Critical Analysis of the Swedish Biofuel Policy using Emergy Synthesis

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ABSTRACT

Emergy synthesis is used as a tool for a critical analysis of biofuels promoted by the Swedish energy policies. We evaluate the production process of three different biofuels in Sweden: Ethanol from wheat (Transformity: 9.19E+04 seJ/J, Renewability: 12% Emergy Yield Ratio: 1.15); methanol from willow (second generation biofuel) (Transformity: 6.06E+04 seJ/J, Renewability: 10% Emergy Yield Ratio: 1.11) and biodiesel from rapeseed (Transformity: 13.6E+04 seJ/J, Renewability: 11% Emergy Yield Ratio: 1.27). Furthermore, the discourse analysis shows that the Swedish Government also promotes the biofuel import from Brazil because it is considered to be more efficient and environmental safe than comparable options taking in consideration the energy and life cycle assessments results. Because of that, the production and use of ethanol from Brazil has been and still are strongly supported by the Swedish authorities. Therefore we also include the evaluation of the ethanol production in Brazil from sugarcane (Transformity: 7.07E+04 seJ/J, Renewability: 19% Emergy Yield Ratio: 1.38). Result shows that ethanol from sugarcane in Brazil presents a lower transformity and a higher degree of renewably than biofuels produced in Sweden. However, all the analyzed biofuels are heavily dependent of non renewable resources and have higher transformity than fossil fuels. From the information gained in the emergy synthesis, none of the analyzed biofuels can be considered a sustainable substitute for fossil fuels due to their very low Emergy Yield Ratio and low renewability degree. Furthermore, important negative impacts on the natural and social capital still are not considered in those evaluations. Because of that we believe that the findings of this work can be improved by the inclusion of these considerations and we strongly propose that the results from emergy system’s perspective must be taken into consideration in the decision process for biofuel polices.

INTRODUCTION

Sweden is among the leading countries worldwide in the utilization of alternative energy resources and is firmly in the forefront with regard to biofuel utilization within the transport sector as well. This is due in large part to measures taken by the Government of Sweden to promote the utilization of biofuels, mainly through tax incentives. Sweden has been a driving force in EU decisions for ambitious climate targets and was one of the leading member-countries in bringing about an agreement to cut greenhouse gas emissions by at least 20% from 1990 levels by 2020. Sweden wants to set an example that it is possible to link economic growth with proactive climate policies. In January 2008, the European Commission presented a new climate and energy package. According to the new EU climate target proposal, Sweden is to reduce carbon dioxide emissions by 17% and increase the use of renewable energy sources to 49% by 2020, using 2005 as a base year (Dahlbacka, 2008).

Ethanol is the most common liquid biofuel in Sweden, comprising almost 90% of all liquid biofuel use in 2007. About 80% of Sweden’s ethanol production is based on cereals. The remaining 20% is based on wood through fermentation of sulphite liquor, a by-product of chemical paper pulp production. Cereal-based ethanol is the additive used to reach the 5% ethanol requirement for gasoline in Sweden. Ethanol produced from sulphite liquor is utilized in 85% ethanol – 15% gasoline blend (E85) for clean flexi-fuel vehicles (Dahlbacka, 2008; Börjesson, 2009).
Regarding to biodiesel, as of August 2006, Swedish regulations allowed a 5% blend of biodiesel in conventional diesel. As a result of the increased blending of biodiesel and the tax exemption on this biofuel, very extensive plans for new biodiesel plants were advertised in Sweden. However, due to the high rapeseed and rapeseed oil prices in 2007/2008, many planned projects have been cancelled or postponed. The cultivated area for rapeseed is estimated to increase to 100,000 ha in 2008, from 90,000 ha in 2007 (Dahlbacka, 2008).

Sweden’s rising ethanol consumption is based on imports, of which a large share is sourced in Brazil. In 2007, total imports are estimated at about 250 million liters according to Swedish statistics (Dahlbacka, 2008). Sweden was the fourth main importer of ethanol from Brazil in 2006 (Cerqueira Leite et al., 2009).

In 2005 the Government of Sweden appointed a commission to draw up a comprehensive program to reduce Sweden oil dependence, the so called Commission of Oil Independence (COI). The three main objectives were: (a) to reduce the dependency on oil prices, (b) to use the great potential for Swedish raw materials as alternatives to oil and (c) to reduce the extensive burning of fossil fuels threatens the living conditions of future generations. This commission presented a plan to achieve oil independence, proposing the route of using biofuels mostly to replace fossil fuel. In this document, it is proposed a number of far-reaching, measures that can end Swedish dependence on oil by the year 2020 and tangibly reduce Swedish use of oil products. Between the ambitious objectives are that through more efficient use of fuel and new fuels, consumption of oil in road transport shall be reduced by 40 - 50%. The COI also pointed that: (a) In the present situation imports of Brazilian ethanol are economically advantageous for Sweden. However, to accommodate the market’s rapidly growing needs, continued development of acreage- and energy-efficient fuels, the second generation of biofuels, is required, (b) Sweden should also continue to be proactive in the EU to bring about rules that enable a higher admixture of ethanol and biodiesel from rapeseed in petrol and diesel respectively; (c) Promote free trade of ethanol between Sweden and Brazil (COI, 2006).

In this context, it is possible to identify by the discourse analysis shows that the Swedish Government strongly promotes the biofuel production in Sweden but also the ethanol import from Brazil (Rydberg and Cavalett, 2010). The Brazilian ethanol is considered to be more energy efficient and environmental safe than comparable options taking in consideration the energy and life cycle assessments studies (Macedo et al., 2008; Cerqueira Leite et al., 2009; Bernesson, 2004; 2006; Hagström, 2006; Pereira and Ortega, 2010; Börjesson, 2009).

In this study the Emergy Synthesis is used as a tool for a critical analysis of biofuels promoted by the Swedish energy policies. We evaluate the production process of three biofuels produced in Sweden: (a) Ethanol from wheat; (b) Methanol from willow (second generation biofuel); and (c) Biodiesel from rapeseed. The production and use of ethanol from Brazil which has been strongly supported by the Swedish Government is also included in this evaluation to compare with the Swedish biofuels options.

MATERIAL AND METHODS

Emergy Analysis

Odum (1996) and Brown and Ulgiati (2004) give a detailed explanation of the application of emergy accounting procedures for a variety of systems. Emergy accounting is particularly suitable for studies in agricultural products, as it is a system in which natural and man-made contributions interact in order to obtain the final product, emphasizing the role of ecological inputs (Brandt-Williams, 2002). All the transformities used in this paper were considered in relation to the annual global budget of 15.83E+24 seJ/year (Brown and Ulgiati, 2004).

Ethanol production from wheat

In Sweden, 80% of the ethanol produced is from cereals, mainly wheat. The ethanol fuel production was assumed to take place at plants that process winter wheat (Triticum aestivum L.) cultivated in the flatlands of Svealand in Central Sweden. Wheat is planted from seeds and its maintenance includes the machinery use, application of herbicides, pesticides and industrial fertilizers.
Most of agricultural and industrial data used for the emergy evaluation of ethanol production from wheat were based on the study from Berenness et al., (2006). In Sweden, the use of ethanol has increased over the past few years and now accounts for more than 3% of fuels consumption for transportation by road. Most of this ethanol is imported, mainly from Brazil, while domestic ethanol from grain accounts for barley a fifth (Börjesson, 2009). The production of ethanol from cereals in Sweden was 101 million liters in 2009. The amount of wheat used to produce ethanol was about 135,000 metric tons in 2009. The area planted with wheat used to produce ethanol in 2007 was estimated in 23,000 ha (Dahlbacka, 2008).

In the agricultural phase, it was assumed that the annual yield was 6340 kg wheat per hectare. The ethanol is produced by the fermentation process. The fermented wheat is distilled to extraction of the ethanol fuel. The ethanol yield is 0.37 liters of ethanol per kg of wheat. Figure 1 shows the simplified energy system diagram of the ethanol production from wheat.

**Biodiesel production from rapeseed**

The biodiesel production was assumed to take place at plants that process winter rape (Brassica napus L.) cultivated in the matlands of Svealand in Central Sweden. Rapeseed is planted from seeds and its maintenance includes the machinery use, application of herbicides, pesticides and industrial fertilizers.

Most of agricultural and industrial data used for the emergy evaluation of biodiesel production from rapeseed were based on the study from Bernesson et al. (2004). The production of biodiesel in Sweden was 68 million liters in 2009. The amount of rapeseed oil used to produce biodiesel was 55,000 metric tons in 2009. The area planted with rapeseed used to biodiesel in 2007 was estimated in 25,000 ha (Dahlbacka, 2008).

It was assumed that the annual yield was 2670 kg of rapeseed per hectare with oil content of 44%. In the plant, the oil is extracted and then transesterified to produce biodiesel. The oil extraction takes place in two steps, mechanical pressing and hexane extraction. The extraction is carried out with strainer oil expellers. The oil extraction efficiency is around 70-88%. The more advanced solvent extraction technique with hexane was used in order to extract more oil from the seeds.

The oil is converted to biodiesel by the transesterification process. In this process, three methanol molecules replace a glycerin molecule in the presence of a catalyst (KOH). The biodiesel yield is 0.38 liter of biodiesel per kg of rapeseed. Figure 2 shows the simplified energy system diagram of the biodiesel production from rapeseed.

**Methanol production from willow**

Willow (Salix viminalis L.) is a commonly used species for energy crops in Sweden. The commercial introduction of willow cultivation started in 1991, when Sweden received a new agricultural policy for decreasing overproduction of food. Most of agricultural and industrial data

![Figure 1. Simplified energy system diagram of the ethanol production from wheat.](image-url)
used for the emergy evaluation of methanol production from willow were based in the study from Hagström (2006). In 2007, the area of cultivated willow was about 14,000 ha, which corresponds to approximately 0.5% of total arable land in Sweden (Dahlbacka, 2008).

The first harvest is performed in the fourth year. After the first harvest, willow is harvested every three years. It is assumed that the average harvested amount is 8300 kg\textsubscript{dm} per hectare per year. Willow is planted using cuttings and its maintenance includes the machinery use, application of herbicides, pesticides and industrial fertilizers.

In this study the willow is converted to methanol fuel by gasification process. In this process methanol is produced by the hydrogenation of carbon oxides over a Cu/Zn/Al catalyst. The efficiency considered for conversion of biomass via gasification is about 60% for methanol. The methanol yield is about 0.73 liter of methanol per kg\textsubscript{dm} of willow. Figure 3 shows the simplified energy system diagram of the methanol production from willow.

**Ethanol production from sugarcane in Brazil**

The ethanol production was assumed to take place at plants that process sugarcane (Saccharum spp.) cultivated in the São Paulo State region. Most of agricultural and industrial data used for the emergy evaluation of ethanol production from ethanol were based in the work from Pereira and Ortega (2010). The production of ethanol in Brazil in 2006 was 22.3 billion liters. The exports of ethanol from Brazil in 2006 correspond to 3.4 billion liters. Sweden was the fourth main importer of ethanol from Brazil in 2006 with 0.2 billion liters (Cerqueira letie et al., 2009).

Sugarcane is planted using cane seedlings. Its maintenance includes the application of herbicides, pesticides and fertilizers (industrial fertilizers and nutrient-rich wastes from ethanol distillation). Once planted, a stand of cane can be harvested five times, in average, until the declining yields justify replanting.
The harvest is mainly manual, which includes burning of sugarcane tops and leaves before the harvest. In the sugarcane mill, the sugarcane is washed, chopped, shredded, mixed with water and crushed. The sugarcane juice is converted into ethanol by fermentation process. After fermentation the ethanol is extracted by distillation. The fibrous waste from sugarcane milling (bagasse) is burned to generate steam and electricity for the process, but also surplus electricity can be generated. The ethanol yield is about 0.08 liter of ethanol per kg of sugarcane. Figure 4 shows the simplified energy system diagram of the ethanol production from sugarcane.

**RESULTS AND DISCUSSION**

Emergy calculations to obtain the results presented here are not included in this study, but are available upon request from the authors. Figure 5 shows the emergy signature of biodiesel production from the different biofuel production systems. In this figure all the inputs are aggregated into nine different categories: (1) Environmental flows; (2) Limestone, agrochemicals and seeds; (3) Fertilizers; (4) Fossil fuels, machinery and electricity; (5) Labor and services from the agricultural phase; (6) Purchased materials from transport phases; (7) Labor and services from transport phases; (8) Purchased materials conversion phase; and (9) Labor and services from conversion phase.

The environmental flows for the ethanol from sugarcane are the highest due to the higher rainfall (evapotranspiration rate) in Brazil in comparison to Sweden and the higher soil loss in the sugarcane agricultural production stage. It is important clarify that the soil loss is included as a local nonrenewable resource (N) in the emergy calculations while the other environmental inputs (rain and deep heat) are accounted for as local renewable resources (R).

**Figure 4.** Simplified energy system diagram of the ethanol production from sugarcane.

**Figure 5.** Emergy signature of biodiesel production from the different biofuel production systems.
Ethanol production from sugarcane also requires more emergy in the items (a) limestone, agrochemical, seeds; (b) fossil fuels, electricity and machinery; (c) agricultural labor and services and (d) biofuel conversion labor and services than the other biofuels. However ethanol from sugarcane has lower transformity due its highest energy output of biofuel per hectare (1.54E+11 J ha⁻¹ year⁻¹) in comparison with the other biofuels produced in Sweden (ethanol from wheat: 1.20E+10 J ha⁻¹ year⁻¹; methanol from willow: 5.60E+10 J ha⁻¹ year⁻¹; and biodiesel from rapeseed: 4.03E+10 J ha⁻¹ year⁻¹). However, the transport phase of sugarcane ethanol from Brazil to Europe requires high amount of resources.

Also, the conversion phase of willow to methanol requires high amount of emergy, mainly due the use of electricity and machinery in the gasification process. Table 1 present the emergy flows and emergy indicators calculated for the evaluated biofuels.

The Swedish biofuels transformities are close to those values obtained by Giampietro and Ulgiati (2005) for biodiesel from sunflower (23.1E+04 seJ J⁻¹) and Brown and Ulgiati (2004) for ethanol from corn (17.3E+04 seJ J⁻¹). The transformity calculated for ethanol from sugarcane in Brazil is close to the values calculated by Pereira and Ortega (2010) (4.87E+04 seJ J⁻¹).

Results show that less emergy is required to produce one Joule of ethanol from sugarcane in Brazil (5.76E+04 seJ J⁻¹) than methanol from willow (6.06E+04 seJ J⁻¹) and ethanol from wheat (9.19E+04 seJ J⁻¹) and biodiesel from rapeseed (13.6E+04 seJ J⁻¹) in Sweden. It indicates that the production process of ethanol from sugarcane in Brazil is more able to convert resources to final product than the biofuels produced in Sweden. These results are in accordance with the Swedish policy of promote the imports and use ethanol from Brazil. However, the transport of the ethanol from Brazil to Sweden requires additional use of nonrenewable resources. Its transformity increases 23% becoming slightly higher than the transformity of methanol from willow.

The emergy embodied in the labor and services account for 30.3% of the biodiesel transformity; 33.0% of the ethanol from sugarcane transformity; 34.0% of the ethanol from sugarcane transformity delivered in Europe transformity, 38.0% of the ethanol from wheat transformity; and 19.9% of the methanol from willow transformity.

The emergy yield ratio (EYR) is a measure of the ability of the product to contribute to the economic system by amplifying the economic investment. EYR values range from 1.1 to 1.5 for case studies of biofuel production, while it ranges from 3 to 11 for fossil fuels (Odum, 1996). Based on this indicator, one can say that biofuels cannot be seen as a source of energy since they have low ability to exploit and deliver local resources to the consumers of the biofuels. The EYR value for ethanol from sugarcane is higher than the others biofuels produced in Sweden, indicating generally lower relevant use of external inputs, which is a higher level of dependence on local ones in the ethanol from sugarcane production system. However, the better EYR to the sugarcane in Brazil is achieved due its higher soil loss in comparison with the biofuels produced in Sweden. Additionally, the sugarcane production methods in Brazil are characterized by intensive use of fossil fuels, herbicides, industrial fertilizers, agrochemicals, machinery and cheap labor.

The high dependency on economy resources (F) for all the biofuel production systems also can be noticed by high environmental loading impact (ELR) which vary from 3.3 for ethanol from sugarcane in Brazil to 8.8 to methanol from willow in Sweden. For example, the ELR value for ethanol from sugarcane in Brazil show that the non-renewable part of the emergy is 3.3 times higher than the renewable part.

### Table 1: Emergy flows and indicators for the evaluated substrate and biofuel production

<table>
<thead>
<tr>
<th>Emergy flow or ratio</th>
<th>Rapeseed</th>
<th>Wheat</th>
<th>Willow</th>
<th>Sugarcane</th>
<th>Sugarcane</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Local renewable (R)</td>
<td>5.94E+14</td>
<td>5.94E+14</td>
<td>5.94E+14</td>
<td>2.06E+15</td>
<td>2.06E+15</td>
<td>seJ/ha/yr</td>
</tr>
<tr>
<td>Locally non renewable (N)</td>
<td>5.72E+14</td>
<td>2.53E+13</td>
<td>0.00E+00</td>
<td>9.29E+14</td>
<td>9.29E+14</td>
<td>seJ/ha/yr</td>
</tr>
<tr>
<td>Purchased without services (F)</td>
<td>2.83E+15</td>
<td>2.22E+15</td>
<td>4.03E+15</td>
<td>2.79E+15</td>
<td>4.00E+15</td>
<td>seJ/ha/yr</td>
</tr>
<tr>
<td>Labor and services (S)</td>
<td>1.49E+15</td>
<td>1.94E+15</td>
<td>1.20E+15</td>
<td>3.11E+15</td>
<td>3.91E+15</td>
<td>seJ/ha/yr</td>
</tr>
<tr>
<td>Total (Y)</td>
<td>5.49E+15</td>
<td>4.78E+15</td>
<td>5.82E+15</td>
<td>8.88E+15</td>
<td>1.09E+16</td>
<td>seJ/ha/yr</td>
</tr>
<tr>
<td>Transformity</td>
<td>1.36E+05</td>
<td>9.19E+04</td>
<td>6.06E+04</td>
<td>5.76E+04</td>
<td>7.07E+04</td>
<td>seJ/J</td>
</tr>
<tr>
<td>Emergy Yield Ratio</td>
<td>1.27</td>
<td>1.15</td>
<td>1.11</td>
<td>1.51</td>
<td>1.38</td>
<td></td>
</tr>
<tr>
<td>Emergy Loading Ratio</td>
<td>8.23</td>
<td>7.05</td>
<td>8.80</td>
<td>3.32</td>
<td>4.30</td>
<td></td>
</tr>
<tr>
<td>Emergy Investment Ratio</td>
<td>3.71</td>
<td>6.72</td>
<td>8.80</td>
<td>1.97</td>
<td>2.65</td>
<td></td>
</tr>
<tr>
<td>Renewability</td>
<td>11</td>
<td>12</td>
<td>10</td>
<td>23</td>
<td>19</td>
<td>%</td>
</tr>
</tbody>
</table>
The %R values shows that biofuels are not fully renewable source of energy because they just use part of emery to its production from renewable sources. The renewability ranges from 10% to 12% when biofuel is produced from wheat, rapeseed or willow in Sweden. This means that these biofuels production processes uses around 89% of external resources to a high degree of non renewable origin. Nevertheless, it is still better than fossil fuels that are considered non renewable resources. Fossil fuels are considered a non renewable resource since its use exceeds the rate that this resource is generated by the biosphere. Ethanol form sugarcane in Brazil presents the best renewability ratio between evaluated biofuels. However, the renewability of ethanol from sugarcane drops from 23% to 19% when the emery requirement to the transport from Brazil to Europe is considered.

**Emergy Exchange Ratio**

The emery exchange ratio (EER) is calculated as the total solar emery of a product divided by the solar emery value of the currency paid for it. The EER is a measure of the relative advantage of one partner over the other, providing a measure of who “wins” and who “loses” in the economic trade. Usually, agricultural systems transfer emery to urban systems. Odum (1996) reports EER values between 5 and 10 for agricultural and other primary processed products. When trade is carried out between nations, suppliers of raw commodities give more to buyers than they receive in exchange. When trade is measured in terms of emery, there is usually a large net emery flow to the more economically developed buyer, for two reasons: first, environmental products that are easy to extract have a high portion of ‘free’ emery; second, the emery/money ratio is larger in less economically developed nations that supply the product than in those countries that purchase the product (Cuadra and Rydberg, 2006).

The price paid for Sweden to the Brazilian ethanol is around 0.45 USD l⁻¹. The amount of ethanol imported by Sweden from Brazil was 0.2 billion liters of in 2006 (Cerqueira et al., 2009). The emery per market for Sweden is 1.00E+12 seJ USD⁻¹ (Cuadra and Rydberg, 2006). Therefore the emery flow of the money paid by Sweden to Brazil for the ethanol from sugarcane is 9.1E+19 seJ year⁻¹. On the other hand the specific emery of the Brazilian ethanol delivered in Europe was calculated as 7.1E+4 seJ l⁻¹. Therefore, the emery flow of the ethanol exported to Sweden is 3.3E+20 seJ year⁻¹. This value is equal to 1.8% the total emery used to support the Swedish agriculture in 2003 (18.5E+21 seJ year⁻¹) (Johansson, 2005). The EER value obtained for ethanol trade between Brazil and Sweden is 3.7. This figure shows that Brazil is delivering around four times more emery with the ethanol exported than the emery it is receiving in the money paid for it. The consequence of this unequal exchange can be the depletion of the natural resources in the biofuel production country (Brazil).

In order to assess the inequity in terms of the price paid for the ethanol, it was also calculated what would be a fair price to be received by the ethanol from sugarcane in Brazil. This fair price of the ethanol is calculated as the product of the EER and its market price. Therefore, considering a balanced emery trade scenario, the fair price for ethanol would be 1.66 USD l⁻¹. An increase in the prices of ethanol would probably be the easiest and most direct way to decrease the EER in favor of Brazil. These results demonstrate quantitatively that Brazil is losing a great amount of local resources by exporting ethanol to Sweden at the current prices.

**Critical Analysis of the Swedish Biofuels Policy**

The discourse analysis performed by Rydberg and Cavalett (2010) shows that Swedish Government is promoting biofuels production and use as one of the solutions for decrease oil dependency while diminishing the greenhouse gasses emissions. However the emery results showed that the considered biofuels are not a fully sustainable and renewable alternative for fossil fuels. Biofuels contribution to decrease oil dependency because is small because they are not a source of energy. In the modern industrial agriculture model based on external non renewable resources, they are only converting one form of energy into another with a very small net emery gain as shown by the emery yield ratios. Results indicate that the potential for Swedish feedstock as alternatives to oil is very low.

Sweden is promoting the use of ethanol and biodiesel through tax relief. There are no energy taxes for ethanol or biodiesel. Without tax relief, these fuels would be unable to compete with
conventional gasoline and diesel at today’s production costs. However, biofuels cannot help to reduce the dependency on oil prices since its production is based on fossil fuels as it is showed by the renewability results. The options of biofuels for Sweden presented renewability between 10 to 19%. It means that more than 80% of the resources used to produce these biofuels are direct or indirect supported by fossil fuels resources. Furthermore, import of significant quantities of ethanol from developing countries such as Brazil might contribute to the depletion of local natural resources and increasing the environmental pressure in these biofuels producing countries.

There is no doubt that the extensive burning of fossil fuels threatens the living conditions of future generations. However, the large-scale biofuels production have a limited capacity to play an important role to decrease the greenhouse gasses emissions in the atmosphere when its production is supported by non renewable resources derived from fossil fuels. The use of emergy analysis provides comprehensive information about the biofuel production process and its link with environment and society. From this information we can indicate that biofuels production might not help to meet the three main objectives pointed by the Commission on Oil Independence (COI): (a) to reduce the dependency on oil prices, (b) to use the great potential for Swedish raw materials as alternatives to oil and (c) to reduce the extensive burning of fossil fuels.

The COI also pointed that, in the present situation, imports of Brazilian ethanol are economically advantageous for Sweden. The EER pointed in the same direction showing that there is great benefit for Sweden purchasing the Brazilian ethanol at current prices. Additionally it might be contributing to promote depletion of natural resources and Brazil is not being equitably paid for it, increasing the ecological debt as shown by EER values (3.7). This information is very important to access and enrich the discussion about equitable trade of biofuels in the international market. It also has implications on the sustainable development process, since it provides comprehensive knowledge on the environmental requirements for the biofuels production, processing and transport.

The alternatives for oil dependency should necessarily pass through multi-product ecological production for local consumption. These systems are able to prevail in a future with lower oil and land availability and are oriented according the ideas of the prosperous way down. These ideas include eliminate wasteful consumption of fuel without reduce empower, declining the dominance of automobiles diminishing the excess use of machinery and fuel by rethinking the landscape and commuting the drivers, more use of communication in place of transportation, consider the global greenhouse climate changes in the energy public policy, measures to save energy in all the economic sectors (Odum and Odum, 2000).

CONCLUSION

We evaluated four different options of biofuels to the Swedish transport sector. Renewability results showed that the biofuels production processes are strongly dependent on non renewable resources in the direct and indirect form. The transformities of biofuels are higher than those for fossil fuels indicating they require more resources from biosphere than most of the fossil fuels. The EYR results are much lower than fossil fuels indicating that they have lower net emergy and they are not a source of energy to solve the problem of oil scarcity.

The emergy synthesis results provide comprehensive information to understand the direct and indirect inputs from economy and nature to the biofuel production systems. From the information gained in the emergy synthesis, none of the analyzed biofuels can be considered a sustainable substitute for fossil fuels due to their very low emergy yield ratio and low degree of renewability. The EER calculated showed that there are great benefits for Sweden purchasing the Brazilian ethanol. This information is useful to access and enrich the discussion about equitable trade of biofuels in the international market. It also has implications on the sustainable development process, since it provides comprehensive knowledge on the environmental requirements for the production and processing systems.

Based on a critical analysis of the Swedish biofuels policy we can notice that is necessary to reformulate the Swedish energy polices. This reformulation should be based on more comprehensive information such as provided by the emergy synthesis perspective.

Furthermore, important negative environmental and social impacts on the natural and social capital still are not considered in those evaluations. Because of that we believe that the findings from the emergy evaluation can be improved by the inclusion of these considerations and we
strongly propose that the results from emergy evaluation must be taken into consideration in the decision process for biofuel policies.

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