Biomasses for energy: Application of some synthetic-quantitative indexes

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Abstract: *Looking at the biomasses as sources for energy production, in this paper a full application to three very different cases-studies of two well experimented quantitative indexes, the LCA and the EROEI, is shown. The cases are different for the type of biomasses used as primary sources and for technical and environmental context. The results obtained show the relevance of boundary definition in order to obtain a objective evaluation of the possible choices and consequently the usefulness of the concept of microsystem in analysing the convenience of any "energy production chain". An example for the use of a decision supporting system (ELECTRE®) is also shown as crucial tool to obtain a reliable ranking among different alternatives subjected to quantitative and qualitative criteria.*

Keywords: *LCA; EROEI; Biomasses; Energy.*

Introduction

The use of biomass for energy production is, as well as the general debate on energy, of topical interest at present time from both social and scientific point of view. We will present the issue with the objectivity we can have from the use of quantitative indexes whose validity is recognized at an international level, primarily the LCA (*Life Cycle Assessment*) and the EROEI (*Energy Return On Energy Investment*). EROEI is based on the economic concept of return of investment, which is an estimation of the time needed to recover investments at the beginning. The index applies this concept using energy as precise physical measurements which can be translated in a well defined amount of money, thus overwhelming the problem of quantitative estimation of profit when different not homogeneous variables enter the process.

However, there is another aspect that distinguishes the EROEI from other simpler economic indexes: the intrinsic robustness of the method in data definition and handling allows, together with the economic evaluation of the energy involved in every step of the process, to surround the typical problems of the complex systems for energy production. Latter are related to their long lifetimes with unavoidable variation of economic parameters such as inflation, discount rate, cost of fuel etc. - the variations in this long time could make every forecast very difficult and sometimes absurd.

With the help of LCA and EROEI indexes, three different cases-studies, inserted in totally different contexts have been analysed; after a deep inspection at the results from evaluation of the indexes, in order to obtain a more reliable ranking among these different cases, considered as alternative strategies in using biomasses for energy production, we took advantage from a decision supporting system from the group of ELECTRE® programs (*Elimination Et Choix Traduisant la Réalité*), belonging to the family of the so called not optimizing multicriteria method.

This paper is organized as follows: in the second section we recall some concepts about biomass as possible source for energy production. In the third section we define in a more precise way the two indexes LCA and EROEI with a short reminder about ELECTRE® methods. In the fourth section we apply these concepts to three cases-studies by explicit calculation of the two indexes for each case and obtain the final ranking of possible alternatives. Some conclusion follows in the fifth section.

Biomasses and Energy

A general definition of biomass is “the mass produced from living beings in their life cycle”. Its formation is in some way a consequence of the flow of solar energy, which is the primary energy source for any more or less complex sequence of biochemical processes on the Earth. Looking at the use of biomass for energy production, it is possible to specify this concept by defining biomass as any organic compound of vegetable or animal origin from which it is possible to obtain energy through thermochemical or biochemical processes.

The chain for energy production from biomasses can be divided in four phases:

- production
- harvesting
- conversion
- use

Each phase has its own energy and financial cost: this is why any evaluation has to take into account every step of the full chain from a quantitative point of view.

Biomass can be considered as potential sources of energy for three important usage lines: direct heating; electrical energy production and fuel for engines. For each of these lines the fundamental point is to gather enough biomass where they will be used in order to have enough power and good continuity in energy production. This involves directly the first point of the chain (production) and partially the second one (harvesting) because it is crucial to have a clear choice between two scenarios: in the first one an intensive use of waste matter is considered; in the second one, dedicated crops are the sources for conversion.

The last two phases (conversion and use) are strongly conditioned by the efficiency of the chosen process: a rough index of this efficiency is represented by the specific heating power. However, this index is not relevant in presence of further intermediate transformation, as is the case of biofuel production through chemical or biochemical processes: in this case the heating power of the fuel should be considered, while in the general balance the expenses (energy and/or money) introduced in the new steps have to be taken into account.

Two quantitative indexes and decision supporting systems: LCA, EROEI and ELECTRE®

As underlined in the previous section is the evaluation of the entire chain from the biomass production to the energy use highly complex, as every step of the process has to be considered in all its components. We assume here that the fundamental concept in the evaluation of a specific chain in a specific context is the profit of the process, whereby the profit is considered from two standpoints: the economical point of view and the environmental point of view. Both aspects are fundamental, because neglecting one of them can result in worst choices (AA.VV., 2004; Midilli et al, 2006). Furthermore the profit itself depends on (and varies with) many local conditions, thus making any abstract evaluation of a biomass source (i.e. without reference to the real context) scientifically useless. This is why any realistic quantitative index has to refer to the full chain of the process embedded in its own context, where the boundaries (and boundary conditions) play a fundamental role in the evaluation. Along this way two very promising indexes argue, looking at the concept of profit: the LCA, especially referring to the energy/environment aspect and already standardized at international level (UNI EN ISO 14040 2006); and the EROEI (Shapouri et al, 1995; Cleveland, 2005), which especially refers to the economic aspect.

The LCA is based on the compilation of inventories related to emissions and to resources consumption during the overall life cycle. Herewith, it is looking at a balance involving all the flows between the environment (ecosphere) and the human activities (technostructure). The approach for LCA evaluation consists of four phases:

1. definition of the objectives and field of application

2. life cycle inventory, i.e. compilation of the full list of in/out flows for the system
3. life cycle impact assessment, i.e. evaluation of the effects of the full life cycle (Lee et al, 1995)
4. interpretation of the life cycle from the data discussed in the previous phases

High scientific criteria should be applied in all phases in order to have a neutral approach without any bias, as well as good data quality (Vigon et al, 1995). Furthermore, with the aim of improving the significance of the index, it is useful to introduce in the procedure some decision supporting system, such as multicriteria/multiobjectives programs (Miettinen et al, 1997; Hanegraaf et al, 1997).

For what concerns the EROEI, it is a totally quantitative index related to the economic concept of investment and return, applied also to the financial quantification of the energy produced/spent during the lifetime of the system. It is a positive index with the obvious property that the unity value is the boundary between profitable (0<EROEI<1) and not-profitable (1<EROEI) system: the larger the EROEI, the more advantageous the process. In Table 1 the EROEI for few well known energy sources is reported: the large limits of oscillations are related to the strong dependence on many local parameters.

Table 1. EROEI index for some source of energy (Bardi, 2005).

Source of Energy	EROEI
Hydroelectric	50 – 250
Oil	5 – 100
Wind	5 – 80
Nuclear	5 – 100
Photovoltaic	0.5 – 80
Carbon	2 – 17
Natural gas	5 – 6
Biomass	0.6 – 27

Finally, as already cited for the LCA index, some qualitative criterion is often present in any choice among different alternatives, e.g. general environmental impact, or social impact, or political reasons (i.e. specific agreement at higher level inserted in more general strategy). The presence of mixed requirements, qualitative and quantitative, suggests the use of some multicriteria approach as decision supporting system. We used the well known program ELECTRE® for its simplicity and its adaptability at very different contexts - its different releases (I-II-III-IV) suit very well a large spectrum of mixed conditioning criteria (Rogers et al, 2000; Ben Mena, 2001).

Three cases-studies

In this section we analyse three case-studies with great differences among them which are related to the geographic/environmental context, the organic matter used as energy source and to the specific technique employed in the process.

The three cases are the following:

- A1 - a typical farm in middle Italy (Honorati Farm) already analysed in the Italian project SIPEAA (AA.VV., 2006) in which dedicated crops (sunflowers) supply biomass;
- A2 - the municipality of Aboyne (Aberdeen County, Scotland: Vetrano, 2008), in which sawdust and other wood by-products are used;
- A3 - the experimental farm of Bologna University in Ozzano Emilia, Northern Italy, in which dedicated crops (millet) are used as primary energy source.

In Table 2 relevant characteristics of the three examples are summarized, while in Table 3 and in Table 4 the LCA and EROEI indexes are presented for the three cases. In this paper, only an overview can be provided, detailed calculations can be found e.g. in Vetrano (2009).

Table 2. Characteristics of the three structures analysed as case-studies.

A1:

Site: middle Italy, hill
Farming: sunflowers (dedicated)
Production: 2.4 t/he
Functional unity: energy produced/he
Process: oil extraction from sunflowers seeds and local use by combustion (heating and electricity)

A2:

Site: eastern Scotland, low mountain
Source: sawdust and wood by-product from saw-mills in local forest
Production: 80 t/month
Functional unity: energy produced/time
Process: direct combustion boiler for local use (heating)

A3:

Site: northern Italy, plain
Farming: millet (dedicated)
Production: 25 t/year
Functional unity: mean energy produced/month
Process: direct combustion for local use

Before the realization of the LCA index evaluation, the functional units of the three cases have been unitized to the mean energy (kcal) produced per unity of surface (hectare) and per unity of time (month) in order to have homogeneous quantities.

Table 3. Evaluation of the LCA index for the three cases (A1 – A3).

A1:

Boundaries

Resource/emission	*Activity*	*Internal (Y/N)*
Energy consumption	-Production and use of wearable out tools	Y
	-Transportation of wearable out tools	N
	-Production and maintenance of machines	N
	-Use of machines	Y
Use of the soil	Agricultural activities	Y
Manpower	Agricultural activities	N
Chemical compounds	Fertilizers production and use	Y
Disinfestants	For agricultural activities	Y
Sulphur compounds	Combustion	Y
Organic compounds	Combustion	Y
Dust of different kind	Combustion	Y
Boiler production		N
Boiler use		Y

Balance deriving from the flows inventory

Energy consumed (kcal/kg)	-856
Energy produced: - Heating	+5000
- Electricity	+2000
Pollution:	
CO_2 (g)	300000
N_{tot} (mg)	30
P_{tot} (kg)	200
NO_x (ppm)	10
N_2O (mg/nm^3)	196
SO_2 (mg/nm^3)	49
Dust (mg/nm^3)	5
Disinfestants (l)	4.5

Impact on the environment (with respect to the obtained saving; *** = high; ** = medium; * = low)

Impact category/Pollutant	CO_2	N_2O	NO_x	SO_2	N_{tot}	P_{tot}	Dis.	Dust	Mean value
Global warming	***	***	-	-	-	-	-	-	***
Acidification	-	-	*	***	-	-	-	-	**
Eutrophyzation	-	-	*	-	**	***	-	-	**
Smog	-	-	-	-	-	-	-	*	*
Others	-	-	-	-	-	-	*	-	*

to be continued … Table 3. Evaluation of the LCA index for the three cases (A1 – A3)

A2:

Boundaries

Resource/emission	*Activity*	*Internal (Y/N)*
Forest	Any activity	N
Saw-mill	Recycling and transportation	Y
Pollutant	Transport and combustion	Y
Building the system	Energy and material use	Y
Using the system	Energy production	Y

Balance deriving from the flows inventory

Energy consumed (Mj)	- 11200
Energy produced: (Mj)	+39599
Pollution:	
CO_2 (g)	181800
Dust (mg/nm^3)	50

Impact on the environment (with respect to the obtained saving: *** = high; ** = medium; * = low)

Impact category/Pollutant	CO_2	Dust	Mean value
Global warming	*	-	*
Smog	-	*	*

A3:

Boundaries

Resource/emission	*Activity*	*Internal (Y/N)*
Energy consumption	-Production and use of wearable out tools	Y
	-Transportation of wearable out tools	Y
	-Production and maintenance of machines	N
	-Use of machines	Y
Use of the soil	Agricultural activities	Y
Manpower	Agricultural activities	N
Chemical compounds	Fertilizers production and use	Y
Disinfestants	For agricultural activities	Y
Sulphur compounds	Combustion	Y
Organic compounds	Combustion	Y
Dust of different kind	Combustion	Y
Boiler production		N
Boiler use		N

Balance deriving from the flows inventory

Energy consumed (kcal/kg)	-1000
Energy produced: - Heating	+2000
- Electricity	+1000
Pollution:	
CO_2 (g)	300000
Dust (mg/nm^3)	40
Others(mg/nm^3)	200

Impact on the environment (with respect to the obtained saving: **** = very high; *** = high; ** = medium; * = low)

Impact category/Pollutant	CO_2	Dust	Others	Mean value
Global warming	****	-	-	****
Acidification	-	-	***	***
Eutrophyzation	-	-	***	***
Smog	-	***	-	***

Table 4. Evaluation of the EROEI index and of the time needed for recovering the investment for the three cases.

A1:

Buying the machines (€)	30000 (-)
Buying the wearable out tools (€)	10000 (-)
Building and functioning the installation (€)	80000 (-)
Total (-)	120000
Net monetary value of produced energy per year (€)	10000 (+)
Time needed to recover the investment (y)	**12**
EROEI index ([Energy produced/Energy spent] during one year)	**8.2**

A2:

Building and functioning the installation (£)	156000 (-)
Total (-)	156000
Monetary value of produced energy per year (£)	53000 (+)
Time needed to recover the investment (y)	**3**
EROEI index ([Energy produced/Energy spent] during one year)	**3.54**

A3:

Buying the machines (€)	30000 (-)
Buying the wearable out tools (€)	40000 (-)
Functioning the installation (€)	80000 (-)
Total (-)	150000
Monetary value of produced energy per year (€)	5000 (+)
Time needed to recover the investment (y)	**30**
EROEI index ([Energy produced/Energy spent] during one year)	**3**

A look at the results in the previous Tables shows that the SIPEAA farm (A1) has a good performance for energy production, but the return of the investment is not satisfactory; furthermore the pollution is at a moderate high level.

For what concerns the Aboyne systems (A2), every indicator is good: very low pollution, good performance for energy production, short time for recovering the investment.

The worst result is for the experimental farm in Ozzano (A3): very high level of pollution, poor efficiency, very long time for recovering the investment.

We try to have a deeper look inside the ranking of these structures by using the ELECTRE® programs. Generally, three alternatives do exist (A1, A2, A3):1) reasonable criteria of choice are the economic convenience (C1, weight 0.50, ascending), 2) the technical efficiency (C2, weight 0.10, ascending) and 3) the environmental impact (C3, weight 0.40, descending).

Standard use of ELECTRE III® furnishes a clear dominance of A1 and A2 over A3, while ELECTRE IV® leads to a sharp dominance of A2 over A1 and A3. The final ranking is A2 > A1 > A3, with a very well defined difference (Vetrano, 2009).

Conclusions

The use of biomass for producing energy has been analyzed in three different contexts by using two well known indexes, the LCA and the EROEI in order to obtain reliable evaluation of the convenience. The concept of convenience is used here in the twofold meaning of economic and environmental convenience, well identified by LCA and EROEI procedures. Generally speaking the best way to use biomass is to profit by co-generation with some more efficient sources, especially by recovering by-products from other activities instead of using dedicated crops. Many parameters may influence in a crucial way the result meaning that the concept of microsystem is fundamental because of its role played in the boundary definition process which allows an identification of the in/out flows for the system. Finally, a fine handling of robust decision supporting system might be of great help in defining a reliable ranking of the alternatives.

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