Biomass for energy

how much is there?

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Biomass for energy: How much is there

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1. Introduction

In order to view the agricultural system (crops, animals, forestry) as an integrated food-energy-raw materials system, and particularly in order to derive quantitative estimates for the potential production of each product in the triangle, it is necessary to define more closely what principles are used to manage the agricultural system. This involves priorities, such as "food first" and basing the energy production primarily on residues, rather than from dedicated energy crops. The same principle may be used for raw materials, although today there is substantial dedicated growth for the wood industry. It further requires the principles of agriculture to be fixed, from chemical to organic growth philosophy. Fig. 1 gives the nomenclature that I am going to use. The preferred scenario for the future direction is the "sustainable agriculture", although neighbouring categories may also become of interest. The future use of agricultural residues for energy may well be totally different from the present, which is centred on the use of wood fuel, straw fuel, etc. With high-temperature gasification and further processing it is possible to derive energy in the form of ethanol, methanol or hydrogen, fuels that are much more useful in the future energy system than the present ones, and particularly in the transportation sector.

The Technology Council hosted some of the first quantitative estimates of Danish bio-energy potentials (Sørensen *et al*., 1994), and also in 1996 staged the consensus conference that defined the term "integrated agriculture" (cf. Fig. 1). The present estimates are based on a global study (Sørensen and Meibom, 2000; Sørensen, 2000), which supports the assumptions made for Denmark in the earlier work mentioned. I feel that it is important to view the development of agriculture in a global context, due to the extensive trade of food products taking place, and of course due to the global requirement of providing food and energy for an increasing population. Ecological farming in Denmark may yield some 10% less than the chemical agriculture, but it still yields several times more than agriculture in many poor countries. It is thus not so surprising, that it turns out to be possible to introduce at least sustainable agriculture globally and still feed everyone (assuming that distribution problems are solved) and leave a handsome surplus for energy needs.

Figs. 2 and 3 gives the analysis from the 1994 study of the present and possible future agricultural system in Denmark, spelled out in energy units. It is instructive to note that only about 10% of the harvested biomass ends up as food energy for Danish consumers. The implication is that there are residues along the conversion path from vegetable and animal production through the food industry and the household preparation tasks that may be used for substantial energy extraction. Many of these residues are already used today, for a variety of purposes, but outside the energy sector (ploughing residues down to provide nutrients in soil, using straw as spread in stables, making fodder from intestines of animals and building materials from bone flour, and so on). The proposal is to use new technology, that allows energy to be extracted from the residues, before they are passed on to the range of non-energy purposes (e.g. returning material from biogas or methanol plants to be used as fertiliser on the fields).

FIG. 1: NOMENCLATURE (Sørensen, 2000b)

Chemical agriculture (US)	**(nearly) anything goes**
Chemical agriculture (EU)	**no artificially manipulated genetic alterations**
Integrated agriculture	**chemical pesticides only when strongly needed**
Sustainable agriculture	**no genetic manipulation, no chemical pesticides**
Ecological agriculture	**no genetic manipulation, no chemical pesticides, no chemical fertiliser**
Biodynamic agriculture	**no genetic manipulation, no chemical pesticides, no chemical fertiliser, sow at new moon, etc.**

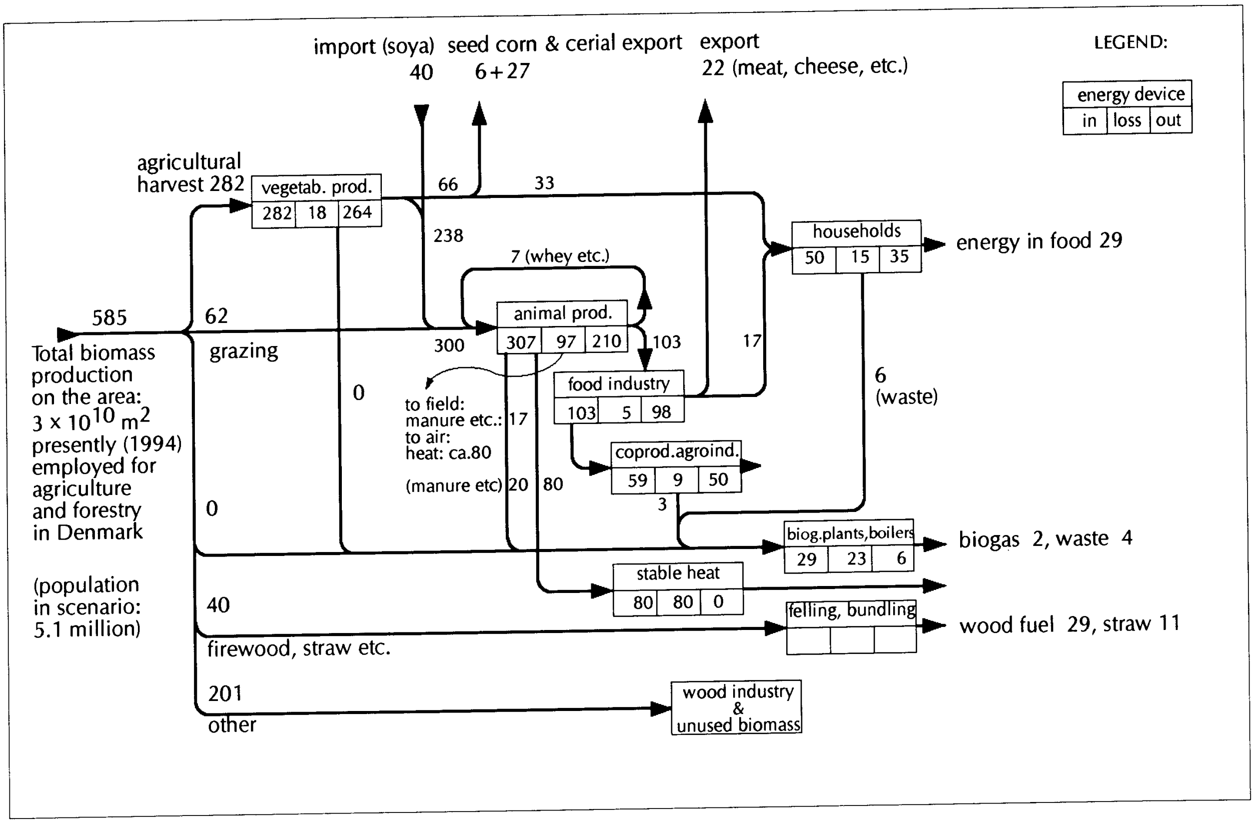


Figure 2. Overview of 1992 Danish biomass sector, with energy links but excluding indirect energy inputs for fertilisers, farm machinery etc. (units are PJ/y; Sørensen *et al.*, 1994; Kuemmel, Nielsen and Sørensen, 1997).

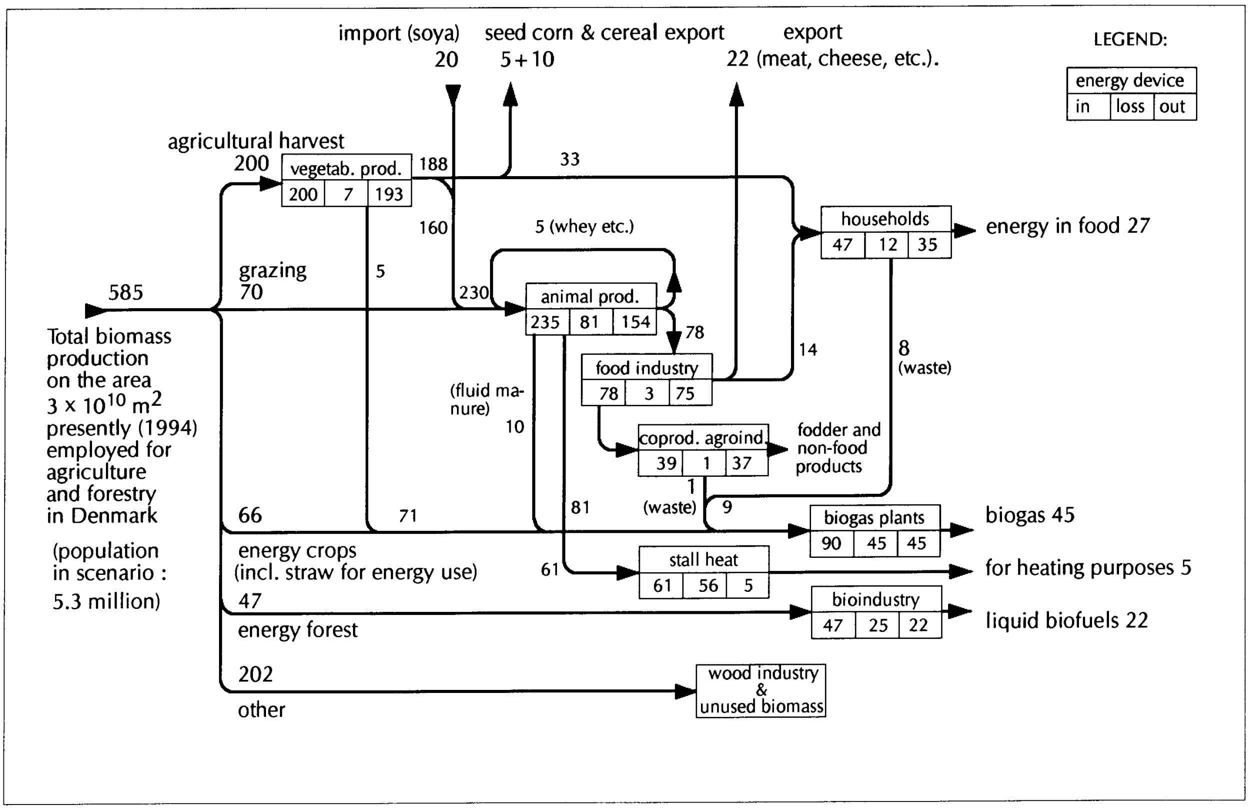


Figure 3. Danish 2030 ecologically sustainable scenario for the agricultural sector (Sørensen *et al*., 1994; Kuemmel, Nielsen and Sørensen, 1997).

2. Biomass model

The largest current use of renewable energy sources is in agriculture. Although the primary aim is food production, increasing amounts of residues are made useful for energy purposes and as feedstock in manufacturing industries. The same is true for fisheries and silviculture, where again the aim is to make productive use of the entire variety of products associated with biomass. The technologies employed have also changed in response to environmental concerns, from simple burning of straw and woodfuel to production of new bio-derived fuels, e.g. ethanol, methanol, methane and hydrogen. Here, it will generally be assumed that biomass used in a "decentralised" mode means using the land areas already devoted to agriculture and forestry, possible for other crops than those grown today and farming in a more efficient manner. Like for solar and wind power we then add some further potential uses that we denote "centralised", meaning in the biomass case cultivation of dedicated energy crops or energy forest.

The general model used for the biomass sector is shown in Fig. 4. It is a refinement of a model developed earlier (Sørensen *et al.*, 1994; Sørensen, 1995). Below each part of the model is explained and the numerical assumptions made are discussed.

2.1 Food production

The land area used for food crops is considered to be the same in 2050 as now. This primarily includes the cropland area fraction (*AF* in Fig. 4) given in Sørensen (2000), and for grazing also the rangeland. Some of the latter is today used for grazing in a little intensive way, in contrast to the use of cropland in rotation for occasional grazing. Crop cultivation on the cropland fraction is in some areas (e.g. Africa) little intensive, and present yields strongly reflect the agricultural practices of each region. As an indication of the potential biomass production on these areas, the calculated net primary production data from the “Terrestrial Ecosystem Model (TEM)” of the Woods Hole group is used (Melillo and Helfrich, 1998). Global warming may induce increased primary production in a fairly complex pattern and the borders of natural vegetation zones will change, sometimes by several hundred kilometres.

No consideration is made of greenhouse warming induced change in area fractions, because it is considered that diligent farming practices will allow a gradual replacement of the crops cultivated in response to such altered conditions, which are anyway long-term compared to the lives of annual crops. The present model does not specify which crops will be cultivated at a given location, but simply assumes a productivity consistent with growing crops suited for the conditions. The TEM data are for a mature ecosystem, and they take into account natural water, humidity and nutrient constraints along with solar radiation and temperature conditions. Annual crops are likely to have smaller yields, because of only partial ground cover during part of the year and the corresponding smaller capture of radiation. On the other hand, the crops selected for cultivation may be favourably adapted to the conditions and therefore give higher yields than the natural vegetation at the location. Furthermore, irrigation may prevent yield losses in dry periods, and application of chemical fertilisers may improve overall yields.

The value basis driving the 2050 scenario implies restrictive use of these techniques and suggests a move towards increased use of the ecological agriculture principles currently showing at the 10% level, area-wise, and mostly in Europe. The basis for the scenario will be an extension (corresponding to the concept "sustainable agriculture" defined above) of what is called “integrated agriculture” (Danish Technology Council, 1996), a concept where use of pesticides is banned and recycled vegetable residues and animal manure are the main sources of nutrient restoration, but where biological pest control and limited use of chemical fertilisers are not excluded. The yield losses implied by this method of farming is under 10%, according to current experience.

On cultivated land (including grazing land and managed forests) in regions such as Denmark, characterised by modest radiation and good soil and water access, the average annual biomass production is 0.62 W per m^2 (of which 0.3 W/m^2 are cereal crops; Sørensen *et al.*, 1994). This is exactly the value for a grid cell in Denmark given in the TEM database for mature natural productivity. In Southern Europe the current production is about half (Nielsen and Sørensen, 1998), while the TEM database gives a slightly higher value than for Denmark. The reasons for this are less intensive agricultural practice in Southern Europe and water limitations for the growth pattern of the crops cultivated (limitations that would be less severe for a mature ecosystem). It thus seems reasonable in the scenario to use the TEM as a proxy for cultivation yields, provided than one assumes better farming techniques used by year 2050, and assumes that irrigation and chemical fertilisers are used when necessary. These are precisely the assumptions stated above as the basis for the scenario. The net natural primary production data of the TEM are thus used globally, but without adding further increases on the basis of irrigation (which in dry regions can double agricultural output) and use of chemical fertilisers (which can provide a further doubling, if the soil is poor in nutrients or nutrients are not returned to the fields). In other words, one offsets the disadvantage in going from mature vegetation to annual crops against the advantage of reducing limiting factors related to water and nutrients. In Fig. 4, this means disregarding the irrigation and fertiliser parameters *IF* and *FI*, and proceeding with the potential production *PP* taken from the TEM database.

The TEM global biomass production estimates for *PP* are shown in Fig. 5, expressed in energy units (1 gram carbon per year is equal to a rate of energy production of 0.00133 W).

Currently, in Denmark only about 10% of this energy is contained in the food consumed domestically. The indication from this is, that there is room for altered management of the system, by diverting residues to energy extraction and later returning the nutrients to the fields. One may also note, that the current system is based on high meat consumption and the associated emphasis on animal raising, and in the Danish case export. By even the modest change in vegetable to animal food consumption ratio assumed in the demand scenario described in Sørensen (2000), it is possible globally to divert substantial amounts of biomass to energy purposes, without jeopardising the need to provide food for a growing world population.

It is not assumed that the intensive agricultural practices of Northern Europe will have been adopted globally by year 2050. The agricultural efficiency factor *AE* in Fig. 4 is taken as unity only for regions 1 and 2 (the industrialised countries). For Africa (region 6) it is taken as 0.4 and for the remaining regions as 0.7. The fraction of the biomass production actually harvested is taken globally as *HF* = 0.4. The remaining fraction consists of roots and residues plowed down in order to provide natural fertilisation for the following growth season.

Regarding the land areas classified as cropland, we assume the distribution on uses given in Table 1, based on cropland scarcity and traditions for animal raising. The low animal fodder value for Africa reflects the fact, that the African tradition for animal raising is based on rangeland, not cropland providing fodder.

Table 1. Parameters used for cropland biomass production in 2050 scenario (cf. Fig. 4)

Region	AE(cropland)	HF	UF (veget. food)	UF (fodder)	UF (energy crops)
1	1	0.4	0.4	0.5	0.1
2	1	0.4	0.4	0.5	0.1
3	0.7	0.4	0.5	0.5	0
4	0.7	0.4	0.4	0.5	0.1
5	0.7	0.4	0.7	0.3	0
6	0.4	0.4	0.8	0.2	0

The amounts of vegetable type food that can potentially be produced and delivered to the end-users in this scenario can now be calculated on an area basis, assuming the losses in going from vegetable food produced to vegetable food delivered as 25% (*IE(veg. products)* = 0.75 for vegetable food products in Fig. 4),

Delivered vegetable food = AF(cropl.) ´PP[W/m2] ´AE ´HF ´UF(veg. food) ´IE(veg. prod.),

where *AF* and *PP* depend on the precise geographical location, the others only on region. The calculated distribution of vegetable food delivered to the consumers is shown in Fig. 6. Regional totals are given in Sørensen (2000).

For food from animals, such as meat, milk and eggs, the average efficiency in transforming biomass to delivered animal products is assumed to be *IE(animal products)* = 0.15, a value reflecting a typical average of a smaller efficiency for meat production and a higher one for milk and eggs

(Sørensen et al., 1994). The amounts of animal-based food using cropland-derived fodder and delivered to the consumer is thus

Delivered animal food(1) = AF(cropl.)´PP[W/m2]´AE´HF´UF(fodder)´IE(anim. prod.).

The distribution of potential animal food deliveries based on the route where livestock is fed fodder produced on cropland is given in Sørensen (2000).

The other part of animal food is from animals grazing on rangeland, where we shall assume that livestock grazes *HF* = 0.4 of the biomass production per unit of area, and put *AE* = 1. The use of rangeland is assumed to be 50% for grazing and 50% for other purposes (such as energy crops or no commercial use). Thus the utilisation factor is taken as *UF(grazing)* = 0.5:

Delivered animal food(2) = AF(rangeland)´PP[W/m2]´HF´UF(grazing)´IE(anim. prod.).

The distribution of potential animal foodstuff delivered to the end-users through the route of rangeland grazing is shown in Fig. 8. The ratio of the two contributions (crop feeding and grazing routes) is determined by the area set aside for each. The resulting fraction of animal food derived from rangeland grazing is 37%, in terms of energy content.

The efficiency in the end-user's making use of the delivered food, denoted *EE* in Fig. 4, has for all the bioenergy routes been included in the definition of gross demand used in Sørensen (2000).

2.2 Biofuel production

A number of fuels may be produced from biomass and residues derived from vegetable and animal production, or from forestry and dedicated energy crops, ranging from fuels for direct combustion over biogas (mainly methane mixed with carbon dioxide) to liquid biofuels such as ethanol or methanol, or gaseous fuels such as synthesis gas (a mixture of mainly carbon monoxide and hydrogen, also being an intermediate step in producing methanol) or pure hydrogen. The production of biofuels by thermochemical processes is based on high-temperature gasification and various cleaning and transformation processes (Sørensen, 2000; Nielsen and Sørensen, 1998).

Whether the biofuel production is by thermal or biological processes, the expected conversion efficiency is of the order of *FE* = 50% (cf. Fig. 4). This is to be compounded with a factor describing the ability of the biofuel production industry to collect the necessary feedstocks. This collection efficiency factor, which is called *CF*, describes the efficiency in collecting biomass for such industrial uses. For vegetable foods, it is assumed that *CF(veg. waste)* = 25% of the gross production is available for energy production (some of this would come from the food industry losses of *(1-IE(veg. prod.))* = 25%, some from the subsequent household losses of 30%, cf. the previous section). The overall yield of biofuels from vegetable crops is then

Biofuels from vegetable foodcrops =

AF(cropl.)´PP[W/m2]´AE´HF´UF(veg. food)´CF(veg. waste)´FE.

Considering manure, this would be available only when livestock are in stables or otherwise allows easy collection. The assumption is here that grazing animals leave manure in the fields and that this is not collected (although it could be in some cases), but that animals being fed fodder from crops will be in situations where collection of manure is feasible. Furthermore, although the 85% of animal biomass not ending up in food products will both be used to maintain the metabolism of livestock animals and the process of producing manure, it will also contain a fraction that may be used directly for fuel production (e.g. slaughterhouse wastes). Combined with manure this is assumed to amount to *CF(anim.)*= 0.6, giving for the fodder to animal route to biofuels:

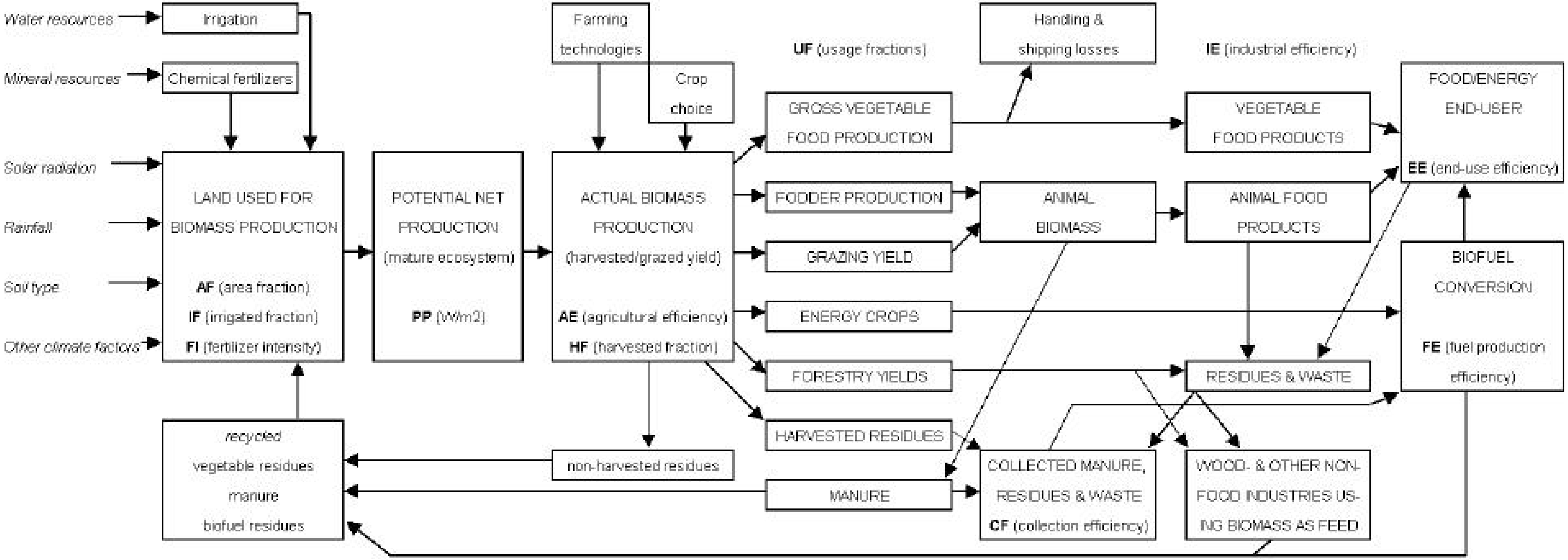


Figure 4. Overview of the model used for the agricultural and silvicultural system.

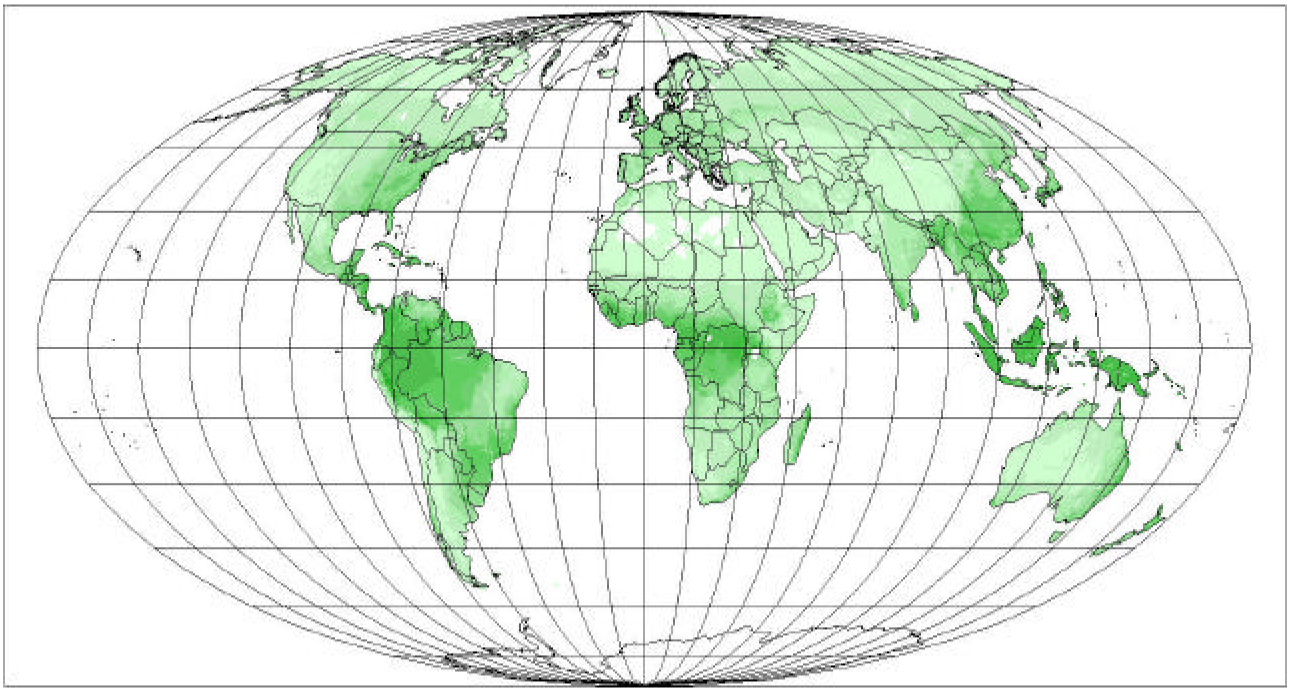
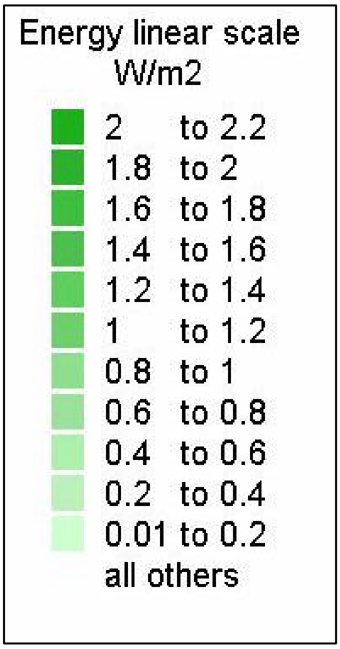
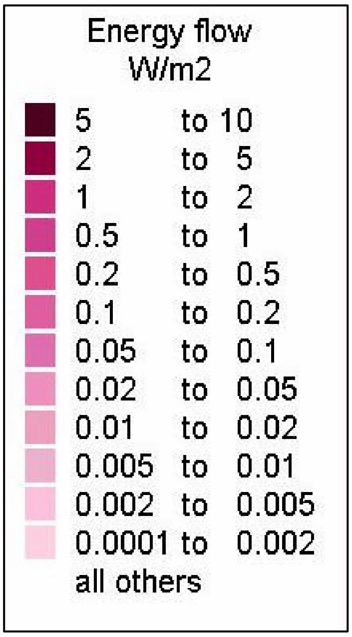


Figure 5. Annual average energy content of potential net biomass production in mature ecosystems (based on Melillo and Helfrich, 1998; scale given below).

Scale for Figure 5. Net primary production energy scale (W/m^2, the scale is linear).





Scale for Figures 6-11. Scale of energy flow (used for both energy production and use) (W/m^2).

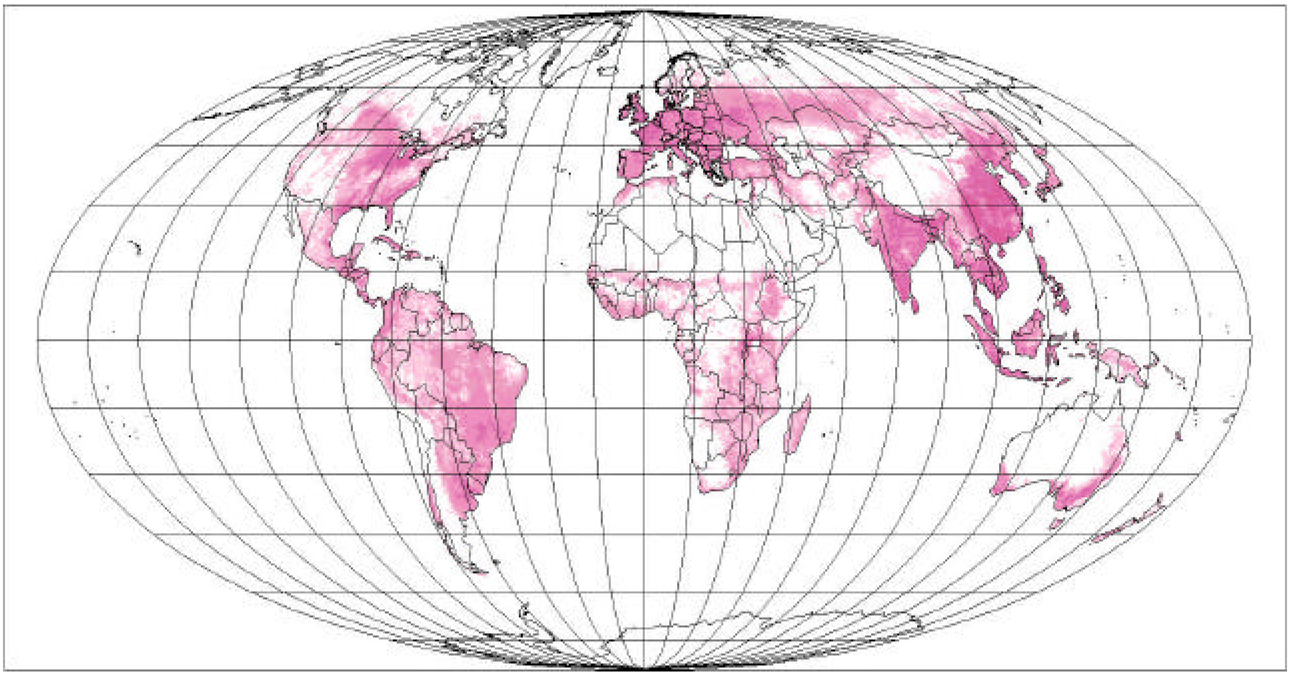


Figure 6. Potential vegetable food delivery to final consumers in 2050 scenario, derived from cropland production and expressed by annual energy content (scale above).

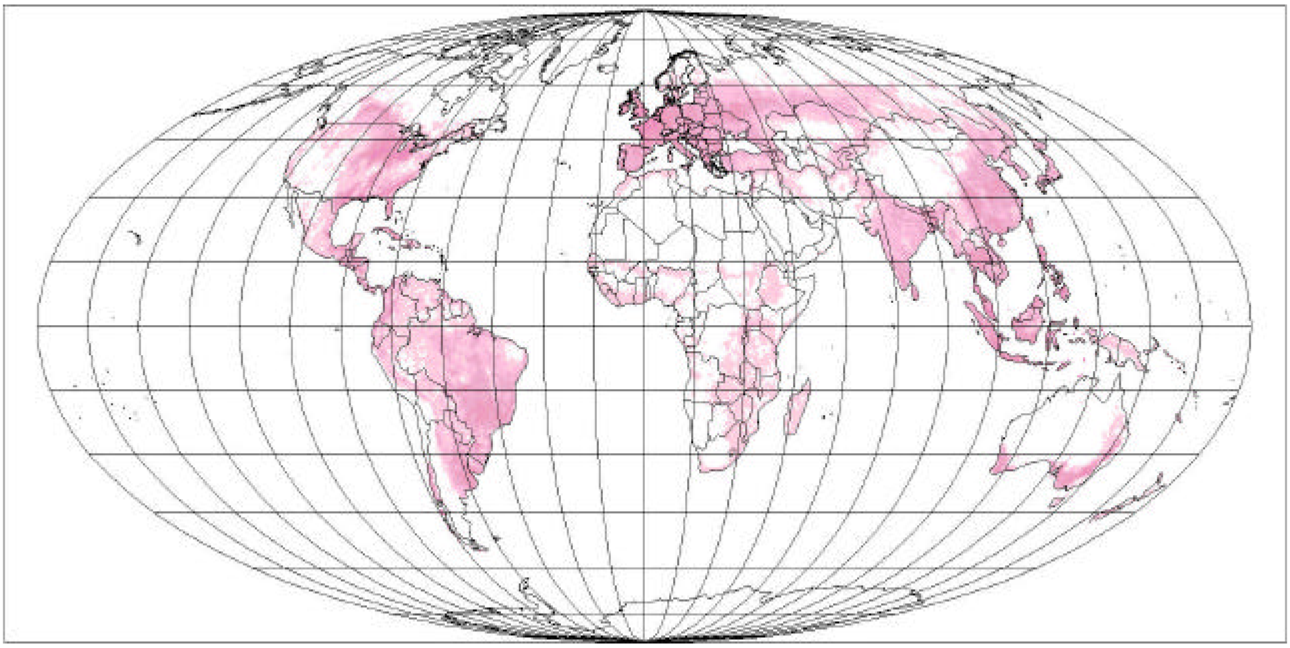


Figure 7. Potential animal food delivery to final consumers in 2050 scenario, for the fraction of animals being fed fodder grown on cropland, expressed by annual energy content (scale above).

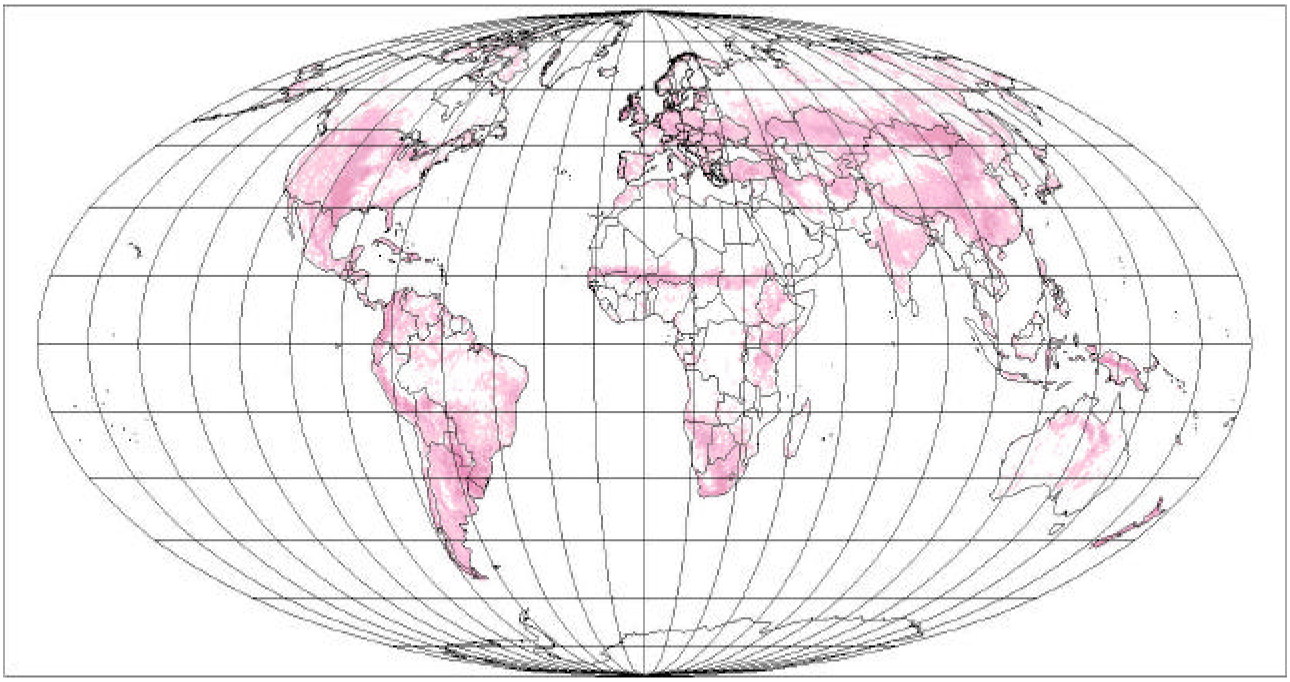


Figure 8. Potential animal food delivery to final consumers in 2050 scenario, for the fraction of animals grazing on rangeland, expressed by annual energy content (scale above).

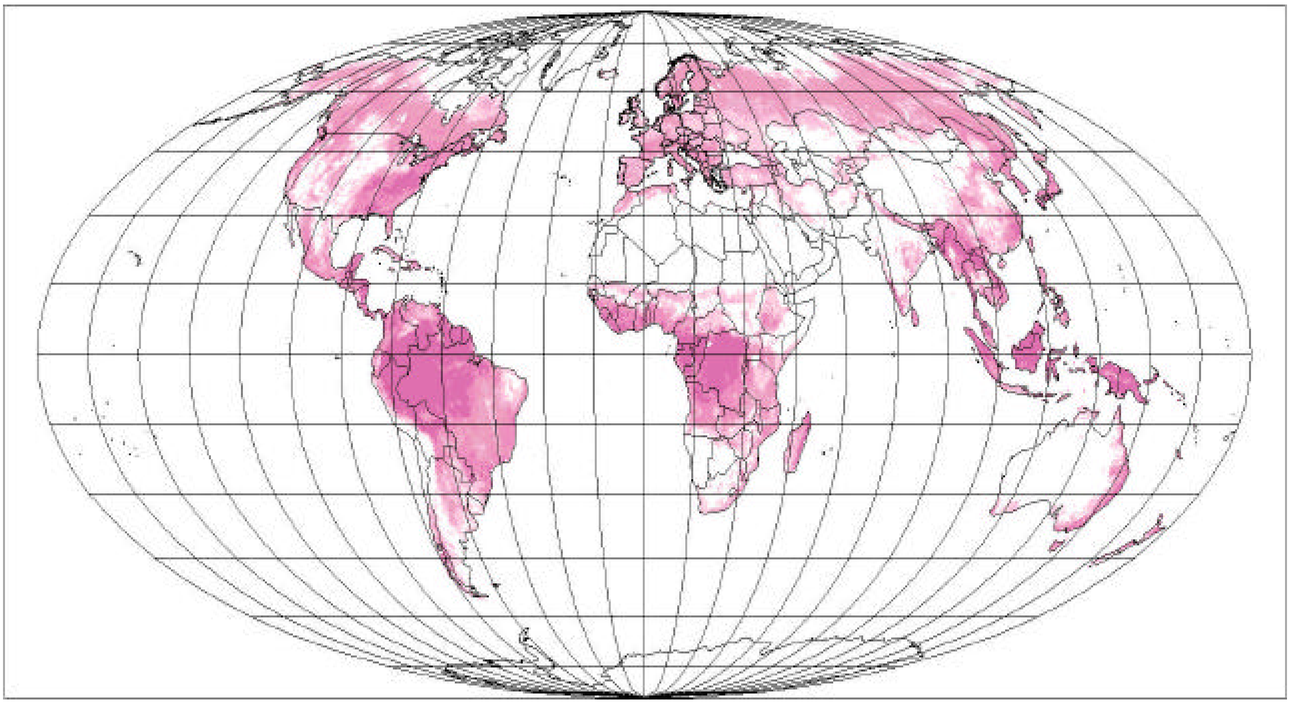


Figure 9. Potential biofuels produced and delivered to final consumers in 2050 scenario, from use of forestry residues and wood waste, expressed by annual energy content (scale above).

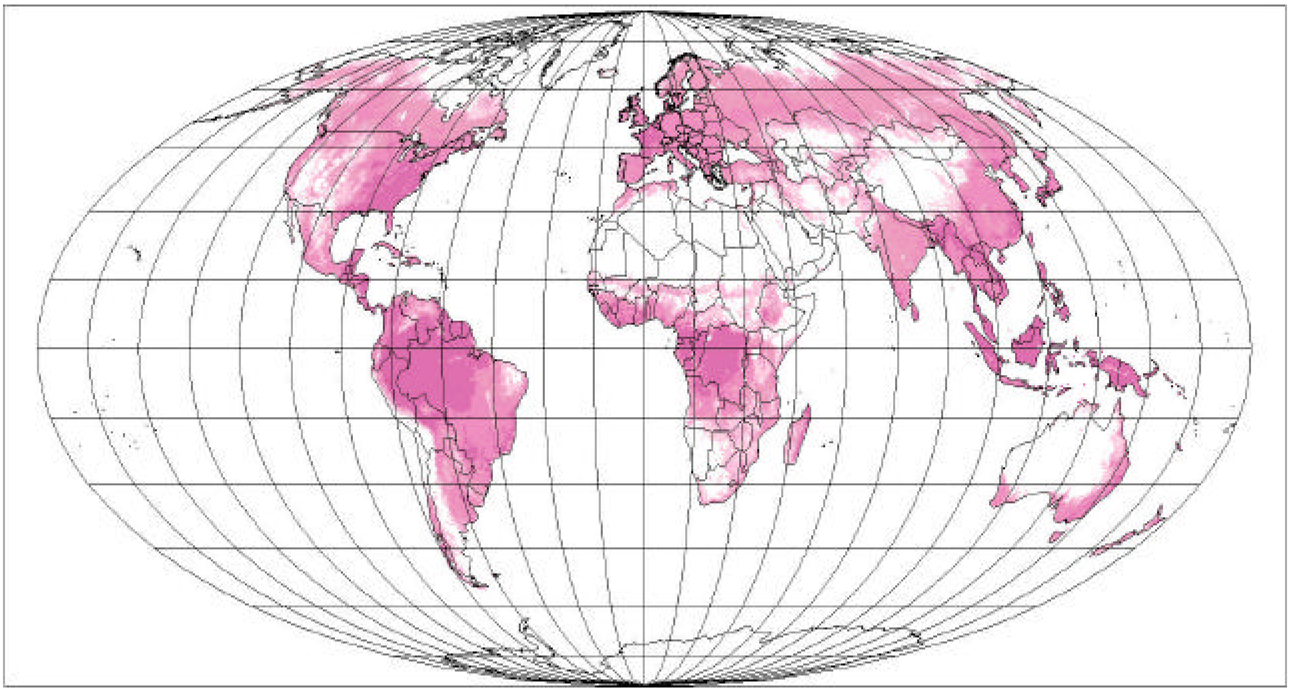


Figure 10. Potential delivery of biofuels to final consumers in 2050 scenario, from forestry (cf. Figure 9) and from agricultural residues, manure and waste from households and food industry, expressed by annual energy content (scale above).

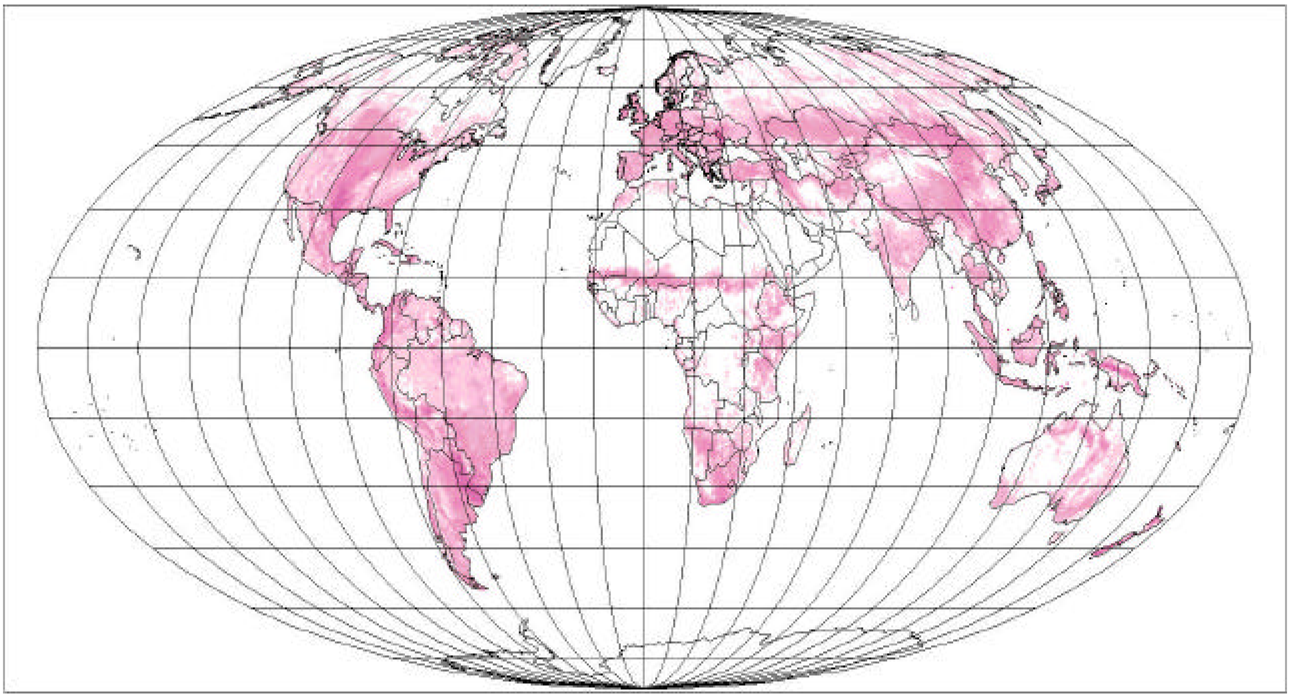


Figure 11. Potential delivery of biofuels to final consumers in 2050 scenario, from centralised production, i.e. special energy crops grown on part of rangeland and minor parts of cropland, expressed by annual energy content (scale above).

Biofuels from manure and other animal residues =

AF(cropl.) ´PP[W/m2] ´AE ´HF ´UF(fodder) ´(1-IE(anim. prod.)) ´CF(anim.) ´FE

The further possibility of producing biofuels from forestry residues (either scrap derived from the wood industry or residues collected as part of forest management) may be described by a factor *CF(forestry)* = 0.3, defined as a percentage of the total forest biomass production. This is the fraction collected, expressed in energy units. For managed forests it depends on the fraction of wood being suitable for the wood manufacturing industry (furniture etc.), which again depends on the tree type. Adding wood scrap from industry and discarded wooden items, as well as from forest management would in many regions exceed 30%. However, as the basis is an enumeration of all forests including the rainforests and other preservation-worthy forest areas that are not suggested to be touched, and considering only managed forests that deliver to wood industries, 30% is probably a maximum for year 2050. The forest residue to biofuel route is then

Biofuels from forest management =

AF(forestland) ´PP[W/m2] ´HF ´CF(forestry) ´FE

The potential amounts of biofuels that could be derived from forestry are shown in Fig. 9, and the sum of the three routes to biofuels described above are given on an area bases in Fig. 10. This is denoted "decentralised fuel production", although forestry may not be seen as entirely decentral in nature. However, it is an ongoing activity and distinct from producing biofuels from land used exclusively for energy crops. Two energy crop routes are included:

While the biomass production on rangeland does not give rise to biofuel production because manure from grazing livestock is not collected, some of the rangeland may be suited for cultivation of dedicated energy crops. As only 50% has been assumed used for grazing, the remaining 50% shall be regarded as potentially exploitable for energy purposes, in the scenario versions where centralised energy schemes are found acceptable (i.e. *UF(rangeland energy crops)*=0.5). On cropland it is further assumed that 10% may be set aside for energy crops in areas of generous resources, such as Western Europe and the Americas (see the *UF(cropland energy crops)* values of 0.1 or 0 in Table 1). The potential biofuel production from these areas is

Biofuels from energy crops on cropland =

AF(cropl.) ´PP[W/m2] ´AE ´HF ´UF(cropland energy crops) ´FE,

Biofuels from energy crops on rangeland =

AF(rangeland) ´PP[W/m2] ´HF ´UF(rangeland energy crops) ´FE.

where *FE* =0.5. The area distribution of these two potential sources of biofuels from energy crops is shown in Fig 11.

References

Danish Technology Council (1996). Lysegrønt landbrug, Konsensus konference rapport 1994/5

Kuemmel, B., Nielsen, S., Sørensen, B. (1997). Life-cycle analysis of energy systems, Roskilde University Press, København

Melillo, J. and Helfrich, J. (1998). NPP database created under NASA and EPRI grants, cf. Melillo *et al.*, Nature, vol. 363 (1993) 234-240

Nielsen, S. and Sørensen, B. (1998). A fair-market scenario of the European energy system, pp. 127-186 in "Long-term integration of renewable energy sources into the European energy system" (LTI Research Group), European Commission/Physica Verlag, Bonn

Sørensen, B. (1979). Renewable Energy, Academic Press, London, 692 pp

Sørensen, B. (1995). Strategy for a rich, fulfilling and sustainable society, pp. 83-101 in "Expanding environmental perspectives" (Lundgren, Nilsson and Schlyter, eds.), Lund University Press.

Sørensen, B. (2000). Renewable Energy, 2nd edition, Academic press, London, 912 pp

Sørensen, B. (2000b). Biofuel potential assessment. In Workshop Proc. "Energy and food from biomass". (C. Azar and B. de Vries, eds.), Chalmers/Göteborg University

Sørensen, B. and Meibom, P. (2000). A global renewable energy scenario, Int. Journal Global Energy Issues, vol. 13, pp. 196-276

Sørensen, B., Nielsen, L., Petersen, S., Illum, K., Morthorst, P. (1994). Fremtidens vedvarende energisystem. 68 pp. Danish Technology Council, Report 1994/3 (in Danish; available at website http://www.tekno.dk/udgiv/943/943all.htm)