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Assessment of the potential biomass supply in Europe using a resource-focused approach

Karin Ericsson*, Lars J. Nilsson

Environmental and Energy System Studies, Lund University, Gerdagatan 13SE-223 62 Lund, Sweden

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Abstract

This paper analyses the potential biomass supply in the 15 EU countries (EU15), 8 new member states and 2 candidate countries (ACC10), plus Belarus and the Ukraine. The objective of this study is to make a more detailed assessment of the potential in Europe than previously undertaken. For this purpose five scenarios were designed to describe the short-, medium- and long-term potential of biomass for energy. The scenarios are based on assumptions regarding residue harvests, energy-crop yields and surplus agricultural land. Energy-crop yields are correlated with the national wheat yields, a methodology we have not seen used in biomass assessments before. Our assessments show that under certain restrictions on land availability, the potential supply of biomass energy amounts to up to 11.7 EJy^{-1} in the EU15 and 5.5 EJy^{-1} in the ACC10. For comparison, the overall energy supply in the EU15 totalled 62.6 EJy^{-1} in 2001. Consequently, there are no important resource limitations in meeting the biomass target, 5.6 EJy^{-1} in the EU15 by 2010, which was set by the European Commission in the 1997 White paper on renewable energy sources (RES). However, given the slow implementation of the RES policy it is very unlikely that the biomass targets will be met.

1. Introduction

The generation of energy from biomass has a key role in current EU strategies to mitigate climate change and enhance energy security. Biomass can contribute in stabilizing carbon dioxide concentrations in the atmosphere in two ways, through: (1) biomass production for fossil fuel substitution and (2) carbon dioxide storage in vegetation and soil. This study is concerned only with biomass production for energy use, which has been shown to be the most effective strategy of the two [1]. In order to reduce the carbon dioxide emissions in Europe, the Commission adopted a Green Paper in 1996, which calls for an increase in the proportion of renewable energy sources (RES) in the primary energy supply from 6% (1996) to 12% in 2010 [2]. Subsequently, two directives have been adopted. Biomass-based electricity is being promoted in the Green Electricity Directive, which aims to increase the fraction of electricity from RES to 22% by 2010 [3]. Electricity from RES accounted for 13.7% in the EU in 2002 [4]. Biofuels are also being promoted in the transportation sector. The Renewable Transportation Directive from 2003 sets out to increase the share of biofuels in transportation fuels to 2% by 2005 and 5% by 2010 [5].

Apart from its positive environmental aspects, bioenergy is also perceived as a means for the EU to decrease its dependence on external energy supplies. The EU15 imported some 50% of its energy requirements in 2002, a figure that will rise to about 70% in 2030 if current trends persist [6]. Diversifying energy carriers and supplying regions/countries and expanding the use of local energy resources, such as biomass, would improve security of supply.

In order to understand the future role of bioenergy in Europe, it is important to analyse potential biomass-for-energy resources. Berndes et al. distinguish between two different approaches for these assessments: demand-driven[1]

*Corresponding author. Tel: +46 46 222 3286; fax: +46 46 222 8644.
E-mail address: karin.ericsson@miljo.lth.se (K. Ericsson).

[1]Demand-driven assessments analyse the competitiveness of biomass-based electricity and biofuels, or estimate the amount of biomass required to meet exogenous targets on climate-neutral energy supply (demand side).

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and resource-focused[2] [7]. This paper applies the second approach. A number of resource-focused assessments have been made in recent years regarding the potential bioenergy supply on an aggregated level, i.e. by Hall et al. [8], Johansson et al. [9], Fischer and Schrattenholzer [10], Yamamoto et al. [11] and Hoogwijk et al. [12]. Because of the worldwide geographical scope of these studies, assumptions about the average productivity of forest and agricultural land were typically made for continents or large regions. Competition for land was taken into account through utilization of projections on population and economic development, making the assessments rather realistic, but also complex and non-transparent. Although several national assessments have been made over time in Europe, the methodologies used differ greatly, thus making it difficult to compare their results. This paper presents more detailed assessments of the potential in Europe than previously reported, and has a European geographical scope. The same methodology is applied to all countries. Competition for land is also considered, although in a strictly European perspective. Assuming national implementation of the EU policies on renewables and bioenergy, knowledge about the distribution of the potential biomass resources may give insight into how the biofuel market in Europe may develop; whether there will be mostly local/national markets or an international market. Since the European countries are widely heterogeneous in terms of agriculture, forestry and population density, the opportunities for biomass production differ considerably. Thus, expanding the use of bioenergy may both require and lead to a growing intra-continental biofuel trade. Obviously, treating Europe as being isolated from the rest of the world to some extent limits the possibility of drawing conclusions about future biofuel markets. This and other simplifications, however, also make the assessments transparent.

The objective of this study was to analyse the potential biomass resources available for energy in the EU15, eight new EU member states and two candidate countries (collectively referred to as the ACC10, which consists of Bulgaria, the Czech Republic, Hungary, Poland, Romania, Slovakia, Slovenia, Estonia, Latvia and Lithuania), plus Belarus and the Ukraine. For this purpose we designed five scenarios. The distribution of the potential biomass supply in Europe, both in absolute numbers (PJ) and relative numbers (GJ/capita), is mapped. The potential supply from agricultural land relative to forest land is also studied. The following biomass categories are included: forest residues and industry by-products, straw, maize residues and energy crops. Due to the fact that there is limited experience of energy-crop cultivation in most of Europe and no reliable national data on energy-crop yields, we utilized national statistics on wheat yields and correlated them with energy-crop yields. This is a method which we have not seen used before in assessments of biomass potential. It has the advantage of being transparent and simple.

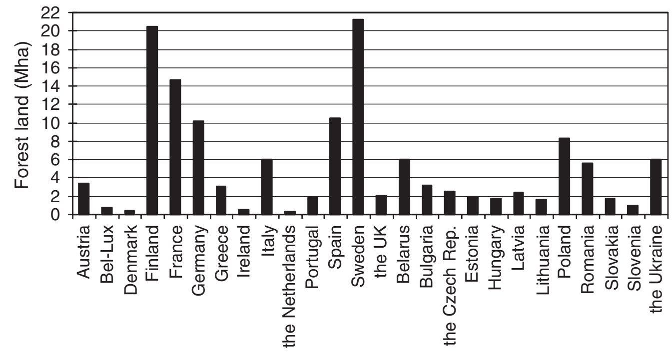

Fig. 1. Distribution of exploitable forest land in the EU15, the ACC10, Belarus and the Ukraine [13].

2. Forest and agricultural land in Europe

The exploitable forests[3] cover about 92 Mha (29%) in the EU15 and 30 Mha (29%) in the ACC10. Within these regions the distribution of forest land varies greatly, from 67% and 51% in Finland and Slovenia, respectively, to 8% and 18% in Ireland and Hungary, respectively (Fig. 1). In addition, other forest land totals 23 and 1.1 Mha, in the EU15 and ACC10, respectively [13]. The exploitable forest area is expected to remain unchanged in the future, although a number of countries have policies for forest expansion. Afforestation, however, will mainly compensate for the loss of productive forest land to other uses including nature reserves. Most of the afforestation is anticipated in Spain, France and Poland [14].

European forests are very diverse in their ecology and natural productivity. The growing stock per hectare varies greatly, being rather low in Northern and Southern Europe (90 $m^3 ha^{-1}$ in Finland, 50 $m^3 ha^{-1}$ in Spain)[4] compared with Central Europe (310 $m^3 ha^{-1}$ in Austria) [14]. Ecologically, the forests vary, from boreal forests near the tree line in northern Scandinavia to Mediterranean scrub in the south.

The most important land use in the EU15, as well as the ACC10, is agriculture, covering 141 Mha (45%) and 60 Mha (57%) of the land areas, respectively. The proportions of agricultural land, however, vary considerably over the continent, being only 7% and 8% in Sweden and Finland, and 70% and 60% in the UK and Poland, respectively (Fig. 2) [15].

Based on a study by Olesen and Bindi [16], European agriculture can be divided into a number of regions determined by soil and climate. Typical constraints on productivity in Northern Europe are length of growing season and the geological conditions (low incidence of clay soils), which explain the low proportions of agricultural

[2] Resource-focused assessments focus on the total bioenergy resource base and the competition between different uses of the resource (supply side).

[3] Forests available for wood supply according to the definition of the Temperate and Boreal Forest Resource Assessment 2000 (TBFRA-2000).

[4] Standing volume; stem volume over bark from stump to tip.

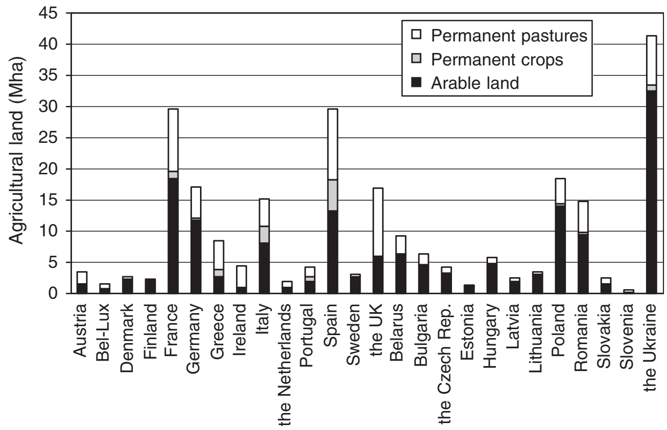

Fig. 2. Distribution of agricultural land in the EU15, the ACC10, the Ukraine and Belarus. [15].

land in Sweden and Finland. The areas along the Atlantic coast, including Ireland and the UK, and the Alpine countries, are characterized by wet conditions that favour permanent pastures but lead to yield and quality losses for several arable crops. Livestock production thus dominates farming in these regions, while arable farming is less common. Arable land, on the other hand, is the most common form of agricultural land use in most of Europe, notably in the ACC10, the Ukraine, Denmark and Germany. The most productive regions, in terms of soil and climate, are located on the great European plain, stretching from Southeast England, through France, Benelux[5] and Germany into western Poland. Equally good conditions can be found in Hungary. The continental climate of Eastern Europe (central Poland and eastwards) is somewhat less favourable, due to relatively little precipitation and the amplitude of the annual temperature cycle, which reduces the choice of crops. Restricted rainfall is to an even larger extent characteristic for the Mediterranean region, which enjoys a relatively warm climate and long growing season. Due to these conditions, permanent crops such as olives, grapes and fruit trees play an important role in Mediterranean farming. Arable farming, however, is constrained by the dry conditions which largely explain the relatively low cereal yields in Southern Europe.

Agricultural productivity also varies widely over Europe due to variations in management practices. For example, it is clear that the yields in the ACC10 are relatively low compared with those in the EU15, a fact that mirrors the disparity of the socio-economic conditions in these regions rather than soil and climatic conditions.

3. Methods, data and assumptions

3.1. General approach

The potential bioenergy supply in Europe is analysed using a resource-focused approach. Biomass categories included in the study are: forest residues, forest industry by-products, straw, maize residues and energy crops. Municipal solid waste, used wood (e.g. demolition wood and railway sleepers) and manure are excluded.

The biomass assessments are made on the national level and include the EU15, eight new EU member states and two candidate countries (collectively referred to as ACC10), plus Belarus and the Ukraine. The ACC10 consists of: Bulgaria, the Czech Republic, Hungary, Poland, Romania, Slovakia, Slovenia, Estonia, Latvia and Lithuania. Sometimes the first seven of these countries, i.e. all but the Baltic countries, are referred to as Central and Eastern Europe (CEE), due to their common historical and economical development. In addition, FSU is sometimes used here to refer to the countries that belonged to the Former Soviet Union: the Baltic countries, Belarus and the Ukraine. Belarus and the Ukraine are included, although they are not negotiating for EU membership. They are, however, geographically rather large countries in Europe.

The assessments are carried out for five scenarios, designated hereafter 1, 2a, 2b, 3a and 3b. Each scenario describes the potential for development of biomass production within a given time frame, dependent on a number of factors, where 1, 2 and 3 refer to periods of short-term (10–20 years), medium-term (20–40 years) and long-term (>40), respectively. The letters in the scenario names indicate (a) low and (b) high biomass harvests in terms of forest residues and energy crops. Table 1 outlines the scenario criteria and Table 2 summarizes important assumptions used in the scenarios. The assumptions are presented in more detail in Sections 3.2–3.5.

In spite of the wide time frame in this study, we assume constant population in Europe using data for 2000. According to projections by the UN Population Division the population in Europe, Russia excluded, will decrease by 1.6% during the period 2000–2025 and by 7.4% from 2025 to 2050. The projected changes, however, differ greatly between individual countries [17].

For consistency in the assessments, we use international statistics instead of collecting data from national sources. Forestry data are taken from the Temperate and Boreal Forest Resource Assessment [13]. Agricultural data are taken from the Food and Agricultural Organization [15].

3.2. Forest residues and forest industry by-products

Assessments of the potential supply of forest residues and forest industry by-products are based on forest biomass growth rather than on current national fellings and forest industry locations. Only fellings from exploitable forests are included. In addition, all roundwood removals, excluding delicate stemwood from thinning operations, are assumed to be used in the forest industry. Thus indirectly, this assessment includes projections of the supply of industrial roundwood.

[5]Belgium, The Netherlands and Luxemburg.

Table 1
Descriptions of the five scenarios regarding yields and land use

Scenario	Forest res-idues (m^3 ha^{-1})	Forest industry by-products (m^3 ha^{-1})	Crop residue (t ha^{-1} y^{-1})	Energy crops (t ha^{-1} y^{-1})	Area for energy crops (ha)
1	FR1	FB	CR1	E1	A1
2a	FR1	FB	CR2	E2	A2
2b	FR2	FB	CR2	E3	A2
3a	FR1	FB	CR2	E2	A3
3b	FR2	FB	CR2	E3	A3

Table 2
Explanations of the notation used in Table 1

Notation	Explanation
FR1	Tonnes residue per tonne stemwood = 0.15 (coniferous) and 0.1 (deciduous).
FR2	Tonnes residue per tonne stemwood = 0.3 (coniferous) and 0.2 (deciduous).
FB	25% of industrial roundwood
CR1	Based on the average cereal and maize crop yields (1998–2002)
CR2	For the EU15: the same as CR1 For CEE: 40% increase compared with CR1 For FSU: 100% increase compared with CR1
E1	Yields established through correlation to the average wheat yields (1998–2002)
E2	For the EU15: the same as E1 For CEE: 40% increase compared with E1 For FSU: 100% increase compared with E1
E3	30% increase compared to E2
A1	10% of arable land
A2	25% of arable land
A3	Agricultural land above that which is assumed to be required for food production (0.24 ha/capita)

Note: Energy content for biofuels used in this study: Forest residues 6.8 GJ m^{-3}, forest industry by-products 7.2 GJ m^{-3}, straw 14.4 GJ t^{-1}, maize residues 14.7 GJ t^{-1} and energy crops 18 GJ t^{-1}.

The national annual fellings for each scenario are assumed to remain constant in absolute terms at a level of 100% of the increment in 2000. Currently, the felling rate is lower, about 61% in the EU15 and 77% in the ACC10 [13]. As the removals are currently well below the increment, the growing stock per hectare is increasing. This biomass accumulation will, however, slow down and eventually cease as the forest stand matures and the proportion of dead trees increases. Overall, the growing stock in European forests has been projected to increase by 27% until 2020 compared with 1990 [14]. Assuming that the felling rate continues to be well below 100% in the coming 20 years, our assumed absolute fellings will in fact correspond to a felling rate lower than 100%.

Final fellings and thinning operations enable harvest of forest residues, i.e. tops and branches and undergrowth trees. The potential harvest of residues varies with species and age of the trees. The residue-to-stemwood ratio for spruce is roughly twice that for pine and three times that for birch [18]. The age of the trees also influences this ratio. We assume the residue-to-stemwood ratio to be 50% higher for coniferous trees than for deciduous trees.

Since harvesting of forest residues may cause nutrient depletion and affect long-term productivity of forest land, we apply a low and a high harvest ratio. The low harvest ratio is established taking current ecological restrictions into consideration, which aim to prevent nutrient depletion of forest land. The high harvest ratio, on the other hand, can only be applied if the mineral loss is compensated for through fertilization, for instance by ash recycling [18,19]. The low residue-to-stemwood ratio is assumed to be 0.15 and 0.1, for coniferous and deciduous trees, respectively (FR1). The high harvest ratios are set to be twice as large, i.e. 0.3 and 0.2, respectively (FR2).

Regarding forest industry by-products, it is assumed that three quarters of the felled roundwood is turned into final products. The remaining quarter consists of by-products (bark, sawdust, wood chips and black liquor) available for energy purposes. The fraction of available by-products suggested above (25% of felled roundwood) is a rough approximation. The actual fraction varies from country to country depending on forest industry structure and degree of technological development. For example, in mechanical pulp-making some 95–97% of the debarked wood raw material is converted into product, whereas in the chemical processes the figure is about 50%, with most of the other half of the wood being used for energy in the form of black liquor [18]. At sawmills, about 25–30% of the sawn logs become available for energy purposes [18].

3.3. Crop residues

Crop residues in this paper include straw from wheat, barley, rye and oats, plus maize residues. Straw is the most abundant crop residue in terms of energy. As a general rule, only part of the residues should be harvested to avoid depletion of organic matter in the soil and thus to ensure long-term productivity [19]. Based on a study by Hall et al. [8] we assume the residue generation ratio for straw to cereal grain to be 1.3, and for maize residues to maize to be 1. Moreover, it is assumed that one quarter of the residues can be harvested. Assuming also that roughly one third of the harvested straw is used in animal husbandry leaves 0.22 tonne straw per tonne cereal available for energy use. Regarding maize residues, 0.25 tonne residues per tonne maize is available for energy purposes.

Assessments of these residues are based on the average cereal and maize yields for 1998–2002. The average yields are applied in order to decrease the influence of annual yield fluctuations. Recognizing that the cereal and maize yields were relatively low in CEE and FSU during this period, assumptions about yield increases are included for these regions for the medium and long-term perspectives. In an analysis of regional production potentials in Europe, Rabbinge and Diepen [20] showed that large increases in rain-fed crop production are feasible for CEE and FSU. Based on their findings[6], we assume that within the next 20–40 years the cereal and maize yields will increase by 40% and 100% in CEE and FSU, respectively. Thus, for these countries the cereal and maize yields are set 40% and 100% higher in scenarios 2 and 3 than in scenario 1. Such yield increases are not assumed for the EU15, although this may be motivated in certain countries, notably in Southern Europe. It is a fact that maize and cereal yields have been increasing during the past 10 years in the EU15 [15]. Possible cereal yield increases in the future will, however, not proportionally increase residue production, since on-going plant breeding leads to less straw per tonne of grain produced. Furthermore, as the area used for energy crops increases, from 10% of arable land in scenario 1 to 25% in scenario 2, the cereal and maize crop areas are reduced by an equivalent area.

3.4. Energy-crop yields

A number of crops have been investigated with regard to their suitability for bioenergy production in Europe, but few dedicated energy crops have reached beyond the scale of field trials. On the commercial scale, experience is limited to short-rotation forestry, such as willow, poplar and eucalyptus[7] [21]. In this analysis, the species of the energy crops are not specified. The selection, however, is restricted to short-rotation forestry and herbaceous crops (e.g. Miscanthus), since these perennial crops generally perform much better in energy terms than annual food crops [19,21]. Due to lack of experience in commercial cultivation of energy crops in most European countries no reliable statistics on yields are available. In general, yields obtained from field experiments should not be extrapolated so as to apply on regional and national scales. Typically, yields in field trials are higher than those in commercial plantations due to better management and less waste [22].

In order to analyse the potential energy-crop production we assumed that the energy-crop yields are 50% higher than the wheat yields. Thereby, the wheat yields serve as an indicator for the national agro-climatic conditions, although they also reflect existing socio-economic conditions, including agricultural policy. The relationship was established on the basis of Swedish willow and wheat yields. In Sweden, where willow is currently grown on a commercial scale, $9\,\mathrm{t\,ha^{-1}\,y^{-1}}$ [8] is perceived as an attainable yield in the near future for modern willow clones. In order to achieve this yield, however, the crop should be grown on soils of at least average quality and be well managed. Management includes fertilization and weed control, but not irrigation [23]. The Swedish average wheat yield is $6.0\,\mathrm{t\,ha^{-1}}$, which means that the willow yield is 50% higher than the wheat yield (Table 3). This relationship has also been used by Helby et al. [24] in order to calculate farmers' opportunity costs for willow production in Sweden. Assuming this relationship for all countries is obviously an approximation. In addition, wheat is usually grown on the best soils, whereas, based on Swedish experience, energy crops have mostly been grown on average quality soils [25].

As in Section 3.3 we assume 40% and 100% higher yields in the medium-term perspective for CEE and FSU, respectively. In order to account for learning effects over time, we ascribe 30% higher yields to scenarios 2b and 3b than 2a and 3a. This yield increase roughly equals an annual yield increase of 1% over a 30-year period. During the past 30 years the wheat yields in the EU15 have on average increased by over 2% in the EU15. The fact that energy crops are relatively new to the agricultural sector suggests that the yields could improve considerably as the accumulated cultivation experience grows and plant breeding progresses. So far, the yields have not increased to the extent that was expected some 20–30 years ago, which partly explains our choice of rather modest assumptions for the high-yield scenarios.

3.5. Energy-crop plantation areas

The energy-crop potentials are estimated on the basis of three alternatives for available land. These areas suggest

[6]Rabbinge and Diepen [20] compared simulated water-limited wheat yields for Europe with observed national wheat yields. Whereas the two yields were in fairly good agreement with each other for Western Europe, the simulated yields for the former socialist countries were considerably higher than the observed yields. Rabbinge and Diepen estimated that it should be possible to raise the yields in CEE by 30–50% by intensifying farming practices, thereby reaching yield levels achieved in Western Europe. Furthermore, they suggested that the yields in the Baltic countries, Belarus and the Ukraine have the potential to double, at least in the long run.

[7]Eucalyptus has primarily been investigated with regard to pulp production.

[8]Oven-dry tonnes per hectare per year.

Table 3
Energy crop yields in all countries for the five scenarios

Country	Yields ($t\,ha^{-1}\,y^{-1}$)		
	E1 (1)	E2 (2a/3a)	E3 (2b/3b)
Austria	7.6	7.6	9.8
Belgium–Luxembourg	11.6	11.6	15.0
Denmark	10.9	10.9	14.1
Finland	4.5	4.5	5.9
France	10.8	10.8	14.1
Germany	11.0	11.0	14.4
Greece	3.5	4.2	4.5
Ireland	12.7	12.7	16.5
Italy	4.8	4.8	6.2
The Netherlands	12.2	12.2	15.9
Portugal	2.0	2.0	2.6
Spain	3.9	3.9	5.1
Sweden	9.0	9.0	11.7
UK	11.6	11.6	15.1
Belarus	3.3	6.7	8.7
Bulgaria	4.2	5.8	7.6
The Czech Rep.	6.8	9.5	12.4
Estonia	2.9	5.8	7.5
Hungary	5.8	8.1	10.5
Latvia	3.9	7.8	10.1
Lithuania	4.7	9.4	12.2
Poland	5.3	7.4	9.6
Romania	3.8	5.3	7.0
Slovakia	5.9	8.3	10.8
Slovenia	6.6	9.2	12.0
Ukraine	3.9	7.8	10.2

the potential for development of energy-crop production in Europe in the short, medium and long term.

In scenario 1, it is assumed that energy crops are grown on 10% of the arable land, which is currently the basic rate for set-aside in the EU15. Compulsory set-aside of land was introduced in the Common Agricultural Policy (CAP) reform of 1992 with the aim of reducing the surplus production of food in the EU. The basic rate for set-aside has changed over the years, as well as the actual areas set aside. In 1993, 8.2 Mha was set aside of which 3.6 Mha was compulsory [26]. For the period 2000–2006 farmers producing more than 92 t cereals per year are obliged to set aside 10%[9] of their arable land. Crops intended for non-food purposes, such as energy crops, are, however, permitted on this land. In 2002, 6.4 Mha was set-aside in the EU15 [27].

The enlargement of the EU will increase the proportion of arable land from 23% in the EU15 to 28% in the EU25. In 2002, a time plan was decided on for the enlargement of the EU. Ten new countries joined the EU in May 2004: Cyprus (not included here), the Czech Republic, Estonia, Hungary, Latvia, Lithuania, Malta (not included), Poland, Slovakia and Slovenia. Bulgaria and Romania are scheduled to join in 2007. Assuming that the yields in the ACC10 approach those in Western Europe within the coming decades, this enlargement will call for a higher set-aside rate. Maintaining the EU15 ratio of *utilized arable land*[10] (0.18 ha/capita) in EU25 will require a set-aside quota of 25%, which was defined as plantation area in scenarios 2a and 2b.

In scenarios 3a and 3b, it is assumed that energy crops are grown on agricultural land that is not required for food production, i.e. surplus agricultural land. Self-sufficiency in food products is thus prioritized, whereas other claims on agricultural land are disregarded. Surplus *agricultural land* is calculated on a national basis, assuming that 0.24 ha/capita is required for food production. This assumption is based on data from Gerbens-Leenes and Nonhebel [28]. They estimated the per capita consumption (including losses) of 20 commodities in the EU15 for 1995, including both domestic and imported commodities. Multiplying these data by each commodity's claim on land produces an EU mean of 0.24 ha/capita. This assumption is corroborated by a Swedish study, in which it was estimated that the land requirement for food was about 0.23 ha/capita in Sweden [29]. For practical reasons, 0.24 ha/capita is applied to all countries although yields and consumption patterns differ over Europe. Agricultural land used for growing energy crops is assumed to have the same composition of arable land, permanent crop land and permanent pastures as the national total. Energy crops on permanent pastures, however, are restricted to a maximum of 50% of the total permanent pasture area in each country. This restriction is included in order to account for the fact that in many cases permanent pastures cannot be converted into crop land due to their location in mountainous areas, etc. It should also be noted that, similar to scenarios 1, 2a and 2b, energy-crop yields are based on wheat yields. Since wheat is an arable crop, we thus indirectly assume that permanent pastures and permanent crop land have the same energy-crop productivity as arable land, which is a somewhat optimistic assumption.

4. Potential supply of biomass energy

4.1. Forest residues and forest industry by-products

Our assessments show that forest residues from thinning operations and final felling constitute a significant and relatively untapped biomass resource that could be exploited for energy purposes. The potential of forest residues amounts to 440–880 $PJ\,y^{-1}$ for the EU15 and 150–290 $PJ\,y^{-1}$ for the ACC10, where the ranges refer to low and high residue harvest rates (Fig. 3). Four countries stand out by having considerably larger potentials than the

[9] The actual rate may be altered during the time period in question. Due to the relatively low harvests in the EU15 for 2003 the rate was changed to 5% for 2004.

[10] NB: arable land is *one* component of agricultural land. *Utilized* arable land means that the 10% set-aside land was excluded from the area.

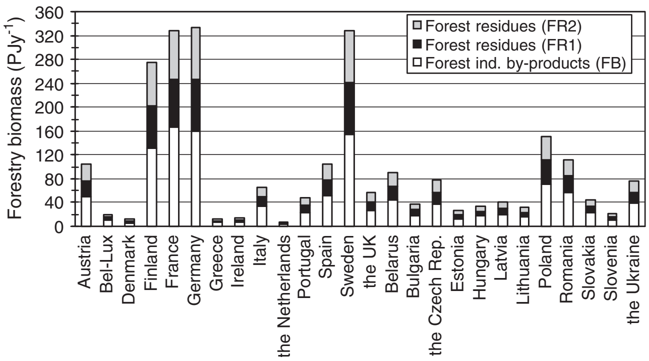

Fig. 3. Potential supply of forest residues and forest industry by-products, assuming roundwood removals that amount to the annual increment in 2000.

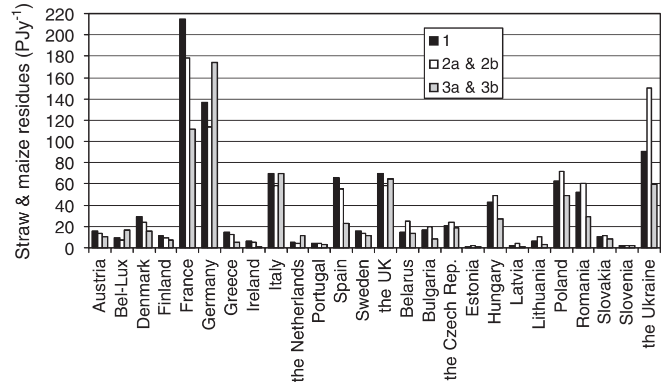

Fig. 4. Potential supply of straw and maize residues for energy purposes. The assessments are based on the average annual cereal and maize production for 1998–2002 [15].

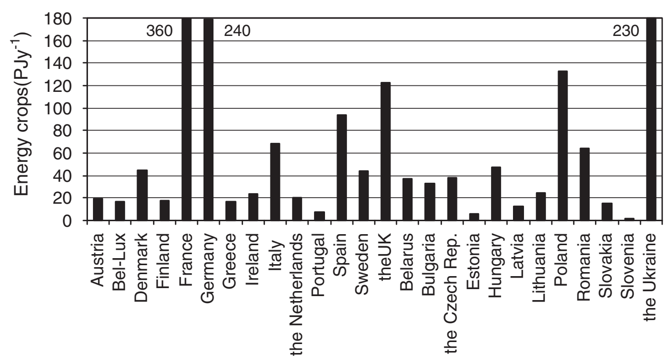

Fig. 5. Energy crops on 10% of arable land in scenario 1. Yields are obtained from Table 3 (E1).

others: Sweden, Germany, France and Finland. Furthermore, our estimates for Sweden correspond quite well with those from a more detailed national study, which estimated that the equivalent of 86–216 PJ of forest residues could be harvested annually in Sweden [29].

In addition to residues, forest industry by-products have the potential to contribute about 830 PJ y^{-1} in the EU15 and 220 PJ y^{-1} in the ACC10 (Fig. 3). Much of these by-products, for instance bark, sawdust and black liquor, are currently being used in sawmills and pulp mills for the production of heat. For comparison to the calculated potentials given above, it can be mentioned that in 2000 the annual increment amounted to 3080 EJ[11] and 1050 EJ in the EU15 and the ACC10, respectively.

4.2. Crop residues

Large untapped biomass-for-energy resources are found in Europe when considering straw residues from wheat, barley, rye and oats, and maize residues. We estimate these residues to be 470–670 PJ y^{-1} in the EU15, 150–260 PJ y^{-1} in the ACC10 and 60–150 PJ y^{-1} in the Ukraine (Fig. 4). The estimates vary over time due to assumed yield increases in CEE and FSU, and due to the assumed area reductions for cereal and maize for the benefit of energy crops. The largest potentials are found in France, the Ukraine and Germany, countries with important cereal production. So far, however, straw has mainly served as fuel in Denmark and to some extent in Poland.

4.3. Energy crops

Our assessments show that energy crops constitute the largest biomass potential in Europe. In scenario 1, the energy-crop potentials amount to 1150 PJ y^{-1} in the EU15 and 390 PJ y^{-1} in the ACC10, assuming a plantation area of 10% of arable land (Fig. 5). In scenarios 2a & 2b, in which energy crops are grown on 25% of arable land, these potentials amount to 2870–3730 PJ y^{-1} in the EU15 and 1380–1800 PJ y^{-1} in the ACC10 (Fig. 6). Based on the assumptions regarding surplus agricultural land, the potentials in 3a and 3b are found to be 7330–9530 PJ y^{-1} for the EU15, 3800–4940 PJ y^{-1} for the ACC10, 560–720 PJ y^{-1} for Belarus and 3710–4820 PJ y^{-1} for the Ukraine (Fig. 7). In scenarios 3a and 3b, energy-crop potentials are zero for Germany, the Netherlands and Belgium–Luxembourg. This means that on the basis of our assumptions on land availability, there is less agricultural land in these countries than is required for national self-sufficiency in food products. This shortage of land, however, was not deducted from the total European surplus agricultural area, which we found to be a fair approximation. Firstly, the land shortage is relatively small (5.2 Mha) and secondly, taking it into account would complicate the analysis since the negative food production would have to be allocated to the other European countries. France, Spain and the Ukraine, on the other hand, show large surpluses (Fig. 8). Regional aggregated

[11] Assumptions: 0.84 m^3 solid under bark (sub) per m^3 standing volume; 0.16 m^3 bark per m^3 standing volume; 0.8 t/m^3 sub; 0.67 t/m^3 (bark); wood energy content: 8.6 GJ/t.

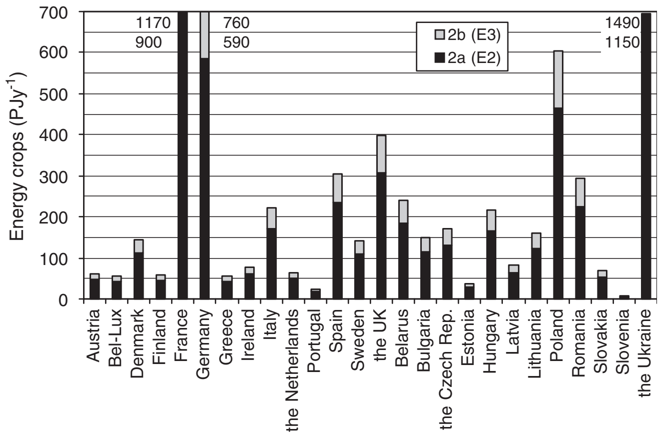

Fig. 6. Energy crops on 25% of arable land in scenarios 2a and 2b. Yields are obtained from Table 3 (E2, E3).

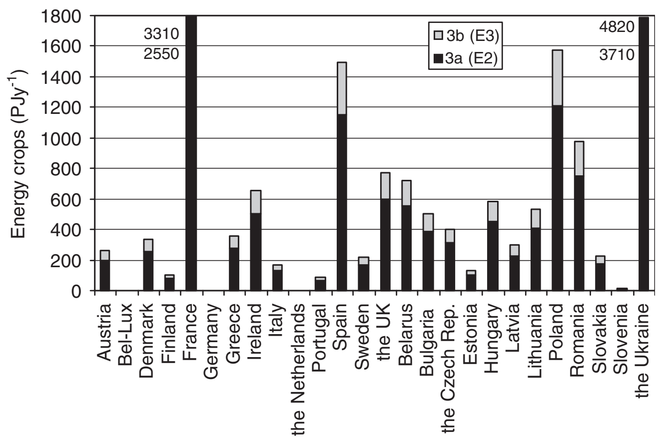

Fig. 7. Energy crops on agricultural land in scenarios 3a and 3b (from Fig. 8), assuming food production accounts for 0.24 ha/capita. Yields are obtained from Table 3 (E2, E3).

values for energy-crop potentials and plantation areas are presented in Table 4.

4.4. Overall assessment of biomass resources

Our study indicates that overall biomass could supply up to 11.7 EJ y^{-1} in the EU15 and 5.5 EJ y^{-1} in the ACC10. These potentials correspond to 19% and 48% of the total primary energy supply in 2002 in the EU15 and the ACC10, respectively. Figs. 9–14 illustrate the overall potential biomass supply for scenarios 1, 2b and 3b, in both absolute and relative terms (per capita). The results for scenarios 2a and 3a are not shown since they are relatively similar to those for 2b and 3b, but roughly 20% lower. The aggregated potentials for each biomass category are presented for each scenario in Table 4.

Our analysis shows that for all five scenarios and for Europe as a whole, the potential supply of biomass from agricultural land is greater than from forest land. In scenario 1 this predominance for agricultural biomass is

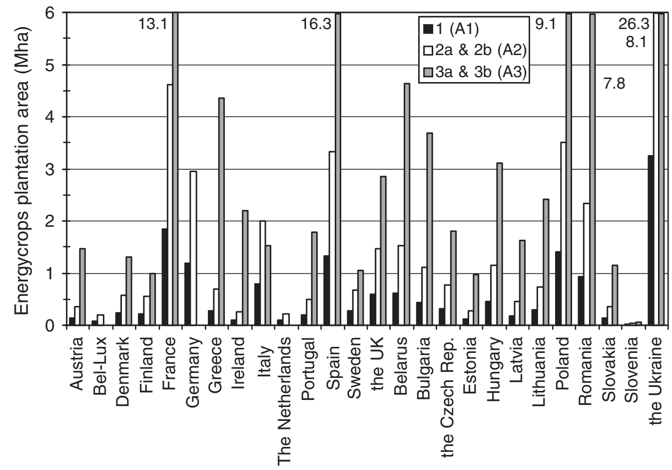

Fig. 8. Energy-crop plantation areas in the five scenarios. For scenarios 3a and 3b the energy-crop plantation areas are zero for Germany, the Netherlands and Belgium–Luxembourg.

fairly moderate. Nonetheless, forest biomass dominates the potential supply in a number of countries. Over time, however, the relative importance of agricultural biomass, energy crops in particular, increases to such a degree that for most countries forest biomass appears negligible in comparison (Figs. 13 and 14) For Finland, Sweden and Slovenia, however, forest biomass still accounts for more than half of the total potential.

It comes as no surprise that geographically large countries, such as France and the Ukraine, have large absolute biomass potentials. The distribution of biomass, however, appears very different when taking the population into account. In scenario 1, Finland and Sweden have the largest biomass potential per capita, whereas the resources are more evenly distributed between countries in scenarios 2a and 2b. In scenarios 3a and 3b Ireland and the three Baltic States have the largest biomass potentials per capita. Energy crops on permanent pastures dominate the total biomass potential in Ireland, despite the restriction regarding available permanent pastures for energy crops. The Irish biomass potential without this restriction would be about 25–30% higher. This is also the case for Spain.

5. Discussion

5.1. Scenario results in relation to RES targets

Biomass is increasingly being seen as an important energy resource for Europe. In 1996, the European Commission (EC) set the indicative target of doubling the share of all renewables of the EU's gross inland energy consumption to 12% by 2010 [2]. Since further exploitation of large-scale hydroelectric power is rather limited, this increase will have to be met by other renewable energy sources such as biomass, solar and wind power. One possible strategy suggested by the Commission is to triple

Table 4
Potential supply of biomass energy in Europe: aggregated results from the present study and results from four previous studies

Study (time perspective)		Forest biomass ($EJ\,y^{-1}$)	Crop residues ($EJ\,y^{-1}$)	Energy crops			Total ($EJ\,y^{-1}$)
				(EJy^{-1})	($t\,ha^{-1}y^{-1}$)	Mha)	
Scenario1	EU15	1.3	0.7	1.1	8.4	7.3	3.1
	ACC10	0.4	0.2	0.4	5.2	4.3	1.0
	Bel + Ukr	0.1	0.1	0.3	4.3	3.9	0.5
Scenario 2a	EU15	1.3	0.6	2.9	8.7	18.4	4.8
	ACC10	0.4	0.3	1.4	7.2	10.7	2.1
	Bel + Ukr	0.1	0.2	1.3	7.5	9.7	1.6
Scenario 2b	EU15	1.7	0.6	3.7	11.2	18.4	6.0
	ACC10	0.5	0.3	1.8	9.3	10.7	2.6
	Bel + Ukr	0.2	0.2	1.7	9.7	9.7	2.1
Scenario 3a	EU15	1.3	0.5	7.3	8.7	47.0	9.1
	ACC10	0.4	0.1	3.8	7.0	30.3	4.3
	Bel + Ukr	0.1	0.1	4.3	7.7	30.9	4.5
Scenario 3b	EU15	1.7	0.5	9.5	11.2	47.0	11.7
	ACC10	0.5	0.1	4.9	9.0	30.3	5.5
	Bel + Ukr	0.2	0.1	5.5	9.9	30.9	5.8
Hall et al. [8]	Eur. excl. FSU	2.0	1.3[a]	11.4	15	38	14.7
Johansson et al. [9] (2025)	OECD Europe	1.7	1.4	9.0	15	30	12.1
	FCP Europe	3.0	1.8	4.0	10	20	8.76
Johansson et al. [9] (2050)	OECD Europe	1.7	1.4	9.0	15	30	12.1
	FCP Europe	3.1	2.1	12.0	15	40	17.1
Fischer and Schratten-Holzer	W. Europe	2.6–3.4	2.1[a]	11–14	5.6–7.1	110[b]	16–20
[10] (2050)	CEE	1.2–1.5	0.90[a]	3.9–5.0	10.7–13.8	20[b]	6.0–7.3
Yamamoto et al. [11] (2050)	W. Europe	5–10[c]		16	15	53	21–26
	USSR + CEE	8–20[c]		21	15	70	29–41
(2100a)	W. Europe	7–17[c]		4	15	13	11—21
	USSR + CEE	11–28[c]		5	15	10.7	16–33
(2100b)	W. Europe	7–17[c]		0		0	7–17
	USSR + CEE	11–28[c]		0		0	11–28

The time perspective is given in parenthesis. The regions defined differ, but some of them are more or less similar in terms of biomass potentials, to be precise: the EU15, OECD Europe and Western Europe. The ACC10 comprises CEE and the Baltic countries. The ACC10, Belarus, the Ukraine and the European part of Russia form Former Centrally Planned (FCP) Europe. The former USSR includes areas in both Europe and Asia. Unless there is a footnote *crop residues* includes cereal straw and maize residues. Forest biomass includes forest residues and forest industry by-products.

[a]Includes straw and residues from maize and other food crops.

[b]Energy crops from grassland (incl. permanent pastures, woodland and shrubs).

[c]Includes agricultural residues, such as straw, dung and maize residues, forest residues and industry by-products.

the use of biomass energy compared with 1997 [30]. Biomass energy would then account for 5.6 $EJ\,y^{-1}$ or 8.5% of the energy consumption in the EU15. Currently, biomass energy, including the renewable part of municipal solid waste (MSW), accounts for 3.4% (2.1 EJ, 2001), but the proportions vary greatly between countries, being highest in Finland and Sweden with 19% and 16%, respectively [4].

Fig. 15 shows that the EC biomass target of 8.5% is compatible with our scenarios for the medium and long term, but not with that for the short term. In order to make this comparison, MSW and biogas from the EC biomass target were added to our scenarios. Hence, on the basis of our assessments, meeting the biomass targets by 2010 will be difficult. Johansson and Turkenburg reached the same conclusion in their analysis of present RES policies in the EU [31].

By 2010, the EU will have 27 member states if the enlargement proceeds according to plan. Fig. 16 shows results for the EU25[12] and presents the use of biomass energy, the EC biomass target and our scenario estimates. Roughly the same conclusions can be drawn for the EU25 as for the EU15 regarding meeting the biomass target. The biomass target for the EU25 was derived from the EU15 target through extrapolation, for which the use of primary energy in ACC10 was assumed to remain at the current level.

5.2. Methodology and results—comparison with previous assessments

The important role of biomass in future energy supply necessitates better assessments of the potential biomass supply. A number of resource-focused studies with a global geographical scope have been made in recent years to

[12]Contrary to how the EU25 is usually defined, we include Bulgaria and Romania, but not Cyprus and Malta.

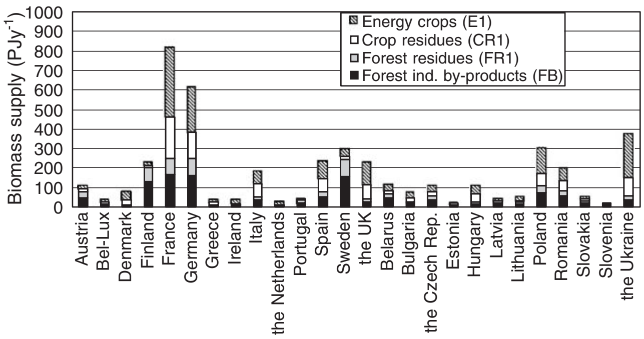

Fig. 9. Scenario 1: potential supply of biomass energy in the EU15, the ACC10, Belarus and the Ukraine.

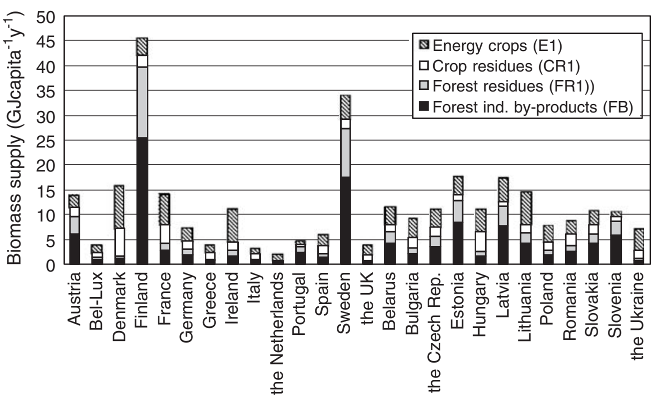

Fig. 10. Scenario 1: potential supply of biomass energy per capita in the EU15, the ACC10, Belarus and the Ukraine.

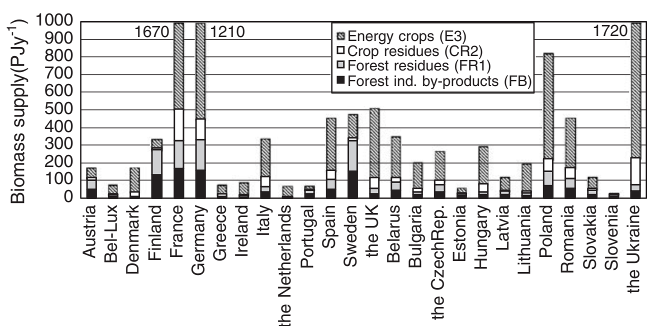

Fig. 11. Scenario 2b: potential supply of biomass energy in the EU15, the ACC10, Belarus and the Ukraine.

analyse the potential supply of biomass energy on an aggregated level. This paper presents more detailed assessments of the potential in Europe than previously reported, and has a European geographical scope. Table 4 presents biomass potentials for Europe from four previous studies and the aggregated results from our study. It should be noted that these studies differ from each other, as well as from our study, in several aspects, such as approach, geographical scope, the regions defined, biomass categories and time frame. For example, in all studies, except for that by Hall et al. [8], the results refer to a specific time frame.

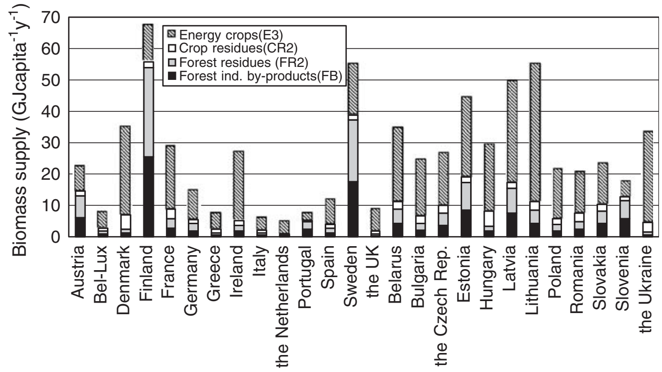

Fig. 12. Scenario 2b: potential supply of biomass energy per capita in the EU15, the ACC10, Belarus and the Ukraine.

The straightforward approach used in this paper, as well as by Hall et al. [8], differs fundamentally from the approach employed by Yamamoto et al. [11], Johansson et al. [9] and Fischer and Schrattenholzer [10]. In these three studies the assessments are based on similar approaches, namely utilizing projections of population, economic development and the demand for food and materials. Our study and that of Hall et al. [8], do not use modelled projections and the assessments are instead based on fixed assumptions regarding energy-crop plantation areas, removal of roundwood, etc.

Energy crops dominate the total potential biomass supply in all five studies, which means that estimates of plantation areas, i.e. surplus agricultural land, and energy-crop yields are central to the assessments. In scenarios 3a and 3b in our study, surplus agricultural land is estimated by assuming that 0.24 ha/capita is required for food production in each country. Johansson et al. [9] and Yamamoto et al. [11], on the other hand, established surplus agricultural land on the basis of global projections of population, economic development and demand for food and materials. Hall et al. [8] assumed that energy crops are grown on 10% of available crop land (arable and permanent), woodland and permanent pastures. In Johansson et al. [9] and Yamamoto et al. [11], surplus agricultural land refers to arable land and permanent crop land. Surplus agricultural land in scenarios 3a and 3b in our study refers to agricultural land in general. The cultivation of energy crops on permanent pastures is, however, restricted to a maximum of 50% of the total permanent pasture area in each country. Fischer and Schrattenholzer [10] estimated the bioenergy potential on grasslands, including permanent pastures, woodland and shrubs, which explains the vast area assigned for energy crops.

Our estimates of the potential supply of crop residues are generally lower than those in previous studies. One explanation for this is that crop residues in this study only include cereal and maize residues, whereas more residues were included by Hall et al. [8], Fischer and Schrattenholzer [10] and Yamamoto et al. [11].

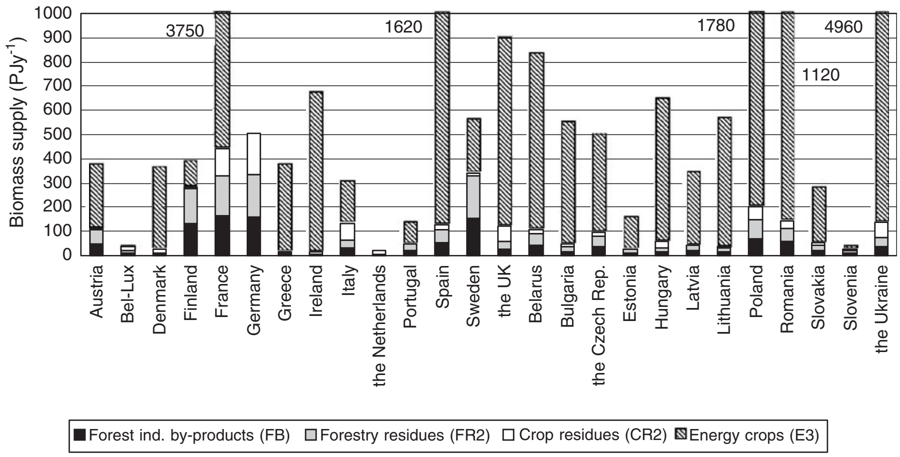

Fig. 13. Scenario 3b: potential supply of biomass energy in the EU15, the ACC10, Belarus and the Ukraine.

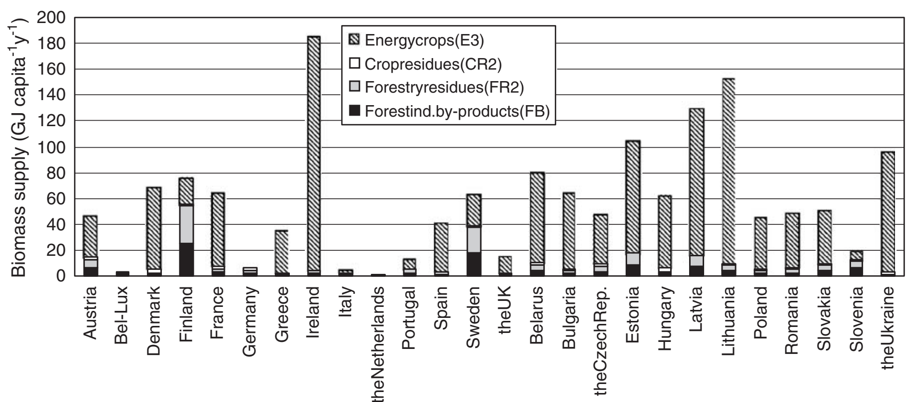

Fig. 14. Scenario 3b: potential supply of biomass energy per capita in the EU15, the ACC10, Belarus and the Ukraine.

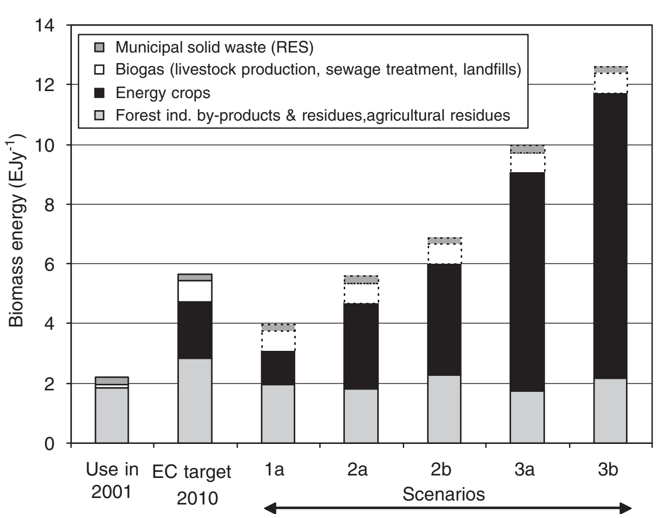

Fig. 15. The first bar shows the use of biomass energy in the EU15 in 2001 [4]. The second bar illustrates the EC biomass target for 2010 [30]. The other bars show the biomass potentials in our five scenarios, to which MSW and biogas from the EC proposal have been added. Note: *Forest industry by-products and residues and agricultural residues* include firewood and charcoal in the first two bars (use in 2001 and EC target 2010).

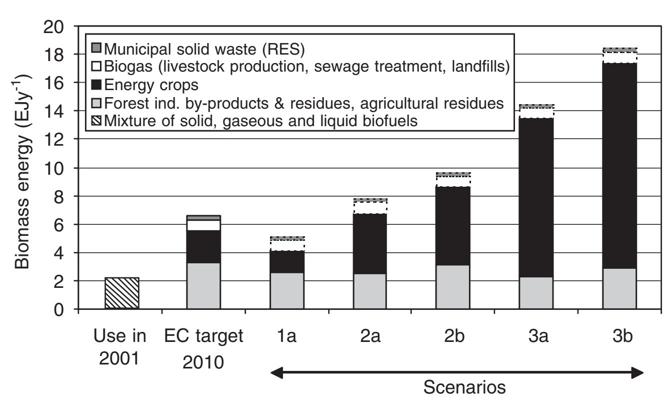

Fig. 16. The first bar shows the use of biomass energy in the EU25 (EU15 + ACC10) in 2001, municipal solid waste included [4]. The second bar illustrates the EC biomass target for 2010 [30]; this target has been extrapolated in order to apply to EU25. The other bars show the biomass potentials in our five scenarios to which MSW and biogas from the EC proposal have been added. Note: *Forest industry by-products and residues and agricultural residues* include firewood and charcoal in the first two bars (use in 2001 and EC target 2010).

Overall, Yamamoto et al. [11] (excluding 2100b) and Fischer and Schrattenholzer [10] present the most optimistic scenarios for bioenergy. Most of the assessments indicate greater development of the potential biomass supply in CEE compared with Western Europe. Further details regarding studies on biomass potentials and their relation to each other are provided by Berndes et al., who have reviewed 17 resource- and demand-focussed assessments [7].

5.3. Establishing energy-crop yields—comparison with other methodologies

In several of the previously mentioned studies, the assessments are based on estimated average energy-crop yields for large regions such as the European part of the OECD, etc., whereas energy-crop yields were estimated for each country in this study. We assumed that the energy-crop yields are 50% higher than the wheat yields. Alternatively, the energy-crop yields could be estimated by using a crop growth model into which data on climate and soil are entered. Such models have been developed and used, for example, by Lindroth and Båth [32], who estimated the water-limited willow yields for various regions in Sweden, and by Nonhebel [33], who estimated various types of yields for a number of energy-crop species and small regions in the EU12. A comparison of Nonhebel's estimated willow and poplar yields with our estimates reveals certain differences. Most importantly, for Northwestern Europe (the UK, Ireland, Benelux, Germany & Denmark) the *actual yields* in Nonhebel's study are lower than ours, whereas for Southern Europe (Spain, Portugal, Greece & Italy) they are slightly higher than ours. Regarding the *water-limited yields*, for Northwestern Europe Nonhebel's estimated yields are slightly higher than our yields, whereas for Southern Europe they are up to 10 times higher than ours. *Actual yields* refer to yields that can be achieved in the near future with current management practices. The *water-limited yields*, on the other hand, refer to yields that can be achieved if the crop is optimally supplied with nutrients, is free from pests and disease and is only limited by the availability of water. The rationale for estimating the water-limited yields is that often water is recognized as being the major limiting factor for crop growth, especially in Southern Europe, but sometimes even as far north as Denmark and Southern Sweden [21,32]. In many ways the water-limited yields can be seen as the potential yield for the long-term since irrigation of energy crops is often not economic. Irrigation with sewage water, however, may be economically viable in certain areas and at the same time it provides additional benefits, such as fertilization of the crop and lower costs for wastewater treatment [34].

5.4. Uncertainties regarding future energy-crop plantation areas

The most serious uncertainties related to biomass potential lie in the assumptions regarding energy-crop plantation areas and yields. In scenarios 1, 2a and 2b in our study, the plantation areas are based on the basic rate for set-aside land in the EU. This seems a reasonable choice, although it is important to bear in mind that the set-aside regulation per se does not favour energy-crop cultivation. So far, the volatility of this regulation and the CAP in general has been a major barrier to energy-crop production. In order for energy crops to be of interest to farmers there is need for long-term stability with regard to the status of energy crops in the CAP, since energy-crop cultivation is a long-term investment [21,24]. In general, energy crops enjoy the same area aid as cereals. Energy crops and other non-food crops, however, may be grown on set-aside land and still be eligible for area aid. Since the 2003 CAP reform, energy crops that are grown on agricultural land that is not part of set-aside area are eligible for an annual subsidy of 45 €/ha in addition to the area aid. This subsidy is guaranteed for a maximum area of 1.5 Mha throughout the EU and will be reduced if production exceeds that area. In order to be eligible for this subsidy the farmer must have a contract with a processing industry that will buy the harvested energy crop, unless the farmer is to undertake processing himself on the holding [35].

In fact, it is extremely difficult to estimate the future areas of agricultural land available for energy-crop production, especially when the time frame extends over several decades. Energy-crop cultivation faces competition from several other kinds of land-uses, primarily food production, but also fibre and chemical production, infrastructure, afforestation schemes, nature reserves, etc. In scenarios 3a and 3b, we give food production priority over energy crops by assuming that agricultural land is used in the first place to ensure national self-sufficiency in food products. This priority is in line with the objectives of the CAP, which, however, strives towards a balanced food production in the EU as a whole, and this priority is probably also favoured by a large part of the European public. Theoretically, however, it is not obvious that Europe should strive to be self-sufficient in food, while it imports 50% of its energy requirement. The claims on land for food production, which will be discussed below, are mainly determined by: (i) the demand for food, (ii) farming practices and (iii) agro-climatic factors.

Population and diet are the main factors shaping the demand for food. In Europe, the population is expected to decrease moderately within the next 50 years according to UN projections [17]. Food consumption patterns, on the other hand, may continue to move towards more affluent diets that require larger land areas per calorie produced. This has been a trend in Europe during the past decades [28]. For example, assuming constant yields, Dutch land requirements for food increased by 38% between 1950 and 1990. This increase was primarily due to a growing consumption of meat, dairy products and beverages [28]. If the global population, which is expected to increase to 8.9 billion by 2050, undertakes a similar change in diet, this will have enormous consequences for land use [17]. One possible consequence of such a development is demonstrated in the biomass assessments made by Yamamoto et al. [11], who applied two scenarios for 2100, a reference case (2100a) and a case which included a diet switch in Centrally Planned Asia[13] (2100b). The diet switch consisted of an increase in demand for animal foodstuffs to the current level of Japan. As a consequence of the increased demand on land for food production, there was no surplus agricultural land for energy crops in the second scenario (2100b), in Europe or globally.

Farming practice is of great importance for agricultural yields. Agricultural yields have increased dramatically in Europe since World War II, primarily due to the development of high-yielding crop varieties, mechanization and increasing use of fertilizers and pesticides [36]. There is, however, a growing awareness of the negative effects that intense farming have on the environment in the form of loss of biodiversity, nitrogen and pesticide leakage into watercourses, etc. This concern is mirrored in the CAP, in which environmental aspects have gained importance during recent years. There is also concern for possible negative health effects caused by food products containing remnants of pesticides. From these points of view, introducing low external input (LEI) farming, i.e. reducing the use of artificial fertilizers and pesticides, may be perceived as an attractive strategy. Implementation of such a strategy also provides a means to control overproduction of food. The opportunities for LEI farming will improve significantly when the new CAP enters into force in 2004–2005. As a result of this reform the vast majority of subsidies will be paid independently of the volume of production, and compliance will be required with EU standards regarding the environment, public and animal health, and animal welfare. Also, organic farmers will be exempt from the set-aside obligation [35]. Whereas LEI farming has potential ecological advantages, such practices will increase claims on agricultural land for food production and consequently leave less land available for energy-crop production. Based on these arguments, it is clear that large-scale bioenergy production on agricultural land is to some degree in conflict with environmental goals other than reducing greenhouse gas emissions. Again, the CAP will be an important factor governing the future role of energy crops in Europe.

Estimates of yields for the medium- and long-term perspectives are further complicated by uncertainties regarding future climatic conditions in Europe. Climate research suggests that the average agricultural productivity for Europe as a whole will probably increase as a result of higher concentrations of carbon dioxide, warmer weather and changes in precipitation. The effects on agriculture may, however, differ greatly between regions; Northern Europe is expected to enjoy mainly positive effects due to extension of the growing season, whereas Southern Europe may suffer from water shortages [37].

In the long-term perspective, crop breeding and biotechnology may play an important role in increasing agricultural yields while reducing the need for agro-chemicals. Application of these methods will, however, largely depend on public acceptance.

5.5. *Uncertainties regarding future supply of forest residues and by-products*

The supply of forest residues and by-products is ultimately dependent on the supply of industrial roundwood. Regarding forest residues, their supply also depends on the residue harvest rate, which was discussed in Section 3.2.

In our analysis, we assumed rather high annual fellings and thus also a large supply of industrial roundwood. The supply of roundwood is, however, determined by: (i) the demand for wood and paper products, (ii) forestry management methods and (iii) soil and climatic factors. Actually, these factors are mere translations of the factors determining the claims on agricultural land by food production. The second and third factors will be discussed below.

Since 1980s, there has been a growing awareness of the importance of the functions of forests other than wood production. In accordance with this, the conservation of biodiversity and provision of recreation are now receiving the same attention as sustainable wood supply in forest policy objectives in all European countries. Measures designed to meet these objectives include increasing the area of nature reserves and adopting more ecologically sustainable management guidelines [14]. Despite the transformation of exploitable forest to nature reserves, the European forest area available for wood supply is expected to remain unchanged due to the implementation of afforestation schemes in many European countries [14]. Enhancing the role of ecologically sustainable management does not necessarily reduce the supply of wood. It may, however, provide forest owners with less incentive to harvest, which would then reduce the supply of forest residues and by-products as well [38].

The future supply of roundwood from European forests will also depend on the effects of climate change and rising carbon dioxide concentrations in the atmosphere. Most climate change scenarios suggest a displacement to the north of the climate zone that is suitable for boreal forests. As a consequence, the proportion of deciduous trees would increase at the expense of conifers. In addition, forest growth is expected to increase in Europe as a whole, but there may be large inter-regional variations. Climate research suggests that the positive effects on forest productivity are likely to dominate in Northern Europe, whereas the outcome is rather uncertain in the rest of Europe. In the south of Eastern Europe, however, it is likely that forest growth will decline [37].

[13]E.g. China.

6. Conclusions

This study indicates that domestic biomass could contribute significantly to the total energy supply in Europe, in the long-term perspective up to 11.7 EJ y^{-1} in the EU15 and 5.5 EJ y^{-1} in the ACC10, under certain restrictions on land availability. Consequently, there are no important resource limitations in meeting the biomass target (5.6 EJ y^{-1}) in the 1997 EC White Paper on renewables. However, from the current state of implementation of the renewable energy policy in the EU15, it can be concluded that it is very unlikely that the EC biomass target will be met within the intended time frame (2010). To do so requires immediate action, especially since our assessments show that the largest biomass potentials lie in energy crops, which have long lead times. For that reason agricultural policy in Europe will also be a key factor for the future of bioenergy. In the light of current surplus food production in the EU, energy crops should be regarded as an interesting alternative to food crops; even more so when considering the enlargement of the EU, since accession of the countries in CEE will accentuate the problem of overproduction.

This analysis also shows that the potential biomass resources are unevenly distributed. Tougher biomass targets in the EU over time may therefore increase international biofuel trade within Europe and be a driving force for biofuel imports from other continents.

Acknowledgements

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