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Systemic Evaluation of Energy Production from Biomass in a Life Cycle Perspective

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Abstract. The study is aimed at evaluating the potential of biomass energy production as an alternative to fossil fuel depletion and to analyse the environmental benefits and drawbacks of using biomass. Synthetic data related to Romanian case are presented and a method of biomass potential assessment is developed. A life cycle assessment methodology is presented in order to evaluate the environmental impacts. The paper concludes by summarizing the biomass energy production potential and suggests steps for identifying and utilisation of biomass for energy.

Key words: biomass, evaluation, environmental impacts, bio-energy, life cycle

INTRODUCTION

The potential source for bio-energy in Romanian agriculture is large, where diverse and high biomass production are possible. The growing concerns on needs to develop sustainable energy sources, as well as, on environmental impacts of all processes involving fossil fuels have renewed the interest in using biomass for energy production.

On the other hand, the potential environmental benefits of biomass utilization as alternative source of energy are numerous. In addition to a dramatic decrease in the amount of carbon dioxide produced per kWh, implementation of biomass energy production will reduce fossil fuel consumption and significant mitigate sulphur and nitrogen oxide emissions.

Additionally, compared to conventional crops, biomass plantations may increase biodiversity and reduce soil erosion. However, biomass used for energy production may also have some negative effects on the environment and on the costs of energy which is higher than that of fossil fuel [2].

METHODOLOGY OF EVALUATION

There are many questions in connection to energy production from biomass: What parts of the integrated system are responsible for the emissions? Is biomass a potential source of renewable energy for the case of Romania?

To answers to these questions a systemic analysis of the whole energy production process is required. Broadly speaking, the overall system consist of biomass production, its primary processing and transportation to the power plants, conversion of biomass to energy, environmental stressors that are associated with converting the raw material to energy (e.g. emissions, resources, consumption and energy use).

Fig. 1 shows on integrated system of energy production from biomass.



Fig. 1. Integrated system of energy production from biomass

Thus, systemic analysis of integrated energy production system from biomass must be based on quantitative descriptions of the interaction among the input factors (e.g. fuel consumption for biomass production and primary processing and transportation, tractor and implement manufacture and operation, fertilizer application, harvested yield) and the output factors (e.g. resulted energy, emissions, waste).

The equation that govern the biomass energy production system may be written as

$$Q = f(I) \tag{1}$$

Where Q represents the output of the process and includes the final products of the process (energy, emissions and waste) and I - input of the process consists of total energy applied to the whole process and the material involved (e.g. raw materials, intermediate feedstock).

The factors in equation (1) are abstract because each is not clearly defined quantitatively, but they do represent distinct elements in the integrated biomass energy production system. If we can express and correlate the elements of equation (1) in quantitative terms, the total economic and environmental benefits and drawbacks of the process can be quantified.

To complement this study, a life cycle assessment (LCA) methodology is presented to quantify the total benefits and drawbacks of the entire system from biomass crops including emissions and costs from diverse sources such as planting and harvesting, transportation and energy production.

It should be emphasized that the evaluation of biomass and energy production from biomass in a life cycle perspective is a very hard and complex task. In this activity should be involved experts, researchers, decision-makers and people who are involved in the overall processes of production and utilisation of bio-energy.

Generally, such an evaluation is developed as a comparative analysis highlighting the economical and environmental benefits and drawbacks of one over the other (e.g. biomass over the coal).

The systemic analysis is considered to be suitable to conduct this study. This method has the potential to consider the overall processes as a system or black box, in which there may be introduce all category of data related to the system of energy production from biomass (Fig.1).

Most and difficult work in a systemic analysis is to define, quantify and correlate the factors included in the system (e.g. energy required for soil cultivation, energy embodied in the machines involved in the process, CO_2 emissions, energy embodied in biomass etc.).

Other problem of this method is the system boundaries and data availability for the evaluation of energy from biomass in a life cycle perspective. The system boundaries should

be drawn as large as possible (e.g. from the extraction of raw material for fertilizer needed to grow biomass). If a large system can not be quantified, it may be divided in subsystems which can be expressed in a quantitative way.

The methodology for analysis of energy production from biomass has mainly three components: *evaluation*, *impact analysis* and *continuum improvements*. The evaluation involves quantifying the energy and material requirements, air and water emissions, and soil waste from all stages in the life of products and processes involved in the production of bio-energy.

Evaluation of biomass and biomass energy potential

Biomass is a short cycle renewable fuel that has potential to reduce or even substitute the current fossil fuel. It may be used for transportation (e.g. ethanol, methanol, vegetal oil, biogas), for electricity production, for heating and for chemical production. For electricity and heating, may be use as a single source of combustion or in combination with other sources.

The biomass is being divided in two main category: virgin and waste biomass.

Virgin biomas refer to that part of biomass which is grown on soil (terrestrial biomass) and into water (aquatic biomass) and is destined for the production of energy or other product. A realistic assessment of biomass production, as energy resources, can be made by calculating the average surface areas needed to produce sufficient biomass at different annual yield to meet certain percentages of fuel demand for our country, and then to compare these area with those that might be made available. For an hypothetic scenario, it is assumed that biomass, whether it be trees, plants, grasses, algae, or water plants, has a heating value of 15.5 GJ/dry t [6], is grown under controlled conditions, at yield of 15 tonne dry mass per hectare per year and is converted to energy. This condition of biomass production and conversion either are within the range of present technology and agricultural practice, or are believed to be attainable in the near future. Let assume that we want to reduce or eliminate the import of natural gas and replace it with virgin biomass energy. According to Romanian statistical yearbook, 10.2 % of total primary energy resources in 2006, come from imported natural gas (Fig. 2) . It represents approximately 4883 thousands toe (tonne of oil equivalent), respectively 204,360 thousand GJ (one toe = 41.85 GJ), respectively 13065 thousands tonne of dry biomass per year. Considering a yield of 10 dry tonne of biomass per hectare per year, there are necessary to cultivate 1,306,500 hectare of virgin biomass per year. It may be concluded that, in the case of Romania, this scenario is realistic.



Fig. 2. Structure of primary energy resources, in 2006

This scenario may be applied to any primary energy source substitute by using the following formula:

$$S_{ha} = m_s \cdot C_f / HV_b / P_{ha}$$
⁽²⁾

Where m_s represents the amount of primary energy sources from fossil fuels to be substitute, in toe; C_f - the conversion unit factor (e.g. toe to GJ); HV_b – heating value of biomass, in GJ/dry t; P_{ha} – production of biomass per hectare, in dry t/ha.year and S_{ha} represents the total area to be cultivate to substitute m_s primary energy sources, in hectare.

Another large source of renewable energy supplies is *waste biomas*. It consists of wide range of material and includes agricultural crop and forestry residues, municipal solid waste, sewage, industrial waste, animal manures, landscaping and tree clippings and trash, and dead biomass that results from natures life cycles. Some waste can be recycled but most of the waste biomass is a potential energy source, as virgin biomass is.

According to EU strategy, Romania will increase the energy production from renewable sources up to 11% in 2010. It represents a realistic possibility due to the high energy potential from biomass, evaluated at 7594 thousands toe per year, which represents 19% of total primary resources consumption, in 2000 [4]. The sources of waste biomass are:

- agricultural crop residues 4,799 thousands of toe per year;
- forestry residues and fire wood -1,175 thousands of toe per year;
- wood wastes- wood dust and other wood residues 487 thousands of toe per year;
- biogas 588 thousands of toe per year;
- municipal and industrial waste 545 thousands of toe per year.

The biomass consumption represents an important percentage in the primary energy resources, as it can be seen in Tab. 1. During 1996-2000, the biomass consumption decreased by 21.57% as a result of decreasing total consumption of primary resources and increasing of fossil fuels consumption.

Tab. 1

Specification	Units	1996	1997	1998	1999	2000
Total consumption of primary resources	PJ	2341	2146	1934	1666	1689
Biomass consumption	PJ	205	141	127	118	116
	%	8.76	6.57	6.56	7.10	6.87

Consumption of biomass energy compared to total primary energy resources

Source: Romanian Statistical Yearbook, 2001

It is important to examine the potential amounts of bio-fuels that can be produce from biomass and to compare these amounts with other renewable energy sources. This would make it possible to estimate the percentage of energy demand that may be satisfied by particular renewable energy type. In Tab. 2 is presented a comparison between different category of renewable energy potential in Romania, including biomass energy.

Tab. 2

Energy potential	of renewable energy	sources and	production	plan for 2010
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RES sources	Potential		Potential Destination	
	[toe/year]	[%]		2010, in [toe/year]
Biomass	7594	52.85	Thermal and electric energy	3347
Hidro	3444	21.54	electric energy	1565
Wind	1978	13.70	electric energy	27
Solar	1536	10.71	Thermal and electric energy	7.5

Geothermal	167	1.20	Thermal energy	17.5
Total	14719			4964
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Source: ICEMENERG, ENERO

As it can be seen, there is a considerable potential of biomass energy in Romania, evaluated at about 7600 thousands toe/year (more than 50% of total renewable energy potential). If we take into account new dedicated plantations for biomass (poplar, willow, sorghum, aquatic biomass etc.) a more realistic assessment of bio-energy potential might be developed.

Analyses of environmental impacts

Biomass cultivation offers the benefit of reducing CO_2 , NO_x , and SO_2 , being in line with EU new energetic police. One of its target is to reduce the emissions of greenhouse gases up to 20% in 2020, in comparison with 1990 [4]. For CO_2 , various studies indicate that its concentration will double by the latter period of this century. Oil is the largest CO_2 source, followed by coal and natural gas [3]. To develop more quantitative information regarding atmospheric CO_2 , the emissions on combustion of oil, coal and natural gas per energy input unit is used to calculate the CO_2 from fossil fuel combustion.

Because of the environmental trends today, it appears that international agreements to limit fossil fuel consumption will be implemented. This will require much greater usage of alternative fuels produced from biomass. The most significant negative environmental effects, from this fuel cycle are caused by the use of chemicals and fertilizers to cultivate biomass.

The environmental impacts and socio-economical benefits of all processes involved in producing and converting biomass to energy might be quantified by using life cycle assessment (LCA) methodology. LCA is a tool that can be used to evaluate the potential environmental impacts of a type of biomass throughout its entire life cycle by quantifying the use of resources (*"input"* such as energy to produce biomass, raw material for chemicals, fertilizer and manufacturing of machinery for transport and biomass cultivation etc.) and environmental emissions (*"outputs"* to air, water and soil, such as CO₂, NO_x, SO₂ and CO). LCA performed in conjunction with a techno-economic feasibility the total economic and environmental benefits and drawbacks of the process can be quantified. This technique can be used in project decision-making and in comparing the viability of different technologies and processes and primary energy sources. The methodology of LCA, generally includes three phases: inventory, impact analysis and improvements.

The inventory stage involves quantification of energy and material requirements, air and water emissions and solid waste from all stages in the cycle of bio-energy production. According to systemic analysis which had been discussed in introduction and methodology, the biomass life cycle might be presented as a process tree (Fig. 3). Each box represents a process which forms part of the life cycle.



Fig. 3. Schematic representation, as a process tree, of bio-energy production: I-input; O-output; E-energy; E_m -emissions

Bio-energy processes have defined inputs and outputs. The inputs are raw materials and energy (e.g. energy for soil cultivation, input of products such fertilizer which is output from other process etc). The outputs are emissions (environmental outputs), and energy (economic output) and disposals.

With information about each process and a process tree of the life cycle, it is possible to draw up a life cycle inventory of all the environmental inputs and outputs associated with the bio-energy production. The result is called the *table of impacts*. Each impact is expressed as a particular quantity of a substance (e.g. emission values of one energy unit of biomass - CO_2 , NO_x , SO_2 and CO). The data collected in the table of impacts are used for systematic evaluation of the impacts through life cycle impact assessment (LCIA).

In conclusion, LCA has the potential to identify, evaluate and help minimize the environmental impacts of bio-energy production process or competing process. Material and energy balances are used to quantify the emissions, resource depletion and energy consumption of all processes between transformation of raw materials into useful products and the final disposal of all products and by-products.

CONCLUSION

Romania has a high potential of energy production from biomass. By developing a new concept of biomass energy production and an industry based on bio-energy, biomass have the potential of becoming basic energy sources and to substitute part of fossil fuels. Increasing feedstock flexibility and smaller scale relative to fossil-fuel power plants present an opportunity for bio-power in rural area, where the biomass is cultivated.

Biomass offers the benefit of reducing CO_2 , NO_x , SO_2 and CO emissions and soil erosion can be substantially reduced. LCA methodology can be used to evaluate the environmental impacts of a type of biomass throughout its entire life cycle.

Much more studies have to be conducted in order to evaluate the potential of all type of biomass in term of ecological and socio-economic criteria.

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