BIOMASS FOR ENERGY: HOW MUCH IS SUSTAINABLE?

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ABSTRACT: It is demonstrated that it is possible to provide the projected 21st century world population with adequate food (if trade and distribution problems can be solved), and still extract energy in substantial quantities while recycling nutrients to fields and forests. The scenario is consistent with sustainability and a global abolition of chemical pesticides and genetic manipulation of crops.
Keywords: Carrying capacity estimate, ecological farming methods, sustainability, energy production scenarios.

1 INTRODUCTION

The largest current use of renewable energy sources is associated with 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 the aim is to make productive use of the entire variety of products associated with biomass. The technologies employed for bio-energy conversion have 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. The aim of the present paper is to estimate the total amounts of biomass that could be made available in either a "decentralised" or a "centralised" mode, by use of a model developed recently, on the basis of soil classification and satellite measurements of biomass standing crops, solar input and precipitation ([3,5], with use of [1]). Parameters in the calculations include the cultivation method used, such as use of irrigation, recycling of nutrients, and integrated management of animal and plant production. Full details are given in [5], preliminary versions have been presented in [6,7].

In the "decentralised" mode, only land areas already devoted to agriculture and forestry are used, but possibly for other crops than those grown today and by farming in a more efficient manner. Several limiting factors have been considered. In the "centralised" mode, further biomass resources are put in use, based upon cultivation of dedicated energy crops or energy forest, but with respect for maintaining biological diversity. The model allows food, bio-energy and industrial bio-feedstock to be estimated on a geographical basis and with specified cultivation techniques (such as conventional or ecological farming). The results are used for construction of scenarios for future uses of biomass in the energy sector, under the constraint of the required delivery of food to a growing world population.

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 a substantial dedicated growth for the wood industry. It further requires the principles of agriculture to be fixed, from chemical to organic growth philosophy. Table 1 defines the nomenclature that I am going to use. The preferred scheme assumed in the work described here is the "sustainable agriculture", although neighbouring categories may also be considered.

2 BIOMASS MODEL

The general model used for the biomass supply sector is shown in Fig. 1. It is a refinement of a model developed earlier [4], and is fully described in [5].

The land area used for food crops is considered to be the same in 2050 as now. This primarily includes the cropland area given in [5], 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.

Greenhouse warming-induced change in areas are not included, 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 scenarios presented here 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, in parts of Europe. The basis for the scenarios will be a sustainable and integrated agriculture (cf. Table 1), 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 [4]). 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, 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 could double agricultural output), or 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. 1, 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. 2, 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 [5], 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. 1 is taken as unity only for the industrialised countries. For Africa it is taken as 0.4 and for the remaining parts of the world 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 ploughed down in order to provide natural fertilisation for the following growth season.

3 POTENTIAL BIOFUEL PRODUCTION

In the decentralised 2050 scenario, biofuels are produced on the basis of residues from agriculture and forestry, as well as from manure and waste from both households and selected industries, such as the food industry. A set of restrictions on the amount of biomass material, that can be conveniently recycled and used for energy purposes, are used to estimate the potential feedstock. For example, manure is only collected during the winter season, when livestock animals are in stables and mechanical collection is feasible. For forestry residues, 30% are assumed to be collected. The full range of assumptions are listed in [5]. When these biomass resources are converted to biofuels, an efficiency of 50% has been assumed (current technologies for biogas, methanol or hydrogen production have overall efficiencies in the range of 40-60% [5]). Following energy extraction, it is often possible to recycle nutrients to the fields or forests. In the case of biogas production, the residue is a homogeneous fertiliser of much higher quality than the feedstock. For high-temperature non-biological conversion processes, there is a solid residue containing the residues, which may be incorporated in fertiliser products to replace or supplement the chemical fertilisers.

Fig. 3 shows the energy content in the biofuels produced in this way, on a geographical basis (using the same 50 by 50 km grid as in Fig 1). The total world production of biofuels is then sufficient for covering the needs of highly energy-efficient 2050 scenario (which are notably in the transportation sector), provided that energy trade is securing supplies to cities in Europe and Asia. The largest source of surplus is in South America [5].

The centralised 2050 scenario allows a modest amount of dedicated energy crops, in order to yield larger flexibility in supply, as compared with the very tight decentralised scenario. The energy crops are assumed to be grown on parts of the rangeland areas (typically 50% for grazing and 50% for energy crops), plus very small parts of cropland (10% in areas of surplus arable areas). Fig. 4 shows the geographical distribution of such potential biofuel production. Several of the areas are areas of deficit, implying that the imports can be reduced, but there is still major biofuel exports from South America.

4 CONCLUSION

This work has estimated the global potential production of biomass and the amount that may be used for energy purposes once the food needs of a growing world population has been satisfied. It is found that there is sufficient biomass resources, if they are converted by appropriate techniques and if nutrients are recycled, to cover the biofuel requirements of scenarios for the mid-21^{st} century, in scenarios based upon efficient end-use conversion equipment and for the rest of the energy supply uses solar, wind and (existing) hydro energy. Details are in [5]. The variant called "centralised" adds a modest amount of dedicated energy crops grown on land not used for agriculture. It provides enhanced resilience of the scenario, making it much more robust against changes in demand assumptions or the possibly adverse implications of climatic change on crop yields.*

Table 1: Nomenclature of sustainability levels **(**based upon [6,7])

Totally manipulated agriculture	**chemical agents used for weeding & pest control, artificial biological and genetic substances used**
Classical chemical agriculture	**chemical agents accepted, artificial genetic alter-ations not (except by cross-breeding and selection)**
Integrated agriculture	**chemical pesticides only when perceived as strongly needed**
Sustainable agriculture	**no genetic manipulation, no chemical pesticides (biological pest control used instead)**
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.**

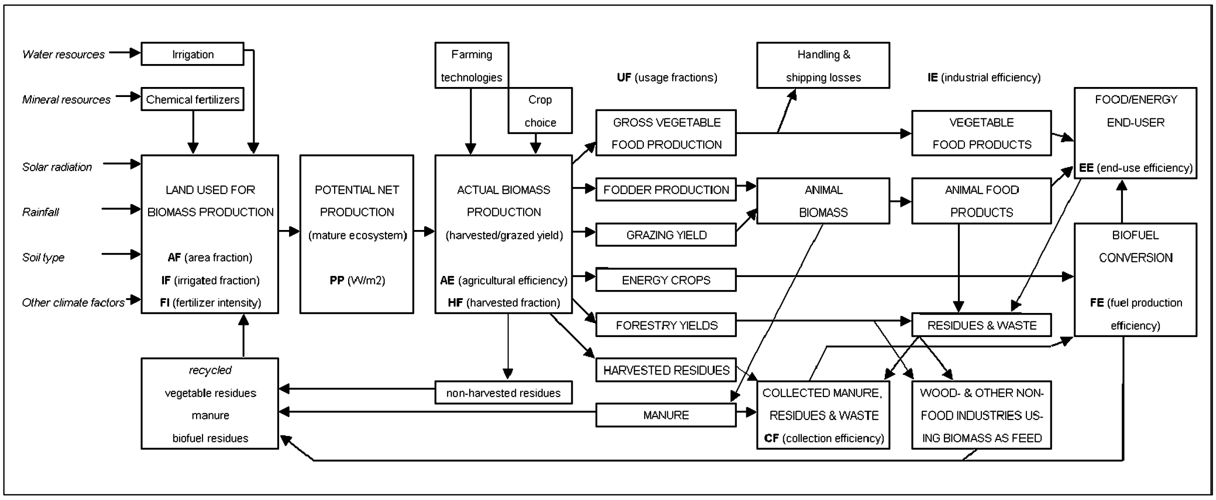

Figure 1. Overview of the model used for the agricultural and silvicultural system [5]

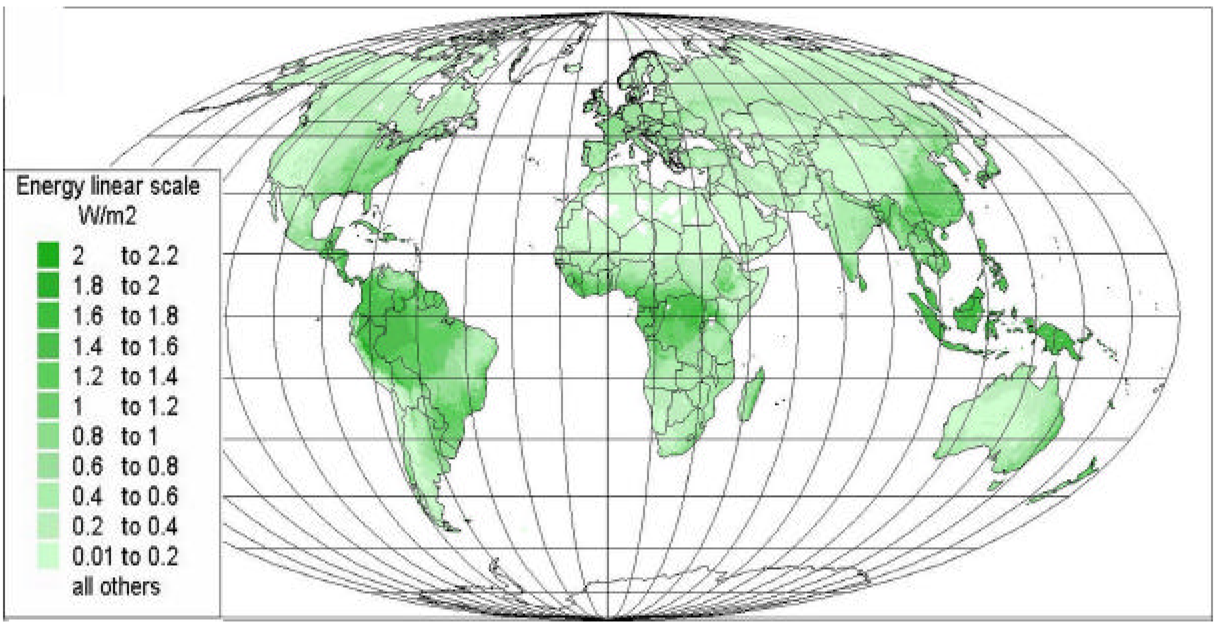

Figure 2. Annual average energy content of potential net biomass production in mature ecosystems ([5], with use of [1]; the employed scale in W/m^2 is linear).

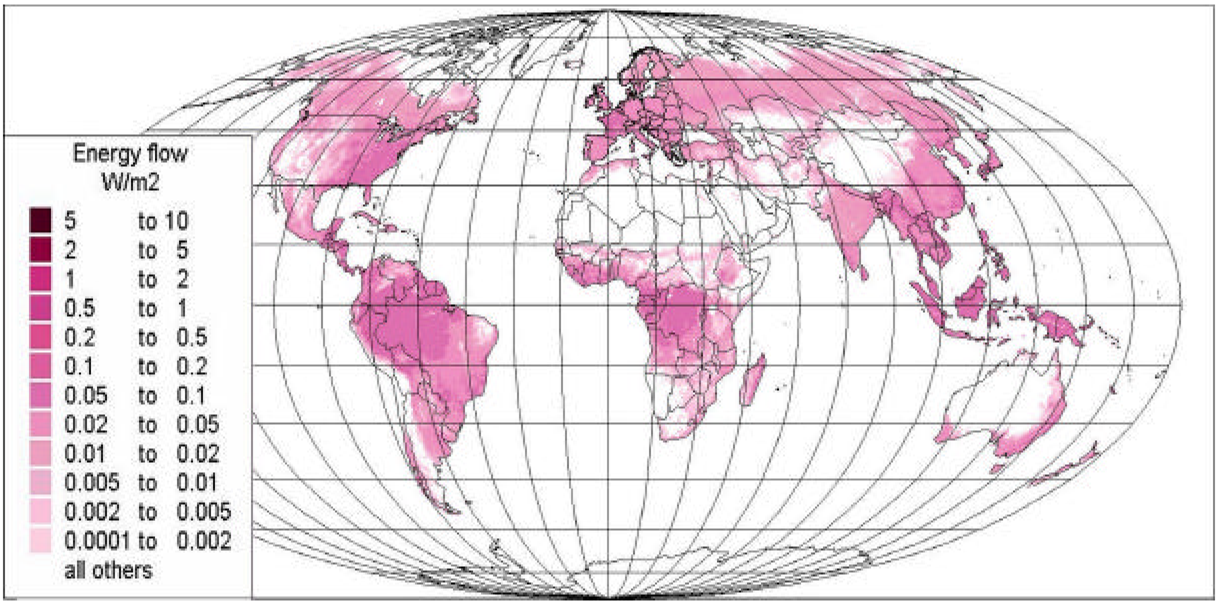

Figure 3. Potential delivery of biofuels to final consumers in 2050 scenario, from forestry and agricultural residues, manure and waste from households and food industry, expressed by annual energy content ([5]; logarithmic scale).

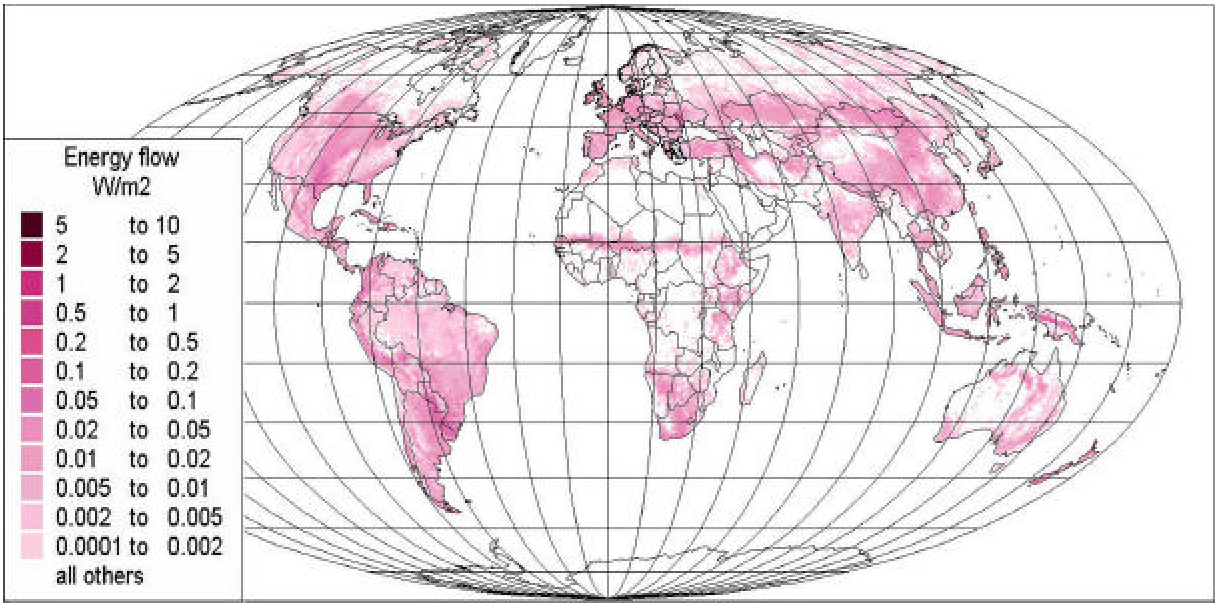

Figure 4. Potential delivery of biofuels to final consumers in 2050 scenario, from centralised production, i.e. energy crops grown on part of rangeland and minor parts of cropland, expressed by annual energy content ([5]; logarithmic scale).

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