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# Biomass supply in EU27 from 2010 to 2030

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A B S T R A C T

With biomass staying high in the EU political agenda and most of the recent documents acknowledging that it has the potential to make a very significant contribution to reaching the 20% target [COM, 2008, 2006], the issue of supply in terms of feedstock types, availability constraints and costs in different Member States is set to determine the future technology uptake and market deployment prospects.

This paper is based on one of the initial studies, 'Bioenergy's role in the EU market. A view of developments until 2020', and presents a structured review for EU biomass resources, aiming to map technical potentials and provide detailed information on availability, costs and future trends for biomass potentials of different residual feedsctocks in EU27.



## 1. Introduction

With biomass staying high in the EU political agenda and most of the recent documents acknowledging that it has the potential to make a very significant contribution to reaching the 20% target (COM, 2008, 2006) the issue of supply in terms of feedstock types, availability constraints and costs in different Member States is set to determine the future technology uptake and market deployment prospects.

This paper is based on one of the initial studies, 'Bioenergy's role in the EU market. A view of developments until 2020', and presents a structured review for EU biomass resources (except energy crops), aiming to map technical potentials based on recent literature, EUROSTAT statistics and country level reports across Europe and to collate a series of answers to key questions arising for biomass resource availability. More specifically:

- Which types of biomass feedstocks are produced within the available land resources of EU27?
- How much of this is estimated as available in different Member States?
- What are the supply costs ranges for different feedstock types?
- Which are the future projections for biomass potentials based on trends for the different resource supply sectors involved, namely agriculture, forestry and wastes?

The paper is divided in to five sections. The first one provides the scope of the study and the definitions for biomass resource classifications and quality characteristics. The second one outlines the data collection methods and related assumptions used in terms of biomass availability, supply costs and sector trends. The third section analyses biomass availability at country level (with EU27 aggregations) for the feedstock categories under study while the fourth one presents the supply cost ranges per feedstock type and Member State. Finally, the fifth section provides estimates of biomass availability in 2010, 2020 and 2030 timeframes based on a set of hypotheses for the respective sectors' growth patterns.

## 2. Scope and definitions

The purpose of this study has been to review EU27 biomass supply in terms of feedstock types, available quantities, quality characteristics, supply costs and future potentials for 2010, 2020 and 2030 based on individual sector analysis for agriculture, forestry and wastes. Data presented here are based on literature and refer to country level with EU27 aggregations.

The work has been organized in four different tasks:

- Classification of biomass sources according to fuel quality and supply sector.
- Analysis of potential supply quantities.
- Analysis of supply costs.
- Sector analysis to define the future trends.

The biomass resources considered as well as their classification based on fuel quality and conversion technology are presented in Table 1.

- Agricultural residues include a wide range of plant material produced along with the main product of the crop. Examples of

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**Table 1**
Biomass resources classification.

| Sector | Resource | Physical state/type | Properties | |
|---|---|---|---|---|
| | | | Moisture (%) | Ash (%) |
| Agriculture | Crop residues | Dry | 15–50 | 2.2–17 |
| | Livestock waste | Wet | 74–92 | 27–35 |
| | | Dry | 75 | 17–28 |
| Forest | Wood fuel | Dry | 40–60 | 0.4–5 |
| | Forest residues | Dry | 40–50 | 0.4–5 |
| Industry | Industrial residues | Dry | 10–30 | 0.71–18.34 |
| | | Wet | 90 | 3.8–5.9 |
| | | Black liquor | 90 | 3.8–5.9 |
| Waste | Regulated waste | BMW (not landfilled) | 30 | 36 |
| | | Demolition wood | 30–40 | 0.58 |
| | Non-regulated waste | BMW (landfilled) | 30 | 36 |
| | | Sewage sludge | 70–80 | 26.4 |
| | Urban wood | Dry | 35 | 39.4 |
| | Cut grass | Wet | 75–80 | 8.4 |

*Source*: Siemons et al. (2004).

these types of residues that could be used for energy production are cereal straw, fruit tree prunings, corn stems and cobs, etc.

- Livestock wastes include wet animal manure for biogas production and dry manure such as poultry litter that can be used in thermo-chemical conversion technologies.
- Two types of forest biomass were considered: wood fuel and forest residues produced during logging activities, forest thinnings and cleanings, etc.
- Industrial residues that can be used as biomass resources for energy production are produced mainly in forest and food industries. These residues may consist either from dry lignocellulosic material (e.g., saw dust, husks, kernels, etc.) or from wet cellulosic material (e.g., sugar bagasse).
- Black liquor, the lignin naturally occurring in wood, dissolved out with the hemi-cellulose during sulphate pulping normally burnt in recovery boilers to provide process heat and to recover the chemicals, was also included in this category.
- A large proportion of the resource base for biomass consists of wastes (ALTENER, 2000). In the framework of this paper it has been decided to consider separately: demolition wood, municipal solid waste that can be used in incineration plants for energy production, landfill gas, and sewage sludge gas (Siemons et al., 2004; EEA, 2009).

## 3. Methodological approach

### *3.1. Availability*

Biomass resource assessments are determined by various definitions for availability as well as the reliability of homogeneous datasets across regions. The accuracy of the predictions is further restricted by the constantly expanding set of assumptions on which the availability is based on (EEA, 2006). From land uses and resource yielding potentials to conflict with other markets and future demand (policy and industry related).

Adding to the complications, the biomass feedstock matrix across Europe is variant, disparate and some resource types have no market and remain in forest and agricultural fields after harvesting operations. These are not traded and hence there are no official statistics. Large quantities of residues are traded informally – such as domestic firewood, straw for animal feed – but the respective trade records are heterogeneous and not comparable.

**Table 2**
High calorific values (dry basis) for biomass resources under study (Phyllis, 2004, Jenkins and Summer, 1986).

| | HCVd (GJ/odt) |
|---|---|
| **Tradables** | |
| Forestry by-products and refined wood fuels | 18 |
| Solid agricultural residues | 18 |
| Solid industrial residues | 18 |
| **Non-tradables** | |
| Wet manure | 9 |
| Organic waste: | |
| Bio-degradable municipal waste | 12 |
| Demolition wood | 18 |
| Dry manure | 14.5 |
| Black liquor | 10 |
| Sewage gas | 9 |
| Landfill gas | 9 |

The resource assessment in this study was structured in four steps:

1. The first step was to find country specific information on the technical resource potential, defined as the total annual production of all resources, given no economic limits. This potential represents the *total quantity of biomass resources* in a region and can be considered as the upper bound (if disregarding international trade). To allow comparison and conversion, all resource estimates were expressed as dry tonnes (zero moisture content).
2. The second step was to find country specific information on the *available resource potential*, defined as all resources available with estimated, realistic limits, considering: technical, physical, environment, agronomic and silvicultural factors. Economic boundaries were taken into account as far as alternative uses create unrealistically high opportunity costs for biomass to be used for energy.
3. Third, the energy potential of different biomass feedstocks (in Mtoe/year) was estimated on the basis of the high calorific value of each resource category (see Table 2).
4. Sector analysis to allow future projections for biomass availability in 2020 and 2030.

The reference year for all data is 2000, or as close to 2000 as possible in view of data availability. For each biomass feedstock type, the specific features that were employed to estimate biomass quantities and supply costs are elaborated.

*Field agricultural residues*: In the case of field crop residues, this paper considered the crops that cover over 1% of the total utilised agricultural area (UAA) in EU 27 and produce dry lignocellulosic residues (moisture content <50%). These crops are common and durum wheat, barley, corn, sunflower, rapeseed, sugarbeet, olive trees, and vines.

The estimation of the technical potential of the above crop residues in each EU Member State (subscript $i$), was calculated based on the following formula:

$$Btp_i = c_i A_i Y_i$$

Here $Btp_i$ biomass is the technical potential ($t$), $A_i$ the harvested area (ha), $Y_i$ the yield (t/ha) and $c_i$ the by-product factor ($t/t$).

The total technical potential was obtained by adding the potential from all major crops produced in each state (subscript $j$):

$$Btp_{agr} = \sum_j Btp_j = \sum_j \sum_i c_i A_i Y_i$$

Agricultural area and yield data were sourced from EUROSTAT and average product to residue ratios or residue yields (in dry tons/ha) derived from literature (Tables 3 and 4).

Straw estimates were based on an average of 0.5 grain/straw ratio for central–northern EU countries and on a 0.9 grain/straw ratio for southern European countries. Corn residues include stalks and ear cobs and were estimated according to a 0.7 corn grain/corn residue ratio. The respective ratio for rapeseed according to the same source is 1.6 seed/residue ratio, and for sunflower 3.3.

The estimates for olive tree prunings were based on an average of 120 trees/ha and 25 kg dry prunings per tree, resulting in a yield of 0.3 t/ha. The estimates for grapevine prunings were based on an average production of 1.5 t/ha.

*Livestock wastes*: The average volume of faeces and urine largely differ from one type of animal to another and mainly depend on their age and life weight (Steffen et al., 1998). However in order to assist planning, design and operation of manure collection, storage, pre-treatment and utilisation systems for livestock enterprises mean values have been developed by various researchers. This analysis adopted ASAE standards coefficients, presented in Table 4. The values represent fresh faeces and urine.

Taking into account the possibilities for collection and energy use of the manure, it is assumed that only 50% can be considered available for energy production. In the case of poultry manure, a co-efficient of 0.03 dry kg/animal/day was applied (Loehr, 1974).

*Landfill gas*: The resource potential for landfill gas was assumed to be the biodegradable fraction of the waste that is landfilled (EUBIONET, 2003). The resource potential for incineration was assumed to be the waste that is not landfilled excluding the quantities composted or recycled. All sewage sludge has been assumed to be available for anaerobic digestion with energy recovery.

**Table 3**
Product/residue ratio (wet basis) and moisture content of the main agricultural crop residues in Europe (Dalianis and Panoutsou, 1995).

| Crop | Residue | Moisture (%) | Product/residue ratio |
|---|---|---|---|
| Cereals | Straw | 15 | 0.5 (Central–Northern Europe) |
| | | 15 | 0.9 (Southern Europe) |
| Maize | Stalks | 50 | 0.7 |
| Rapeseed | Stalks | 45 | 1.6 |
| Sunflower | Stems and Leaves | 40 | 3.3 |
| Vineyard | Prunings | 45 | 1.5 t/ha |
| Olive trees | Prunings | 35 | 0.3 t/ha |

**Table 4**
Coefficients of waste generated per animal category (ASAE, 1999).

| Animal category | Typical live animal mass (kg) | Total fresh manure per 1000 kg animal live weight per day | Total solids (%) |
|---|---|---|---|
| Dairy | 640 | 86 | 0.14 |
| Veal | 91 | 62 | 0.08 |
| Swine | 61 | 84 | 0.13 |

### 3.2. Supply costs

The cost of the biomass feedstock has been widely acknowledged as an important element to the final cost of the energy carrier (Dornburg and Faaij., 2000.).

Some biomass types (e.g., straw) may already have an opportunity cost in non-energy markets such as food, feed, fibre, etc. The delivery costs of the different types of biomass for different European countries, were recorded in €/GJ and further analyzed (if possible) to "production", "transportation" and "other costs" in order to establish better understanding of cost allocation. In the cases where biomass had an alternative market and therefore an opportunity cost, this cost was also recorded separately. Since the collection of reliable data for biomass is difficult, cost ranges were used. Reference year for all costs is 2000.

### 3.3. Sector analysis

The objective of the sector analysis was to assess the future potential of biomass resources in Europe, based on per sector market trends and policy developments. The sectors considered were:

- Agricultural sector
- Forestry sector
- Industrial sector
- Waste sector

*Agriculture sector*: Cereals are the world's most important source of food, both for direct human consumption and indirectly as inputs to livestock production. The growth rate in cereal production in industrial countries (including EU countries) has been 1.4% per year in the decade 1989–1999 and according to the study of FAO on "World Agriculture Towards 2015/2030" (FAO, 2002), is expected to fall to 1.1% per year for the period 1999–2015 and to 0.9% for the period 2015–2030. The growth rate in cereal production in transition economies was negative in the decade 1989–1999 (−4.2%) but it is expected to rise to 1% per year for the period 1999–2030. More specifically, at EU27 level, long term productivity growth rates for cereals are expected to be about 1% as a recent study on the 'impact of a minimum 10% obligation for biofuel use in the EU27 in 2020 on agricultural markets' reports. (European Commission, 2007).

The consumption of livestock products has grown considerably during the past three decades, especially in the newly industrializing countries. In EU27, future growth in consumption of both meat and milk may not be as rapid as in the recent past, given the reduced scope for further increases in major consuming countries. In WEC countries the scope for increased demand is limited. Population growth is slow and the consumption of livestock products is already very high. At the same time health and food safety concerns are holding back demand for meat. The growth rate in meat consumption in terms of kg/capita/year in industrial countries (including EU countries) is expected to be around 0.5%

between 1999 and 2030 and in new Member States around 1% in the same period (European Commission, 2001). The respective growth rates for milk and dairy product consumption for the same period are expected to be lower (0.15% for the industrial countries and 0.4% for transition countries).

Concerning set aside land, according to the EC report "Prospects for agricultural markets 2002–2009" an increase of ~1% in the total set aside land (compulsory and voluntary) is expected mainly due to a decline in the relative profitability of arable crops.

*Forestry sector*: Some European countries (e.g., Bulgaria, France, Finland, Hungary, Ireland, Spain and the United Kingdom) have had long-term policies to expand their forest resource or to improve its quality (Van den Broek, 1997). These programmes, along with natural extension onto marginal agricultural land have outweighed losses of forest land to other uses, notably urban and infrastructure, causing Europe's forest area and growing stock to expand steadily since the early 1950s. According to the Forest Resource Assessment 1990, the European forest area increased by 1.9 million hectares between 1980 and 1990. Losses of forest land to other uses, notably urbanisation and transport infrastructure, were outweighed by the afforestation of former agricultural land and natural extension. Several approaches are used to project future wood supply at the national or regional level, such as: detailed modelling of the biological processes; aggregation of management plans registered with the forest authority; econometric models, etc. In the ECE/FAO (2004) study on European timber trends and prospects: into the 21st century, national correspondents made a synthesis of available national information and used their judgement when necessary. According to this study, no major changes are expected in the area of exploitable forest in Europe which is expected to expand by 3.3% in the years between 1990 and 2020.

Removals are expected to rise by about 0.7% per year (ECE/FAO, 2004). In summary, the European forest is expected to continue to accumulate wood as the harvest will remain well below the biological potential, even though a larger proportion of the increment will in fact be utilised. It is expected that wood energy supply and use to grow at around 1% a year from 1990 to 2020.

*Industrial sector*: The largest producer of dry industrial residues that can be used as a biomass resource for energy production is the wood industry (including pulp and paper industry).

According to the study mentioned above on European timber trends and prospects: into the 21st century wood energy supply (including wood processing residues and black liquors) is expected to grow at around 1% a year from 1990 to 2020, which is about the same speed as sawn wood consumption.

**Table 5**
Sectorial trends for biomass availability (ECE/FAO, 2004; European Commission 2007; Brodersen et al., 2002).

| Sector | Resource | Category | Trend |
|---|---|---|---|
| Agriculture | Crop residues | Dry | +1% a year |
| | Livestock waste | Wet or dry | +0.5% a year |
| Forest | Woodfuel | Dry | +1% a year |
| | Forest residues | Dry | +1% a year |
| Industry | Industrial residues | Dry | +1% a year |
| | | Wet | +2% a year |
| | | Black liquor | +1% a year |
| Waste | Regulated | Not landfilled BMW | +1% a year |
| | | Demolition wood | +1% a year |
| | Non regulated | Landfilled BMW | −3% a year |
| | | Sewage sludge | +2% a year |

*Waste sector*: The progressive implementation of the Urban Waste Water Treatment Directive 91/271/EEC in all Member States is increasing the quantities of sewage sludge. The European Environment Agency (EEA Technical Report 69, 2002), projections on sewage sludge generation for 2005 are presented and increases between 2000 and 2005 range between 0.4% a year in Spain to 4% a year in Belgium the average value being ~2% a year. This trend was adopted for both industrial and sewage sludges.

EU is aiming for a significant cut in the amount of waste generated, through new waste prevention initiatives, better use of resources, and encouraging a shift to more sustainable consumption patterns. Furthermore, the European landfill directive set a target to reducing the quantities of biodegradable municipal solid waste sent to landfill to 35% of 1995 levels by 2020, corresponding to a reduction of ~3% a year. On the other hand projections on household waste generation in EU (Brodersen et al., 2002) showed that an increase of ~1% a year can be expected between 2000 and 2010 corresponding to respective increase in the quantities of waste available for incineration (Table 5).

### 3.4. Regional distribution

The Member States considered in this study are Austria, Belgium, Bulgaria, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, the Netherlands, Poland, Portugal, Romania, UK, Slovak Republic, Slovenia, Spain and Sweden. During the analysis and interpretation they are grouped in two categories which reflect the stage of biomass market development and time of joining the European Union (Fig. 1).

- Western European Countries: AU, B, DK, DE, FIN, FR, HE, IRL, IT, NL, PT, ES, S, UK.
- Central and Eastern European Countries: BUL, CZ, EST, HUN, LV, LT, POL, RO, SK, SL.

Data for Malta, Cyprus and Luxemburg was either not available or presented very low values for the examined feedstocks and therefore it was decided not to include them in the paper.

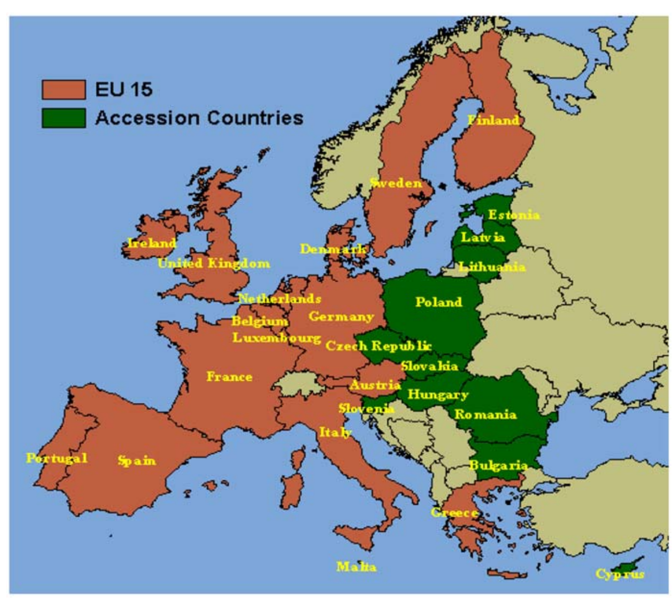


**Fig. 1.** EU 27 Member States grouped as Western European countries (WEC) and Central and Eastern European countries (CEEC) for the purposes of this study.

## 4. Availability of tradable and non tradable biomass feedstocks

### 4.1. Agricultural biomass

In the framework of this study agricultural biomass comprises of solid agricultural residues, and livestock wastes in the form of wet and dry manure.

Detailed estimates for each feedstock type are presented below:

*Agricultural field crop residues*: The availability of these types of residues for energy purposes is restricted by several technical, environmental or economic factors that are difficult to be quantified.

According to Dalianis and Panoutsou (1995) from the total agricultural residues produced in WEC, 48% are being exploited in non-energy (e.g., animal feeding) or traditional energy applications and a further 40–45% of the unexploited quantity cannot be exploited for various technical and/or economical reasons. Based on the findings of this study it was chosen to use conservative availability factor of 30% for all agricultural field crop residues under consideration in Europe. Table 6 shows their availability on a country basis.

It was estimated that in the EU27 about 32.7 Mtoe/year of agricultural residues are produced, of which 25.4 and 7.3 Mtoe result from the WEC and the CEEC, respectively.

*Wet manure*: The average volume of faeces and urine largely differ from one type of animal to another and mainly depend on their age and live weight (Steffen et al., 1998). However, in order to assist in the planning, design and operation of manure collection, storage, pre-treatment and utilisation systems for livestock enterprises mean values have been developed by various researchers. In this analysis we adopt the ASAE standard coefficients, presented in Table 4.

The values represent fresh faeces and urine. Having in mind the possibilities for collection and energy use of the manure (in view of keeping animals outdoors, or in small farms), it is assumed that only 50% can be considered available for energy production (Table 7).

About 13 Mtoe of wet manure is available for anaerobic digestion in the EU27 of which 10.4 Mtoe in the WEC and 2.6 Mtoe in the CEEC.

*Dry manure*: Dry manure consists of poultry manure. To estimate the relevant quantities, the FAOSTAT chicken stocks were used, combined with a co-efficient of 0.03 dry kg/animal/day (Loehr, 1974). It was assumed that 50% of the poultry manure could be utilised for energy purposes.

About 2.22 Mtoe of wet manure is available for anaerobic digestion in the EU27 of which 1.85 Mtoe in the WEC and 0.37 Mtoe in the CEEC.

### 4.2. Forest biomass

The European continent has nearly 215 million ha of forests and other wooded land, accounting in total for nearly 30% of the continent's land area and about 5% of the world's forests (FAOSTAT, 2000). There is about 0.28 ha of forest and other wooded land for every European, while the world average is 0.63 ha per capita. Unlike those of many other regions, where deforestation is proceeding at a rapid pace, European forests have been expanding steadily since the beginning of the 20th century (apart from times of war) in both area and growing stock (FAOSTAT, 2000). Almost all of Europe's forests are managed, and have been managed for a very long time and primary or virgin forests are limited (Nabuurs, et al., 1997).

The total energy potential of the sector for EU27 was estimated to 30.88 Mtoe/year and for the CEEC under study 7.06 Mtoe/year

**Table 6**
Availability of agricultural crop residues in EU27.

| Country | Available quantity (ktonnes/year) | Reference | Energy potential (ktoe/year) | | |
|---|---|---|---|---|---|
| | | | 2000 | 2010 | 2020 |
| AT | 500 | 4 | 215 | 237 | 262 |
| BE | 379 | 2 | 163 | 180 | 199 |
| BG | 2681 | 11 | 1153 | 1273 | 1406 |
| CY | – | | – | – | – |
| CZ | 796 | 9 | 342 | 378 | 417 |
| DE | 7222 | 5 | 3105 | 3430 | 3789 |
| DK | 1605 | 5 | 690 | 762 | 842 |
| EE | 54 | 2 | 23 | 26 | 28 |
| EL | 3833 | 3 | 1648 | 1820 | 2011 |
| ES | 7006 | 2 | 3012 | 3327 | 3675 |
| FI | 541 | 2 | 233 | 257 | 284 |
| FR | 22,889 | 1, 2 | 9840 | 10,870 | 12,007 |
| HU | 1439 | 5 | 619 | 683 | 755 |
| IRL | 117 | 7 | 50 | 55 | 61 |
| IT | 9072 | 6 | 3900 | 4308 | 4759 |
| LT | 340 | 9 | 146 | 161 | 178 |
| LUX | – | | – | – | – |
| LV | 72 | 10 | 31 | 34 | 38 |
| MAL | – | | – | – | – |
| NL | 620 | 8 | 267 | 294 | 325 |
| PL | 6930 | 5 | 2979 | 3291 | 3635 |
| PT | 1433 | 6 | 616 | 681 | 752 |
| RO | 4128 | 2 | 1775 | 1960 | 2165 |
| SE | 304 | 5 | 131 | 144 | 159 |
| SI | 56 | 5 | 24 | 27 | 30 |
| SK | 512 | 5 | 220 | 243 | 269 |
| UK | 3600 | 5 | 1548 | 1710 | 1889 |
| **Total** | **76,129** | | **32,730** | **36,151** | **39,935** |

1: Vesterinen and Alakangas (2001); 2: FAOSTAT (2000); 3: Mardikis et al., (2003); 4: Worgetter, et al. (2003); 5: AFB Network (2002); 6: ALTENER (2002); 7: Rice (2003); 8: Faaij et al. (1997); 9: Vrubliauskas and Krusinskas (2000); 10: Rochas (2003); 11: Ministry of Agriculture & Forestry Bulgaria (2001a,b).

**Table 7**
Availability of wet and dry manure in EU27.

| Country | Available quantity (ktonnes/year) | | Reference | Total energy potential (ktoe/year) | | |
|---|---|---|---|---|---|---|
| | Wet manure | Dry manure | | 2000 | 2010 | 2020 |
| AT | 110 | 118 | Eurostat (2002), ASAE (1999) | 49 | 54 | 60 |
| BE | 1990 | 468 | Eurostat (2002), ASAE (1999) | 529 | 583 | 645 |
| DE | 10,570 | 917 | Eurostat (2002), ASAE (1999) | 2469 | 2728 | 3012 |
| DK | 2486 | 179 | Eurostat (2002), ASAE (1999) | 572 | 632 | 699 |
| EL | 516 | 516 | Mardikis et al. (2003) | 162 | 179 | 198 |
| ES | 4857 | 1090 | Eurostat (2002), ASAE (1999) | 1278 | 1412 | 1560 |
| FI | 768 | 67 | Eurostat (2002), ASAE (1999) | 179 | 198 | 219 |
| FR | 9441 | 1984 | Eurostat (2002), ASAE (1999) | 2456 | 2713 | 2996 |
| IE | 2644 | 100 | Rice (2003) | 590 | 652 | 720 |
| IT | 5828 | 852 | Eurostat (2002), ASAE (1999) | 1436 | 1586 | 1752 |
| NL | 4010 | 916 | Eurostat (2002), ASAE (1999) | 1059 | 1169 | 1292 |
| PT | 832 | 298 | Eurostat (2002), ASAE (1999) | 243 | 268 | 296 |
| SE | 974 | 62 | Eurostat (2002), ASAE (1999) | 222 | 246 | 271 |
| UK | 4950 | 1338 | Eurostat (2002), ASAE (1999) | 1352 | 1493 | 1649 |
| BG | 145 | 119 | Ministry of Agriculture Bulgaria (2001a, b) | 56 | 62 | 69 |
| CZ | 1988 | 116 | FAO (2002) | 452 | 500 | 553 |
| EE | 90 | 21 | FAO (2002) | 24 | 26 | 29 |
| HU | 1950 | 220 | FAO (2002) | 466 | 515 | 569 |
| LT | 247 | 54 | Department of statistics of Lithuania | 65 | 72 | 79 |
| LV | 135 | 28 | Rochas (2003) | 35 | 39 | 42 |
| PL | 9300 | 422 | FAO (2002) | 2090 | 2308 | 2550 |
| RO | 1308 | 589 | FAO (2002) | 408 | 451 | 497 |
| SK | 120 | 120 | FAO (2002) | 52 | 56 | 62 |
| SI | 552 | 36 | FAO (2002) | 127 | 140 | 155 |
| **Total WEC** | **49,976** | **8905** | | **12,596** | **13,913** | **15,369** |
| **Total CEEC** | **15,835** | **1725** | | **3775** | **4169** | **4605** |
| **Total** | **65,811** | **10,630** | | **16,371** | **18,082** | **19,974** |

(Siemons et al., 2004). More specifically, the energy potential of woodfuel in WEC was estimated to 16.07 Mtoe/year and of forest residues 14.78 Mtoe/year. The respective values for the CEEC under study were for woodfuel 6.95 Mtoe/year and forestry residues 0.095 Mtoe/year. The low value of forest residues compared to woodfuel in CEEC can be attributed to the fact that no separate figures were found in literature at the time of this study (2003–2004) for these biomass resources in all countries. The energy potential of forest residues combined with the energy potential of agricultural residues is in line with the targets mentioned in the White Paper (European Commission, 1997).

More specifically, according to the White Paper the contribution of biomass in the European energy market that could be made by agricultural and forest residues is estimated at 30 Mtoe. In this study the estimated energy potential of solid agricultural field crop residues and forest residues is approximately 47 Mtoe.

### 4.2.1. *Forestry by-products*

The total energy potential of forestry by-products in the WEC is estimated at 17.5 Mtoe/year (Table 8). No separate figures were found for forestry residues and wood fuels in CEEC. The combined figures are reported in the next section on wood fuels and presented in Table 9.

### 4.2.2. *Refined wood fuels*

Refined wood fuels, defined by Vesterinen and Alakangas (2001) as *pellets, briquettes and other such solid wood fuel products* are made from residues deriving from the forestry sector and the wood processing industry. Because of the additional processing costs, they are evaluated separately from forestry by-products and solid industrial wastes.

Data on the use and availability of wood fuels in the WEC were mainly taken from Vesterinen and Alakangas (2001).

The future availability of wood fuels in the WEC should not be regarded as limited by the numbers presented in Table 8, since forestry residues and solid industrial residues can also be used as raw material to produce refined wood fuels.

In the CEE countries a large part of the wood fuels originate directly from forest residues, contrary to refined wood fuels used in the WEC. Given the fact that these wood fuels are often collected directly from the forest, the difference between them in the examined literature was not always that obvious. Table 9 presents aggregated data for both categories.

## 4.3. *Industrial biomass*

Industrial waste types that were assessed in this paper include waste wood from wood processing industries and industrial black liquors.

Solid industrial residues consist mainly of clean wood fractions from the secondary wood processing industry. These residues are often already dried and are released at a central location, which reduces logistic and pre-treatment costs. Wood industries already use part of these residues for heating purposes like space heating and wood drying. Some residues like sawdust are suitable for wood pellet production.

Table 10 shows the availability of industrial residues in the European countries. With 12.9 Mtoe/year in the EU27, of which 2.1 Mtoe from the CEEC and 10.8 Mtoe from the WEC it is a substantial biomass resource.

Industrial black liquors are liquid by-products from the pulp industry that contain valuable energy and converted inorganic cooking chemicals. There are several processes which have been developed for recovering the organic combustion heat and chemicals (Thraen et al., 2006).

They are usually utilised at the production site where the black liquor is produced. Its heat can be used elsewhere in the process. Table 10 shows that especially Finland and Sweden produce almost 61% of all black liquor in the EU27.

**Table 8**
Availability of forest by-products and refined wood fuels in WEC.

| Country | Available quantity (ktonnes/year) | | Energy potential (ktoe/year) | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | 2000 | | 2010 | | 2020 | |
| | Forestry by-products (FBP) | Refined wood fuels (RW) | FBP | RW | FBP | RW | FBP | RW |
| AT | 8333[a] | 2389[a] | 3583 | 1027 | 3958 | 1134 | 4372 | 1253 |
| BE | 411[a] | 18[a] | 177 | 8 | 195 | 8 | 216 | 9 |
| DE | 7900[a] | 4722[a] | 3396 | 2030 | 3752 | 2243 | 4144 | 2477 |
| DK | 611[a] | 389[a] | 263 | 167 | 290 | 185 | 321 | 204 |
| EL | 99[b] | 1100[e] | 43 | 473 | 47 | 522 | 52 | 577 |
| ES | 3250[a] | 672[a] | 1397 | 289 | 1543 | 319 | 1705 | 353 |
| FI | 5333[a] | 2778[a] | 2293 | 1194 | 2533 | 1319 | 2798 | 1457 |
| FR | 2111[a] | 14,333[a] | 908 | 6162 | 1003 | 6807 | 1107 | 7519 |
| IRL | 128[c] | 189[a] | 55 | 81 | 61 | 90 | 67 | 99 |
| IT | 860[b] | 4611[a] | 370 | 1982 | 408 | 2190 | 451 | 2419 |
| NL | 260[b] | 639[b] | 112 | 275 | 123 | 303 | 136 | 335 |
| PT | 1173[b] | 1522[a] | 504 | 654 | 557 | 723 | 615 | 799 |
| SE | 9333[d] | 3961[a] | 4013 | 1703 | 4432 | 1881 | 4896 | 2078 |
| UK | 889[a] | 1500[a] | 382 | 645 | 422 | 712 | 466 | 787 |
| **Total** | **40,691** | **38,823** | **17,496** | **16,690** | **19,324** | **18,436** | **21,346** | **20,366** |

[a] Source: Vesterinen and Alakangas (2001).
[b] Source: AFB Network (2002).
[c] Source: Rice (2003).
[d] Source: Richardson et al. (2002).
[e] Source: CRES, (2002).

**Table 9**
Availability of forest by-products and refined wood fuels in CEEC.

| Country | Available quantity (ktonnes/year) | Energy potential (ktoe/year) | | |
|---|---|---|---|---|
| | | 2000 | 2010 | 2020 |
| BG | 2654[a] | 1141 | 1260 | 1392 |
| CZ | 300[b] | 129 | 142 | 157 |
| EE | 1600[D] | 688 | 760 | 839 |
| HU | 874[b] | 376 | 415 | 458 |
| LT | 1917[c] | 824 | 910 | 1006 |
| LV | 2267[D] | 974 | 1076 | 1189 |
| PL | 2267[b] | 975 | 1077 | 1189 |
| RO | 6103[b] | 2624 | 2898 | 3202 |
| SK | 90[b] | 39 | 43 | 47 |
| SI | 305[b] | 131 | 145 | 160 |
| **Total** | **18,377** | **7,901** | **8,726** | **9,639** |

[a] Source: Ministry of Agriculture & Forestry Bulgaria (2001a, b), Ministry of Agriculture & Forestry Bulgaria (2002).
[b] Source: European Commission (2001).
[c] Source: Lithuanian Energy Institute (2001).

### 4.4. Waste biomass

The total energy potential of industrial biomass and waste is estimated for the WEC at 21 Mtoe/year and for the CEEC at 5.5 Mtoe/year. The total energy potential of waste in the WEC was 18.2 Mtoe/year and for the CEEC countries 2.6 Mtoe/year.

*Sewage sludges*: In waste water treatment of urban and industrial wastewater sewage gas is recovered which can be used for energy purposes. Sewage sludge is a residual product from the treatment of urban and industrial wastewater. The quantities of sewage sludge were taken as a measure for the amount of biogas that can be produced. It was assumed that 1 dry tonne of sewage sludge corresponds with 9 GJ of sludge. For every country, data on sludge production could be obtained. In total about 2.1 Mtoe of sewage gas is reported as available in the EU27 (Table 11). It should be stressed out that this number is expected to be significantly higher but at the date of this review very limited data were available for CEEC countries.

*Biodegradable waste (BMW)* is defined by Article 2 (m) of the Council Directive (1999/31/EC)60 on the landfill of waste, i.e. as follows: 'biodegradable waste' means any waste that is capable of undergoing anaerobic or aerobic decomposition, such as food and garden waste, and paper and paperboard". Synthetic organic materials such as plastics are excluded from this definition, since they are not biodegradable. It is recognised that energy recovery from these non-renewable materials like plastics takes place and could be encouraged. However, the focus is on biomass residues that can contribute to a net reduction in carbon emissions.

The technical potential offered by BMW was estimated by means of Crowe et al. (2002), who presents an operational baseline for BMW in the WEC by 1995, which is subject to the agreement of each EEA-member country and Eurostat. The growth of waste quantities in 2000, 2010 and 2020 are based on GDP growth. For 2010 and 2020 an annual growth of waste quantities of 3% was assumed.

The following assumptions were further made:

- Member States will fulfill their obligations at the latest time possible. Thus, a reduction of 75% of the 1995 number is assumed in 2010, and 35% in 2020.
- All WEC and accession countries will comply with the Landfill Directive.
- In case countries presently produce less BMW for landfill than stated in the Landfill Directive, these countries will limit the amount of landfilled waste at the present level, and not increase these quantities.
- All BMW that does not go to landfill is available for incineration.
- The moisture content of BMW was estimated at 35% (wet basis).

The resulting quantities of waste for landfill and incineration were reviewed and have been further translated in terms of energy for two applications: (i) landfill gas and (ii) incineration with energy recovery.

**Table 10**
Availability of industrial biomass (solid industrial residues and black liquor).

| Country | Available quantity (ktonnes/year) | | Energy potential (ktoe/year) | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | 2000 | | 2010 | | 2020 | |
| | Solid industrial (SI) | Black Liquor (BL) | SI | BL | SI | BL | SI | BL |
| AT | 2778[b] | 2491[a] | 1194 | 595 | 1319 | 657 | 1457 | 726 |
| BE | 700[b] | 760[b] | 301 | 182 | 332 | 201 | 367 | 221 |
| DE | 2222[b] | 1676[a] | 955 | 400 | 1055 | 442 | 1166 | 488 |
| DK | 278[b] | 161[a] | 119 | 38 | 132 | 42 | 146 | 47 |
| EL | 590[d] | *n.a* | 254 | 0 | 280 | 0 | 310 | 0 |
| ES | 4850[b] | 2250[b] | 2085 | 537 | 2303 | 594 | 2544 | 656 |
| FI | 2611[b] | 14,354[c] | 1123 | 3428 | 1240 | 3787 | 1370 | 4183 |
| FR | 2333[b] | 4508[a] | 1003 | 1077 | 1108 | 1189 | 1224 | 1314 |
| IRL | 260[e] | 0[b] | 112 | 0 | 123 | 0 | 136 | 0 |
| IT | 2000[b] | 177[a] | 860 | 42 | 950 | 47 | 1049 | 52 |
| NL | 189[b] | 0[b] | 81 | 0 | 90 | 0 | 99 | 0 |
| PT | 1500[b] | 2240[b] | 645 | 535 | 712 | 591 | 787 | 653 |
| SE | 4148[f] | 12,500[b] | 1783 | 2966 | 1970 | 3298 | 2176 | 3643 |
| UK | 667[b] | 195[a] | 287 | 47 | 317 | 51 | 350 | 57 |
| BG | 70[g] | 86[a] | 30 | 21 | 33 | 23 | 37 | 25 |
| CZ | 760[h] | 573[a] | 327 | 137 | 361 | 151 | 399 | 167 |
| EE | 350[b] | 48[a] | 150 | 11 | 166 | 13 | 184 | 14 |
| HU | 378[h] | *n.a* | 162 | 0 | 179 | 0 | 198 | 0 |
| LT | 416[i] | *n.a* | 179 | 0 | 198 | 0 | 218 | 0 |
| LV | 667 [k] | *n.a* | 287 | 0 | 317 | 0 | 350 | 0 |
| PL | 806[h] | 1103[a] | 347 | 263 | 383 | 291 | 423 | 321 |
| RO | 1278[b] | 300[b] | 549 | 72 | 607 | 79 | 670 | 87 |
| SK | 161[h] | 674[a] | 69 | 161 | 77 | 178 | 85 | 196 |
| SI | 92[h] | 170[a] | 40 | 41 | 44 | 45 | 48 | 50 |
| **Total WEC** | **25,126** | **41,312** | **10,802** | **9847** | **11,931** | **10,899** | **13,181** | **12,040** |
| **Total CEEC** | **4978** | **2954** | **2140** | **706** | **2365** | **780** | **2612** | **860** |
| **Total** | **30,104** | **44,266** | **12,942** | **10,553** | **14,296** | **11,679** | **15,793** | **12,900** |

[a] Source: FAOSTAT, 2000.
[b] Source: Vesterinen and Alakangas, 2001.
[c] Source: AFB Network, 2002.
[d] Source: Mardikis et al., 2003.
[e] Source: Rice, 2003.
[f] Source: Richardson, et al, 2002.
[g] Source: Ministry of Agriculture and Forestry in Bulgaria, 2001b
[h] Source: European Commission, 2001.
[i] Source: Rochas, 2003.

For the energy potential of landfill gas the maximum quantity of gas that can be extracted from a given quantity of dumped waste is taken, using a calorific value of 3.71 GJ/tonne dry BMW. This value was derived by making use of the IPCC method (Cost E9, 2001) for total landfill gas production. As a result of implementing the Landfill Directive, the quantities of landfill gas will decrease significantly over time.

In Tables 12 and 13 the resulting quantities of wastes for landfill and incineration are reviewed.

In Fig. 2, these quantities have been translated in terms of energy for two applications: (i) landfill gas and (ii) incineration with energy recovery.

For the energy potential of landfill gas the maximum quantity of gas that can be extracted from a given quantity of dumped waste is taken, using a calorific value of 3.71 GJ/tonne dry BMW. This value was derived by making use of the IPCC method for total landfill gas production. As a result of implementing the Landfill Directive, the quantities of landfill gas will decrease significantly over time.

In determining the availability of BMW for incineration with energy recovery, it was assumed that all BMW not sent to landfill is available for this purpose. These results are presented above in Fig. 3. A net calorific value (NCV) of 12 GJ/tonne dry matter was assumed. It is worthwhile to note the considerable increase of the availability of BMW for incineration with energy recovery. Its resource is expected to quadruple in 20 years.

### 4.4.1. *Demolition wood*

Data on available quantities of demolition wood were difficult to collect. Brodersen et al. (2002) provided useful information. In countries for which no data were identified the availability of demolition wood was set at zero. For the EU27 total of 5.8 Mtoe was considered by this study as conservative.

The total energy potential of waste for EU was found to be 18 Mtoe/year and for the CEEC under study approximately 3 Mtoe/year. More specifically, the energy potential of sewage sludge gas in EU was estimated to 73 PJ/year (~2 Mtoe), landfill gas ~4 Mtoe/year, municipal waste for incineration to ~7 Mtoe/year and demolition wood ~5 Mtoe/year.

The respective values for the CEE countries under study were 0.5 Mtoe/year for sewage sludge, 1.03 Mtoe/year for landfill gas, 0.3 Mtoe/year for municipal waste for incineration and 0.79 Mtoe/year for demolition wood.

According to EU's White Paper for renewable energy, the contribution of biomass in the European energy market that could be made by biogas exploitation from animal waste, agro-industry effluents, sewage treatment and landfill is estimated at 15 Mtoe.

In the summary report on biomass survey in Europe (April 2003) of the project EUBIONET–European Bioenergy Networks (EUBIONET, 2003) the potential of all the European Union countries in terms of biogas production from the same biomass resources is estimated at nearly 18 Mtoe. In this paper the respective estimate was 16 Mtoe.

**Table 11**
Availability of gas from sewage in EU27.

| Country | Available quantity (ktonnes/year) | Total energy potential (ktoe/year) | | |
|---|---|---|---|---|
| | Sewage sludge | 2000 | 2010 | 2020 |
| AT | 212[a,c] | 46 | 50 | 56 |
| BE | 113[a,d] | 24 | 27 | 30 |
| DE | 2661[a] | 572 | 632 | 698 |
| DK | 200[a] | 43 | 47 | 52 |
| EL | 86[a] | 18 | 20 | 23 |
| ES | 787[a] | 169 | 187 | 206 |
| FI | 158[a] | 34 | 38 | 41 |
| FR | 878[a] | 189 | 208 | 230 |
| IE | 43[a] | 9 | 10 | 11 |
| IT | 924[b] | 199 | 219 | 242 |
| NL | 349[a,c] | 75 | 83 | 92 |
| PT | 238[a] | 51 | 56 | 62 |
| SE | 236[a] | 51 | 56 | 62 |
| UK | 1193[a] | 256 | 283 | 313 |
| BG | 74[a] | 16 | 18 | 19 |
| CZ | 1165[d,c] | 250 | 277 | 306 |
| EE | 35[d] | 8 | 8 | 9 |
| HU | 65[b,c] | 14 | 15 | 17 |
| LT | 57[b] | 12 | 13 | 15 |
| LV | 14[a] | 3 | 3 | 4 |
| PL | 256[b,c] | 55 | 61 | 67 |
| RO | 110[d] | 24 | 26 | 29 |
| SK | 90[d,c] | 19 | 21 | 24 |
| SI | 4[d,c] | 1 | 1 | 1 |
| **Total WEC** | **8078** | **1736** | **1916** | **2118** |
| **Total CEEC** | **1870** | **402** | **443** | **491** |
| **Total** | **9948** | **2138** | **2359** | **2609** |

[a] Source: Brodersen et al., 2002.
[b] Source: Altener, 2002.
[c] EEA, 1999.
[d] Merl, 2001.

**Table 12**
Availability of biodegradable municipal waste (BMW) in 2000, 2010 and 2020 for landfill and incineration with energy recovery (ktonnes dry/year).

| | | 2000 (and 1995) | | 2010 | | | 2020 | | |
|---|---|---|---|---|---|---|---|---|---|
| | Total | Landfill | Incineration | Total | Landfill | Incineration | Total | Landfill | Incineration |
| AT *la* | 972 | 196 | 775 | 1367 | 196 | 1170 | 1610 | 196 | 1413 |
| B[a] | 2603 | 1556 | 1245 | 3981 | 1558 | 2423 | 4735 | 981 | 3754 |
| DE[a] | 16,655 | 13,096 | 5559 | 26,495 | 13,096 | 13,395 | 31,360 | 6529 | 24,631 |
| DK[a] | 1178 | 133 | 1045 | 1674 | 133 | 1540 | 1942 | 133 | 1609 |
| EL[a] | 1747 | 1747 | 1747 | 2941 | 1310 | 1631 | 3034 | 612 | 3322 |
| E3[a] | 7561 | 5735 | 1827 | 11,730 | 5671 | 6105 | 14,768 | 2647 | 12,141 |
| Fl *la* | 1062 | 735 | 376 | 1684 | 705 | 979 | 1993 | 373 | 1615 |
| FR[a] | 10,235 | 3592 | 6343 | 14,536 | 3892 | 10,644 | 17,375 | 3582 | 13,793 |
| IE *la* | 644 | 587 | 57 | 1363 | 483 | 880 | 1678 | 225 | 1453 |
| IT[a] | 5961 | 4434 | 1527 | 8131 | 4434 | 3747 | 9633 | 2086 | 7597 |
| NL[a] | 314-0 | 887 | 2252 | 4750 | 887 | 3863 | 5791 | 887 | 4903 |
| PT[a] | 2146 | 2142 | 4 | 3718 | 1609 | 2109 | 4973 | 75 | 4222 |
| SE[a] | 1726 | 621 | 1135 | 2331 | 621 | 1760 | 2763 | 604 | 2159 |
| UK[a] | 10,638 | 9539 | 1099 | 15,407 | 7978 | 7420 | 18,506 | 3723 | 14,783 |
| BG[b] | 2320 | 1600 | 720 | 3237 | 1740 | 1547 | 4269 | 812 | 3477 |
| *CZlb* | 837 | 790 | 48 | 1105 | 628 | 476 | 1442 | 293 | 1149 |
| *EElb* | 568 | 568 | 0 | 809 | 426 | 383 | 1056 | 199 | 857 |
| HLUb | 1259 | 1161 | 99 | 1722 | 945 | 778 | 2247 | *n.a* | 1806 |
| LT[c] | 278 | 278 | 0 | 403 | 209 | 194 | 526 | 97 | 429 |
| LV[b] | 410 | 225 | 184 | 598 | 307 | 291 | 780 | 143 | 636 |
| PL[b] | 3360 | 3360 | C | 4471 | 2520 | 1951 | 5834 | 1175 | 4658 |
| RO[b] | 3796 | 3417 | 379 | 5394 | 2847 | 2547 | 7038 | 1326 | 5709 |
| SK[b] | 442 | 296 | 146 | 614 | 331 | 283 | 801 | 155 | 647 |
| SI[b] | 314 | 274 | 39 | 425 | 235 | 190 | 554 | 110 | 445 |
| **TotalWEC** | **63,128** | **45,000** | **23,244** | **10,108** | **42,573** | **50,246** | **117,127** | **22,578** | **97,395** |
| **TotalCEEC** | **13,584** | **11,969** | **1615** | **18,778** | **10,188** | **8640** | **24,547** | **4310** | **19,813** |
| **Total** | **76,712** | **56,969** | **24,859** | **11,886** | **52,761** | **58,886** | **141,674** | **26,888** | **117,208** |

[a] Crowe et al., 2002.
[b] Rice, 2003.
[c] Vrubliauskas and Krusinskas, 2000.

**Table 13**
Supply costs of solid biomass residues (€/GJ).

| Country | Refined wood fuels | Solid agricultural residues | Industrial residues | References |
|---|---|---|---|---|
| AT | 2.3–4.1 | 2.9–3.4 | 0.92 | AFB Network (2002) |
| BE | 6.1 | *n.a* | 1.05 | Sintzoff (2000) |
| BG | 2.2 | 1.4–3.2 | 1.07 | Ministry of Agriculture & Forestry Bulgaria (2001a, b) |
| CZ | 4.1 | 1.5 | 4.1 | Siemons et al. (2004) |
| DE | 5.6–8.2 | 3.1–3.6 | 1.5–6 | AFB Network (2002) |
| DK | 2–3.35 | 3–4 | 1.05 | AFB Network (2002) |
| EE | 1.05 | 2.39 | *n.a* | AFB Network (2002) |
| EL | 6 | 1.2–5 | *n.a* | Mardikis et al. (2003) |
| ES | 3.8 | 1.1–1.7 | 1.38–2.28 | Varela et al., (2000) |
| FI | 2.1 | 1.4–3.3 | 2.1 | AFB Network (2002) |
| FR | 2.4–2.8 | 3.6–3.9 | 2 | AFB Network (2002) |
| HU | 4.2 | 1.6 | 4.3 | AFB Network (2002) |
| IRL | 2.2 | *n.a* | 1.4–3.5 | Rice (2003) |
| IT | 4.81 | 1.1–2.8 | 2.39 | AFB Network (2002) |
| LT | 1.5 | 2.3 | 0.8 | AFB Network (2002) |
| LV | 1.5 | 2.2 | 0.8 | European Commission (2001) |
| NL | 4.1 | 2.8–5 | 0–2.8 | Scherpenzeel (1999) |
| PL | 3.4–4 | 1.8 | 0–1.8 | AFB Network (2002) |
| PT | 2.78 | 3 | 1.37 | AFB Network (2002) |
| RO | 1.24 | 1.3–2.6 | 0.58 | AFB Network (2002) |
| SE | 3.39–4.75 | 3–4 | 2.89 | AFB Network (2002) |
| SI | 4.2 | 2.5 | 6.9 | Siemons et al. (2004) |
| SK | 3.8 | 1.3–4 | 3.7 | Siemons et al. (2004) |
| UK | 3.33–14 | 1.6–2.8 | 0–2.6 | AFB Network (2002) |

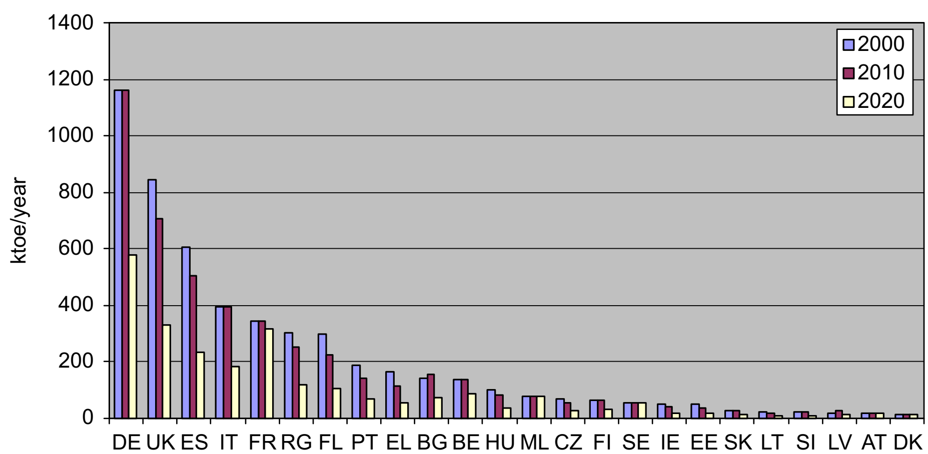


**Fig. 2.** Estimated landfill gas potentials (ktoe/year).

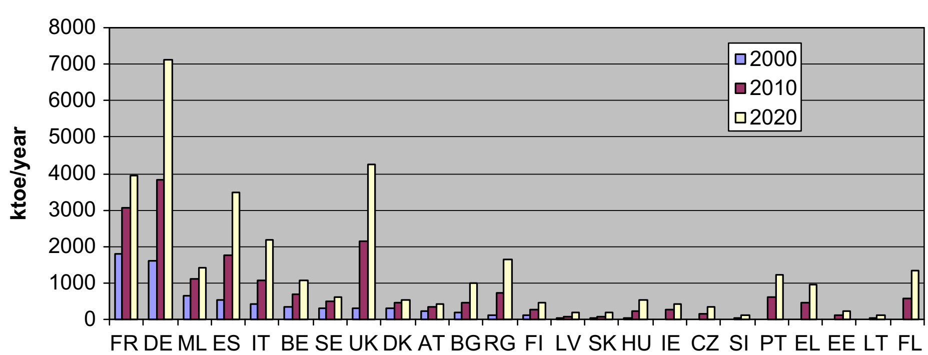


**Fig. 3.** Estimated incineration potentials (ktoe/year).

## 5. Analysis of supply costs

### 5.1. Agricultural biomass

#### 5.1.1. Solid agricultural residues

A well-designed collection–transport–storage system has to be established to ensure the successful use of field agricultural residues for energy and other purposes. As their bulk density is rather low, densification to bales, etc. is normally used to reduce costs and increase the energy density of the transported material (Varela et al., 2000). In most of the reviewed studies, even if the residues could be purchased at zero cost, the supply costs were at least in the range of 1–1.5 €/GJ.

The supply costs for agricultural residues could increase substantially under the influence of transport costs, costs of storage, and opportunity costs.

Table 13 shows the supply costs for solid biomass residues of agriculture and forest origin in the EU countries included in the study.

#### 5.1.2. Forestry by-products

The supply costs of forestry by-products found in literature shows considerable variation within and between countries. It is assumed that the costs of collection and transport of forestry residues at least implies supply costs of 1.5 €/GJ. Table 13 shows the supply costs found in literature.

#### 5.1.3. Refined wood fuels

Wood fuels are available in many types, varying from simple wood chips and pieces of wood used in fire places up to high-quality pellets that can be automatically fed into central heating systems. The variation in supply costs among countries reflects such differences in type and quality (see Table 13).

#### 5.1.4. Industrial residues

The supply costs of industrial residues can be very low if the residues are used on site where the biomass is released. If pre-treatment and transport is required, supply costs present a slight increase. However, in general fairly low supply costs of 1–3 €/GJ have been found in literature (Table 13). Industrial residues like sawdust from softwood are suitable for the production of wood pellets, and could lead to higher prices because of competition.

## 6. Future potentials

### 6.1. Availability

According to the findings of this study the total availability of biomass fuels in the WEC and CEEC countries under study was 135 Mtoe/year for the year 2000, increasing to 186 Mtoe/year in 2020 (Table 14).

The availability of agricultural residues is almost 60 Mtoe for 2020 with field agricultural residues accounting for two thirds of the total and wet manure for 17 Mtoe. Forest biomass presents slightly lower potential with 51 Mtoe for 2020, in which refined wood fuels have a major share (30 Mtoe).

The growth in the availability of organic wastes is the most striking, but can be attributed to the measures suggested by the Landfill Directive.

### 6.2. Supply costs

The cost for crop residues in the WEC ranges from 1.4 to 6.45 €/GJ and in the CEEC from 1.5 to 2.65 €/GJ. The respective costs for woodfuel in the WEC range from 2.1 to 8.7 €/GJ and in the CEEC from 1.05 to 7 €/GJ. The cost of forestry by-products in WEC ranges from 1.4 to 6.7 €/GJ and in the CEEC between 0.8 and 7.7 €/GJ (Table 15).

The cost of solid industrial residues in the WEC ranges between 0.92 and 3.3 €/GJ and in the CEEC between 0.8 and 6.9 €/GJ.

**Table 14**
Biomass availability in EU27.

| Feedstock type | Available quantity (ktonnes/year) | Energy potential (ktoe/year) | | |
|---|---|---|---|---|
| | | 2000 | 2010 | 2020 |
| **Agricultural Biomass** | | | | |
| Solid agricultural residues | 76,128 | 32,729 | 36,153 | 39,936 |
| Wet manure | 65,808 | 14,145 | 15,623 | 17,260 |
| Dry manure | 10,630 | 2226 | 2459 | 2716 |
| **Forest Biomass** | | | | |
| Forest by-products | 40,692 | 17,494 | 19,325 | 21,346 |
| Refined wood fuels | 57,200 | 24,592 | 27,164 | 30,006 |
| **Industrial Biomass** | | | | |
| Solid industrial residues | 30,103 | 12,942 | 14,296 | 15,792 |
| Black liquor | 44,265 | 10,573 | 11,679 | 12,901 |
| Sewage sludges | 9945 | 2135 | 2362 | 2609 |
| **Waste Biomass** | | | | |
| Biodegradable municipal waste | | | | |
| Landfill gas | | 5072 | 4675 | 2489 |
| Incineration | | 7116 | 19,010 | 33,708 |
| Demolition wood | 13,585 | 5841 | 6452 | 7127 |
| **Total** | | **134,865** | **159,198** | **185,890** |

**Table 15**
Average supply costs of biomass and fossil fuels (€/GJ).

| | EU27 | WEC | CEEC |
|---|---|---|---|
| **Biomass fuels** | | | |
| Forestry by-products | 2.3 | 2.4 | 2.1 |
| Wood fuels | 3.6 | 4.3 | 2.7 |
| Dry agricultural residues | 2.6 | 3.0 | 2.1 |
| Solid industrial residues | 2.0 | 1.6 | 2.5 |

## 7. Conclusions

Biomass availability in the examined Member States totals approximately 159 Mtoe/year for 2010 with agricultural biomass share being 54 Mtoe, forestry 46 Mtoe and waste derived biomass 30 Mtoe. The remaining 29 Mtoe derive from industrial biomass such as solid industrial residues, black liquor and sewage sludges.

As expected the CEEC present significant biomass potentials and in most cases supply costs are relatively lower that the WEC. However, this fact will gradually change and within the next few years supply costs in the respective region will rise due to the increase in labour and land purchase/rent costs.

However, as the study that the paper is based (Siemons et al., 2004) was mainly a literature review and did not follow harmonised methodological approach for the estimation of the country potentials, some of the data remain unverified and detailed analysis at regional/local level is highly recommended to ensure accuracy and capture any individual features omitted in the literature review. Some key observations for biomass potentials in the different sectors examined (namely agriculture, forestry and waste) are presented below:

Agriculture

- Member States with large agricultural area (FR, DE, PL, BU, RO) result in higher potentials both for field residues.

- Potentials from eastern EU Member States (PL, HUN, BU, RO, etc.) are expected to rise up to three-fold (improved yields, management practices, etc.) but their respective cost is also expected to rise (improved salaries, higher economic standards, land prices will increase).

Forestry

- Scandinavia and northern Member States have higher potentials and well developed forest industries due to landscape and climate.
- South Member States face increasing forest fires which along with less-developed infrastructure restricts forest potential.

Wastes

- Untapped potential but a lot needs to be done for pre-conditioning and pre-sorting.

Biomass availability remains a critical issue for successful bioenergy deployment and the recent increased interest in the bioenergy/biofuels sector has posed more restrictions for current and future planning and investment opportunities.

Managing the resource base as well as sustainably increase yields and technology efficiency will be the key pillars for the strategic research and deployment priorities at EU level till 2030 (EBTP, 2008).

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