Environmental Engineering and Management Journal September/October 2008, Vol.7, No.5, 617-640
http://omicron.ch.tuiasi.ro/EEMJ/

"Gh. Asachi" Technical University of Iasi, Romania

BIOMASS POWER FOR ENERGY AND SUSTAINABLE DEVELOPMENT

Maria Gavrilescu

"Gheorghe. Asachi" Technical University of Iaşi, Faculty of Chemical Engineering and Environmental Protection, Department of Environmental Engineering and Management, 71 Mangeron Blvd.,700050 Iasi, Romania, e-mail: mgav@ch.tuiasi.ro

Abstract

The paper discusses some aspects concerning the utilization of biomass as a bioenergy resource worldwide and in Romania, since biomass is considered a sustainable, potentially environmentally sound and a replenishable resource.
The biomass categories for bioenergy are analyzed, considering the factors which influence its availability. Biomass energy potential and current use in different regions as well as in Europe is accounted. Also, biomass power as an important alternative for providing energy in rural sector is described and some technologies for biomass conversion are evaluated briefly. Biomass and renewable energy from biomass are considered end products, which involve new and advanced technologies to improve power production efficiency.
It is evidenced that biomass provides a clean, renewable energy source, which could improve economic, energetic and environmental sectors. Also, many factors converge in making bioenergy a key issue toward the achievement of the Millenium Development Goals.
Contributions of bioenergy to sustainable development of humanity are also discussed, based on some sustainability considerations and indicators.
The investments in biomass and bioenergy in Romania are also considered as important, since the production of renewable energy for Romania is an important topic.
The future projection on the use of renewable energy resources points toward actions for economic development where renewable energy from biomass will play more and more a growing role, without affecting the community food security.

Keywords: biofuel, bioelectricity, environmental impact, rural energy, renewable resources, sustainability indicators

1. Introduction

Organic matter, particularly cellulosic or ligno-cellulosic matter is available on a renewable or recurring basis, including dedicated energy crops and trees, wood and wood residues, plants and associated residues, agricultural food and feed crop residues, plant fiber, aquatic plants, animal wastes, specific industrial waste, the paper component of municipal solid waste, other waste materials, all of them being well-known as *biomass*. In the same context, the term *biobased product* is used to designate any commercial or industrial product (either from food or feed) that utilizes biological products or renewable domestic agricultural (plant, animal, or marine) or forestry materials (ABB, 2003; Industry Report, 2008; OCAPP, 2007). Both in the application in chemistry and in transport and the generation of energy, biomass offers great opportunities for the conservation of energy management (IPM, 2007).

At some stage in human history, biomass in all its forms has been the most important source of various basic needs: food, feed, fuel, feedstock, fibers, fertilizers (Rosillo-Calle, 2007). Nowadays, biomass continues to be a subject of growing significance worldwide, in particular due to its suitability as source of bioenergy, as a result of global increase in the demand for energy, the constant rise in the price of fossil fuels and the need to reduce greenhouse gas emissions (Perlack et al., 2005; Thornley and Cooper, 2008; Thornley et al., 2008; Yuan et al., 2008).

Throughout the past decades, bioenergy and other renewable energies have been the subject of several international declarations and commitments on sustainable development (FAO, 2005; http://www.fao.org/docrep/meeting/009/j4313e.htm#P42_5511):

- United Nations Conference on New and Renewable Sources of Energy (NRSE), in 1981
- United Nations Conference on Environment and Development: in Agenda 21, emphasis was given to the role of bioenergy
- UN Millennium Declaration

- World Summit on Sustainable Development (WSSD), where energy was high on the agenda
- International Conference for Renewable Energies held in Bonn in June 2004
- Other important initiatives promoting bioenergy include the Global Environmental Facility (GEF), the G-8 Task Force on Renewable Energy; the UNDP Initiative on Energy for Sustainable Development

Since the Kyoto Conference (1997), there has been an increasing interest about renewable energy sources and possible alternatives to fossil fuels that could contribute to a significantly reduction in greenhouse gas emission and enhance the overall sustainability of modern society (http://www.avanzi.unipi.it/ricerca/quadro_gen_ric/biomass_bioenergy/Biomass&bioenergy_ENG.htm). Energy crops may contribute to the goals of the Kyoto Protocol by increasing C sequestration, thus playing a strategic role for development of sustainable energy production systems.

It's obvious that the biomass energy is nothing else than solar energy - stored thanks to photosynthesis – in the vegetable tissues. Bioenergy resources take many forms, which can be broadly classified into three categories (Rosillo-Calle et al., 2007):
(1) residues and wastes,
(2) purpose-grown energy crops
(3) natural vegetation.

Traditionally, conventional biomass is considered to come from three distinct sources: wood, waste, and alcohol fuels as summarized in the Fig. 1 (http://www.greenjobs.com/Public/info/industry_background.aspx?id=13).

From an ethical point of view, only biomass that is not competing with the food chain should be used for the production of fuels, chemicals, power or heat.

Industrialized countries have over 1,500 million hectares of crop, forest and woodland, of which some 460 million hectares are crop land. Achieving the 15 % target could require an average of 1.25 million hectares of crop land per year to be converted to energy plantations. This represents just over 2 % of the total land area in industrialized countries (Bauen et al., 2004).

In USA, the forestry category at 49% is by far the largest contributor to the state biomass, followed by municipal waste with 24%, field with 14%, and animal waste at 11% as the next most important, respectively (Fig. 2)

Under this concern, biomass is a sustainable, potentially environmentally sound and a replenishable resource, since it can be replaced fairly quickly without permanently depleting the Earth's natural resources. By comparison, fossil fuels such as natural gas and coal require millions of years of natural processes to be produced. Alternatively, biomass can easily be grown or collected, utilized and replaced. However, extracting energy from biomass is an ancient practice, dating back to when people first burnt wood to provide heat and light. Growing biomass is a rural, labor-intensive activity, and can, therefore, create jobs in rural areas and help stem rural-to-urban migration (IBEP, 2006).

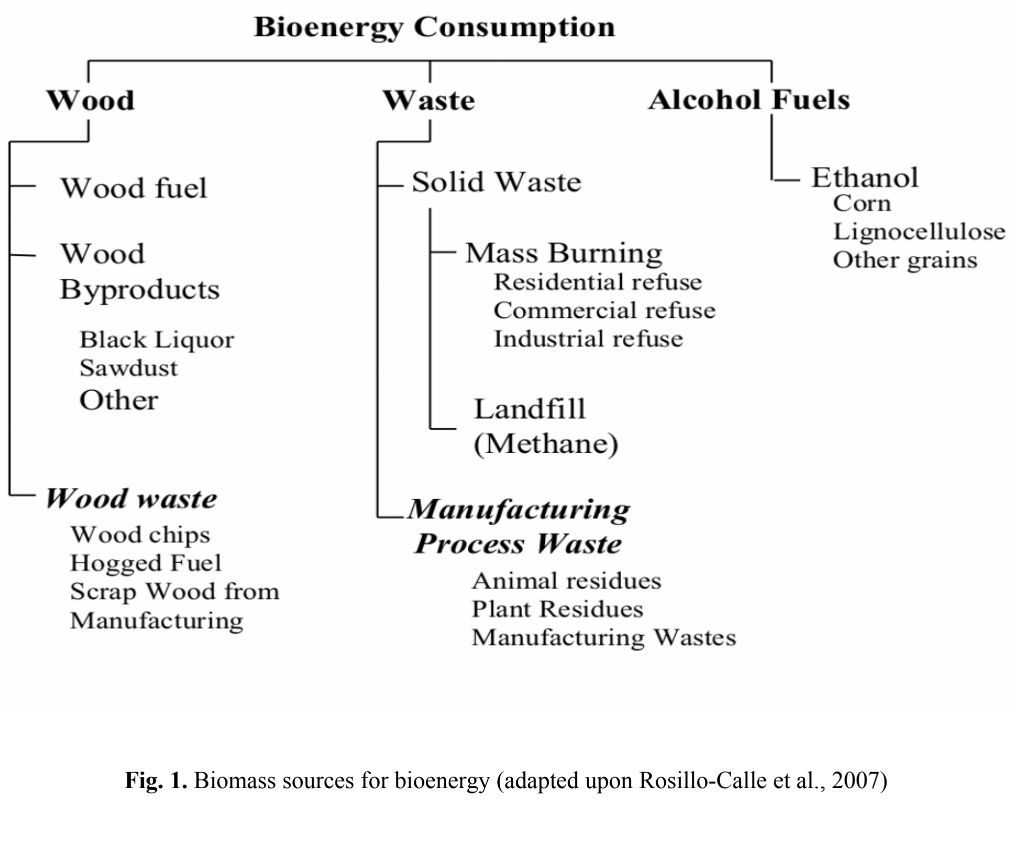

Fig. 1. Biomass sources for bioenergy (adapted upon Rosillo-Calle et al., 2007)

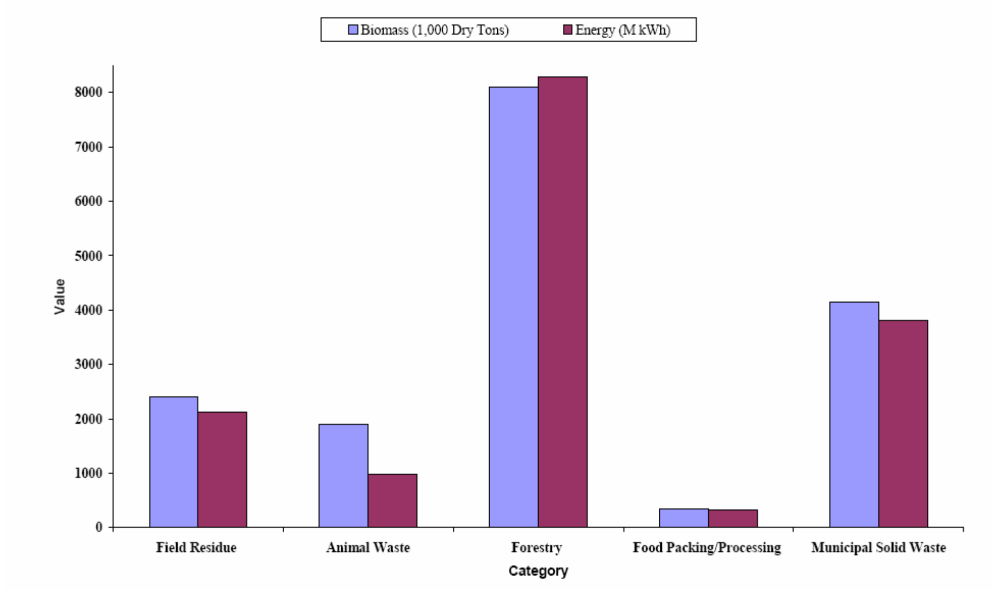

Fig. 2. Biomass categories for bioenergy

Considering the factors which influence the availability of biomass for energy purposes, it can be noted that the worldwide biomass system is complex and so availability is difficult to quantify, particularly in light of the potential competition for biomass for food, fodder, materials and energy (Fig. 3).

The availability of biomass for energy will also be influenced by population growth, diet, water availability, agricultural density, and nature (Bringezu et al., 2007; Long et al., 2006; Olesen and Bindi, 2002; Perlack et al., 2005).

2. The share of biomass as renewable energy resource

Energy is one of the more basic human needs and the trends in energy utilization are major indicators of the economic growth of a particular country/society. In the absence of conventional energy sources, the unsustainable use of biomass fuels is often the only resort. Tables 1 and 2 describe the biomass energy potential in different regions of Earth and in Europe, respectively (AFB-NET, 2000; Parikka, 2006).

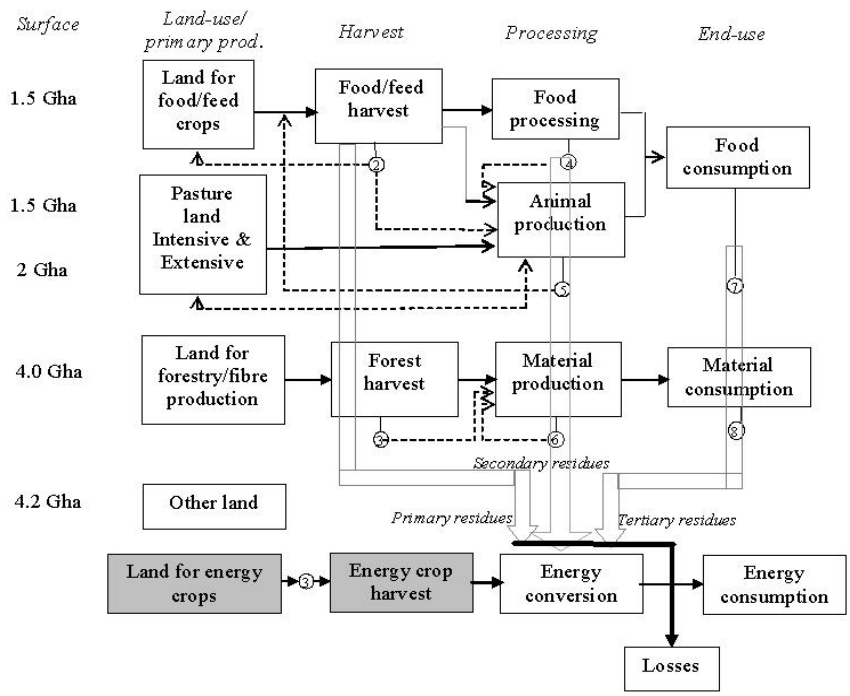

Fig. 3. Pathway of biomass from land to processing and end-uses for materials, food and energy (Bringezu et al., 2007)

Table 1. Biomass energy potential and current use in different regions, EJ/a (EJ=10^{18})

Biomass potential	*North America*	*Latin America*	*Asia*	*Africa*	*Europe*	*Middle East*	*Russian Federation*	*World*
Woody biomass	12.8	5.9	7.7	5.4	4.0	0.4	5.4	41.6
Energy crops	4.1	12.1	1.1	13.9	2.6	0.0	3.6	37.4
Straw	2.2	1.7	9.9	0.9	1.6	0.2	0.7	17.2
[a]*Other*	0.8	1.8	2.9	1.2	0.7	0.1	0.3	7.6
=Potential (EJ/year)	19.9	21.5	21.4	21.4	8.9	0.7	10.0	103.8
Use (EJ/year)	3.1	2.6	23.2	8.3	2.6[b]	0.0	0.5	39.7
Use potential (%)	16	12	108	39	29[b]	7	5	38

Table 2. Biomass energy potentials in Europe (PJ per year)

	Forest residues	*Solid ind. by-products*	*Ind. black liquors*	*Firewood*	*Wood wastes*	*Densified wood fuels*	*Other biomass fuels*	*Peat*	*Total*
Austria	150.0	50.0	0.0	40.0	18.0	3.0	9.0	0.0	270.0
Belgium	7.0	13.0	8.0	0.0	3.0	0.0	0.0	0.0	31.0
Denmark	11.0	5.0	0.0	3.0	0.0	4.0	46.0	0.0	69.0
Finland	96.0	47.0	135.0	49.0	0.0	1.0	11.0	165.0	504.0
France	38.0	42.0	0.0	258.0	111.0	0.3	412.0	0.0	861.3
Germany	142.0	40.0	0.0	0.0	81.0	0.0	511.0	0.0	774.0
Greece	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ireland	3.0	7.0	0.0	3.0	1.0	0.0	0.0	40.0	54.0
Italy	0.0	36.0	0.0	83.0	24.0	0.0	0.0	0.0	143.0
Netherlands	4.0	30	0.0	0.0	45.0	1.0	24.0	0.0	77.0
Portugal	68.0	27.0	22.0	0.0	0.0	0.0	0.0	0.0	117.0
Spain	59.0	87.0	23.0	12.0	52.0	0.0	386.0	0.0	619.0
[1]Sweden	238.0	46.4	125.0	27.0	27.0	18.0	22.0	13.0	516.4
UK	16.0	12.0	0.0	27.0	175.0	0.0	70.0	0.0	300.0
Estonia	30.0	0.0	0.0	0.0	0.0	0.0	19.2	30.0	79.2
Latvia	8.0	12.0	0.0	32.0	0.0	1.0	0.0	15.0	68.0
Poland	101.0	68.0	16.0	26.0	40.0	0.0	205.0	122.0	578.0
Romania	0.0	23.0	3.0	58.0	0.4	0.0	0.1	0.0	84.5
Slovakia	6.0	0.1	5.0	3.0	3.0	0.1	13.0	0.0	30.2
Slovenia	2.0	7.0	0.0	8.0	0.1	0.0	0.0	0.0	17.1
Total	979.0	525.5	337.0	629.0	580.5	28.4	1728.3	385.0	5192.7

Leible and Kälber (2005) consider that the scientific dedication to bioenergy experienced three stages:

- the first stage of discussion started with the 1973 oil crisis and the publication of the Club of Rome's report on *The limits of growth*
- the second stage at the beginning of the 1980s was a discussion on reducing agricultural overproduction and creating income in agriculture by growing energy crops.
- the third stage started at the end of the 1980s, which continues today, triggered by increasing efforts for the mitigation of climate change and not only.

Using biomass to generate energy has positive environmental implications and creates a great potential to contribute considerably more to the renewable energy sector, particularly when converted to modern energy carriers such as electricity and liquid and gaseous fuels (IBEP, 2006; http://www.unido.org/index.php?id=4781).

Biomass is available in a variety of forms and is generally classified according to its source (animal or plant) or according to its phase (solid, liquid or gaseous) (Bauen et al., 2004; IBEP, 2006).

Biomass can be burned directly or converted to intermediate solid, liquid or gaseous fuels to generate heat and electricity. All organic materials can potentially be converted into useful forms of energy but the advantage of modern biomass-to-electricity systems is that these conversion systems can cope with a range of lignocellulose-rich materials. This is in contrast to liquid biofuel production chains that are primarily dependent on sugar, starch or oil-rich crops, typically annuals. The options for biomass conversion to energy re described below.

There are three ways of using the biomass resources, which represent the bioenergy sector (EREC, 2007; IBEP, 2006):

- biomass for heating purposes (*bio-heating*),
- biomass for electricity production (*bio-electricity*),
- biomass for transport fuels (*transportation biofuels*).

All these processes enable to take profit of the CO_2 mitigation potential of biomass. Since biomass is the result of storing sun light as chemical energy in plants through photosynthesis, when sunlight transforms CO_2 from the atmosphere and water into complex plant polymers over short periods of time, the use of this resource as a material or durable product keeps the CO_2 stored. The CO_2 released is equivalent to the amount of CO_2 absorbed by the biomass (photosynthesis) in the growing phase (Wiedinmyer and Neff, 2007).

Practically, the equivalent of 10 to 30% of the energy content of the raw biomass is used in cropping, transport, conversion and upgrading. This amount of energy can partially come from the biomass itself, which makes the overall CO_2-balance nearly neutral (Yamasaki, 2003). Therefore, biomass can substantially contribute to reach the targets of the Kyoto protocol and to reduce long-term greenhouse gas emissions (IBEP, 2006; Kashianet al., 2006; Wiedinmyer and Neff, 2007).

In European Union, renewable energies come mainly from biomass and waste, representing almost 72 million tons of primary production in 2004 (UNEP, 2007). Primary production of renewable energy: primary production of biomass, hydropower, geothermal energy, wind and solar energy are included in renewable energies (Fig. 4) (EUROSTAT, 2007). In Germany, bioenergy produced an overall turnover of €3.5 billion in 2004, without consideration of the fuel-provision businesses. For comparison, the largest German energy company E.ON AG achieved a transaction volume of €49.1 billion in the same year (EON, 2005; Plieninger et al., 2006); €1.6 billion was invested in the construction of bioenergy plants, while €1.9 billion turnover came from operation and maintenance (BMU, 2005; Plieninger et al., 2006).

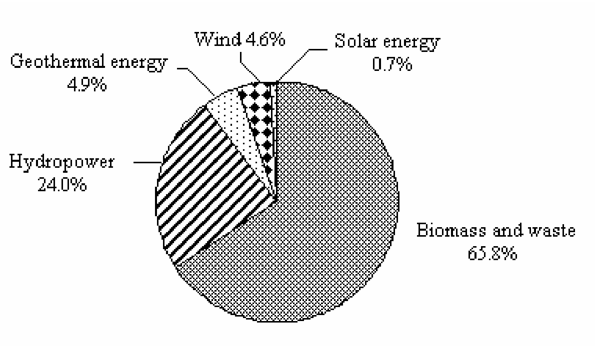

Fig. 4. Primary production of renewable energy in European Union (2004, % of total, based on 1000 tonnes of oil equivalent) (Eurostat, 2007)

Biomass is the biggest contributor (65%) to renewable energy sources, which represented 6% from energy consumption in 2002 (EIA, 2003; EUROSTAT, 2007; Parikka, 2006) (Fig. 5). Energy from biomass already contributes to about 4% of the total EU energy supply, for the most part in heat, and to a minor extent, in combined heat and power (CHP) applications (Parikka, 2006) (Fig. 5). Biomass is expected to cover as much as 8% of the total EU energy supply in 2010 (Parikka, 2006).

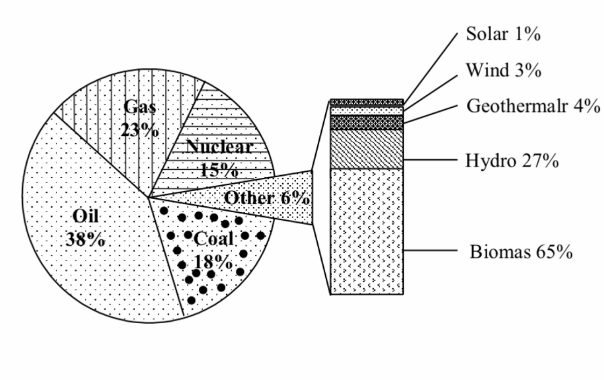

Fig. 5. Structure of energy consumption in European Union state members in 2002 (EIA, 2003; Eurostat, 2007)

Also, the share of electricity generated in EU from renewable sources relative to gross national electricity consumption was situated at almost 14% in 2004, but several of the Member States showed much higher ratios (Austria: 59 %, Sweden: 46 %) (EUROSTAT, 2007). However, the weight of biomass and waste in the primary production of production of renewable energy is not too high, comparative with that of wind, for example (Fig. 6) (EUROSTAT, 2007).

Some 40 to 50 exajoules (EJ = 10^{18} joules) per year of biomass is used for energy today out of some 400 EJ per year of total global energy use (Kartha and Larson, 2000). In order to compare various scales of using biomass as a renewable resource, some data are given in Table 3 (http://lib.kier.re.kr/common/tech/tech017/bio05.pdf).

As is suggested by the data from Table 3, biomass power became very important. It is appraised that biomass is the second-largest renewable source of electricity after hydropower, providing the baseload power to utilities. Various energy scenarios simulate high share of biomass energy in the future energy mixture.

Several scenarios of energy evolution worldwide indicate that biomass has the potential to contribute 25%-50% of the present global energy, up to 2050 (Hall et al., 2000; Hoogwijk et al., 2003). Shell International Petroleum Co. scenario calculations (1994-1996) indicate certain conditions in which new biomass sources could contribute 45%-50%.

Hoogwijk et al., (2003) studied the potential availability of primary biomass for energy and found that it is influenced by:

1) the demand for food as a function of population and diet consumed;

2) the food production system that can be adopted worldwide, taken into account the water and nutrient availability;

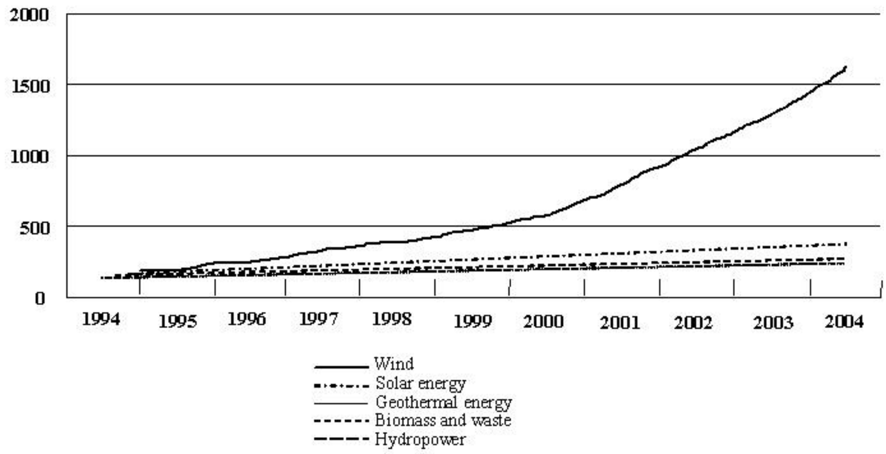

Fig. 6. The weight of different renewable energy sources in the total production of renewable energy in EU countries (1994 is the basis of reference, based on tones of oil equivalent) (Eurostat, 2007)

3) productivity of forest and energy crops;
4) other competing options for land-use like for nature development.

Biomass utilization in developing countries contrasts severely with biomass use in developed countries, where fuelwood and charcoal remain the dominant energy source for most households (IBEP, 2006; Kammen et al., 2003). Wood energy is also becoming an increasingly important industrial energy option in the industrialized countries of Western Europe, Asia and the Pacific and North America, as it is based on locally available, renewable and environmentally friendly raw material (IBEP, 2006).

Table 3. Energy equivalent of various energy resources worldwide

Source	***Energy equivalent (exajoule, EJ) (1EJ = 10^{18} joules)***
All cereals worldwide	31.3
All merchantable boles	14.3
Fuel wood and charcoal used primarily in developing countries	15.3
Usable portion of the current biomass	60.9

In a report of UNEP it is shown that, on average, biomass accounts for 3 or 4 percent of total energy use in the poor areas, although in countries with policies that support biomass use (e.g., Sweden, Finland, and Austria), the biomass contribution reaches 15 to 20 percent (Kartha and Larson, 2000). Most biomass in industrialized countries is converted into electricity and process heat in cogeneration systems (combined heat and power production) at industrial sites or at municipal district heating facilities (http://socrates.berkeley.edu/~kammen/er120/ER120_L3-BiomassEnergy_for_web.pdf).

3. Conversion of biomass into energy

Biomass energy has the potential to be *modernized* worldwide, i.e., produced and converted efficiently and cost-competitively into more convenient forms such as gases, liquids, or electricity (IBEP, 2006; Larson and Katha, 2000). Modern biomass now represents only 3% of primary energy consumption in industrialized countries, and this value has remained steady over recent years. However, much of the rural population in developing countries, which represents about 50% of the world's population are reliant on traditional biomass, mainly in the form of wood for fuel.

Traditional biomass accounts for 35% of primary energy consumption in developing countries, raising the world total to 14% of primary energy consumption (http://www.rise.org.au/info/Res/biomass/index.html

Biomass power is an important alternative for providing energy in the rural sector. The inherent advantages in utilization of biomass are that employment opportunities are created even for cultivation, collection, transportation and storage of biomass.

In evaluating biomass energy chains, it is clear that simple cost-benefit analysis does not capture a range of 'external' costs and benefits that arise from the supply of energy services. Fig. 7 provides a schematic representation of biomass fuel chains (Bauen et al., 2004).

The technologies for biomass conversion mainly consist in: direct combustion processes, thermochemical processes, biochemical processes and agrochemical processes (Demirbas, 2001; IBEP, 2006).

EPA (2007) classifies technologies for biomass conversion into inert gases and organic oils, gases, and fuels that can be further used to yield desired energy products as follows:

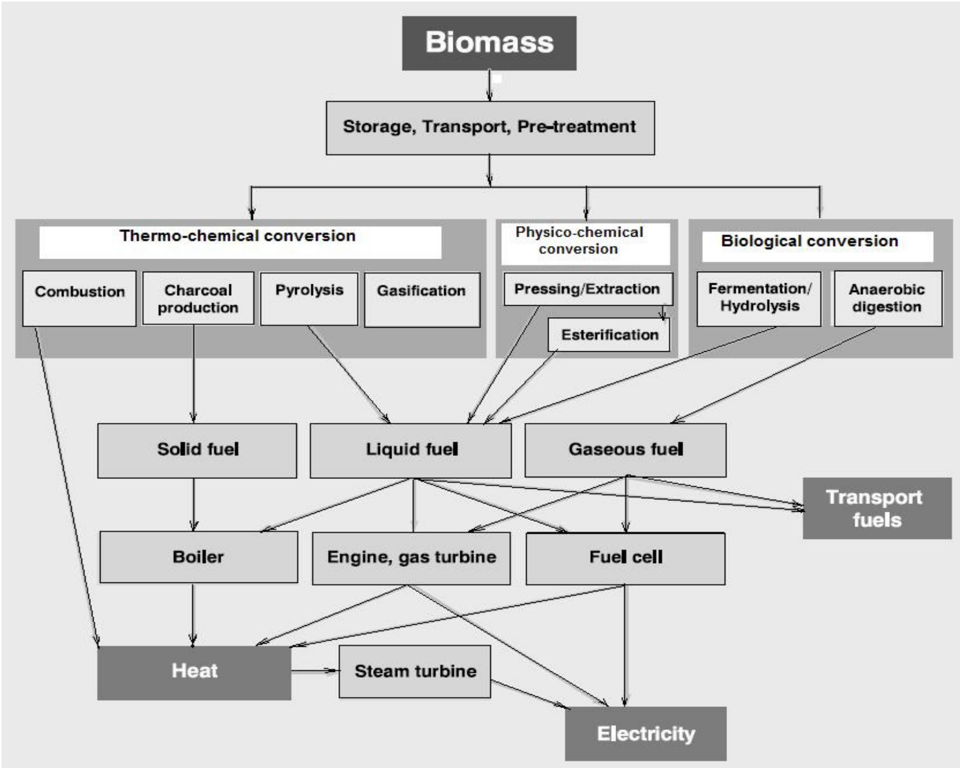

Fig. 7. The chains of biomass fuel (Bauen et al., 2004).

- **thermochemical technologies:** biomass feedstocks is converted using high temperatures to energy, typically in the form of electricity and heat. However, the technologies have the potential to produce electricity, heat, bioproducts, and fuels;
- **biochemical technologies:** biological agents convert biomass to energy (liquid and gaseous fuels).
- **chemical technologies:** chemical agents are used to convert biomass feedstocks to energy, typically in the form of liquid fuels.

These three biomass conversion technologies may also produce byproducts that can be valuable biobased products (EPA, 2007). Table 4 lists a variety of technologies, which can convert solid biomass into clean, convenient energy carriers (Demirbas, 2001; Kaltschmitt and Weber M., 2006; http://www.esmeet.org/journal3.html).

Most of these technologies are already in commercial use, although some more than others. Each technology description - gasification, anaerobic digestion, ethanol, steam turbine, and gas turbine - includes a general discussion of key technical issues that must be addressed in any project involving these technologies. It also includes more detailed technical discussion of basic operating principles, feedstock and other material input requirements, operating and maintenance issues, capital and operating costs, environmental issues, and other factors.

Table 4. Some actual technologies for conversion of biomass in energy (Demirbas, 2001)

Technology	***Scale***	***Energy services provided***
Biogas	Small	- Electricity (local pumping, mining, lighting, communication, refrigeration, etc. and possible distribution via utility grid) - Cooking - Heating
Producer gas	Small to medium	- Electricity (local pumping, mining, lighting, communication, refrigeration, etc. and possible distribution via utility grid) - Cooking - Heating
Ethanol	Medium to large	- Vehicle transportation - Cooking
Steam turbine	Medium to large	- Electricity (for industrial processing and grid distribution) - Heating process heat
Gas turbine	Medium to large	- Electricity (for industrial processing and grid distribution) - Heating process heat

The research and development of the new technology of biomass energy, such as the research of highly efficient and low cost conversion and application of biomass energy, the making of liquefied oils at normal pressure by fast liquefaction, the research of the technology of catalytic chemical transformation and equipment for the transformation of biomass energy as well as fluidized gasification techniques are the focuses of research.

4. Biofuels from biomass

Biomass fuels in their unprocessed form comprise wood, straw, animal dung, vegetable matter, agricultural waste, while processed biomass includes methane, charcoal, sawdust and alcohol produced from fermentation processes. In developing countries they can account for 35%, on average, of primary energy needs, while in some other areas, this rises to as much as 90% with marked effect on the environment (http://www.scienceinafrica.co.za/2006/june/biomass.htm; IBEP, 2006).

Using biomass to generate heat or to drive steam engines is not new. But old-fashioned methods of burning wood, field residues, or waste were not environmentally sound because they emitted polluting smoke and volatile organic compounds into the air (Bauen et al., 2004; DOE, 2000). Today, scientists and engineers use improved processes to develop several new methods that cleanly and efficiently convert biomass to electricity. One new method uses biomass to replace a portion of the coal used to fuel a power plant through cofiring.

The cost of biomass fuel supply depends on the cost of producing or recovering the ‘feedstock’ – raw materials – and those incurred during its transport and pre-processing prior to use in a power plant.

4.1. Biogas

Biogas can provide a clean, easily controlled source of renewable energy from organic waste materials replacing firewood or fossil fuels.

Biogas primary energy production grew from virtually zero in 1992 to surpass renewable municipal wastes in 2002. Electricity production from biogas grew from an estimated 5,000 GWh in 1990 to 13,617 GWh in 2001 (IEA, 2007). While in the early 1990’s, nearly the entire amount of biogas electricity was produced in the United States, the largest proportion of this production has moved to OECD Europe, which contributes 58.1% of biogas electricity today. Therefore, most production takes place in the member countries of the European Union. The largest producer in the European Union is the United Kingdom, which provided 2,870 GWh of biogas electricity in 2001. While the United States, with 4,860 GWh, remains the largest individual producer, its growth of 5.4% per annum since 1992 has been much slower than that of many European Union countries. Germany has an average annual growth rate of 22.7% (reaching 1986 GWh in 2001), Italy of 55.3% (684 GWh) and France of 19.8% (601 GWh) since 1992. Most of the growth in the biogas segment has taken place in the late 1990s and early 2000s, and continued strong growth is expected for the near future.

4.2. Liquid biofuels

Liquid biofuels have gained importance in the last decades in Latin America, and more recently in Europe and other countries of the Organisation for Economic Co-operation and Development (OECD), particularly in the transport sector (IBEP, 2006).

In the late 1990s and early 2000s, liquid biofuels grew in European Union from 7TJ in 1990 to almost 7,400TJ in 2002 (http://www.greenjobs.com/Public/info/industry_background.aspx?id=13). Today, biomass is the only available renewable energy source that can produce competitive fuels for transport in larger quantities (Parikka, 2006). The biomass resources considered as well as their classification based on fuel quality and conversion technology are presented in Table 5 (Nikolaou et al., 2003).

Liquid biofuels cover biogasoline and biodiesels:

Biogasoline: this category includes bioethanol (ethanol produced from biomass and/or the biodegradable fraction of waste), biomethanol (methanol produced from biomass and/or the biodegradable fraction of waste), bioETBE (ethyltertio-butyl-ether produced on the basis of bioethanol: the percentage by volume of bioETBE that is calculated as biofuel is 47%) and bioMTBE (methyl-tertio-butyl-ether produced on the basis of biomethanol: the percentage by volume of bioMTBE that is calculated as biofuel is 36 %).

Liquid biofuels cover biogasoline and biodiesels:

Biogasoline: this category includes bioethanol (ethanol produced from biomass and/or the biodegradable fraction of waste), biomethanol (methanol produced from biomass and/or the biodegradable fraction of waste), bioETBE (ethyltertio-butyl-ether produced on the basis of bioethanol: the percentage by volume of bioETBE that is calculated as biofuel is 47%) and bioMTBE (methyl-tertio-butyl-ether produced on the basis of biomethanol: the percentage by volume of bioMTBE that is calculated as biofuel is 36 %).

Biodiesels: this category includes biodiesel (a methyl-ester produced from vegetable or animal oil, of diesel quality), biodimethylether (dimethylether produced from biomass), Fischer Tropsch (Fischer Tropsch produced from biomass), cold pressed bio-oil (oil produced from oil seed through mechanical processing only) and all other liquid biofuels which are added to, blended with or used straight as transport diesel.

Table 5. Classification of the biomass fuel resources under study (Nikolaou et al., 2003).

Sector	***Resource***	***Fuel category***	***Fuel quality (indicative)***		***Conversion technology***
			Moisture content (% wet basis)	***Ash content (% dry basis)***	
Agriculture	Agricultural residues	Dry lignocellulosic (e.g. straw, pruning)	30-50	2.2-17	Combustion, gasification, liquefaction
	Livestock waste	Wet cellulosic	74-92.1	27.1-35.4	digestion
		Dry lignocellulosic (e.g. poultry litter)	75	17.5-28	Combustion, gasification, liquefaction
	Energy crops	Dry lignocellulosic	12.5-50	0.3-8.4	Combustion, gasification, liquefaction
		Oil seeds for methylesters	na	<0.02	Extraction
		Sugar/starch crops for ethanol	na	<0.02	Fermentation
Forestry	Wood fuel	Dry lignocellulosic	46.7	0.4-5	Combustion, gasification, liquefaction
	Forest residues	Dry lignocellulosic	46.7	3.2	Combustion, gasification, liquefaction
Industry	Industrial residues	Dry lignocellulosic	10-30	0.71-18.34	Combustion, gasification, liquefaction
		Wet cellulosic	80-99	3.8-5.9	digestion
		Black liquor	90	36.4	combustion
Waste	Regulated waste	Municipal waste	30	36	combustion
		Demolition wood	30-40	0.58	combustion
	Non- regulated waste	Landfill waste	30	36	Digestion
		Sewage sludge	72.8	26.4	digestion
Parks and gardens	Urban wood	Dry lignocellulosic	35	39.4	Combustion, gasification, liquefaction
	Cut grass	Wet cellulosic	75-80	8.4	digestion

Liquid biofuels grew from 7TJ in 1990 to almost 7400TJ in 2002 and represented about 1.5% in total fuel consumption for transport (Germany, in 2004) (Fig. 8, Eurostat, 2007). The price range is dependent upon plant scale and efficiency factors. Also, the price of biofuels is dependent on the source (Fig. 9). The average price for biofuels in Europe varies between 1.0 €/GJ (recovered wood) to 8.4 €/GJ (densified biofuels).

5. Renewable electricity from biomass

Electricity generation from biomass fuels currently uses the same basic technology used in power plants that burn solid fossil fuels. However, new technologies are being developed to improve power production efficiency from biomass.

The electricity directive (2001/77/EC) defines renewable electricity as the share of electricity produced from renewable energy sources in gross electricity consumption (http://themes.eea.europa.eu/Sectors_and_activities/energy/indicators/EN30,2007.04).

Worldwide, electricity production benefited during the last decade from the rise in importance of new renewable electricity production industrial sectors (wind power, biomass, geothermal energy and solar energy).

While they only represented 11% of renewable electricity in 2006, these sectors (new by their degree of industrialization) have contributed 29.3% of the increase in renewable electricity production between 1996 and 2006 (228.5 TWh out of a total of 779.6 TWh). Their share in total electricity production gained 0.9 points between 1996 and 2006 (from 1.2% to 2.1%), while that of hydraulic power lost 2.3 points (from 18.9% to 16.6%). The share of renewable energy in EU-25 electricity consumption grew only slightly over the period 1990-2004 to reach 13.7%, despite a substantial increase in the total amount of renewable electricity generation (up by 49 % since 1990) (Fig. 10).

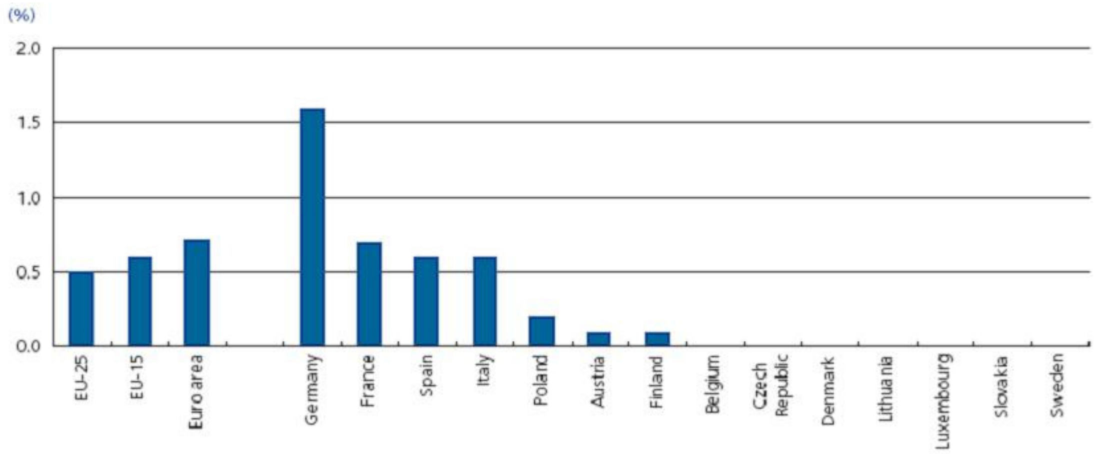

Fig. 8. Share of biofuels in total fuel consumption for transport in 2004

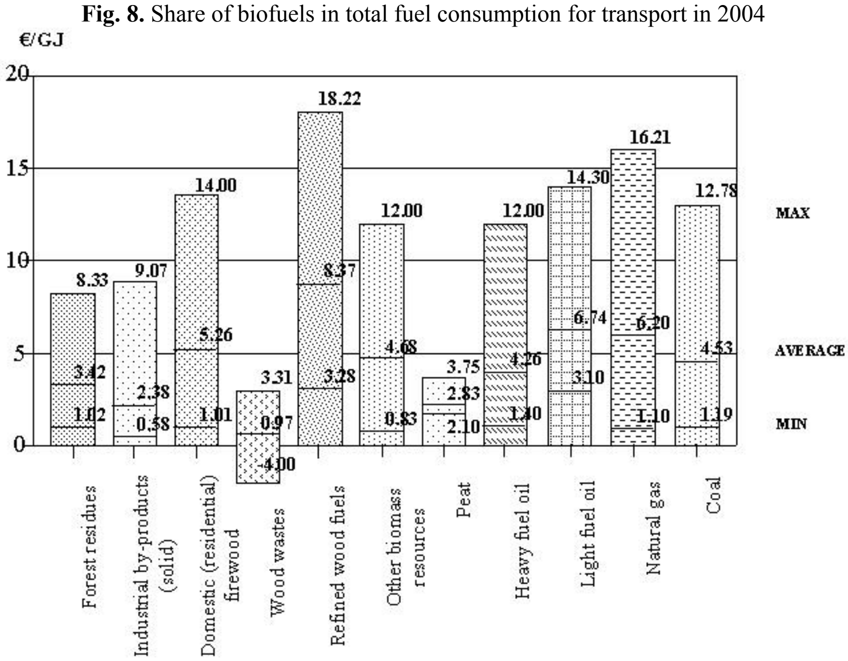

Fig. 9. Average price for biofuels in Europe (Eurostat, 2007)

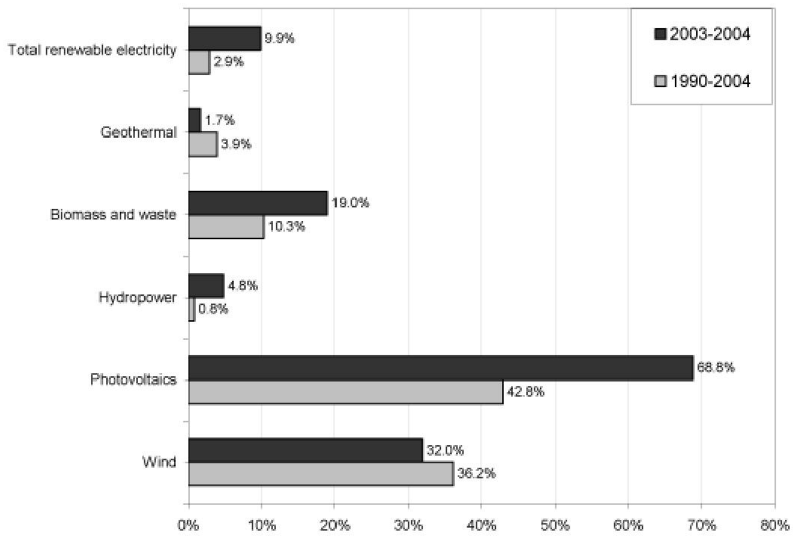

Fig. 10. Renewable electricity as a percentage of gross electricity consumption, 2004

In 2001 about 33,379 GWh of electricity were produced from renewable solid waste in the OECD. By far the largest producer of electricity from renewable municipal solid waste is the United States, generating 16,818 GWh, or 50.4% of OECD production. The second largest producer is Japan, with a production of 5,338 GWh. With 2,044 GWh, Germany represents the third largest producer. The remaining electricity production from renewable municipal solid waste is spread among smaller producers in OECD Europe. Denmark and Italy experienced the highest growth rates, increasing their production from 47 GWh to 1,068 GWh (at 32.8% per year) and from 71 GWh to 1,258 GWh (at 29.9% per year) respectively between 1990 and 2001 (IEA, 2002).

Bauen et al. (2004) estimated that bioelectricity, excluding municipal solid waste to electricity, today represents a very small fraction of world electricity production, about 30 GW representing about 1 % of installed capacity, but has a very strong potential for growth. Its growth will be driven by the need to increase the use of renewable energy sources for electricity production to ensure sustainable production of electricity.

By factoring in the pollution-related environmental and social costs generated by fossil and nuclear fuels, bioelectricity became a very competitive energy source.

6. Impacts of biomass conversion to energy

6.1. Overall environmental impacts

Biomass provides a clean, renewable energy source that could dramatically improve the environment, economy and energy security. The use of biomass for energy has effects on all the environmental media i.e. soil, water and air. In addition, these effects may have impacts on human and animal health and welfare, soil quality, water use, biodiversity and public amenity. These impacts arise from each of the individual stages of the biomass energy fuel chains (Bauen et al., 2004; http://www.fvm.dk/Environmental_impacts.aspx?ID=19789).

Although there is a large body of research in this area, the environmental costs and benefits associated with bioenergy can be difficult to assess because of the complexity of the production systems. One technique which has been used extensively in the literature to compare the energy and greenhouse gases balances of bioenergy chains is life cycle assessment (LCA), an internationally recognised technique for evaluating the natural resource requirements and environmental impacts from the whole process and materials involved in the manufacture of a product or service (Rowe, 2008).

Several studies examined the life-cycle impact of bioenergy for power (Carpentieri et al., 2005; Heller et al., 2004; Rowe et al., 2008). That is, the studies examined the air, land and water impacts of every step of the bioenergy process, from cultivating, collecting, and transporting biomass to converting it to energy (http://www.azocleantech.com/Details.asp?ArticleId=87).

Fig. 11 provides a diagram which indicates some of the process steps that should be included in LCA calculation, the emissions or energy requirement associated with each process step (Rowe et al., 2008). In addition, very different impacts are likely to arise depending on which category of biomass feedstock is used and which technologies are used to convert the biomass to useful energy. Contamination with non-biomass or modified biomass streams also represents a particular problem as, even in very small quantities; these contaminants can lead to measurable toxic emissions and health hazards. The production of bioenergy on the basis of residual products such as straw, slurry, animal fat, grass and perennial crops provides a better energy balance and environmental effect when used in direct combustion, biogas or thermal gasification.

The development of biomass resources and the conservation of biodiversity and local environments can go hand in hand. The biomass production has several environmental advantages, including: substituting fossil fuel use with a CO_2-neutral alternative; reducing emissions of other atmospheric pollutants, such as sulphur; protecting soil and watersheds; increasing or maintaining biodiversity: and reducing fire risk in forestry (Bauen et al., 2004).

Biomass energy systems have a wide range of potential socioeconomic and environmental impacts—both positive and negative. Such impacts are often treated as only "secondary" effects in the planning and implementation of energy projects, even though they can greatly influence whether a project is appropriate and sustainable in the local context.

Biomass energy generates far less air emissions than fossil fuels, reduces the amount of waste sent to landfills. Energy derived from biomass results is potentially greenhouse neutral, because the carbon dioxide released by combustion was taken out of the atmosphere as the biomass grew. Carbon dioxide emissions could be cut by around 1,000 megatonnes per year, if OECD countries used biomass - fuel generated from agriculture and forest products - instead of coal to generate electricity (Bauen et al., 2004; Perlack et al., 2005).

Biodiesel, produced from vegetable oil, can substitute for fossil-diesel in transport and heating and electricity generation.

Biofuels such as biodiesel, ethanol and methanol, can be a greenhouse-neutral, renewable energy source for use in transport vehicles, stationary engines, and small electricity generators.

Biomass electricity is potentially greenhouse neutral if produced from biomass such as plantation fuel-wood.

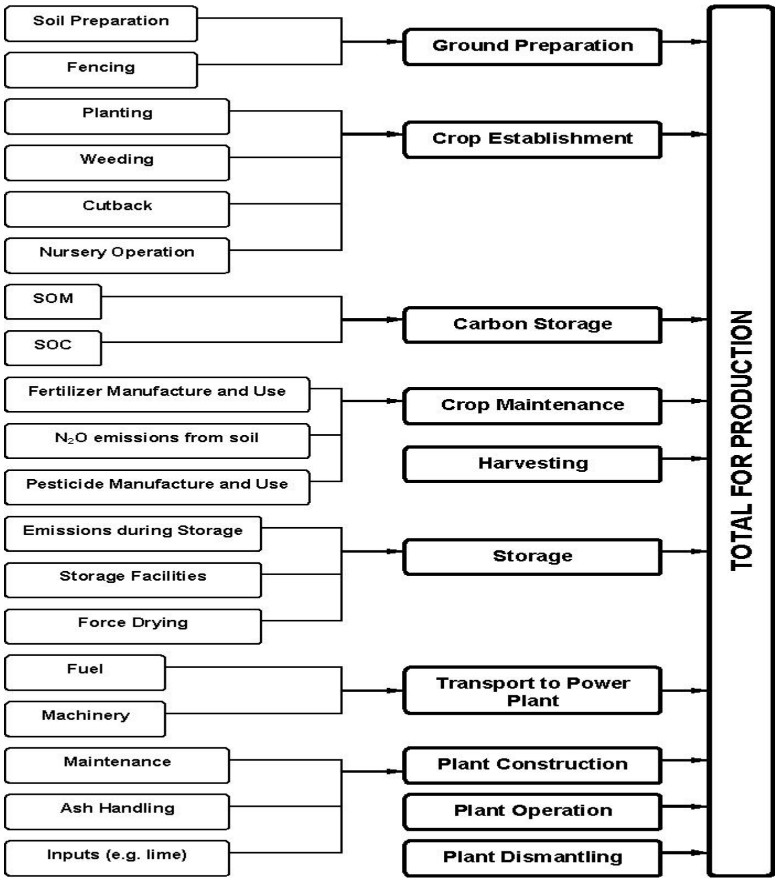

Fig. 11. Diagram of emissions breakdown for heat and power production, necessary for each bioenergy chain (Rowe et al., 2008)

Modernized bioenergy systems have environmental impacts associated both with the growing of the biomass and with its conversion to modern energy carriers. Significant impact is expected from bioenergy with respect to mitigation of climate change, development of rural areas and employment options as well as the provision of alternative energy forms.

However, the environmental impact induced by using biomass as a source of fuel varies according to the type of conversion technology.

6.2. Impact on soil

Environmental impacts of biomass production must be viewed in comparison to the likely alternative land-use activities. For example, at the local or regional level, the relative impacts of producing bioenergy feedstocks depends not only on how the biomass is produced, but also on how the land would have been used otherwise.

Biomass crops pose a particular challenge for good soil management because the plant material is often completely harvested, leaving little organic matter or plant nutrients for recycling back into the soil (Kartha, 2006). Increasing the production of biomass involves a risk of growing pressure on biodiversity and of increased leaching of nutrients unless there is sufficiently effective environmental regulation of this, for example in the form of demands for extensive land cultivation (Bauen et al., 2004).

The use of perennial crops, where they replace annual crops, will result in reduced oil disturbance, greater soil cover and hence lower erosion, improved soil organic matter and soil carbon levels and increased biodiversity, particularly where the change results in a decreased application of inputs (fertilizers and pesticides) (Bauen et al., 2004).

Also, plants can selectively and actively absorb toxins, including heavy metals and ash recycling could cause such toxins to be concentrated in the bioenergy plantation's soils. This characteristic of certain plant species to selectively absorb toxins is sometimes used to rehabilitate polluted soils in a process known as phytoremediation.

Sometimes, the feedstock's nutrient content can be recovered from the conversion facility in the form of ash or sludge and then converted into a form that can be applied to the field rather than put in a landfill, so that the nutritive value of the ash or sludge is less than optimal (Kartha, 2006).

Soil organic matter and nutrient levels have to be maintained or even improved where bioenergy production is to be based on exploiting agricultural and forestry residues. In many cases, farmers can reduce the risk of nutrient depletion by allowing the most nutrient-rich parts of the plant—small branches, twigs, and leaves—to decompose on the field. Also, monitoring may be required to ensure that.

6.3. Impact on water

The assessment of direct environmental impacts of energy from biomass for energy for water mainly envisages the following aspects (Bauen et al., 2004; Moret et al., 2006): absolute and relative consumption; reuse (consumption/unit produced); discharge of effluents and infiltration; monitoring of contamination by fertilizers, herbicides and insecticides; turbidity; eutrophication; suspended solid particles; environmental suitability of technology used to extract water; use of best available irrigation practices; groundwater depletion; restoration of groundwater etc.

The use of perennial crops and no-till buffer zones along water courses is already being actively considered as a cost effective method for reducing chemical and biological oxygen demand (COD and BOD) levels in agricultural water courses.

There may also be negative impacts from the introduction of energy crops on local and regional hydrology, because a significant increase in the interception and use of rainfall could result from a wide spread implementation, with potentially substantial reductions in rainfall infiltration and negative impacts of aquifers in the region (Bauen et al., 2004; Lyons et al., 2001). Certain practices, like harvesting residues, cultivating tree crops without undergrowth, and planting species that do not generate adequate amounts or types of litter, can reduce the ability of rainfall to infiltrate the soil and restock groundwater supplies, intensifying problems of water overconsumption (Kartha, 2006).

6.4. Impact on atmosphere

The contribution that biomass could make to the energy sector is still considerable, since it creates less carbon dioxide than its fossil-fuel counterpart.

The utilization of biomass is often presented as a key strategy for reducing greenhouse gases (GHG) emissions from electricity generation and transport. Using biomass potentially provides low carbon transport fuel, heat and power, as biomass crops assimilate carbon from the atmosphere during growth. Therefore, the carbon released back to the atmosphere when the biomass is combusted is that which has been recently captured and should not raise atmospheric concentrations.

Burning biomass will not solve the currently unbalanced carbon dioxide problem. Conceptually, the carbon dioxide produced by biomass when it is burned will be sequestered evenly by plants growing to replace the fuel. In other words, it is a closed cycle which results in net zero impact (http://www.azocleantech.com/Details.asp?ArticleId=87).

Some studies found that biomass gasification with combined-cycle power plant technology would release far less SO_2, NO_x, CO_2, particulate matter, methane and carbon monoxide than coal power plants (ABA, 2005; Perlack et al., 2005; REPP, 2006;).

7. Bioenergy and sustainable development

7.1. Biomass energy systems and linkages to sustainable human development

The progress of any nation today is measured in terms of its efforts towards the achievement of the Millennium Development Goals (MDGs). Many factors converge in making bioenergy a key component and a viable opportunity in the great effort towards the achievement of the Millennium Development Goals (MDGs). Although the sustainable access to energy is not treated as a priority in itself in the MDGs, most of them have a direct energy implication, particularly Goal 1 (*Eradicate extreme poverty and hunger*) and Goal 7 (*Ensure environmental sustainability*) (FAO, 2005).According to the WSSD Johannesburg Declaration, energy must be considered a human need on a par with other basic human needs (clean water, sanitation, shelter, health care, food security and biodiversity) (ESC, 2007; IBEP, 2006)

The assessment of the sustainability of energy supply from firewood and other forms of plant biomass has changed greatly since the problems of a strong dependency on fossil energy carriers have come to the forefront (IAEA, 2005; Otto, 2007; Sheehan, 2004; Sims, 2003). Fig. 12 provides a conceptual representation of bioenergy systems, as addressed by United Nations Development Programme, in the context of sustainable human development (Kartha and Larson, 2000).

The socio-economic and environmental benefits of bioenergy projects are accepted by planners and operators of development programmes in forestry, agriculture and energy domains (http://www.spatial.baltic.net/_files/Planning_indicators.pdf). Also they are recognizing and are now seeing bioenergy as a way to reduce poverty and improve livelihoods in rural areas, overcoming the negative perception of bioenergy as a key symptom of under-development or an environmental hazard. Bioenergy projects contribute to the eradication of extreme poverty and to ensure environmental sustainability in several aspects highlighted in Table 6 (FAO, 2005).

7.2. Sustainable biomass use for energy

Concerns about potential negative effects of large-scale biomass production and export, like deforestation or the competition between food and biomass production, have led to the demand for sustainability criteria and certification systems that can control biomass trade (IAEA, 2005; Lewandowski and Faaij, 2006; Sheehan, 2004).

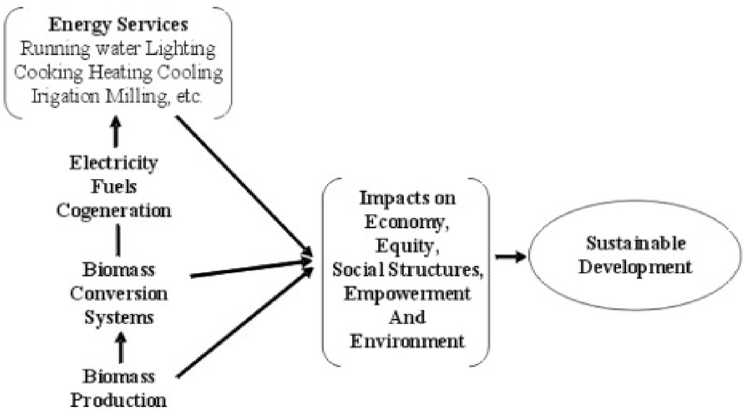

Fig. 12. Conceptual representation of biomass energy systems and linkages to sustainable human development

Table 6. Contributions of bioenergy to sustainability (FAO, 2005)

Sustainability component	*How does bioenergy contribute to MDG achievement*
Economics	- save external currencies through the substitution of imported fossil fuels - leads to improved economic development and poverty alleviation, especially in rural areas by increasing the use of biomass for energy (from sustainable resource management) - provide greater diversification and income opportunities for agriculture, agro-industries and forestry - increase the access of small rural industries to energy services - enhance the value of rural resources, encouraging private and public sector participation and investments - boost national energy security and reduce the oil import bill
Social development	- increase both access to and reliability of energy services for households in rural areas, thus improving the quality of life stimulate governance options, equity and gender equality, especially in view of women's central role in household energy management - attracts investments towards rural areas, generating new business opportunities for small-and medium-sized enterprises in biofuel production, preparation, transportation, trade and use, and generates incomes (and jobs) for the people living in and around these areas - bioelectricity production has the highest employment-creation potential among renewable energy options - bioenergy can be a lever for rural development and regeneration in areas where investment is most needed and the creation of jobs is most difficult - indicators of social accountability include participation of representatives of socio-environmental organizations; participation of the communities as decision-makers and not only being consulted; the degree of inclusion of the local population in the project design, and knowledge of the proposal and the alternatives.
Environment	reduced indoor air pollution from wood energy combustion in poor households associated to the characteristics of cooking devices with positive impacts resource conservation and ecosystem rehabilitation (through sustainable biomass production in marginal lands reduced CO_2 emissions by using cleaner fuels, such as ethanol and biodiesel

To ensure that biomass as a source of renewable sustainable energy will be produced and processed in a responsible manner, some sustainability criteria have to be incorporated into the relevant policy instruments.

Chapter 40 of Agenda 21 calls for the development of indicators for sustainable development. In particular, it requests countries at the national level, and international governmental and non-governmental organizations at the international level to develop the concept of indicators of sustainable development in order to identify such indicators. Minimum criteria for bioenergy sustainability envisage the following *aspects* (Cramer, 2006; Sheehan, 2004):

- comply with present international obligations and local jurisdiction, in addition to other specific indicators.
- comply with specific indicators and active conservation.

Some criteria and indicators of sustainability for the generation of renewable energy from biomass discussed within the Energy Working Group of FBOMS, in an attempt to contextualize and deepen the national and international debate about future initiatives, in a participatory and engaged manner are presented in Table 7. It synthesizes both the general criteria – basic criteria applicable to any type of initiative - and specific criteria - for projects that involve the use of bioenergy (Moret et al., 2006).

Table 7. Criteria and indicators for sustainability (Moret et al., 2006).

Criteria	*Desirable and Prerequisites*	*Indicators*
Economic		
Use of bioenergy	Creating more efficient transport systems Promotion of energy efficiency	Rates of reduction of consumption Increased end-use conservation Capacity for reduction, reuse and recycling of inputs in the final activities for which the energy is destined Inclusion of demand management in the project planning horizon
Technology	Decentralized generation and production Technology appropriation by local population New technology capable of reducing pressure of energy production on ecosystems Horizontal transfer of technologies and knowledge Contribution to diversification of energy matrix	Relation between local workers and outsiders involved in project maintenance Application of clean technologies Technological innovation Capacity of reproduction of technology used Origin of equipment Existence of technology licences Need for international technical support Changes in use of sustainable energy, cogeneration
Organization of production/labor relations	Cooperatives Family agriculture	Sharing of profits from biofuels production chain by family farmers Level of satisfaction with existing contracts
Financing	Credits, access to land	Programs and lines of credit Conditions for government financing
Social		
Social accountability	Information and capacity building	Participation of local population and national socio-environmental organizations in projects design
Participation in decision making	Information and training, political forums for participation with real influence over decisions	Number, sites, nature and types of consultations, form of publicity, access to information, language and accessibility of material used
Type of management	Training for management	Organizational structures and forms of decision-making, number of participants/decision makers, involvement of organizations representing local workers, participation of women
Job creation and income generation	Training for creation of cooperatives, awareness and training of families with technical and political information	Number of jobs per unit of energy (production chain, implementation and operation), profit sharing, generation of new local opportunities and sources of income, relation between local jobs before and after the project, indexes of increase in acquisitive power of the local population

Social inclusion	Sharing of project benefits with local population	Number of families previously without access to energy who benefit from the project Measures of quality and compliance with accepted standards of the involuntary resettlements, when necessary and accepted Impact on quality life of the communities Social programmes, especially for health and education Epidemiological assessment and monitoring Contribution to access to services and infrastructure on the part of local populations to education, energy, waste and sewage services
Gender equality	Recognition of women and key actors in all stages of decision-making processes Education	Existence of programs and policies for women and youth
Environment		
Environmental management	Use of best available practices Diversity of crops Agroforestry systems Agroecology Minimizationor elimination of pesticide use Reduction of soil loss Training of producers	Monoculturea area Soil loss Atmospheric emissions and effluents into water bodies
Land use	Comply with economic/ecological zoning Regions classified as suitable by strategic environmental assessment Defined limits for occupation of biomass Diversification and decentralization of economic activities Protection of natural areas	Decentralization and diversification of production system in an area/region Sizes of continuous areas of monocultures Distance from energy source to consumer Distance traveled and time spent by workers to project area Time necessary to manage crops

Otto (2007) retains a set of internationally agreed criteria, such as:

- wide acceptance to avoid shifting the problem from one area to another
- ease of reference
- cost
- international trade
- complemented by regional/national protocols
- taking into account specificities

Lewandowski and Faaij (2006) have analyzed existing certification systems, sets of sustainability criteria or guidelines on environmental or social sound management of resources with the purpose to learn about the requirements, contents and organizational set ups of a certification system for sustainable biomass trade, by covering the following successive steps:

- first, an inventory of existing systems was made;
- second, their structures were analyzed and key finding from the analysis of internationally applied certification systems were summarized;
- third and fourth steps: different approaches to formulate standards were described and a list of more than 100 social, economic, ecological and general criteria for sustainable biomass trade was extracted from the reviewed systems;
- fifth, methods to formulate indicators, that make sustainability criteria measurable, and verifiers that are used to control the performance of indicators are described.

The Project Group established by Dutch government (IPM, 2007) has formulated sustainability criteria for the production and the processing of biomass in energy, fuels and chemistry. The project group distinguishes six relevant themes concerning bioenergy sustainability:

- *greenhouse gas emissions* (calculated over the whole chain, the use of biomass must produce fewer emissions of greenhouse gases net than on average with fossil fuel)
- *competition with food and other local applications* (the production of biomass for energy must not endanger the food supply and other local applications (such as for medicines or building materials)
- *biodiversity* (biomass production must not affect protected or vulnerable biodiversity and will, where possible, have to strengthen biodiversity)
- *environment* (biomass production must not affect protected or vulnerable biodiversity and will, where possible, have to strengthen biodiversity)

- *prosperity* (the production of biomass must contribute towards local prosperity)
- *social well-being* (the production of biomass must contribute towards the social well-being of the employees and the local population).

8. Rural areas and bioenergy

Using biomass, such as energy crops, crop processing waste, and agricultural residues, to produce energy is beneficial for the nation, especially rural areas: job creation, rural development and development of local economies through the use of bioenergy (Domac, 2002; Hillring, 2002; Plieninger et al., 2006; Sims, 2003).

Rural areas can better serve as indicator for measuring any progress made towards achieving MDGs. Increasing the use of biomass for energy (from sustainable resource management) leads to improved economic development, and poverty alleviation, especially in rural areas.

The OECD definition, taking into account population density at the local level, considers as rural those local government units with less than 150 inhabitants/km^2. Then it identifies three categories of regions (NUTS3 or NUTS2 level): mostly rural (more than 50% of the population in rural communities), intermediate (between 15 and 50% of the population in rural communities) and mostly urban (less than 15% of the population in rural communities).

The new philosophy of rural area development is based upon the concept of sustainable rural development, which presupposes the harmonious blending of the agricultural (and forestry) component and the non-agricultural rural economy component, based upon the following principles (Otiman, 2008):

- harmony between the rural economy and the environment (economy – ecology equilibrium);
- sustainable development programs should have in view a medium and long term time horizon;
- rural area naturalization, by preserving the natural environment mostly intact;
- the anthropized, man-made environment, should be as close as possible to the natural environment;
- the use of local natural resources, mainly of renewable resources, in the rural economic activity;
- diversification of the agricultural economy structure through a large variety of activities such as the development of agri-food economy, non-agricultural economy and services.

The new European rural economy model focuses on sustainable development of the agricultural sector, which implies the natural environment protection, food security, competitiveness, accelerating the economic development of the rural space (Burja and Burja, 2008). Many rural areas are growing and experiencing increasing energy demand. Smaller facilities have fewer environmental impacts and can operate with locally produced biomass fuel. Using biomass delivers a triple benefit by keeping the wealth nearby, paying farmers to grow and harvest biomass feedstocks, and providing clean energy. The national benefits include lower sulfur emissions (which contribute to acid rain), reductions in greenhouse gas emissions, and less dependence on fossil fuels. Rural benefits feature new sources of income for farmers, more jobs, and economic development—all achieved while preserving the high quality of life, local control, and clean environment.

Bioenergy feedstocks can be produced in conjunction with other local necessities—food, fodder, fuelwood, construction materials, artisan materials, other agricultural crops, etc. Feedstock production can help restore the environment on which the poor depend for their livelihoods—re-vegetating barren land, protecting watersheds and harvesting rainwater (Møller, 2006; UNEP, 2006). Bioenergy activities also serve as an efficient use for agricultural residues, avoiding the pest, waste, and pollution problems of residue disposal (Kartha and Larson, 2000). For instance, bioenergy activities can provide locally produced energy sources to:

- pump water for drinking and irrigation,
- light homes, schools, and health clinics,
- improve communication and access to information,
- provide energy for local enterprises,
- ease pressure on fuel wood resources.

Potential benefits for rural areas encompass job creation, use of surplus agricultural land in industrialized countries, provision of modem energy carriers to rural communities in developing countries, waste control and nutrient recycling (Hall, 1997; Plieninger et al., 2006).

The rural area can carry out its supply, recreation and equilibrium functions, much desired by the society, only on the condition it remains an attractive and original living space, equipped with (http://ideas.repec.org/a/iag/reviea/v5y2008i1-2p4-18.html):

– a good infrastructure;
– a viable agricultural and forestry sector;
– local conditions favorable to non-agricultural economic activities;
– an intact environment with a well-cared landscape.

9. Biomass for energy in Romania

9.1. Romanian bioenergy background

Rural development is an essential topic, especially in those countries as Romania and all East European countries, where rural space and production is still a major part of whole economic structure (Naghiu et al., 2005). This can be considered an important way to revitalize declining areas and ensure them possibilities of achieving a sustainable future.

With an area of 238 thousand km^2 and a population of more than 21 million inhabitants, Romania is an important new EU member state in terms of size, although there is a large gap between this country and the old member states as far as the level of economic and social development is concerned. Rural areas play an important part in this respect, both by their size and residential, economic and recreational dimensions.

According to the national definition, rural areas in Romania cover 87.1% of the territory, and include 45.1% of the population (on 1 July 2005 indicators of National Statistical Institute), i.e. 9.7 million inhabitants.

Romania has got various particularities of the sustainable development in the farming sector, concerning poverty in the countryside, scarcity of productive technologies, practicing subsistence agriculture, excessively cutting of the farm land estate. In the same time, there are also some advantages concerning the old traditions of Romanian rural economy, which are based on the ecological technologies and the high productive potential of the agricultural lands (Burja and Burja, 2008).

Romania was one of the first countries to sign the Kyoto Protocol and thereby show its commitment to the fight against climate change by agreeing to reduce greenhouse gas emissions by 8% by 2012. It is now one of the leading new EU Member States in achieving this objective with a reduction of more than 30 % of gas emissions since 1989 (National Strategy, 2005).

The main sources of air pollution and greenhouse gas emissions in Romania are currently the energy producing industry (thermal energy based on the burning of coal and oil still accounts for about 60% of domestic power generation), transportation, and to a lesser extent, agriculture. Low level of mechanization in Romanian agriculture, in contrast with European average, together with small areas covered by greenhouses, are generating a low contribution to climate change. However, the old park of tractors and main agricultural machines, need to be renewed in order to keep a low level of emissions. Available EUROSTAT data indicates that the agricultural emissions of greenhouse gases in 2002 were over 11.02 million tonnes of CO_2 equivalence. Total emissions from agriculture in the EU-12 for the same period were 416.4 million tonnes of CO_2 equivalence.

Romania benefits from hydro-power generation, which combined with other modest sources of renewable energy, generate about 28.8 % of the domestic energy supply (10% is generated by nuclear power plants). Agriculture and forestry also have the potential to provide significant quantities of biomass, the energy potential of which is estimated to be approximately 7 594 000 equivalent oil tons per year. This includes residue from forest enterprises and firewood (15.5%), sawdust and other wood residue (6.4%), agricultural residues (63.2%), household waste (7.2%) and bio-gas (7.7%).

Biomass resources and delivery costs are presented in Table 8 (Nikolaou et al., 2003).

Table 8. Biomass resources supply, energy crops and delivery costs in Romania (Nikolaou et al., 2003)

Sector	*Resource*	*Fuel category*	*Curent use for energy 2000 (PJ/year)*	*Technical biomass potential 2000 (dry tons/year) [a]*	*Biomass not available for various reasons 2000 (dry tons/year) [b]*	*Available biomass (dry tons/year)= [a]-[b]*	*Available energy potential 2000 PJ/year*
BIOMASS RESOURCES SUPPLY							
	Dry agricultural residues	Dry lignocellulosic		7826000	0	4128000	73.304
	Livestock	Wet cellulosic		5735172	4427172	1308000	11.772
Agricul ture	waste	Dry cellulosic	0	757116	0	757116	10.599624
	Energy crops	Dry lignocellulosic	0	n.a	n.a	n.a	n.a
		Oil seeds for methylesters	0	n.a	n.a	n.a	n.a
		Sugar/starch crops for ethanol	0	n.a	n.a	n.a	n.a
Forestry	Woodfuel forestry byproducts	Dry lignocellulosic	109,857	6103200	0	6103200	109.8576

Industry	Industrial residues	Dry lignocellulosic	9	1277800	0	1277800	23,0004
		Wet cellulosic	:	:	:	:	:
		Black liquor	2.5	300000		300000	3
Waste	Regulated waste	Municipal waste	0	379000	0	379000	4.548
		Demolition wood	:	:	:	:	:
	Non- regulated waste	Landfill gas	0	3416700	0	3416700	13
		Sewage sludge	0	134000	0	134000	0.9916
Parks and gardens	Urban wood	Dry lignocellulosic	:	:	:	:	:
	grass	Wet cellulosic	:	:	:	:	:
Biomass imports			Not existing				
Biomass exports			Very small quantities (less than 4000 dry tons annually of wood fuel+wood residues) (110)				0.072

ENERGY CROPS

Cultivated areas in 2000 (ha)		***Yields***	
Solid crops	0	Dry matter tons/ha/year	6
Oil containing crops	44825	Biodiesel t/ha/year	0.45
Sugar rich crops	57903	Ethanol t/ha/year	1.19
Total arable land	9906000		
Set aside land	500000		

DELIVERY COSTS

Sector	***Resource***	***Fuel category***	***Delivery cost (€/GJ)***				
			Production (a)	***Transport (b)***	***Other costs (c)***	***Total (=a+b+c)***	***Oportunity cost (if any)***
Agriculture	Dry agricultural residues	Dry lignocellulosic	0.58-1.9	0.7	0	1.28-2.6	:
	Livestock waste	Wet cellulosic	0	0	0	0	0
	Energy crops	Dry lignocellulosic (triticale, miscanthus)	:	:	:	:	:
		Oil seeds for methylesters (rapessed)	:	:	:	:	:
		Sugar/starch crops for ethanol	:	:	:	:	:
Forestry	woodfuel	Dry lignocellulosic	:	:	:	1.24	:
	Forestry byproducts	Dry lignocellulosic	:	:	:	0.58	:
Industry	Industrial residues	Dry lignocellulosic	:	:	:		:
		Wet cellulosic	0	0	0	0	0
Waste	Regulated waste	Municipal waste	0	0	0	0	0
		Demolition wood	0	0	0	0	0
	Non- regulated waste	Landfill gas	0	0	0	0	0
		Sludge gas	0	0	0	0	0
Parks and gardens	Urban wood	Dry lignocellulosic	0	0	0	0	0
	grass	Wet cellulosic	0	0	0	0	0
Biomass imports							
Biomass exports							

9.2. Bioenergy in rural area

As far as bio-energy is concerned, the National Strategic Plan takes into account the promotion of investment in the biogas and biomass production, as well as investment in the production of wood energy, thus using the agriculture and forest potential, mitigating pollution and combating climate changes, implicitly.

For Romania, production of renewable energy is also an important domain. Investments for producing renewable energy realized by small and medium enterprises from rural areas, involved also in the primary processing of agricultural and forestry products, are supported.

Organic farming

In compliance with the European Action Plan for Ecological Agriculture, the National Strategic Plan takes into account the development of organic farming. Organic farming is an important instrument in nature conservation and revival of rural areas. These aspects have a great importance for Romania, where it was identified the need to maintain the natural value of farmland and the need of an equilibrated rural development. Organic farming could lead to environmental, economic and social benefits for these areas.

A dynamic analysis of the main agricultural sector indicators points to the actual stage of farming in Romania (Tables 9 and 10).

Table 9. Agriculture in Romania (Burja and Burja, 2008)

Indicators	*2006*
Rural population, % (2004)	46
Agricultural labor force, % (2004)	12
Fertilizers used, Kg nutrs/ha (2003)	35
Tractors, number for 1000 ha arable surface (2003)	18
Import of agricultural products, million euro	2424.8
Export of agricultural products, million euro	854.0
Contribution of agriculture to GDP, %	10

10. Future projections

The use of renewable energy resources is an action for economic development, which will bring benefits in the coming decades. It is a consequence of striving towards sustainable economic development, stimulated by a growing concern about the impacts of global warming. Renewable energy will play a growing role in the world's primary energy mix. It is estimated that, non-hydro renewables, will grow faster than any other primary energy source, at an average rate of 3.3% per year over the period to 2030.

The 2020 world capacity projections for energy produced from biomass is shown in Fig. 13.

The data from Fig. 14 shows the large potential biomass conversion in electricity in the OECD, particularly Europe and North America.

There will also however be high growth in Latin America and South Asia.

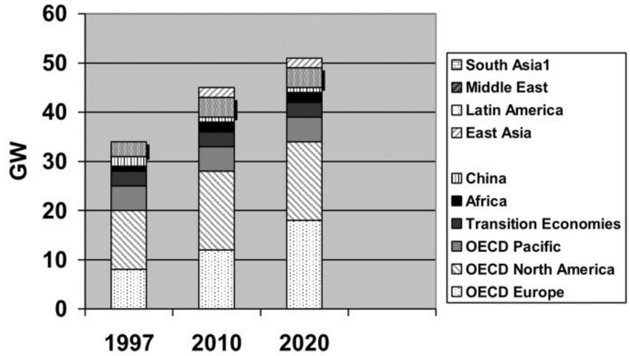

Fig. 13. World biomass capacity projection, 2020 (Kharta and Larson, 2000)

A small number of countries could produce 50 % or more of their current electricity demand from biomass, most countries over 10 % and a few countries less than 10 %.

When compared to the current installed bioelectricity capacity of only 1 % of the total installed capacity, it is obvious that there is a very significant potential to increase renewable electricity supply from biomass in the OECD (Bauen et al., 2004). The 2020 capacity projections for the non-OECD countries clearly show the relative importance of Latin America and the emergence of China and Africa (Fig. 15). Aiming to increase the contribution from biomass from the current level of 5 EJ/year to 200 EJ/year in 2050 would be a realistic but still challenging goal (Fig. 16) (Hoogwijk, 2006).

Hoogwijk (2006) described an analysis which considered four scenarios with different assumptions about the rates of technology development and the levels of international trade in food along with different assumptions on population growth and diet. The projections of the volume of additional biomass that could be made available for energy purposes varied significantly with the scenarios as land use changed.

Table 10. Indicators of sustainable agriculture in Romania, 2000-2006 (Burja and Burja, 2008)

Indicators	*2000*	*2006*	*2006/2000*
Organic farms number	-	3676	3676
Ecologic surface, ha	17400	170000	10
Number of cows in ecologic agriculture	2100	9900	5
Number of sheep in ecologic agriculture	1700	76100	45
Number of poultry in ecologic agriculture	-	7500	7500
Ecologic crops, thousand tons	13.5	131.9	10
Milk ecologic production, thousand tons	58.4	100.0	2
Apicultural ecologic products, to	-	600	600
Contribution of exports in entire ecologic production, %	-	95	-

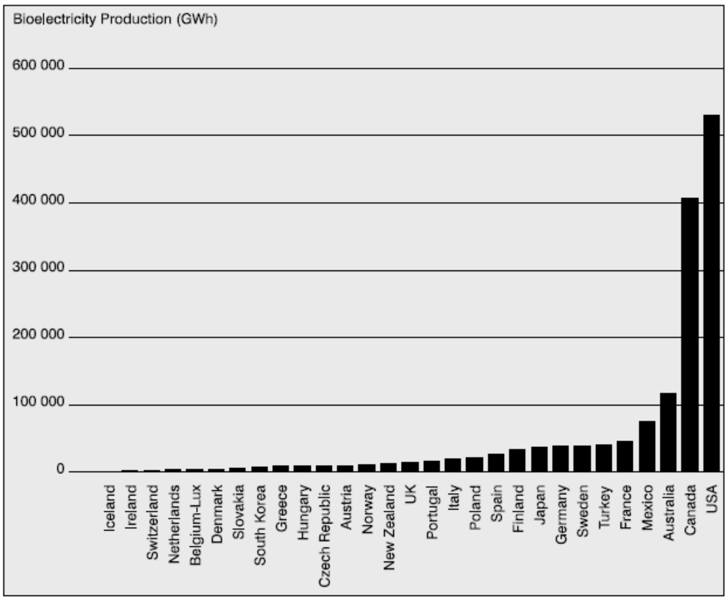

Fig. 14. Potential bioelectricity production in OECD countries by 2020 (Bauen et al., 2004)

One scenario included high population growth, a meat intensive diet with little improvement in agricultural intensity and high demand for biomass for competing uses or as a carbon sink. In this case the potential for additional energy use was low.

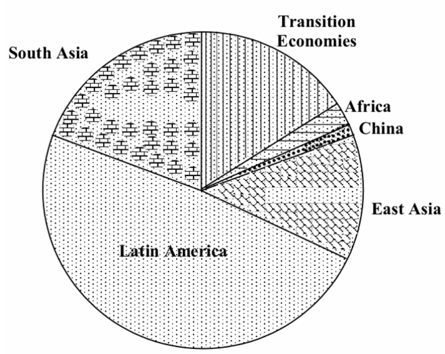

Fig. 15. Biomass capacity projection for non-OECD countries, 2010

By contrast, in the most optimistic scenario for bioenergy, where population growth is low, diet becomes less meat-intensive, agricultural intensity increases significantly (with a 100% increase in production per hectare) and there is less competition for resources, then bioenergy could increase very significantly, providing over 1000 EJ/year (Hoogwijk, 2006).

Biomass energy creates thousands of jobs and helps revitalize rural communities. The increasing use of bioenergy is also stimulated by rural development, energy security, employment and, of course, by the provisions of the Kyoto Protocol. Bioenergy projects – including those that involve the use of landfill gas, biogas, and biomass to produce heat and power – are currently significant (IEA, 2007). However, bioenergy is not a panacea for all energy problems (FAO, 2005). Long lasting solutions should be considered together with other energy options taking due consideration of local characteristics and situations.

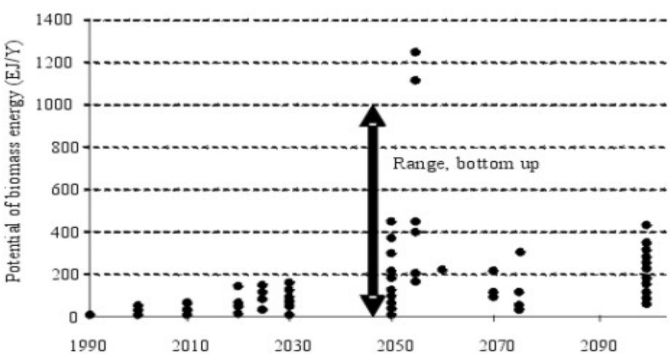

Fig. 16. Range of biomass energy potential (Hoogwijk, 2006)

However, the choice of the most appropriate energy option in relation to poverty reduction and environmental sustainability must consider a combination of local factors such as: existing productive enterprises, local energy resources, and technical characteristics of production/consumption patterns, emissions control and sustainable land-use practices.

11. Conclusions

Bioenergy projects will provide greater diversification and income opportunities for agriculture, agro-industries and forestry: they will increase the access of small rural industries to energy services; and will enhance the value of rural resources, encouraging private and public sector participation and investments. Locally produced bioenergy will boost national energy security and reduce the oil import bill. Modern bioenergy systems will increase both access to and reliability of energy services for households in rural areas, thus improving the quality of life.

The development of socially and culturally sustainable biomass production systems will inevitably stimulate governance options, equity and gender equality, especially in view of women's central role in household energy management.

Experience from different countries around the world supports the view that bioenergy can be a lever for rural development and regeneration in areas where investment is most needed and the creation of jobs is most difficult.

Long lasting solutions should be considered together with other energy options taking due consideration of local characteristics and situations. However, the choice of the most appropriate energy option in relation to poverty reduction and environmental sustainability must consider a combination of local factors such as: existing productive enterprises, local energy resources, and technical characteristics of production/consumption patterns, emissions control and sustainable land-use practices.

The long term biomass energy potential can be significant, but depends highly on: population dynamics; agricultural intensity; diet consumed; food trade influences the regional distribution; for high shares of biomass energy, trade is required; tradeoffs with sustainable forms of agriculture should exist.

Biomass power is the largest source of renewable energy as well as a vital part of the waste management infrastructure. An increasing global awareness about environmental issues is acting as the driving force behind the use of alternative and renewable sources of energy. A greater emphasis is being laid on the promotion of bioenergy in the industrialized as well as developing world to counter environmental issues.

Acknowledgements
The authors would like to acknowledge the financial support from Romanian Ministry of Education and Research (Project ID_595, contract 132/2007).

References

ABA, (2005), *What is Biomass?,* American Bioenergy Association, On line at: http://www.biomass.org/index_files/page0001.htm

AFB-NET, (2000),

Bauen A., Woods J., Hailes R., (2004), Biopowerswitch. A biomass blueprint to meet 15% of OECD electricity demand by 2020, Imperial College London, canter for Energy Policy and technology, E4tech Ltd., UK.

BMU (2005), *Erneuerbare Energien in Zahlen – Nationale und internationale Entwicklung*, Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit, Berlin.

Bringezu S., Ramesohl S., Arnold K., Fischedick M., von Geibler J., Liedtke C., Schutz H., (2007), Towards a sustainable biomass strategy, Wuppertal Institute for Climate, Environment and Energy.

Burja C., Burja V., (2008), Adapting the Romanian rural economy to the European agricultural policy from the perspective of sustainable development, MPRA, Munich Personal RePEc Archive, On line at: http://mpra.ub.uni-muenchen.de/7989/1/MPRA_paper_7989.pdf

Carpentieri M., Corti A., Lombardi L., (2005), Life cycle assessment (LCA) of an integrated biomass gasification combined cycle (IBGCC) with CO2 removal, *Energy Conversion and Management*, **46**, 1790-1808.

Cramer J., (2006), Energy Transition. Criteria for sustainable biomass production, IEA Bioenergy EXCO58 Meeting, Stockholm, Sweden, 3-5 October 2006.

Demirbas A., (2001), Biomass resource facilities and biomass conversion processing for fuels and chemicals, *Energy Conversion and Management,* **42**, 1357-1378.

DOE, (2000), BIOMASS POWER FOR RURAL DEVELOPMENT, ON LINE AT: HTTP://WWW.NREL.GOV/DOCS/FY00OSTI/28024.PDF

Domac J., (2002), Bioenergy and job creation, *Unasylva*, **211**, 18–19.

EIA, (2003), Energy perspectives, United States Energy Information Administration, Annual Energy Review 2003,On line at: http://www.eia.doe.gov/aer/pdf/perspectives.pdf

EON, (2005), *Geschäftsbericht 2004*, E.ON AG, Düsseldorf.

EPA, (2007), *Biomass Conversion:Emerging Technologies, Feedstocks, and Products,* Sustainability Program, Office of Research and Development, EPA/600/R-07/144, U.S. Environmental Protection Agency, Washington, D.C., On line at: http://www.epa.gov/Sustainability/pdfs/Biomass%20Conversion.pdf

EREC, (2007), Bioenergy, European Renewable Energy Council, Brussels, Belgium, On line at: http://www.erec.org/renewableenergysources/bioenergy.html

ESC, (2007), Improving access to modern energy services for all fundamental challenge, Economic and Social Council, ENV/DEV/927, On line at: http://www.un.org/News/Press/docs/2007/envdev927.doc.htm

EUROSTAT, (2007), Europe in Figures-Eurostat Yearbook 2006-2007,

FAO, (2005), *Bioenergy and the Millennium Development Goals*, Food and Agriculture Organization of the United Nations, Forestry Department, On line at: http://www.fao.org/docrep/008/j5135e/j5135e01.htm.

Hall D.O., House J.I.., Scrase I., (2000), *Overview of Biomass Energy*, In: *Industrial Uses of Biomass Energy. The Example of Brazil*, Callé F.R., Bajay S.V., Rothman H., (Eds.), Taylor & Francis, London, New York, 1-52.

Hall, D. (1997), Biomass energy in industrialised countries – a view of the future, *Forest Ecology and Management*, **91**, 17–45.

Heller M.C., Keoleian G.A., Mann M.K., Volk, T.A., (2004), Life cycle energy and environmental benefits of generating electricity from willow biomass, Renewable Energy, **29**, 1023-1042.

Hillring B., (2002), Rural development and bioenergy—experiences from 20 years of development in Sweden, *Biomass and Bioenergy*, **23**, 443-451.

Hoogwijk M., (2006), Global Biomass Availability: Assumptions and Conditions, IEA Bioenergy ExCo58, 4 October 2006, On line at: http://www.ieabioenergy.com/MediaItem.aspx?id=5794

Hoogwijk M., Berndes G., van den Broek R., (2003), Exploration of the ranges of the global potential of biomass energy, *Biomass and Bioenergy*, **25**, 119–133.

http://www.eia.doe.gov/emeu/aer/pdf/pages/sec10_2.pdf).

IBEP, (2006), Introducing the International Bioenergy Platform, Food and Agriculture Organization of The United Nations, Rome, On line at: http://esa.un.org/un-energy/pdf/FAO%20Bioenergy%20platform.pdf

IAEA, (2005), Energy indicators for sustainable development: Guidelines and methodologies, International Atomic Energy Agency, United Nations Department Of Economic And Social Affairs, International Energy Agency, Eurostat And European Environment Agency, Vienna.

IEA, (2007), Summary and Conclusions from the IEA Bioenergy ExCo58 Workshop The Availability of Biomass Resources for Energy, http://www.ieabioenergy.com/MediaItem.aspx?id=5794

IPM, (2007), *Testing framework for sustainable biomass.* Final report from the project group *Sustainable production of biomass,* Commissioned by the Energy Transition's Interdepartmental Programme Management (IPM), The Netherlands, On line at: www.lowcvp.org.uk/assets/reports/070427-Cramer-FinalReport_EN.pdf.

Kaltschmitt M., Weber M., (2006), Markets for solid biofuels within the EU-15, *Biomass and Bioenergy*, 30, 897-907.

Kammen D.M., Bailis R., Herzog A., (2003), Clean Energy for Development and Economic Growth: Biomass and Other Renewable Energy Options to Meet Energy and Development Needs in Poor Nations, UNDP Report, University of California, Berkley Renewable and Appropriate Energy Laboratory, On line at: http://www.earthscape.org/r1/ES14400/

Kartha S., (2006), *Environmental Effects of Bioenergy.* In: *Bioenergy Andagriculture: Promises and Challenges*, Hazell P., Pachauri R.K., (Eds.), International Food Policy Research Institute, On line at: http://www.ifpri.org/2020/focus/focus14/focus14.pdf.

Kartha S., Larson E. D., (2000), *Bioenergy primer - Modernised biomass energy for sustainable development*, United Nations Development Programme, with support from the Government of Norway, On line at: http://www.weea.org/Occasional%20Papers/Documents/Bioenergy%20primer.pdf

Kashian D.M., Romme W.H., Tinker D.B., Turner M., Ryan M.G., (2006), Carbon storage on landscapes with stand-replacing fires, *Bioscience*, **56**, 598-606.

Larson E.D, Katha S., (2000), Expanding roles for modernized biomass energy, *Energy for Sustainable Development*, **4**, 15-25.

Leible L., Kälber S. (2005), Nachwachsende Rohstoffe in der Stromerzeugung – Im Spannungsfeld zwischen Ökonomie und Umwelt', *GAIA*, **14**, 253–261.

Lewandowski I., Faaij A.P.C., (2006), Steps towards the development of a certification system for sustainable bio-energy trade, *Biomass and Bioenergy*, **30**, 83-104.

Lyons H.A, Anthony S.G., Johnson, P.A., (2001), Impacts of increased poplar cultivation on water resources in England and Wales, Aspects of Applied Biology, **65**, 83-90.

Møller I.S., (2006), Criteria and indicators for sustainable production of forest biomass for energy. Forest legislation, forest certification standards, and recommendations and guidelines for forest fuel extraction and wood ash recycling, IEA Bioenergy EXCO58 Meeting, Stockholm, Sweden, 3-5 October 2006.

Moret A., Rodrigues D., Ortiz L., (2006), Sustainability Criteria and Indicators for Bioenergy, Forum Brasileiro dr Ongs e Movimentos Socials papra o meio Ambiente e Desenvolvimento, On line at: http://www.foei.org/en/publications/pdfs/bioenergy.pdf.

Naghiu A., Vázquez J.L., Georgiev I., (2005), Rural development strategies through rural tourism activities in Romania: chance for an internal demand?, *International Review on Public and Nonprofit Marketing*, **2**, 85-95.

National Strategy, (2005), National Strategy Plan for Rural Development 2007-2013, Government of Romania, Ministry of Agriculture Forests and Rural Development, Romania.

Nikolaou A., Remrova M., Jeliazkov I., (2003), Biomass availability in Europe, On line at: http://www.biomatnet.org/publications/2119rep.pdf

OECD (1994), *Creating Rural Indicators of Employment: Focusing on Rural Development*, OECD, Paris.

Otiman P.I., (2008), Sustainable development strategy of agriculture and rural areas in romania on medium and long term - Rural Romania XXI, *Agricultural Economics and Rural Development*, **5**, 4-17.

Otto M., (2007), Ensuring sustainability of bioenergy: need for an international standard/assurance scheme?, Workshop organized by IEA Task 40, Berlin, 10 May, On line at: http://www.bioenergytrade.org/downloads/berlinotto.pdf.

Parikka M., (2006), Biomass Potential in Europe, ExCo2006, Stockholm, 2006.

Perlack R.D., Wright L.L., Tuhollow A.F., Graham R.L., Stokes B., Erbach D.C., (2005), Biomass as Feedstock for a Bioenergy and Bioproducts Industry: The Technical Feasibility of a Billion-Ton Annual Supply, US Department of Agriculture – US Department of Energy, Oak Ridge USA, On line at: http://feedstockreview.ornl.gov/pdf/billion_ton_vision.pdf

Plieninger T., Bens O., Hüttl R. F., (2006), Perspectives of bioenergy for agriculture and rural areas, *Outlook on Agriculture*, **35**, 123–127.

REPP, (2006), Bioenergy, On line at: http://www.repp.org/bioenergy/link1.htm

Rosillo-Calle F., (2007), *Overview of Bioenergy,* In: *The Biomass Assessment Handbook. Bioenergy for a Sustainable Environment*, Rosillo-Calle F., de Groot P., Hemstock S.L., Woods J. (Eds.), Earthscan, London, Sterling, 1-26.

Rosillo-Calle F., de Groot P., Hemstock S.L., (2007), *General Introduction to the Basis ofBiomass Assessment Methodology,* In: *The Biomass Assessment Handbook. Bioenergy for a Sustainable Environment*, Rosillo-Calle F., de Groot P., Hemstock S.L., Woods J. (Eds.), Earthscan, London, Sterling, 27-68.

Rowe R., Whitaker J., Chapman J., Howard D., Taylor G., (2008), Life cycle assessment in the bioenergy sector: developing a systematic review, UK Energy Research Centre, Working paper, UKERC/WP/FSE/2008/002, On line at: http://www.ukerc.ac.uk/Downloads/PDF/L/LifecycleAssesmentwp0408.pdf.

Sheehan J., (2004), Sustainable biomass: a systems view, Biomass and Solar Energy Workshops, August 3-4, Golden, Clorado, USA.

Sims, R. E. H. (2003), Bioenergy to mitigate for climate change and meet the needs of society, the economy and the environment, *Mitigation and Adaptation Strategies for Global Change*, **8**, 349–370.

Thornley P., Cooper D., (2008), The effectiveness of policy instruments in promoting bioenergy, *Biomass and Bioenergy*, **32**, 903-913.

Thornley P., Rogers J., Huang Ye, (2008), Quantification of employment from biomass power plants, *Renewable Energy*, **33**, 1922-1927.

Türk A., (2006),

UNEP, (2006), *Geo Year Book - An overview of our changing environment*, Harrison P. (Ed.), Division of Early Warning and Assessment (DEWA), United Nations Environment Programme, Nairobi, Kenya, On line at: http://www.unep.org/geo/yearbook/yb2006/PDF/Complete_pdf_GYB_2006.pdf

UNEP, (2007), *Buildings and Climate Change. Status, Challenges and Opportunities,* United Nations Environment Programme,

Wiedinmyer C., Neff J.C., (2007), Estimates of CO_2 from fires in the United States: implications for carbon management, *Carbon Balance and Management*, **2**, 2-10.

Yamasaki A., (2003), An overview of CO_2 mitigation options for global warming – Emphasizing CO2 sequestration options, *Journal of Chemical Engineering of Japan*, **36,** 361-375.

Yuan J.S., Tiller K.H., Al-Ahmad H., Stewart N. R., Neal Stewart Jr. C., (2008), Plants to power: bioenergy to fuel the future*, Trends in Plant Science*, **13**, 421-429.