GLOBAL USE OF AGRICULTURAL BIOMASS FOR FOOD AND NON-FOOD PURPOSES: CURRENT SITUATION AND FUTURE OUTLOOK

Stefan Wirsenius

Department of Energy and Environment, Chalmers University of Technology,
SE41296 Gothenburg, Sweden, stefan.wirsenius@chalmers.se

INTRODUCTION

Globally, humans currently harvest roughly 13 petagrams (billion metric tons) dry matter per year of biomass for food (including feed), energy and materials purposes (see Table 1). In energy terms, this use corresponds to about 240 exajoules (~5.7 billion metric ton oil eq.), and is almost of the same order of magnitude as the current use of all fossil fuels, in total 390 exajoules. Food is the dominating use, accounting for about 82 percent of total extraction of biomass, followed by bioenergy, 11 percent, and biomaterials, 7 percent. However, a great part of the biomass used for energy consists of by-products and residues generated in the food and materials systems, which means that biomass use for energy add up to nearly a fifth of the biomass extracted by humans. Noteworthy is also that the rapidly increasing use of crops for transportation fuels (such as ethanol), which is reported to having contributed substantially to recent surges in prices of cereals and other agricultural commodities (OECD-FAO 2007), still only accounts for less than 1 percent of global cropland use. This is much less than other

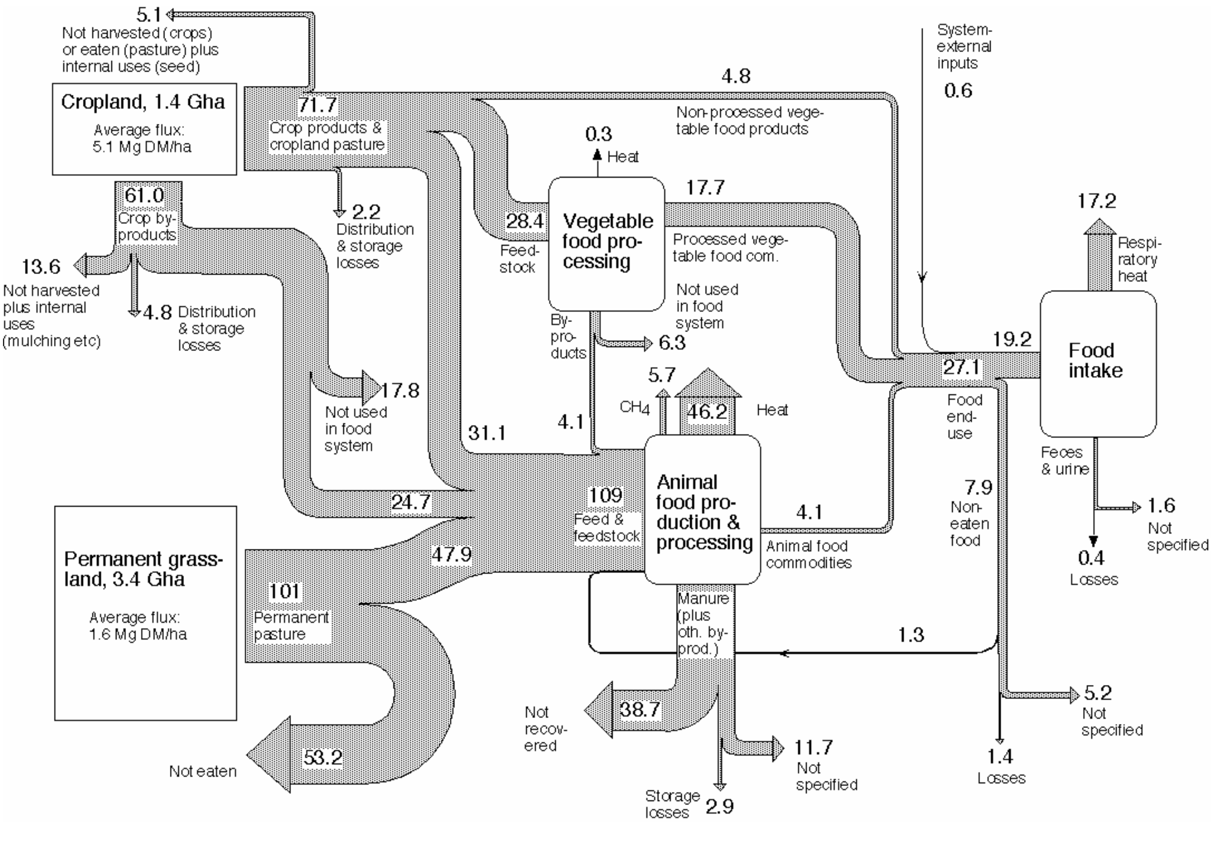

Figure 1. Overview of land use and biomass flows in the global food system in 1992/94. Numbers in exajoules (higher heating value) per year. From Wirsenius (2003a).

Table 1. Current (around 2005) human use of biomass and land by purpose and major types.

	Biomass extraction & use		**Land use**
	Dry weight (million metric tons)	Energy content (heating value, in exajoules[1])	(million ha)
Food			
food & feed crops (incl. harvested crop residues) from cropland (arable land and land with permanent crops)	8,000	140	1,600
cereals	4,700	85	750
other	3,300	60	850
pasture & browse from permanent grassland	2,600	48	3,500
herbage & browse from woodland, forests, other land	400	7	?
TOTAL food	*11,000*	*200*	*5,100*
Materials			
wood from natural and semi-natural forests	550	11	2,400[2]
wood (and rubber) from plantation forests	200	4.0	130
fibres from cropland (cotton, etc)	55	1.2	40
crops from cropland (oil crops, cereals, etc) for other materials (vegetable oils, starch, etc)	100	2.0	50
residues from food & agriculture, mainly for paper production (straw, bagasse, etc)	20	0.4	-
TOTAL materials	*920*	*19*	*2,600*
Energy			
fuelwood collected from woodland, grassland, forests	1,300	26	?
wood from dedicated plantations (tree plantations, etc)	45	0.9	9
crops from cropland (cereals, sugarcane, oil crops) for transportation fuels (mainly ethanol and biodiesel)	150	2.7	15
residues from food & agriculture systems (straw, manure, bagasse, etc)	600	11	-
residues from fibre & forestry systems (harvest residues, bark, sawdust, black liquor, used paper, etc)	350	7.0	-
TOTAL energy	*2,400*	*48*	*(24)*
TOTAL extracted amount (not counting re-use of residues)	13,400	240	7,700

Data compiled from various sources (Mabee et al. 1997; Wirsenius 2000; FAO 2006a; FAO 2006b; IEA 2006b; FAO 2007; Fernandes et al. 2007; OECD-FAO 2007). Numbers rounded to 2 significant digits.

[1] 1 exajoule ≈ 278 TWh ≈ 23.9 million metric tonne oil equivalent

[2] Refers to total area of "semi-natural forest" (280 Mha) and "modified natural forest" (2,080 Mha) as reported in FAO (2006a). Wood harvest per unit area from modified natural forests is much smaller than that from semi-natural forests, due to lower intensity in management for wood production.

non-food uses of cropland such as feedstock for fibres (cotton, etc) and other materials, which in total account for roughly 5-6 percent of global cropland use (see Table 1).

CURRENT USE OF AGRICULTURAL BIOMASS

Food completely overshadows other uses of agricultural biomass (here defined as biomass produced on either cropland or permanent grassland), accounting for about 97 percent of the total extraction. Figure 1 gives an overview of the current global extraction, conversion and end-use of biomass for food. A striking feature of the food biomass turnover is that of the total energy content (heating value) in the biomass that is harvested and grazed, only a rather small fraction, globally about 12 percent, ends up being eaten by humans. The major factor behind this seemingly poor efficiency is the huge energetic losses in the production of animal food, where almost all of the feed energy ingested by animals is lost as manure (~46%), respiratory heat (~43%) or methane (~6%) – only a mere 5 percent of the feed energy is retained in animal tissue, of which about one percentage unit is further lost in the form of slaughter by-products. In contrast, production of vegetable food involves much smaller losses – for processed vegetable food (flours, oils, sugars, etc), on average about 60 percent (in energy terms) of the feedstock is converted into ready-to-eat food. Obviously, this huge difference in biomass-converting efficiency between animal and vegetable food means that human dietary choices have a tremendous influence on the amount of land and biomass required for food. This is a since long well-known fact, and changes towards more vegetarian diets as a way to decrease resource use and ecosystem effects from agriculture has been an option put forward since the beginning of the modern environmental debate, which at least goes back to Borgström (1969). Unfortunately, much less attention in this respect has been paid to dietary changes between different types of animal food, which exhibit larger variation than commonly perceived in land and biomass requirements per unit of food produced. Ruminant meat (beef, lamb, etc) is by far the most resource-demanding animal food product – on average ruminant meat requires 10-20 times more land and biomass per unit produced than pig meat, poultry meat and milk – and even relatively small changes in its consumption level have significant effects on the requirement of agricultural land, not only of grassland but also of cropland (Wirsenius 2003b; Wirsenius et al. in prep).

Another principal factor contributing to the low biomass efficiency of the global food system is the substantial wastage of food commodities in storage, distribution, retail and consumption. Globally, the largest such losses occur in the final stages of the food chain, after the food commodities have reached the retail level, i.e. in food stores, restaurants, households, institutional kitchens, etc. About 30 percent of the food commodities (in energy terms) reaching the retail level is lost, mainly in the form of food wastage. These losses are generally much higher in affluent countries than in poorer ones. In affluent countries, the large part of the food end-use losses can be explained by the rather wasteful behaviour that follows from having income large enough not having to worry about hunger, in combination with high demands on freshness, quality and food safety.

A factor that partly counterbalances the low biomass efficiency of the global food system is the substantial use of crop residues (straw, etc) and food industry by-products (oil cakes, etc) as animal feed. Globally, crop residues and food industry by-products make up about 15 and 5 percent (in terms of metabolizable energy), respectively, of the total feed use in animal food production. The use of by-products and residues as feed is as most vigorous in the regions of Sub-Saharan Africa and South Asia, where crop residues contribute to some 30-35 percent of the total annual feed use (in terms of metabolizable energy).

Current use of agricultural biomass for non-food purposes is small in comparison with that for food, amounting to a little less than 1 petagram (billion metric tons) dry matter per year, which corresponds to about 9 percent of the amount of agricultural biomass harvested and grazed for food (see Table 1). About two-third of this consists of by-products and residues, mainly crop residues, from agriculture used for energy purposes. The remainder is made up of crops grown on cropland for energy (e.g. fuels) and materials (e.g. fibre) purposes – each of which amounts to about 150 teragrams (million metric tons) dry matter per year, corresponding to just about 1.5 percent of the amount of agricultural biomass extracted for food.

OUTLOOK IN THE SHORT AND LONG TERM

Due to the expected increase in global energy demand, supply of CO_2-neutral energy need to grow to levels of the same order of magnitude as current use of fossil fuels, if we are to avoid adverse effects of human-caused climate change. Among several options capable of supplying large amounts of CO_2-neutral energy, biomass ranks as one of the very few already competitive in some markets. It is a relatively low-cost renewable fuel, which is near penetration into new applications. Consequently, several studies have concluded that if stringent CO_2 mitigation policies are implemented – by increasing the costs for emitting CO_2 through e.g. CO_2 taxes or emission cap & trading schemes – demand for biomass for energy purposes will be far greater than today, both in the shorter and the longer term (see, e.g., Gielen et al. 2003; van Vuuren et al. 2004; Grahn et al. in press). In the longer term, in 2050 and beyond, climate-policy driven demand for agricultural land for production of energy crops may amount to as much as 500-1000 million ha, or 30-60 times larger than current use.

Obviously, at the same time, global demand for food, particularly that of animal food, is also expected to rise. So is also that of biomaterials, such as paper, as well as biomass-based substitutes to today's petroleum-based products. However, due to the greater size (in energy terms) of industrial energy use in relation to that of food and materials, the possible span in long-term increase in demand for biomass for energy is considerably larger than that for food and materials. These relations are indicated in Figure 2, which shows estimates of probable long-term magnitudes for bioenergy assuming that CO_2 mitigation policies are put in place.

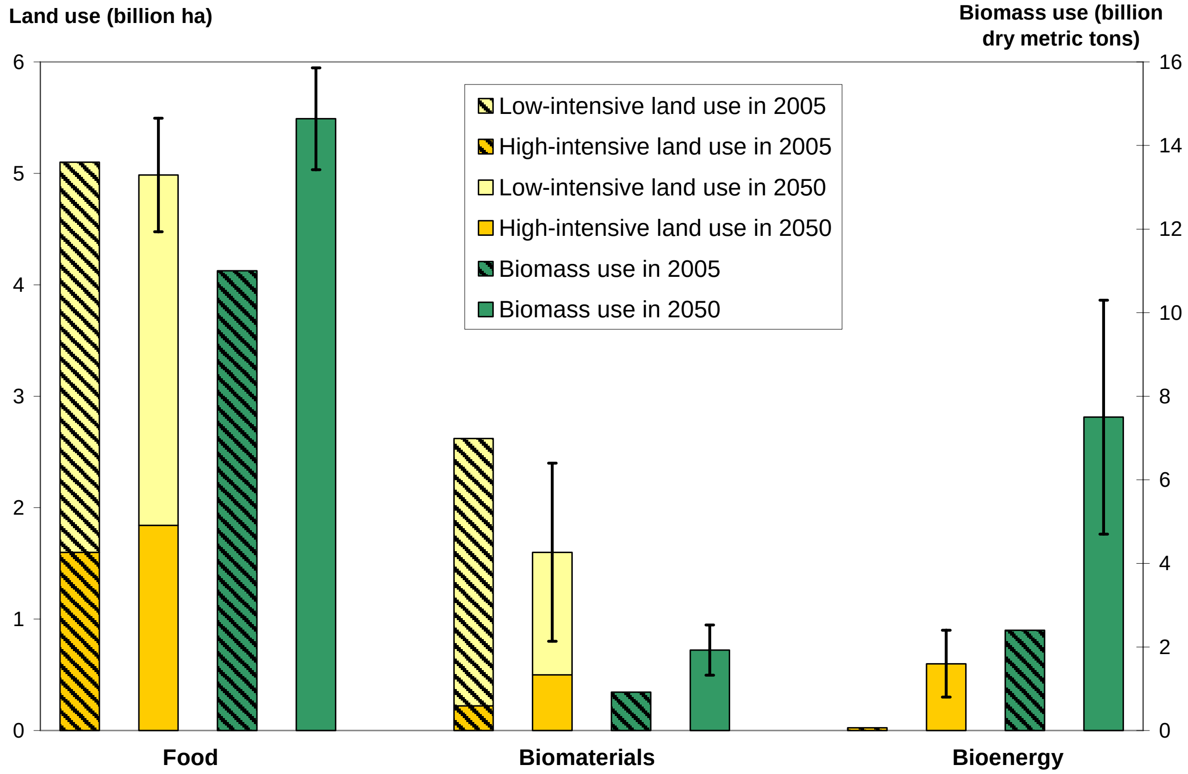

Figure 2. Estimates of land (left axis) and biomass (right axis) use for food, materials and energy in the longer term (to 2050). "High-intensive" land use includes cropland, forest plantations and energy crops plantations, and "low-intensive" land use includes permanent pasture, and semi-natural and modified forests. Uncertainty bars for land areas refer to likely span of the total of high-intensive and low-intensive land use. Data for 2005 from Table 1. Estimates for 2050 based on various sources (Berndes et al. 1996; Sohngen et al. 1999; Sedjo 2001; Berndes et al. 2003; Wirsenius et al. 2004; IEA 2006a; Wirsenius et al. in prep).

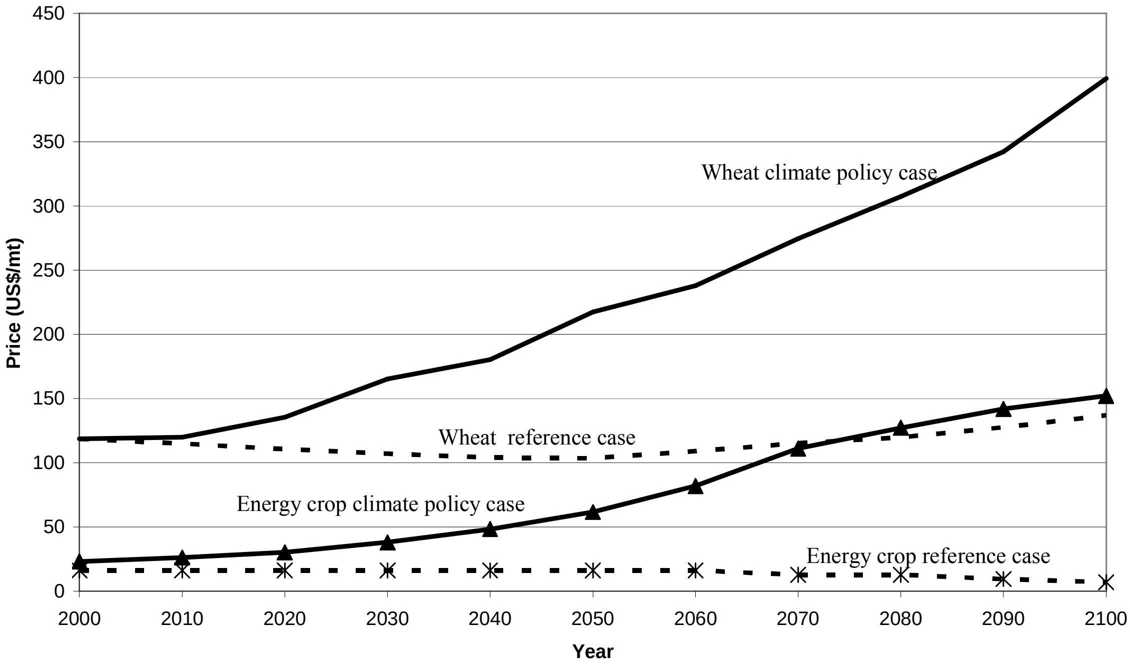

Figure 3. Modelled US farm gate prices for wheat and energy crops assuming gradually increasing costs for emitting CO_2 ("climate policy case"), from US$ 50/metric tonC to US$ 800/metric tonC by 2100. Crop prices given in US$ per dry metric ton. For comparison, US wheat price in June 2007 was about $220 per dry metric ton ($5.3 per Bu). From Johansson et al. (2007).

If stringent CO_2 policies are introduced that substantially increase the cost for emitting CO_2, there will undoubtedly be strong competition for agricultural land between food and bioenergy. Analyses have shown that this competition will lead to significant increases in prices for agricultural land as well as farm gate prices of crops and animal products (Schneider et al. 2003; Johansson et al. 2007). For higher CO_2 emission costs, cereal prices could arrive at levels far higher than today (see Figure 3), even if compared with the recently reached ten-year highs in global cereal prices.

The increases in land competition and food prices resulting from stringent CO_2 policies will have several knock-on effects on sustainable development issues other than those related to climate change. Higher food prices could enhance the development of agriculture in poorer countries and generate higher incomes to poor farmers. On the other hand, higher food prices are also likely to have adverse effects on the nutritional quality of the diet of poor land-less people, especially in developing countries that meet a large share of the food demand by imports at global markets. Due to the increased pressure for land and higher land prices, the risk for exploitation of forests and other pristine ecosystems for food and energy crops cultivation would rise, especially in tropical Latin America and South-East Asia. The increased pressure for agricultural land could also lead to dislocation of poor farmers without proper land owner rights. Policy measures should therefore be put in place to prevent or alleviate such negative knock-on effects, in conjunction with the implementation of policies aiming at reducing global CO_2 emissions.

REFERENCES

Berndes, G., M. Hoogwijk and R. van den Broek (2003). "The contribution of biomass in the future global energy supply: a review of 17 studies." Biomass and Bioenergy 25(1): 1-28.

Berndes, G. and S. Wirsenius (1996). "Biomass for energy, food and materials in an industrial society of 10 billion people." Renewable Energy 9(1-4): 926-929.

Borgström, G. (1969). Too many: A study of earth's biological limitations. New York, Macmillan

FAO (2006a). Global forest resources assessment 2005. Rome, Food and Agriculture Organization of the United Nations (FAO).

FAO (2006b). Global planted forests thematic study: Results and analysis. Rome, Food and Agriculture Organization (FAO).

FAO (2007). State of the world's forests 2007. Rome, Food and Agriculture Organization of the United Nations (FAO).

Fernandes, S. D., N. M. Trautmann, D. G. Streets, C. A. Roden and T. C. Bond (2007). "Global biofuel use, 1850-2000." Global Biogeochemical Cycles 21(2).

Gielen, D., J. Fujino, S. Hashimoto and Y. Moriguchi (2003). "Modeling of global biomass policies." Biomass & Bioenergy 25(2): 177-195.

Grahn, M., C. Azar, K. Lindgren, G. Berndes and D. Gielen (in press). "Biomass for heat or as transportation fuel? A comparison between two model-based studies." Biomass and Bioenergy In Press, Corrected Proof.

IEA (2006a). Energy technology perspectives: Scenarios and strategies to 2050. Paris, International Energy Agency (IEA).

IEA (2006b). World Energy Outlook 2006. Paris, International Energy Agency (IEA).

Johansson, D. J. A. and C. Azar (2007). "A scenario based analysis of land competition between food and bioenergy production in the US." Climatic Change 82(3-4): 267-291.

Mabee, W. E. and H. Pande (1997). Recovered and non-wood fibre: Effects of alternative fibres on global fibre supply. Rome, Food and Agriculture Organization of the United Nations (FAO).

OECD-FAO (2007). OECD-FAO Agricultural Outlook 2007-2016. Paris, Organisation for Economic Co-operation and Development (OECD).

Schneider, U. A. and B. A. McCarl (2003). "Economic potential of biomass based fuels for greenhouse gas emission mitigation." Environmental & Resource Economics 24(4): 291-312.

Sedjo, R. A. (2001). "The role of forest plantations in the world's future timber supply." Forestry Chronicle 77(2): 221-225.

Sohngen, B., R. Mendelsohn and R. Sedjo (1999). "Forest management, conservation, and global timber markets." American Journal of Agricultural Economics 81(1): 1-13.

van Vuuren, D. P., B. de Vries, B. Eickhout and T. Kram (2004). "Responses to technology and taxes in a simulated world." Energy Economics 26(4): 579-601.

Wirsenius, S. (2000). Human use of land and organic materials: Modeling the turnover of biomass in the global food system. Department of Physical Resource Theory. Göteborg, Chalmers University of Technology and Göteborg University.

Wirsenius, S. (2003a). "The biomass metabolism of the food system: A model-based survey of the global and regional turnover of food biomass." Journal of Industrial Ecology 7(1): 47-80.

Wirsenius, S. (2003b). "Efficiencies and biomass appropriation of food commodities on global and regional levels." Agricultural Systems 77(3): 219-255.

Wirsenius, S., C. Azar and G. Berndes (2004). Global bioenergy potentials: A new approach using a model-based assessment of biomass flows and land demand in the food and agriculture sector 2030. Second World Biomass Conference: Biomass for Energy, Industry and Climate Protection. W. P. M. van Swaaij, T. Fjällström, P. Helm and A. Grassi. Florence, ETA-Florence. 1: 471-474.

Wirsenius, S., G. Berndes and C. Azar (in prep). "How much land can livestock productivity increases and dietary changes spare for nature? Scenarios of agricultural land use in 2030" To be submitted to Food Policy.