International Conference on Economic Engineering and Manufacturing Systems
Braşov, 24 – 25November 2011

ANALYSIS OF SUSTAINABLE BIOMASS: A THREE-DIMENSIONAL APPROACH

Daniela Cristina MOMETE
Politehnica University of Bucharest, Romania

Abstract. This paper aims to identify the possibilities of biomass to become more sustainable using a three-dimensional approach that seeks to integrate the economic, social and environmental concerns arisen from the production and use of biomass. This objective encompasses a critical analysis of the challenges faced by biomass. The first goal resides in clarifying the variety of biomass feedstock by exploring its definitions by different normative acts and by introducing a new classification in different categories depending on their sustainability. This explanation also contains considerations regarding origin, composition, characteristics and conversion routes for biomass. The second goal has in view to determine the Advantages and Barriers faced by biomass, accompanied by Corrective actions (ABC analysis). The main findings reveal the great variety of biomass resources that are facing multiple challenges and an inconsistency in defining it at international level. Consequently, a biomass differentiation is introduced by placing sustainability safeguards to different biomass resources. This recommends the use of the term biomass only for residues and wastes derived from agriculture and forestry, while the other resources should bear a name correlated with their specificity (bio-cultures, bio-wastes and bio-tech).

Keywords: renewable energy, biomass differentiation, sustainability

1. Introduction

The world consumes energy products at a pace that soon will push the limits of the planets safe sustaining in terms of material resources, fossil fuels but also water, and good quality air and soil. The global primary energy consumption reached 11,164 million tons oil equivalent (toe; 1 toe = 10 million kilocalories) in 2009, from a value of 9,260 toe in 2000 [1] (a 20% increase over the last ten years). This ever-increasing demand for energy products arises from two main sources: economic growth and population growth that are already straining the energy chain.

Sustainable energy production is a matter of concern since the first oil crisis from the '70s, a golden moment for other energetic options, different from fossil fuels. Even though the sustainable development, as a term, was lately recognised in 1987 [2], the environmental issues together with concerns regarding the volatility in energy prices were the results of the first oil sock. Therefore, the consideration of renewable energy sources (RES) came as a natural answer, but their further development was not according with the expectations of the time [3]. Since then, all RES registered important advances: the modern renewables, like solar energy showed a spectacular increase, the wind energy disclosed a tremendous progress, geothermal was more seriously taken into consideration, while hydro power showcased a milder increase, considering the limited resources, mostly in terms of micro hydro stations [4, 5]. Biomass was the only RES with serious results in terms of contribution in the global primary energy fuel mix, accounting for about 10%, and representing 77% of the world primary renewable energy mix [6].

The drivers of the development RES lay in increased energy needs, security of supply, rising prices of fossil fuels and controlling of pollution and climate change [7]. Moreover, for fossil fuels importing countries, along with security of energy supply also trade balances will be improved whether the energy consumption will switch to RES.

Biomass is a valuable energy resource, but a very controversial one, by possible effects on food chain and environment (affecting soil, water, biodiversity). Biomass problems, if remained unsolved, might lead to cascading effects on sustainable development. Therefore, the paper pursues biomass resources from their harvesting site to the place of utilization, analyzing their sustainable potential, by recognizing the hot issues and then by properly addressing them.

2. Biomass description

There is a large variety of definitions concerning biomass, depending on the legislative body or theory maker, which determines a certain inconsistency in defining this resource. The term biomass is used for a large variety of products being "*a generic term for all forms of energy derived from the biosphere, in a non-fossil form*" [8].

The most comprehensive definition is that revealed by one new European directive, where biomass is defined as "*the biodegradable fraction of products, wastes, and residues from biological origin from agriculture (including vegetable and animal substances), forestry, and related industries including fisheries and aquaculture, as well as the biodegradable fraction of industrial and municipal waste*" [9]. This definition skips the importance of collection and proper selection of the industrial and municipal wastes and also is very vague in defining forestry. This definition coexists with another one, where biomass is more briefly and insufficiently described as "*the biodegradable fraction of products, waste and residues from agriculture (including vegetal and animal substances), forestry and related industries, as well as the biodegradable fraction of industrial and municipal waste*" [10].

In Romania, the term biomass also incorporates rural wastes, that are even harder to select, being defined according to the law of electrical energy [11] as "*the biodegradable fraction of products, waste and residues from agriculture (including vegetal and animal wastes), forestry and related industries and also the biodegradable fraction of industrial and rural, urban and municipal wastes*". It is obvious that biomass comes from various sources, more or less durable, depending on their origin, composition, conversion routes; therefore they are clarified over the next sections.

2.1. Classification of biomass sources

Different biomass categories, with variable sustainable potential, are composing this redoubtable, yet problematic resource. The next listing comprises the biomass sources, from the most sustainable (A) to the worst (C) or in development (D), in accordance with the author' believes. The next labels contain the classification of the main types, showed by letters, and sustainability safeties, revealed by numbers.

A. *Agriculture & forestry residues*

A.a.r *Agricultural residues* (straws and cereal straws, stover, husks, cobs, nut shells, grains, vineyard and orchard prunings or turnings, hay). The most sustainable ones are those residues resulted from environmentally friendly cultures (ecological or organic, having the label A.a.r.1.). However, their percentage in the total agricultural land is quite modest: from 1.7% in Romania [12], to maximum 10% in Austria [13].

A.a.m. Animal manure & slurry (pig, cattle, poultry). However, the manure is commonly used for fertilization purposes, and is perceived as not-in-my-back-yard technology.

A.f. *Forestry*

A.f.r. Forestry harvesting residues (stems, tops, bark, branches, stumps, leaves and coarse roots).

A.f.w. Wood-processing residues (sawdust, shavings, woodchips, wood briquettes and pellets).

A.f.p. Recovered post-consumer wood.

The residues are used for generating heat, electricity and combined heat and power and their constant usage may contribute to stabilizing of the market.

Depending on their main characteristics (moisture content, calorific value, and sulphur content) they are further classified. For instance, the residues resulted from environmentally friendly cultures (A.a.r.1.) with the best qualities in terms of moisture, calorific value and sulphur content become A.a.r.1.1.1.1. Number 1 is reserved for the best categories, while the further will be higher numbers (2, 3, 4, ...). The same judgment also applies for the next categories.

B. *Energy cultures*

B.f. *Forestry cultures* based on ligno-cellulose material (e.g. acacia, eucalyptus tree plantations, poplar, willow).

B. a. *Energy crops* mostly based on monocultures: oil crops (e.g. rapeseed, sunflower, oil palm, soybeans, Jatropha), sugar crops (e.g. sugarcane, sugar-beet), starch crops (e.g. wheat, corn, rye) and herbaceous lignocellulosic crops (e.g. mischantus, switch grass, red canary grass).

In the context of this work only dedicated energy cultures cultivated on abandoned or degraded/marginal land that are not conflicting with food crops are considered sustainable. Nevertheless, a number of dedicated energy crops are drought tolerant and water efficient, but have to be grown under multi-year rotations [14].

The resources of this category are used to produce heat, electricity and transport fuels.

C. *Biodegradable municipal and industrial wastes*

C.m. *Municipal solid waste* (MSW) is generally composed of high cellulose content materials (paper, wood, yard waste, household waste) [15]. However, it should be properly collected, selected and transported as they are a possible source of germs and diseases.

C.s. *Sewage sludge* is a solid by-product of waste water treatment that is composed of organic carbon (40-70% dry matter), but it also contains phosphorous and nitrogen. The main arguments of using it are the effective recycling and that its quantity is approximately constant through the year. However, it posses numerous challenges with respect to emissions of trace elements resulted from the treatment and possible contaminants (heavy metals, pathogens).

C.i. *Industrial wastes* are composed of black liquor (from paper & pulp industries), organic wastes from food industry and other wastes. However, they contain larger amounts of toxic substances as a result of biomass processing. Therefore, they should be treated before entering the biomass conversion routes.

The resources of this category are used to produce heat, electricity and transport fuels.

D. *Aquatic biomass*

Algae fuel has a considerable potential, but only on longer term assumptions, as its application is a work in progress, consequently this field is considered to be still in its infancy.

2.2. Origin and traceability

The production site of biomass is very important as it carries important information on the sustainability and characteristics of the raw materials. Moreover, biomass identification along chain must be realised and all operators must be included:

- producer (e.g. forestry, agriculture, industry);
- storage and delivery;
- analysis laboratory;
- intermediary producer (e.g. for pellets);
- trader;
- end user (e.g. for power plant).

2.3. Composition and characteristics

Biomass composition is highly variable due to large differences in types and origin, together with history of the resource, along with variation in modes of occurrence of the inorganic elements [16]. The mineral content of biomass varies largely as a result of the soil type and also the timing of feedstock harvest, which also influences the moisture content. The elemental chemical analysis of different biomass feedstock revealed a heterogeneous composition [17]. The heating values are quite uniform, despite the large variation in types (16 GJ/ton for agriculture residues and 19 GJ/ton for woody materials). Moisture content for air-dried biomass is rather high, reaching 20%, while their bulk density is rather low, determining lower energy densities than fossil fuels [17].

Ash and mineral contents are also very important for combustion efficiency, but also for the suitable functioning of the employed mechanisms (may produce clogging, fouling, and clinkering) [18].

2.4. Biomass conversion routes

Thermo-chemical conversion: biomass undergoes chemical degradation induced by high temperature:

-*combustion*: solid biomass (e.g. wood/pellets) used for domestic and district heating and combined heat & power;

-*co-firing*: co-combustion of solid biomass materials with coal;

-*gasification*: biomass is transformed into fuel gas; syngas may be converted to methanol, Fischer-Tropsch liquids, di-methyl-ether and hydrogen [19];

-*pyrolysis*: decomposition of biomass occurring in the absence of oxygen that produces solid (charcoal), liquid (pyrolysis oil or bio-oil) and gaseous fractions.

Physico-chemical conversion: produces liquid fuels (biodiesel or vegetable oil) from oil crop by oil extraction, possibly followed by a transesterification process.

Bio-chemical conversion: uses living micro-organisms (enzymes, bacteria) to degrade the feedstock and produce liquid and gaseous fuels. The mechanisms are:

-*fermentation* from sugar (sugar-cane, sugar-beet, etc.), starch (corn/maize, wheat, etc.) and ligno-cellulosic feedstock (grass, wood, etc.) to produce ethanol;

-*anaerobic digestion* (biogas – mainly CH_4- mostly from wet feedstock);

-*bio-photochemical routes* (e.g. hydrogen production using algae) which require the action of sunlight.

3. Assessment of the three-dimensional approach

Biomass potential as a reliable energy source is considered very large, yet different estimates were given that vary widely from 33 EJ/year to 1,500 EJ/year by 2050, depending on the study [14, 20] (1 EJ=1 exajoule= 10^{18} joules = 24 million toe). Biomass potential must be taken into consideration, but first the many economic, social and environmental factors must be fully clarified and properly balanced in order to satisfy the growing world energy demand. Figure 1 portrays the balance of the 3 dimensions of sustainable development biomass must simultaneously cope with: economic prosperity, social well-being and environmental protection.

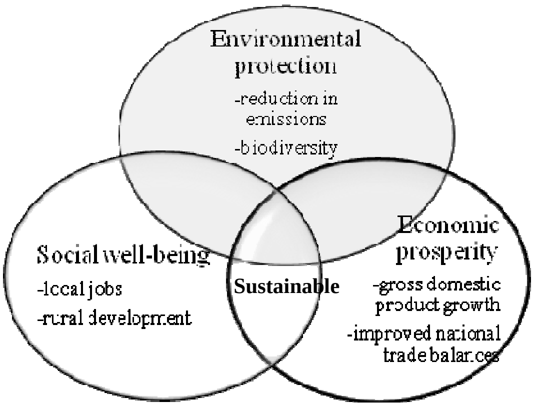

Figure 1. Sustainability requirements for biomass

Significant hurdles are to be overcome by biomass in order to become a resource with a real sustainable production potential. A suggestive ABC analysis of the advantages (A), barriers (B) faced by biomass and their corrective actions (C), in a 10-10-10 key assertions is further presented.

The 10 As: Advantages

1. Widely available renewable resources;
2. Available technology;
3. Diversification of energy sources;
4. Security of energy supply;
5. Can deliver energy in all forms (solid, liquid and gaseous fuels for heating, electricity and internal combustion engines);
6. Rural development;
7. Local jobs creation;
8. Access to energy facilities and alleviation of poverty;
9. Reduced emissions (sustainable biomass is “carbon-neutral”: it absorbs CO_2 while it grows, compensating the emissions; it generates lower SO_2 emissions than fossil fuels).
10. Proper use of wastes/residues.

The 10 Bs: Barriers

1. Difficulties in harvesting and collection;
2. Equipments constraints;
3. Residues/wastes are seasonally available and variable in quantity;
4. Loss of CO_2 sinks as a result of the changes in land use;
5. Low energy densities resources;
6. Costly to transport & storage & handling;
7. Food security (competition for land between energetic cultures and food cultures);
8. Large-scale biomass development have the potential to increase the prices for food crops;
9. Negative effects on soil quality;
10. Biodiversity threats.

The 10 Cs: Corrective actions

1. Well-planned crop rotation that avoid economically attractive monocultures and deforestation (mainly in the case of rain forests);
2. Development of new, more energy efficient cultures together with development of bio-refineries (based on cluster approach that links together several industries);
3. Eco-friendly removal systems: no excessive removal of forest & agriculture residues (the excessive removal deprives ecosystems of vital nutrients and might conduct to irreversible degradation) [21]. Moreover, eco-friendly harvesting of residues may lead to restoration of several biosphere aspects (the harvesting of agriculture residues avoid decomposition emissions; no-excessive removal of forestry residues avoid catastrophic natural forest fires and the development of insects that destroy forests; restores degraded/abandoned land);
4. Biomass can act as carbon sinks, in the case of forestry cultures;
5. Fostering sustainability standards and regulations for biomass;
6. Development of regulations of land use and labour (land use agreements/human rights and land property rights and labour rights);
7. Protection of biodiversity (designated protected areas for rare species);
8. Biomass national inventory;
9. Sustainable management of forest resources that includes forest health;
10. Financial support by RES schemes or other financial instruments, like climate related financing, in accordance with the resources sustainability.

4. Suggested biomass differentiation

Considering all the facts presented so far and the revealed bottlenecks, the resources should be differentiated, accordingly with their footprint. Therefore, the most sustainable ones, category A in the previous classification, are the only ones that bear the name biomass. In order to avoid the conflicts revealed by ABC analysis, all the other categories bear a name correlated with their specificity: category B: bio-cultures, category C: bio-wastes and category D: bio-tech. Figure 2 reveals the first 3 categories, as category D is not commercially available and faces technical barriers and still expensive routes. The colours employed to show the different categories are suggestively selected, with mild green (the lightest colour) for the best and intense red for the worst (the darkest colour). The differentiation of biomass resources depending on their sustainable potential contains two vectors: one horizontal, from the best to the worst class, and one vertical on which the sustainability incrementally increases from one category to the other. The final class contains all the previous ones, being characterised by a cumulative sustainability. Therefore, the best biomass resources are those coming from wastes and residues from organic agricultures that are ecologically collected and not used for soil/animal activities, with proper characteristics that should be empirically identified as moisture content, calorific values, sulphur content and so on.

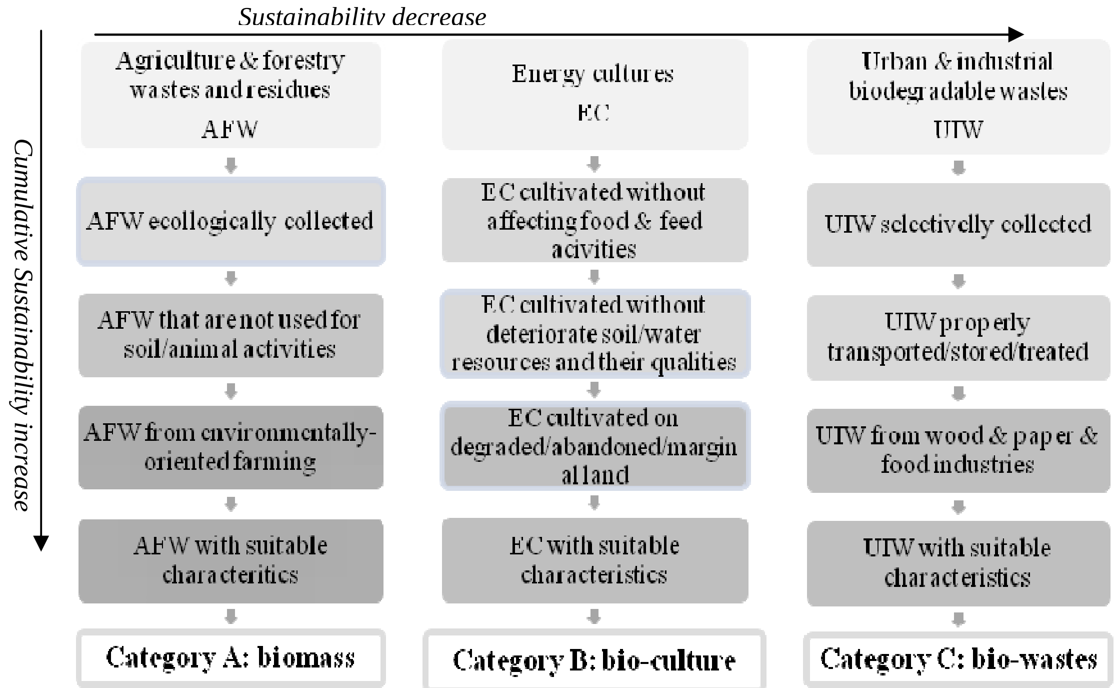

Figure 2. Differentiation of biomass resources depending on their sustainable potential

¶

At present, there is a general perception that the categories considered with the highest sustainable potential cannot supply large enough quantities. However, these impediments might be prevailed over, if an intelligent harvesting scheme that supplies a year-round fuel supply is considered. Moreover, taking into consideration the significant awareness of the global complex effects of biomass use and production, a new meaning should be based on sustainability. A 2009 EU policy directive recognizes the need to demonstrate the sustainability of biomass energy [9]. Moreover, due to recent developments in the European bio-energy sector, the Council of the European Union released a regulation that abolish the financial support for energy crops by stating that "*there is no longer sufficient reason to grant specific support for energy crops*" [22]. In Romania, for instance, in 2008 financial support was given for energy crops cultivated on 32,650 hectares (ha), while in 2009 the surface more than doubled, reaching 69,509 ha [23]. Therefore, for 2010 no financial support was given for energy crops in Romania. However, in the case of Romania the energy crops may not be considered as major threats to food crops, as the country posses 14.7 million ha (Mha) in agricultural area, of which 9.38 Mha is arable land [12, 24] and a significant surface remains non-cultivated [25].

5. Conclusions

The energy sector must be reshaped having in mind the support of the socio-economic development and friendly environmental procedures. The fuel switching to RES faces many challenges, and biomass has to overcome many disadvantages. However, this paper shown that by placing sustainability safeties and by enforcing a proper differentiation and management, biomass is a valuable resource. The ABC analysis revealed that biomass has a great potential for sustainable energy mix, but first, it must cope with specific requirements which must be enforced at national level.

Acknowledgements

This paper is supported by the Sectorial Operational Programme Human Resources Development (SOP HRD), financed from the European Social Fund and by the Romanian Government under the contract number SOP HRD/89/1.5/S/62988.

References

1. *** *BP Statistical Review of World Energy*. British Petroleum. Available from: www.bp.com/statisticalreview, Accessed: 10/05/2011
2. Bruntland, G. (Ed.) (1987) *Our common future: The World Commission on Environment and Development*. Oxford University Press, ISBN 019282080x, Oxford, U.K
3. Momete, D.C. (2007) *A critical analysis of the primary energy consumption trends from a sustainable perspective*. Scientific Bulletin, Series B, Vol. 69, No. 1, p. 73-80, ISSN 1454-2331
4. Bhutto, A.W., Bazmi, A.A., Zahedi, G. (2011) *Greener energy: Issues and challenges for Pakistan—Biomass energy prospective*. Renewable and Sustainable Energy Reviews, Vol. 15, No. 1, p. 3207-3219, ISSN 1364-0321
5. Momete, D.C. (2010) *A critical analysis of the potential of renewable energy in Romania*. Annals of the Oradea University, Fascicle of Management and Technological Engineering, Vol. IX (XIX), No. 1, (2010), p. 170-175, ISSN 1583-0691
6. Macqueen, D., Korhaliller, S. (2011) *Bundles of energy: the case for renewable biomass energy*. IIED Publishing House, ISBN 978-1-84369-792-3, London, United Kingdom
7. Momete, D.C. (2007) *The trinomial sustainable development – economic growth – energy in European context*. RECENT, Vol. 8, Nr. 3a (21a), p. 325-330, ISSN 1582-0246
8. Steger, U., Achterberg, W., Blok, K. (2005) *Sustainable Development and Innovation in the Energy Sector*. Springer, ISBN 978-3-540-23103-5, Berlin, Germany
9. *** European Parliament and Council (2009) *Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources.* Available from: www.eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:140:0016:0062:en:PDF, Accessed: 12/05/2011
10. *** European Parliament and Council (2003) *Directive 2003/30/EC, on the promotion of the use of biofuels or other renewable fuels for transport*. Available from: www.eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2003:123:0042:0042:EN:PDF, Accessed: 12/05/2011
11. *** *The electricity law No. 13/2007*, art. 61. Romanian Monitor. Available from: www.minind.ro/domenii_sectoare/leg_armonizata/energie/EnergyLAW13_2007_27_07.pdf, Accessed: 01/05/2011
12. *** *Statistical yearbook 2009*. National Institute of Statistics, Available from: www.insse.ro, Accessed: 12/05/2011
13. De Wit, M.P., Faaij A.P.C. (2008) *Biomass potential and related costs*. Available from: www.refuel.eu/fileadmin/refuel/user/docs/REFUEL_D9.pdf, Accessed: 10/09/2010
14. Gregg J., Smith, S. (2010) *Global and regional potential for bioenergy from agricultural and forestry residue biomass*. Mitigation and Adaptation Strategies for Global Change, Vol. 15, No. 3 (March 2010), p. 241-262, ISSN 1381-2386
15. Glaser, J. (2007) *Future of energy*. Clean Technology Environmental Policy, Vol. 9, No. 1 (January 2007), p. 57-161, ISSN: 1618-954X
16. Vassilev, S., Baxter, D., Andersen, L. (2010) *An overview of the chemical composition of biomass*. Fuel, Vol. 89, No. 5 (October 2010), p. 913-933, ISSN 0016-2361
17. Boundy, B., Davis, S. (2010) *Biomass energy data book*. Available from: www. cta.ornl.gov/bedb/index.shtml, Accessed: 10/09/2010
18. *** Report of the Ministerial Task Force on BioEnergy (2007) *BioEnergy Action Plan for Ireland*, Ireland
19. Faaij, A. (2006) *Modern biomass conversion technologies*. Mitigation and Adaptation Strategies for Global Change, Vol. 11, No. 2 (March 2006), p. 343-375, ISSN 1381-2386
20. Bauen, A., Berndes, G., Junginger, M., Londo, M., Vuille, F. (2009) *Bioenergy – a sustainable and reliable energy source- a review of status and prospects*. Available from: www.ieabioenergy.com/LibItem.aspx?id=6479, Accessed: 10/09/2010
21. Patzek, T, Pimentel, D. (2005) *Thermodynamics of Energy Production from Biomass*. Critical Reviews in Plant Sciences, Vol. 24 No. 5-6 (September-December 2005), p. 327-364, ISSN 0735-2689
22. *** Official Journal of the European Union, Council regulation (EC) No 73/2009 *Establishing common rules for direct support schemes for farmers under the common agricultural policy and establishing certain support schemes for farmers*. Available from: www.eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:030:0016:0016:EN:PDF. Accessed: 10/05/2011
23. *** Ministry of Agriculture and Rural Development, (2010) *Romanian agricultures: facts and figures*. Available from: www.madr.ro/pages/raport/agricultura-romaniei-noiembrie-2010.pdf. Accessed: 10/05/2011
24. Coyette, C., Schenk, H. (2010) *Agricultural statistics main results 2008–2009*. Available from: www.epp.eurostat.ec.europa.eu/cache/ITY_OFFPUB/KS-ED-10-001/EN/KS-ED-10-001-EN.PDF, Accessed: 10/05/2011
25. Sălăşan, C. (2010) *Rural population in the context of the structural changes in Romanian agriculture*. Available from: ftp://www.ipe.ro/RePEc/iag/iag_pdf/AERD1006_87-103.pdf, Accessed: 10/05/2011