<th>No. of holdings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agricultural plants</td>
<td>17 765</td>
</tr>
<tr>
<td>Vegetables, ornamental plants and nursery plants</td>
<td>868</td>
</tr>
<tr>
<td>Fruit and berries</td>
<td>447</td>
</tr>
<tr>
<td>Mixed plant cultivation</td>
<td>769</td>
</tr>
<tr>
<td><strong>Total, plant cultivation</strong></td>
<td>19 849</td>
</tr>
<tr>
<td>Cattle</td>
<td>17 234</td>
</tr>
<tr>
<td>Sheep and goats</td>
<td>2 624</td>
</tr>
<tr>
<td>Pigs</td>
<td>743</td>
</tr>
<tr>
<td>Poultry</td>
<td>213</td>
</tr>
<tr>
<td>Mixed livestock farming</td>
<td>1 787</td>
</tr>
<tr>
<td><strong>Total, livestock farming</strong></td>
<td>22 601</td>
</tr>
<tr>
<td>Mixed agriculture, mostly plant cultivation</td>
<td>2 095</td>
</tr>
<tr>
<td>Mixed agriculture, mostly livestock farming</td>
<td>3 283</td>
</tr>
<tr>
<td><strong>Total, mixed agriculture</strong></td>
<td>5 378</td>
</tr>
<tr>
<td>Small-scale farming</td>
<td>1 24 781</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>72 609</td>
</tr>
<tr>
<td>2007</td>
<td>72 609</td>
</tr>
<tr>
<td>2005</td>
<td>75 808</td>
</tr>
<tr>
<td>2003</td>
<td>67 888</td>
</tr>
</tbody>
</table>

\textsuperscript{323} Sweden Ministry of Agriculture 2009

<table>
<thead>
<tr>
<th>Crop</th>
<th>2005</th>
<th>2006</th>
<th>2007</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cereals</td>
<td>1,024,000</td>
<td>978,400</td>
<td>990,100</td>
</tr>
<tr>
<td>Leguminous plants</td>
<td>40,900</td>
<td>35,800</td>
<td>28,600</td>
</tr>
<tr>
<td>Ley and green fodder</td>
<td>1,079,800</td>
<td>1,112,700</td>
<td>1,141,800</td>
</tr>
<tr>
<td>Potatoes</td>
<td>30,400</td>
<td>28,200</td>
<td>28,400</td>
</tr>
<tr>
<td>Sugar beet</td>
<td>49,200</td>
<td>44,200</td>
<td>40,700</td>
</tr>
<tr>
<td>Oilseed rape and turnip rape</td>
<td>82,200</td>
<td>90,200</td>
<td>87,800</td>
</tr>
<tr>
<td>Other plant types</td>
<td>42,000</td>
<td>40,700</td>
<td>39,500</td>
</tr>
<tr>
<td>Fallow land</td>
<td>321,300</td>
<td>306,900</td>
<td>280,600</td>
</tr>
<tr>
<td>Unspecified arable land</td>
<td>31,500</td>
<td>21,400</td>
<td>8,200</td>
</tr>
<tr>
<td>Unexploited arable land</td>
<td>1,800</td>
<td>2,000</td>
<td>2,000</td>
</tr>
<tr>
<td>Total, arable land</td>
<td>2,703,100</td>
<td>2,660,400</td>
<td>2,647,700</td>
</tr>
<tr>
<td>Total, pasture land</td>
<td>512,500</td>
<td>503,000</td>
<td>487,800</td>
</tr>
<tr>
<td>Total, agricultural land</td>
<td>3,215,600</td>
<td>3,163,400</td>
<td>3,135,500</td>
</tr>
</tbody>
</table>

According to the Swedish oil commission, by 2020, Sweden intends on reducing about 40% to 50% of fossil fuel in its Transport sector. Fossil fuel/crude oil accounted for 32% of the 647 TWh of the energy that was supplied in 2004.

Table 20a and b below gives a breakdown of the amount of proposed production of bio-fuel in years 2005, 2020, and 2050. In the case of Table 20b, it gives a breakdown of the different bio-fuel sources that would contribute to the projected fuel production seen in Table 20a.

---

324 Ibid
325 Commission on Oil Independence 2006 (page 14)
326 Ibid. page 9
Table 20: Biofuels, supply and use* (TWh) Including import/export opportunities within the respective sector. Source Swedish government\textsuperscript{327}.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2005</td>
<td>2020</td>
</tr>
<tr>
<td>a</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Firewood, logging residues, stumps</td>
<td>20</td>
<td>40</td>
</tr>
<tr>
<td>Industrial by-products for sale</td>
<td>16</td>
<td>22</td>
</tr>
<tr>
<td>Industrial by-products for internal use</td>
<td>19</td>
<td>20</td>
</tr>
<tr>
<td>Spent liquor, etc.</td>
<td>44</td>
<td>45</td>
</tr>
<tr>
<td>Waste, pine tar pitch, peat, demolition wood, etc.</td>
<td>8</td>
<td>15</td>
</tr>
<tr>
<td>Fuels from energy crops (incl. waste products and energy wood) miscellaneous, etc</td>
<td>1</td>
<td>10</td>
</tr>
<tr>
<td>Total</td>
<td>108</td>
<td>154</td>
</tr>
<tr>
<td>b</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Housing</td>
<td>11</td>
<td>16</td>
</tr>
<tr>
<td>Distance heating</td>
<td>20</td>
<td>26</td>
</tr>
<tr>
<td>Electricity production</td>
<td>18</td>
<td>22</td>
</tr>
<tr>
<td>Forestry industry, internal incl. spent liquor, etc.</td>
<td>57</td>
<td>59</td>
</tr>
</tbody>
</table>

\textsuperscript{327} Ibid (page 14)
Bio-fuel as a case to discuss sustainable development

Transport (gas, liquid, electric for plug-in-hybrid, etc)

<table>
<thead>
<tr>
<th></th>
<th>2005</th>
<th>2020</th>
</tr>
</thead>
<tbody>
<tr>
<td>ha</td>
<td>TWh</td>
<td>ha</td>
</tr>
<tr>
<td>Agricultural land in total</td>
<td>3 215 600</td>
<td>0</td>
</tr>
<tr>
<td>comprising agricultural land for energy crops</td>
<td>80 000</td>
<td>0.5</td>
</tr>
<tr>
<td>fallow acreage</td>
<td>400 000</td>
<td>0.5</td>
</tr>
<tr>
<td>waste products, straw, fertiliser, etc.</td>
<td>23 000 000</td>
<td>0.0</td>
</tr>
<tr>
<td>previous agricultural land</td>
<td>0</td>
<td>94</td>
</tr>
<tr>
<td>Forest land in total</td>
<td>26 615 600</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 21 below provides realistic figures of the hectares of land available for planting energy crops; these are the figures that the Oil Commission used in their proposal.

**Table 21: Acreages of land available for biofuel. Provides a breakdown of the acreage of agricultural land that will be required to fulfill the intended for the planting of the various energy crop to produce the intended increase in bio-fuel in years: 200, and 2020.**

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Table 21: Acreages of land available for biofuel. Provides a breakdown of the acreage of agricultural land that will be required to fulfill the intended for the planting of the various energy crop to produce the intended increase in bio-fuel in years: 200, and 2020.

<table>
<thead>
<tr>
<th></th>
<th>2005</th>
<th>2020</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ha</td>
<td>TWh</td>
</tr>
<tr>
<td>Agricultural land in total</td>
<td>3 215 600</td>
<td>0</td>
</tr>
<tr>
<td>comprising agricultural land for energy crops</td>
<td>80 000</td>
<td>0.5</td>
</tr>
<tr>
<td>fallow acreage</td>
<td>400 000</td>
<td>0.5</td>
</tr>
<tr>
<td>waste products, straw, fertiliser, etc.</td>
<td>23 000 000</td>
<td>0.0</td>
</tr>
<tr>
<td>previous agricultural land</td>
<td>0</td>
<td>94</td>
</tr>
<tr>
<td>Forest land in total</td>
<td>26 615 600</td>
<td>0</td>
</tr>
</tbody>
</table>

Production comprising increased productivity in existing forest land intensive afforestation other

---

238 Ibid
According to the biomass commission of the Swedish government, the amount of land estimated that was available for energy crop production was approximately 800,000 hectares (ha), estimated to be 30% of the 26,615,600 ha of arable land for biofuel. According to the commission of the 800,000 ha, 400,000 ha will be used in 2020 to produce energy crop for bio-fuel production according to Borjessen et al 1997\textsuperscript{329}.

### 4.1. The system perspective and its “view”, on the requirement for bio-energy production

At first glance the fact that Sweden will be using half of the 800,000 ha of available agriculture land for energy production might seem trivial. This however can be counted as trivial if the receiver base perspective is adhere to, and thus the “box” or the system in which the proposition is analyzed is narrow, with an input and output perspective seen in figure 2 above. This view however, has been shown to be narrow, and spurious for a complete system perspective to be arrived at regarding the impact on using land for energy crops.

As of such one must look through the microscope of the system view of the donor base perspective. According to Giampietro and Ulgiati (2005)\textsuperscript{330} because of the low input and output ratio of biofuel, an internal loop would be required. Thus making reference for the need of a system of cyclic reinforcement as discussed earlier; a system that provides a feedback into the lower hierarchy. This equally points out the low output of energy that comes from bio-fuel when compared to the input energy in producing it. Giampietro and Ulgiati (2005)\textsuperscript{331} argue that because of this low output and input ratio, there will be a heavy demand for land, labor, and water. With this knowledge they made the argument that bio-fuel will be unable to fulfill the energy requirement of the developed countries economy; given the heavy energy dependency of these societies\textsuperscript{332}.

With most developed countries having an average energy consumption of 250GJ/year per capita, it is postulated that in developed economies such as Sweden, any energy sector

\textsuperscript{329} Börjersson et al 1997 (page 406)  
\textsuperscript{330} Giampietro and Ulgiati 2005 (page 381)  
\textsuperscript{331} Ibid  
\textsuperscript{332} Ibid
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Based on bio-energy will absorb 20-50% of the labor force of Sweden\(^{333}\). Hence not only will it be very land-demanding that is be requiring a lot of land; equally it will impact on the available work force.

The above can be understood by observing the calculation of the emergy and energy analysis for the production of bioethanol using feedstock, wheat and corn; in Table 10 to 12. As will be seen, the input is far more than normally calculated as outlined in Table 4 to 5. While the embodied energy consider all input except unmonied services, and thus does not give a true picture of the true “cost”. Emergy on the other hand takes in consideration all monied and unmonied services. The emergy perspective thus provides the closest view to the cost of using bioethanol as source energy in a country’s economy, such as Sweden.

But if one should backtrack and look at the evaluation of Table 15 to 17 again, similar argument that was made for these tables can be made here; thus they will be rehashed in brief below.

When the net energy of the bioethanol system was looked at it was found that bioethanol provides very low net energy. With the application of the broader systems view, it was found that for both energy crops, wheat and corn, the emergy yield ratio (EYR), as highlighted above, (which gives a measure of the input emergy to output emergy) was also very low. With EYR figures such as 1.24 for wheat and 1.14 for corn, while the EYR figures for fossil fuel was found to be 3 to 7, according to Dong et al. (2008) quoting Odum (1996). This is not the only revealing information but the figures for the transformity (which look at the environmental services, energy, material and labor on a space and time scale; more will be said on this below) are also incomparable for bioethanol to that of fossil fuel. Dong et al.\(^{334}\) quoted transformity figures of \(1.32 \times 10^5\) seJ/J for bioethanol from wheat (China), which is higher than that from corn in Italy \(\left(9.92 \times 10^4\right)\) seJ/J; while those for fossil fuels were found to be as can be seen in the Table 22 below. Referencing to similar figures in their work Dong et al. pointed out that these figures simply means, nature is better at concentrating energy into fossil fuel far more efficient than us, trying to grow crops and converting it into energy for use.

\(^{333}\) ibid

\(^{334}\) Dong et al 2008 (page 3890)
Table 22: Solar, transformities of selected fuels and biofuels. (Assessments include the emery associated to labor and services). Source

<table>
<thead>
<tr>
<th>Fuel</th>
<th>Transformity (sej/J)</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal</td>
<td>6.70E + 04</td>
<td>(Odum et al. 2000)</td>
</tr>
<tr>
<td>Natural Gas</td>
<td>8.04E + 04</td>
<td>(Odum et al. 2000)</td>
</tr>
<tr>
<td>Crude oil</td>
<td>9.05E + 04</td>
<td>(Odum et al. 2000)</td>
</tr>
<tr>
<td>Refined fuels (gasoline, diesel, etc)</td>
<td>1.11E + 05</td>
<td>(Odum et al. 2000)</td>
</tr>
<tr>
<td>Hydrogen from water electrolysis</td>
<td>(◦) 1.39E + 05</td>
<td>(Brown and Ulgiati, 2004)</td>
</tr>
<tr>
<td>Hydrogen from steam reforming of natural gas</td>
<td>1.93E + 05</td>
<td>(after Raugei et al. 2005)</td>
</tr>
<tr>
<td>Hydrogen from water electrolysis</td>
<td>(∗) 4.04E + 05</td>
<td>(Brown and Ulgiati, 2004)</td>
</tr>
<tr>
<td>Methanol from wood</td>
<td>2.66E + 05</td>
<td>“This work”</td>
</tr>
<tr>
<td>Bioethanol from corn</td>
<td>1.89E + 05</td>
<td>“This work”</td>
</tr>
<tr>
<td>Ethanol from sugarcane</td>
<td>1.86E + 05–3.15E + 05</td>
<td>“This work”</td>
</tr>
<tr>
<td>Biodiesel</td>
<td>2.31E + 05</td>
<td>“This work”</td>
</tr>
<tr>
<td>Electricity from renewable</td>
<td>(§) 1.10E + 05–1.12E + 05</td>
<td>(Brown and Ulgiati, 2004)</td>
</tr>
<tr>
<td>Electricity from fuel cells natural gas powered</td>
<td>2.18E + 05–2.68E + 05</td>
<td>(after Raugei et al. 2005)</td>
</tr>
<tr>
<td>Electricity from thermal plants</td>
<td>(#) 3.35E + 05–3.54E + 05</td>
<td>(Brown and Ulgiati, 2004)</td>
</tr>
</tbody>
</table>

“This work” - Represent the research of Mario Giampietro and Sergio Ulgiati, Critical Reviews in Plant Sciences, 24:5, 365 — 384 (Page 381) (381)

(◦) using wind- and hydro-electricity; (§) wind and hydro; (∗) Using coal and oil powered thermoelectricity; (#) coal and oil powered thermal plants.

Note: Transformities have been recently revised, based on a recalculation of energy contributions done in the year 2000 by Odum et al. (2000).

Prior to 2000, the total emergy contribution to the geobiosphere that was used in calculating emergy intensities was 9.44 × 1024 seJ/yr. Adopting a higher global emergy reference base—15.83 × 1024 seJ/yr—changes all the emergy intensities which directly and indirectly were derived from it. This explains a slight difference with values previously published.

Dong et al\textsuperscript{336} stated another critical aspect of the plan of pursuing a sustainable bio-ethanol program; with the case studies from China and Italy (which is very applicable and important in reference to Sweden) they noted that the Environment loading ratio (ELR). The ELR is the measure of the loading on the ecosystem or a measure of the percent renewable fraction of the product [or services]. This thus speaks of the amount of resource input from the

\textsuperscript{335} Giampietro and Ulgiati 2005 (page 381)

\textsuperscript{336} Dong et al 2008 page 3890
Bio-fuel as a case to discuss sustainable development

environment to make a product or service or a measure of renewable to non renewable resource input. For the case studies by Dong et al (2008) the ELR was found to be, 20% and 11% renewable fractions for these biofuels. In other words, bioethanol is not renewable presently as we think; in that it is produced by investing large amounts of nonrenewable resources which would be 80% and 89% in the two cases using wheat and corn.

The EYR of the bio-energy from sugar from Brazil was found to be of ratios between 1.6 and 2.0 according to Dong et al (2008) quoting Pimentel and Patzek (2005). It is believe that it might be even slightly higher than 2.0, but this is believe to occur at the expenses of large environmental disruption and huge social problems. This is not however believed to be feasible on a global scale at the same large scale and intensity as done in Brazil. But one must keep in mind the EYR of fossil fuels is between 3 to 7, which is what the major aspect of world economies are powered on, or in Sweden’s experience over 30% of energy sector (most in the transport sector).

On the mention of Brazil the author must address the issue of verifiable ethanol that was imported in Sweden as supported by a SEKAB press release 26 May 2008 as mentioned earlier in this paper.

According to SEKAB the standards use to verify such type of ethanol are listed below:

- At least 85 % reduction in fossil carbon dioxide compared with petrol, from a well to-wheel perspective
- At least 30 % mechanization of the harvest now, plus a planned increase in the degree of mechanisation to 100 %
- Zero tolerance for felling of rain forest
- Zero tolerance for child labor
- Rights and safety measures for all employees in accordance with UN guidelines
- Ecological consideration in accordance with UNICA’s environmental initiative Continuous monitoring that the criteria are being me

The Question that must be asked here, after looking at the broader systems perspective: In the trans-shipment of the “verified sustainable ethanol”, was fossil fuel used in the ships, or mode of transport use to transport the “verified sustainable ethanol” from Brazil to Sweden? As one gathers that the definition does not include broader system perspective which includes transporting the ethanol from site of production in Brazil to place of use in Sweden.

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337 Ibid
338 Ibid
339 Ibid, page 3890
340 SEKAB Press release 2006
341 SEKAB verifiable ethanol 2009
4.2. Space and time scale in brief

Odum and Odum discussed the significance of the scale of time and space in the system perspective, in their work “A prosperous way down”. They lay out the fundamental scientific fact that systems turnover, recycle depending on the molecular [and geographical] scale they occupy. Using the example of tiny molecule systems that turn over in microseconds, while microbial systems takes minutes; with algal systems taking days; fishery systems taking years; and societies infrastructures taking decades. As the molecular organization of the system increases in time, space, or organization; then the time and space increases. The Odums used the good example of the human being, starting off as a baby, but as it grows bigger, it occupies more space and time (time in terms of organ and system growth).

The argument of space and time scale for bioethanol replacing fossil fuels can be understood to replace by bio-ethanol, as follows. Fossil fuel has mentioned above has very high transformities compare to bioethanol with low transformities of $1.32 \times 10^5 \text{ seJ}/\text{J}$ for bioethanol from wheat (China), $(9.92 \times 10^4 \text{ seJ}/\text{J})$; while that of fossil is $1.11 \times 10^5 \text{ seJ}/\text{J}$. These figures indicate the amount of natural effort that was put in place, for producing fossil fuel. Hence in order to replace fossil fuel it would take a far more efficient process than the inefficient process of bio-fuel production (from energy crops) and far more in weight to provide the same equivalent. This thus means we would need far more land for such process. Equally important is the consideration that taking land to provide energy crops means taking away environmental services, or pushing them to be produced elsewhere. This leads to the question- where would these “free” services be produced?

In order to answer the above question it might be wise for one to understand the significance of the free environmental services and how they interact with the environment.

When human harvest and process environment resources and services such as agriculture crops, fishes, timber from the forest, or enjoying the services nature has to offer in a park, lake or beach, Odum and Odum; products and services go out from the environment. There is circulation of money that controls the use of the resource and service; money is exchange for the product and service. This money is paid for the product and or service, with nothing going back to the environment (ibid). No money or anything normally goes back to the environment to sustain it through reinforcement, or feedback to ensure it remains sustainable or it is sustained. Money generated from the resources from the environment and services, is paid to those who process the resource and exchange them (or sold to the consumer).

The above understanding is what defines the experience of the use of fossil fuel by economies of the world. In this experience the source of the fossil fuels were extracted from the earth, with money generated for the processors and “owner” of the resource/s,

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342 Odum and Odum 2001 (page 73)
343 Ibid. page 95
Bio-fuel as a case to discuss sustainable development

while nothing returned/fed-back to the environment. One could say with this kind of system, what happen is that the resource is exploited until it is finished or runs extremely low and of no further use economically. The 1973 oil crisis possible was a manifestation that could probably be attributed to such practice.

The role that money has to play in all of this process is that, money acts as an engine for the turning of the wheel for resource use, and is not a true valuator of the true value of the resource. Money paid for resources, or price is just an estimator of the availability of the resource or service as alluded to by Odum and Odum\textsuperscript{344}.

There are two set of contribution to products from the environment, which we benefit from directly or indirectly. These contributions are: 1. Free contribution and 2. Inputs from the economy that are fed back in the cycle; these normally involve: human services, foods, fuels, materials. These free contributions are destroyed and removed when the products are taken without attention paid to reinforcement, an argument supported by Odum and Odum\textsuperscript{345}.

The significance of the above regarding Sweden and bio-ethanol, is that, as land is used to produce fossil fuel, then it cannot be done according to the way in which fossil fuel was used; thus reinforcement must be done, to maintain the soil content, and fertility. This is important as a sustainable economic system is built upon a sustainable environmental system an argument posits by Odum and Odum\textsuperscript{346}.

The above argument is critical to the way in which the environment is treated, as it demarcates the way in which the environment is treated under different market attitude. By this, the author means, quoting the Odums, “under stringent free market competition, those who omit care of the land win out in competition in the short run, but their farms lose fertility and become uneconomical in the long run”\textsuperscript{347}. This thus speaks to the issue of the way in which those who care about the market forces alone can bring the environment in serious future questioning or existence. This is seen in the case where market forces for ages have been the driving forces behind exploitation of fossil fuel without even giving consideration of its environmental impact an argument alluded to by Franz Wirlz in “The Exploitation of Fossil Fuels under the Threat of Global Warming and Carbon Taxes: A Dynamic Game Approach”\textsuperscript{348}.

Thus it brings one back to the question, that given the narrow system perspective which looks at the input and output energy of a system to determine its feasibility, as compare to the broader system perspective, as highlighted above; how will the lost services be compensated for in the production of bio-fuel? This is a question to be pondered carefully

\textsuperscript{344} Ibid
\textsuperscript{345} Ibid. page 95
\textsuperscript{346} Ibid. page 240
\textsuperscript{347} Ibid. page 240
\textsuperscript{348} FRANZ 1995 (page 334)
by policy makers. Since these unmonied environmental free services cannot be easily replaced by something artificial, it’s important they are taken in consideration in the future expansion of bio-ethanol.

If Table 15 alone is considered above, it’s very easy for one to fall in the trap as conventional to see the sustainability of a system as a measure of input versus output only; possible extending to immediate cost of conversion from input to output. Or one would simple accept the evaluation of Pal Börjesson, who summed up all the important consideration for bio-ethanol (especially using wheat) as follows- “(i) cultivation efficiency and its emissions of nitrous oxide, (ii) the fuel used in the ethanol plant, (iii) the efficiency with which by-products are dealt with and (iv) the type of land used for cultivation”\(^{349}\). However to accept Börjesson supposition is to ignore scientific evidence and evaluation as laid out in Table 17 above showing the short comings in the consideration of considering embodied energy analysis in the bio-ethanol production using wheat and corn, versus the emergy analysis of bio-ethanol using the same sources. One of the considerations which Börjesson has not considered which Giampietro and Ulgiati (2005)\(^{350}\) pointed out, which is very relevant and important, is labor. It is for obvious reason the crops aren’t reaped by themselves and converted by them-selves into “available energy”, neither is the planting, nor transporting. This thus immediately reveals the shortcomings that would exist in Börjesson evaluation of bio-ethanol sustainability for Sweden; one which he supports.

Sciubba and Ulgiati (2005)\(^{351}\), argues that, emergy analysis takes a top to bottom approach, in other words it takes in consideration the biosphere as input into all energy processes. Though uncertainties are introduce by uncertain quantification of some of the externalities or environmental services\(^{352}\). Still with the uncertain quantification, with the intended conversion to renewable energy by 2020 in the Swedish society; a comprehensive assessment will be required. The interconnection between the examined process (bio-ethanol in this case) and the environmental dynamics cannot be ignored in such analysis. As shown above environmental services should be taken as important input into all energy assessment.

Again the policy makers in Sweden should be fully cognizant of the transformities and EYR, which reveal bio-ethanol efficiency or productivity to be very low compare to that which it will be replacing substantively in 2020, see again Table 14 above. This is important as these data points to or allude to the demand that bio-ethanol will truly place upon the nation of Sweden, in terms of land and water; pointed out earlier in this research paper& concurred

\(^{349}\) Börjesson 2009 (page 593)  
\(^{350}\) Giampietro and Ulgiati 2005 (page 382)  
\(^{351}\) Sciubba and Ulgiati 2005 (page 1986)  
\(^{352}\) Ibid. Page 1986  
\(^{353}\) Ibid. 381
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It’s important that all be considered so that the early lack of consideration (environmental impact) that was initially seen with fossil fuel is not shown with renewable fuel such as bio-ethanol. It’s important because this industrial world has not gone this way before in using renewable energy to sustain vast developed economies such as Sweden. Importantly it’s important to consider these now, as to ensure stages aren’t reached in establishment of systems of the economy which would be difficult to undo years from now. Birgitta Johansson a scientific journalist quoted Magnus Blinge of Chalmers University who put the point in the follow perspective- The trend that exist today is societies are moving away from oil dependence in fuelling the transport sector. Engine alcohol may be one of tomorrow’s fuels, although the risk exists where we bind investments to technology and systems that aren’t the best in the long run\textsuperscript{354}. Johansson highlights the importance of considering the choice now; for the future leads us to the issue of path dependency\textsuperscript{355}. This will now be discussed below, within the confines of this research paper discussion.

5. Path dependency and its implications for bio-ethanol

Path dependency is a neoclassical theory developed and advanced by Paul David in the 1980s. The development of the theory was based upon David study of the now ubiquitous QWERTY keyboard and how it dominated and eventually controls the computer keyboard market over what was a more efficient and simplified keyboard Dvorak version\textsuperscript{356} concurred by Jorg Sydow et al\textsuperscript{357}.

Jorg Sydow et al\textsuperscript{358} explain the theory of path dependency to be the different dynamics, namely those of imprinting of present on the future realities by present and former decisions and solutions; even by random events. It also points to the reality of irreversibility or the lock-in of certain processes and their underlying decisions. Altug YALÇINTAS, of the University of Ankara, Turkey argues that path dependency is not always about inefficiencies. He argues that it is also about errors into which we are locked in the economy and society in general and not necessarily about “market failures” of capitalist market economies. YALÇINTAS, instead see path dependence as a metaphor for disappointment about the institutional matrix of industrialized economies. He summed it up in the following way, “it is about economists’ and other scientists’ contention that thinkers’ will to perfection is a misleading one when institutions of network economies, positive feedbacks, and irreversibilities, and so forth rule”\textsuperscript{359}. Here attempt to point to the width of the theory of path dependency, while involves erroneous decision processes, also involves choice of the...
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market, natural process of positive feedback, right choices all coming together in a matrix of choice. One outcome that is seen in the entire matrix is the fact that, whatever is the combination of the matrix of the dominating choice, we are locked into it.

The important aspect of path dependency to the Swedish bio-ethanol pursuit is the phases of path dependency, which will be discussed now below.

5.1.1. Phases of Path Dependency

Phase I is believe to be an undirected search process, where choices are still unconstrained. Hence there is no limit set on the amount or number of choices that can be made, Sydow et al.\textsuperscript{360} quoting Mahoney (2000.511) pointed out that “decisions are seen as contingent events that cannot be explained by prior events or initial conditions”. Hence the possibility of any decision being made or outcome is not assured. However once the decision or choice is made a process of reinforcement sets in play a motion that will eventually lead to a deterministic pattern. At the point of decision, a critical juncture is approached and thus characterized by the adoption of a particular arrangement. Once these decisions have been made, dynamic self-reinforcing processes may be set into motion, which eventually lead to deterministic patterns. This moment or juncture of setting the path dependency into motion represents a “critical juncture”, Sydow (2005) quoting Collier and Collier (1991). Importantly at this juncture are in place the institutional arrangement among the alternatives. According to Mahoney\textsuperscript{361} once the decision is made it become increasing difficult to return to the initial point where one had multiple choices available.

In Phase II is a development of the latter aspect of Phase 1, where the choice or decision made increasingly reinforces itself. A track or pattern is now laid out, as self reinforcement through increasingly making this choice repeatedly\textsuperscript{362}. This stage narrow the field of choice to the point that it appears that one has no other option anymore. It is in this stage that any event that can be random intentional, can have critical weight in reinforcing the path, creating what Kauffman (1993) quoted by Sydow (20059, call a bifurcation\textsuperscript{363}. These events will thus cause an increasing return on the process of reinforcement, or choice, eventually triggering what Sydow (2005) call critical mass\textsuperscript{364}. In other words, as the choice continues to be made, a promotion by say a celebrity (well known public figure), or access to technology through events in the market, being strategically placed, etc can cause a builds up in popularity, then become the choice of people. A Case that could be used here is that of Microsoft windows versus Linux; where Microsoft windows “won” over the market a case discussed by Carl Shapiro and Hal R Varian 1999; Varian et al.2004 alluded to by Leonhard

\textsuperscript{360} Sydow et al 2005 (Page8)
\textsuperscript{361} Mahoney 2000 page 507-548
\textsuperscript{362} Ibid. page 9
\textsuperscript{363} Ibid. page 9
\textsuperscript{364} Ibid. Page 9
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Dobusch. Importantly in this stage a path emerges and renders the whole process more irreversible. As in the case of Microsoft in the early days of PC, being used on most computers used in government offices, locking out the option of Linux.

In Phase III there is the lock-in stage. It is a stage of the choice of one particular technology or institution which is adopted by the mass. It is forceful in imposing its choice on others to the market that associate with the use or “choice” of the technology or service. At this stage the status gain in the market is enough to sustain and reinforce its position; especially when there is no viable alternative option. Figure 20 below depicts the events in the three (3) stages of path dependency.

![Figure 17: Constitution of a technological or institutional path – The classical model. Source: (ibid. Page 9).](image)

Significance of path dependency for Sweden in its choice of bio-ethanol is that given all the reports of establishing ethanol fuel stations across the country as supported by Bettina Dahlbacka. It alludes to an indication that the critical juncture of Phase I. has been reached.

Why is it important that the Swedish government take note of the critical juncture? Because simply answered it goes hand in hand with the policy as laid out by the Swedish government in the document titled- “Strategic Challenges: A Further Elaboration of the Swedish Strategy for Sustainable Development”.

According to the above mentioned policy document, objective 5.2.1 points out that Sustainable development is an overall objective of Government policy.

This means that all political decisions must take into consideration long term

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365 Dobusch 2007 page 4
366 Ibid. page 9
367 USDA Foreign Agricultural Service, GAIN Report 2008 (Page 5)
368 Swedish government communication 2005
369 Ibid. page 59
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economic, social and environmental consequences.

– The state must serve as a model when it comes to promoting social and environmental consideration. State-owned enterprises – as well as the state in its capacity of fund manager, property owner or employer – must take the long-term economic, social and environmental consequences of”

Hence the Swedish government approach to finding solutions to sustainable development is to consider the long term economic, social and environmental implications for all decision being made. Which is what this paper encourages the policy makers to consider, given the presentation of signs that the nation is standing, so to speak in the critical juncture.

If at this critical juncture the best fuel choice is not made then the society would eventually become locked in, using a fuel that is not of less demand on the environment than fossil fuel, but only in appearance seem to be the better fuel.

You will never be sure about everything. But since it is the policy of the government to consider carefully all the long terms implication then it is important the government look at the figures coming from emery analysis, from other societies with similar biofuel system.

According to the emery analysis figures the net embodied energy is a poor indicator of the performance of a fuel; since a fuel doesn’t extract, process, and supply itself, then all these other aspects of the fuel must be taken in consideration as well as the ‘non-moned’ aspect, especially in the case of bio-fuel. In this case there will be a great demand on the environment, with the lost of free environmental services which are not normally accounted for, because economist has not devised a way to measure them accurately. By doing this the other cost as highlighted above are normally not counted though they are cost. As this is the critical juncture such simple model approach cannot be entertained but instead requires the consideration in the broader system perspective as exposed by the emery model.

And it is at this critical juncture that policy makers should heed the words of Rydberg and Haden\textsuperscript{370}, who provided a word of caution to the nation of Demark on the similar issue of energy and agriculture. Rydberg and Haden\textsuperscript{371} argue that given the low net energy yields of agriculture production, the breadth of non-agriculture economic activity that agriculture system can support is limited, in an economy built upon using high-net-yield imported energy resource. This is a similar point supported earlier in the comparison study of bio-ethanol production from wheat and corn.

\textsuperscript{370} Rydberg and Haden 2006 (page 157)
\textsuperscript{371} Ibid
6. Conclusion

The intention of this paper was never to convince the government of Sweden not to use bio-ethanol. At the outset of this paper the stated intentions were to: 1. Expose the shortcomings of bio-ethanol as a sustainable primary energy source for a country such as Sweden by critically looking analytical tools used to qualify it as the magic fuel to replace fossil fuel 2. Provide a system perspective which policy makers can use to second think themselves on the primary fuel of choice for the nation of Sweden by 2020. 3. To expose the reader to the methodology call emery. 4. To provide substantive evidence in support of the hypothesis that- Presently, if the true energy cost of bio-energy from energy crops are counted, then it cannot be sustainable as defined in chapter 2 of the Brundtland report: Our common future. To a great extent the author thinks this paper has done the aforementioned; anything beyond this endeavor is packaged in a PHD study or such research.

The narrow system models which involves input and output and no account of free environmental resource in energy production, has been shown to be too narrow. This model is inadequate to evaluate the adequacy of a new fuel source that should be sustainable and impact positively on global warming/climate change; identified as one of the greatest challenge.

To compound the problem even further, the idea of a political compromise goes against all real scientific evaluation, to which to bond the next generation to an uncertain fuel source. Hence it is expected that the choice of a fuel will be given a broader evaluation.

In the broader system perspective which emery represents, as much input is taken in consideration as possible, to consider the net output and impact. Unlike in the narrow systems model, the broader perspective does not see the source of energy supply in isolation of the energy they produce or the system in which the energy is produced. The emery model instead produces a holistic approach to energy production, as it is a system of energy memory.

Sweden has thrown out the gauntlet to the future of sustainability it is a challenge that goes beyond just the hope for a sustainable energy future. Given the bold move it has made to shift its economy from a fossil fuel base economy to renewable energy, it is a clear indicator that the nation is serious about the science on climate change and sustainability. It is in this light that this paper proposes to the Swedish government, energy policy makers to consider much carefully and greatly, the broad environmental impact that the use of bio-ethanol [as a primary energy]in the transport sector.

What this paper is beckoning to the policy makers is, if the author is allowed a moment to bask in the use of age old adage or analogy; not to create the a situation where the frog in a

372Brundtland report 1987
moment of enlightenment discovers it is about to be boiled in the pot of hot water and decide to jump straight into the fire. Not that the author proposes the frog remains in the pot of heated hot water while it ponders what to do, but that if it’s going to jump, give it all it got; so that it doesn’t not end up in the fire. In other words instead of using embodied energy, net energy analysis or LCA as the measure of how sustainable a system will be (for future generation), or how much energy it can offer; do not stop at the net energy of input to output energy. This paper proposition the policy makers to go the full way and consider the broader system perspective; to do so is to follow what is laid out in the government’s sustainable policy in one of their objectives (that is considering the long term effect socially, environmentally and economically).

The decision of the nation of Sweden to switch over to almost completely renewable energy by 2020 is too an important decision, to give open ear only to the age old methodologies which though instrumental in building our modern world, weren’t adequate to prevent us from entering in the present confrontation with climate change.

The transport sector in 2004 consumed 95 TWh energy in fossil fuel, as pointed out above (making up 97% of the sector energy use) and this excludes what is used in the agriculture sector which consume 7 TWh of fossil fuel (making up 70% of the energy in the industry). These figures indicate this is not an insignificant sector and require the careful planning and approach to replacing fossil fuel. In other words let’s move carefully while moving with speed, to achieve the goal in 2020.

As pointed out above, Sweden is at the critical juncture of their choices, for bio-fuel to replace the globally “demonized” fuel call fossil. Beyond this juncture Sydow et al (2005) alluded to the point that it becomes very expensive and difficult to undo the option of choice beyond this point. Given the far reaching implications of the wrong choice or using the lesser, of all the choices to replace fossil fuel; it’s worth “pausing” to explore the choice and implications.

Implications

The implications as highlighted above are far reaching for the Swedish government and for the world community. As pointed out, it’s going to take more land than indicated by the narrow system model used by the Swedish oil commission. Hence a call for a broader system perspective considered the choice at this juncture. Beyond the land cost, it is going to place increase demand on a nation fresh water supply, unlike for the nation of Sweden for many nations around the world this has wide implication. Equally and importantly it is going to place heavy demand on available labor in a nation, as pointed out above to supply the demand of energy through bio-ethanol, will be labor intensive, and might require shifting labor from some sectors to the bio-energy sector in a nation such as Sweden. With Sweden taking the lead to provide leadership in sustainable energy use, it’s important they get it
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right, as other nations around the world are looking and making exploratory move to explore bio-ethanol among other bio-fuels as well.

**Recommendations to Swedish government which equally apply to regional and world governments**

To ensure the next step beyond the critical juncture of energy conversion is not one that will later be filled with regrets, this paper proposes that the government carefully explore the far reaching implications of the system’s view [in the form of expanded model such as the emergy model].

- To equally put all second generation bio-ethanol source and bio-fuel under similar broad system energy microscope so to speak.

- Increase funding to Universities in Sweden and researchers to explore the broad systems models (emergy model) for energy use and building sustainable economies.

- Fund researches to deal with the re-education of the Swedish society, using transport fuel efficiently. This is a research topic by itself which has not been discussed in this thesis which should be titled “the socialization of man, fuel and the environment”.

  The re-education of the general citizenry on the use of energy, especially fuel in the transport sector (encouraging life style change in transportation). This is a critical aspect of the solution to energy use in the transport sector; life style change in how energy is use; and this would involve using fuel less and more efficiently.

In conclusion what is bequeathed to the next generation cannot be a system with many questions of non-sustainability. The onus is upon this generation, to ensure that what the next generation inherits is not compromised from the start because policy and decision makers were too tired, or not interested in considering the wider implication or broader perspective.
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**Picture on cover page** - Picture of an open piece of Agricultural land near SLU

**Source of Picture**: Author of thesis, Morris Thompson. 16.06.2009
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9. **Appendix 2.** The life cycle of bioethanol from sugarcane in the future case. 
   Source: (ibid. Page 1616)
10. **Appendix 3** Overall comparison of the environmental impact of all fuel options. According to Lin Luo et al (ibid. Page 1617) in discussing the results or impact assessment on bio-ethanol