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Forest Energy Potential in Europe (EU27)

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Abstract

The aim of this study was to estimate forest energy potential in Europe, in particular in 27 European countries that were members of the European Union as of the beginning of 2007. The study is limited to forests available for wood supply. Positive annual change rate of the growing stock illustrates unutilized surplus, which is currently left in the forests. It could be used for industrial purposes for energy production as it is the difference between net annual increment and fellings. Felling residues that are usually left in the forest are becoming an increasingly important source for energy production.

Forest resources in Europe have been increasing during the last 50 years. Annual change rate is approximately 238.6 million m^3 per year or 35% of the net annual increment. The annual change rate has been clearly positive for several decades, and thus an increasing amount of wood has accumulated in the forests, resulting in them becoming denser with older age class structures. Competition for the wood resources is increasing and obviously fulfilment of the demands for industrial use, energy production and protection would require compromises. The use of roundwood directly for energy purposes would depend on the prices of roundwood, especially that for wood-based panels, pulp and paper as well as for energy production.

The potential sources of forest fuels are felling residues and stumps from current fellings and the complementary fellings from the annual change rate surplus, including the roundwood, crown mass and stump wood. It was estimated that felling residues total 211 million m^3 annually. Annually harvestable residues were estimated to be 76.5 million m^3. Annually harvestable stump wood was estimated to be 7.4 million m^3. The total amount of annually harvestable residues and stumps is altogether 83.9 million m^3 which could be used for energy production. If complementary fellings were to be 25% of the annual change rate surplus and directed entirely to energy use, 101.6 million m^3 of above ground biomass and about 1.2 million m^3 of stump wood could be used for energy annually. Thus the available forest fuel totals about 187 million m^3 per year, i.e. about 150 million tonnes of fresh wood, which corresponds to about 411 TWh of energy or 36 Mtoe.

The study also examined the supply costs of chips made from logging residues in the Czech Republic, Finland, France, Hungary, Poland, Slovakia, Spain and UK. The lowest supply costs were found to be in Finland and the Czech Republic whereas the highest costs were in the UK and France.

Keywords

felling residues, forest fuels, annual change rate, wood energy

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Contents

Summary

The European Union has set a target to considerably increase its use of renewable energy sources. This is expected to have a significant impact on the roundwood and wood residue markets, as the energy sector is becoming a new player in these markets. Reliable, up to date and accurate information about the forest resource base that could be used for energy purposes is essential to any analysis of the forest energy potential in Europe.

The aim of this study was to estimate forest energy potential in 27 European countries (EU27) that were members of the European Union as of January 2007. Estimation of the forest energy potential has been divided into estimation of annual change rate, and estimation of felling residues. The study has been limited to forests available for wood supply. The positive annual change rate illustrates unutilized increment or surplus that could be used for industrial purposes, for energy production or left in the forests. Felling residues that are usually left in the forest are becoming increasingly important source for energy production.

Forest resources in Europe have been increasing during the last 50 years. Annual change rate based on the difference between net annual increment and fellings in the EU27 is approximately 238.6 million m^3 per year or 35% of the net annual increment. The annual change rate has been clearly positive for a long time, and thus an increasing amount of wood has accumulated in the forests, resulting in a denser forest structure and older age class structure. Annual change rate surplus can be regarded as a kind of reserve that is currently left in the forests. Competition for the wood resources is increasing and obviously fulfilling the demands for industrial use, energy production and protection would require compromises. The use of roundwood directly for energy purposes would depend of the prices of roundwood, sawnwood, pulp, paper, energy and carbon emissions trading. It is difficult to estimate how much of the unutilized increment could and would be utilized in the future for energy purposes. However, it is most likely that more wood for energy production will be used than today.

The potential sources of forest fuels are felling residues and stumps from current fellings and complementary fellings from the annual change rate surplus, including the roundwood, crown mass and stump wood. It was estimated that felling residues total 211 million m^3 annually. Annually harvestable residues were estimated to be 76.5 million m^3 and stump wood 7.4 million m^3. The total amount of annually harvestable residues and stumps is altogether 83.9 million m^3, which could be used for energy production.

If complementary fellings were to be 25% of the annual change rate surplus and directed entirely to energy use, 101.6 million m^3 of above ground biomass and about 1.2 million m^3 of stump wood could be used for energy production annually.

Thus the available forest fuel totals about 187 million m^3 per year (Figure A), i.e. about 150 million tonnes of fresh wood (moisture content 40%), which corresponds to about 411 TWh of energy or 36 Mtoe.

The study also examined the supply costs of chips made from logging residues in the Czech Republic, Finland, France, Hungary, Poland, Slovakia, Spain and UK. The lowest supply costs were found to be in Finland and the Czech Republic whereas the highest costs were in the UK and France.

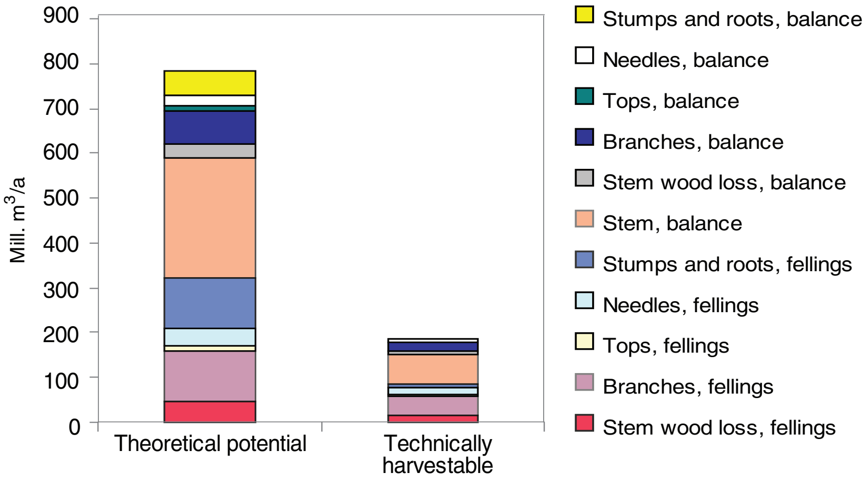


Figure A. Reduction from the theoretical forest fuel potential of 785 million m³ to the technically harvestable volume of 187 million m³. Theoretical potential is net growth of woody biomass excluding current industry and firewood use.

1 Introduction

1.1 Renewables and wood energy in the European Union energy policy

Energy consumption has increased in the European Union (EU) by more than 20% since 1985 (EU 2003). Fossil fuels: oil, coal and natural gas account for 79% of the EU's energy consumption (Figure 1). Their share has decreased by only 2% in the last ten years. Two-thirds of these fossil fuels come from outside the EU. There are risks in being too dependent on fossil fuels as well as on imports (COM 2000). Being too dependent on imports makes the EU vulnerable if international crises affect supplies. In addition, emissions from burning fossil fuels are a major source of greenhouse gas emissions, and thus a significant contributor to global warming. The way forward requires saving energy, its more efficient use, development of alternative sources and increased international cooperation. A decrease in carbon emissions is an essential national and international goal to meet the commitments on climate change mitigation. The efficient use of wood biomass as a renewable energy resource can be a notable replacement for non-renewable and imported energy resources.

In the current 27 EU countries the gross inland consumption of primary energy in 2004 was 1806 million tons oil equivalent or Mtoe (Figure 1 and Table 1). The share of renewables (hydro, wind, geothermal, solar, biomass) was 115 Mtoe, which is 6% of all consumption. That share has basically stayed the same for a decade. There are, however, substantial differences between regions; in North-Western Europe the share is 3%, while in the Nordic and Baltic countries it varies between 8% and 36%, respectively. Biomass, usually from the forest, is the main renewable energy source (Table 1), although the share of hydro was also large in several countries. Biomass totals 66% of the gross domestic consumption of renewables. Most of the biomass used for energy purposes is wood. Its share of the total biomass is 80% (61.2 Mtoe). In absolute terms the largest users of woody biomass for energy purposes are France (9.3 Mtoe), Sweden (8.2 Mtoe), Finland (7.3 Mtoe) and Germany (6.1 Mtoe).

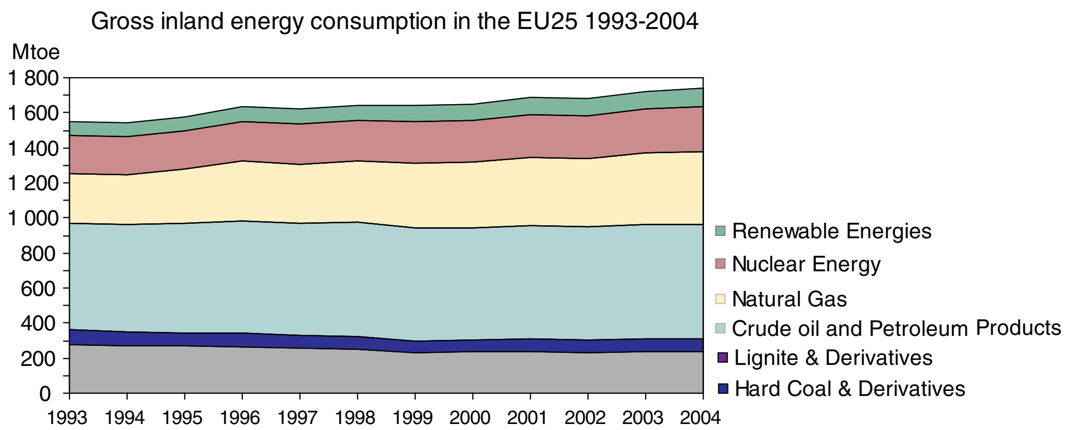


Figure 1. Gross inland consumption of energy in the EU25 between 1993 and 2004 (Eurostat 2007).

Table 1. Gross inland consumption of energy in the EU27, including all fuels, separately for renewables (Mtoe), share of biomass and woodbiomass of the renewables in 2004 (EU 2007)

Country group	Country	Gross Inland Energy Consumption				
		All fuels Mtoe	Renewables Mtoe	Renewables % of all fuels	Biomass % of renewables	Wood biomass % of all biomass
Nordics	Finland	37.7	8.8	23	85	98
	Sweden	53.1	14.1	27	63	92
	Total	**90.8**	**22.9**	**25**		
Baltics	Estonia	5.6	0.6	11	100	100
	Latvia	4.6	1.6	36	84	99
	Lithuania	9.2	0.7	8	95	99
	Total	**19.4**	**3.0**	**15**		
Central-Eastern Europe	Austria	32.7	6.8	21	51	93
	Czech Republic	43.6	1.4	3	87	85
	Hungary	26.2	1.0	4	89	95
	Poland	92.5	4.3	5	95	98
	Romania	39.6	4.6	12	68	100
	Slovakia	18.5	0.7	4	51	91
	Total	**253.1**	**18.8**	**7**		
Central-Western Europe	France	273.7	17.3	6	69	78
	Germany	347.7	13.8	4	68	65
	Luxembourg	4.7	0.1	2	81	25
	Total	**626.1**	**31.1**	**5**		
North-Western Europe	Belgium	54.8	1.2	2	96	53
	Denmark	20.0	2.9	15	80	59
	Ireland	15.7	0.3	2	66	86
	The Netherlands	82.3	2.4	3	92	33
	United Kingdom	232.1	3.7	2	83	37
	Total	**405.0**	**10.4**	**3**		
Iberia	Portugal	26.2	3.9	15	74	93
	Spain	140.2	9.0	6	54	83
	Total	**166.4**	**12.9**	**8**		
South & South-Eastern Europe	Bulgaria	18.9	1.0	5	72	100
	Cyprus	2.5	0.1	4	5	80
	Greece	30.6	1.6	5	61	96
	Italy	184.8	12.5	7	30	59
	Malta	0.9	-	-	-	-
	Slovenia	7.1	0.8	12	57	99
	Total	**244.8**	**16.0**	**7**		
	TOTAL	**1806**	**115**	**6**	**66**	**80**

The need to develop and increase the use of renewable energy has been emphasized in the European Union. The Communication from the Commission entitled "Energy for the future: renewable sources of energy - White Paper for a Community strategy and action plan" (COM 1997) recommends an indicative target of 12% of energy from renewable sources in gross internal consumption in the Community by 2010. The White Paper also outlines the goals for modern bioenergy in Europe; to increase the contribution of bioenergy from 45 Mtoe in 1995 to 135 Mtoe in 2010.

This requires firm decisions and broad co-operation on local, regional and national levels. The Communication from the Commission on the implementation of the Community strategy and action plan for renewable energy sources (1998-2000) notes the progress which has been made,

but stresses that further efforts are needed at the Community and national level to attain these objectives, in particular new legislation on renewable energy sources and their promotion (COM 2001). Measures related to energy efficiency and renewable energy sources are important elements of the action needed to comply with the provisions of the Kyoto Protocol, as provided for in the European Climate Change Programme (ECCP). Based on current trends, the 12% target is unlikely to be met by 2010. Instead the European Commission is expecting a 9% share in 2010.

The White Paper's targets were updated, and a more detailed roadmap for renewables was published (COM 2006). The EU countries have committed to reduce greenhouse gas emissions during the first Kyoto commitment period 2008-2012 by 5% compared to the 1990 reference year (COM 2006). The Commission's roadmap suggests that the EU countries will reduce emissions further so that by 2020 they would be 20% lower than in 1990. If a larger, global agreement will be signed, EU countries may reduce even 30% of their GHG emissions compared to emissions in 1990.

In the roadmap, the goal for the use of renewable energy resources was set at 20% of energy consumption. In addition, 10% of the fuels used in transportation should be bio based. More specifically, the EU's Biomass action plan sets goals to increase the use of biomass for energy. The use of biomass should increase by 80 Mtoe by the year 2010 (COM 2005). This calls for an increased production of biomass in the EU, but also a large part of the biomass has to be imported. However, the EU's own forest energy resources enable the achieving of one-third of the target, which requires the establishment of large scale supply chains for forest energy (Asikainen et al. 2007).

Dependency on oil, mainly from foreign resources, as well as geopolitical instability and environmental issues are the energy security aspects which have made biomass an increasingly important element of the energy, environment and agriculture policy. Forest residues, wood industry residues and short rotation energy crops are the most important sources of solid biofuels. Conventional use of fuelwood has decreased over the decades, while the use of residues from the wood processing industries, recovered wood and demolition waste for energy purposes has increased. Felling residues were usually left on the site, but Finland and Sweden have been collecting residues for energy purposes for years and this practice has also started to spread to other countries. In 2004, residential firewood represented 33.5% (21.9 Mtoe) and forest residue 12.3% (8.1 Mtoe) of the total (142.6 Mtoe) biomass energy use in the EU27 excluding Bulgaria, Cyprus, Lithuania, Luxembourg, Malta, Romania and Slovenia (Alakangas et al. 2004). In this report's predecessor (Karjalainen et. al. 2004) technically available forest energy potential in the EU25 was estimated to be 140 mill. m^3 (24 Mtoe). The extent of wood biomass use as an energy resource varies among the European countries. Forest resources, technology, power plants, national laws and policies, and many other issues affect accelerating the use and the development of the renewable energy sector.

Implementation of the White Paper is expected to have a significant impact on the timber and wood residues markets, as the energy sector will become a new player in these markets (Dielen et al. 2000). Reliable information about the forest resource base that could be used for energy purposes is essential for any analysis on energy wood potential in Europe.

The "*Commission has come to the conclusion that the overall objective of a 20% contribution of renewable energy to the EU energy mix is possible and necessary. Meeting this target will require a massive growth in all three renewable energy sectors, but it is feasible*" (SEC 2006). The biomass sector can grow significantly using wood, energy crops and bio-waste in heat and power plants together with biorefineries. To implement the roadmap, the available biomass resources and the cost of supply must be estimated.

1.2 Aim of the study

The aim of this study is to estimate the forest energy potential in the EU27. It has been divided into two sections. The first section includes estimation of annual change rate of the forest available for wood supply, i.e. estimation of unutilized roundwood potential that could be used for energy purposes, but also for manufacturing conventional products in the forest based industries or not harvested as has been the case so far. This consists mainly of stands that should have been thinned but are left without treatment due to the lack of demand for wood as an industrial raw material. The study has been limited to forests available for wood supply as those include forests where any legal, economic, or specific environmental restrictions do not have a significant impact on the supply of wood, and thus the use of wood for energy purposes is not restricted. This is a practical limitation, as forests with the above mentioned restrictions are likely to have a very small supply of wood and therefore also very limited source of forest energy. Annual change rate is calculated as a difference between net annual increment and fellings, and therefore a major indicator of the long term sustainability of wood supply, provided that both net annual increment and fellings refer to the same area and same time period. In addition to annual change rate, information about roundwood and fuelwood production have been collected and presented. Information about fellings and roundwood production is utilized in the second section.

The second section includes the estimation of felling residues in the forest available for wood supply, as felling residues are becoming an increasingly important source of energy. The section is further divided into three parts, the first concerns the estimation of residue roundwood, crown mass, and stump and roots. The second part includes estimating the potential that is technically possible to harvest. While the third part concerns the estimation of the availability of forest fuels from final fellings at given fuel prices around a fuel plant in selected countries.

This research publication is an updated version of "Estimation of energy wood potential in Europe" (Karjalainen et al. 2004).

1.3 European Union Countries – EU27

The study has been limited to cover the 27 European countries that are members of the European Union (EU) as of January 2007 (Figure 2), later referred to as the EU27. Results and analyses are presented on a country level and by country groups based on available statistics and reports (Table 2). Country grouping is the same as in some international statistics and analyses.

Figure 2. Member countries of the European Union (EU) in 2007, known as EU27, have a yellow background in this map. These 27 countries are analysed in this report. Candidate countries for the EU are shown in blue. Source: http://europa.eu/abc/european_countries/index_en.htm

2 Methods

2.1 Background data

Data for the growing stock, removals and change rate are from the FAO Global Forest Resources Assessment (FRA) 2005 report (FAO 2006). The FRA is the latest in a series of surveys carried out by the FAO, the first of which was published in 1947. The original data collected at the national level have been adjusted to fit internationally agreed terms and definitions (see Annex 2 of the FRA 2005). As a result, data for a country published in the FRA 2005 report does not necessarily correspond to those published in national sources. This is normal and also the inevitable result of adapting national data to improve comparability between countries.

Results in the report are presented as annual values or percentages. Annual values reported in tables and figures are mean values from several years' data. In some cases, data was available only for a one-year period therefore the mean value was not possible to calculate. Roundwood removal figures are national forecasts for 2005.

2.2 Definitions and methodology

2.2.1 Definitions

Definitions and calculation concepts used in this study are presented in Table 2. National definitions are found in FRA 2005 country reports (http://www.fao.org/forestry/site/fra/en/) and terms and definitions for the national reporting tables in Annex 2 of the FRA 2005 (FAO 2006).

2.2.2 Volume of standing trees

Single trees volume is a basic input value for the calculation of the volume of growing stock and can be transformed into woody biomass. The national definitions regarding trees included in growing stock vary significantly. In this study, only the commercial part of growing stock was examined.

The volume figures depend on three factors:

1. How small trees are taken into account (minimum threshold value for the diameter at breast height, d.b.h. – 1.3 meters)
2. Starting point of the stem volume included (ground or stump).
3. End point of the stem volume included (minimum top diameter).

Table 2. Definitions and calculation concepts used in this study. Source: FAO 2006.

Growing stock	Volume over bark of all living trees more than X cm in diameter at breast height. Includes the stem from ground level or stump height up to a top diameter of Y cm, and may also include branches to a minimum diameter of W cm. Explanatory notes 1. The countries must indicate the three thresholds (X, Y, W in cm) and the parts of the tree. 2. The diameter is measured at 30 cm above the end of the buttresses if these are higher than 1 meter. 3. Includes wind fallen living trees. 4. Excludes: Smaller branches, twigs, foliage, flowers, seeds, and roots.
Commercial growing stock	The part of the growing stock that is considered as commercial or potentially commercial under current market conditions (and with a diameter at breast height of Z cm or more). Explanatory notes 1. Includes all commercial and potentially commercial (merchantable) species for domestic and international markets. 2. Excludes growing stock on areas where legal, economic or other specific restrictions prevent felling and removal of wood. 3. The countries must indicate the minimum diameter at breast height (Z cm) applied for considering a tree as being commercial. 4. When most species are commercial, i.e. in the temperate and boreal zone, the commercial growing stock can be close to the total growing stock. On the other hand, when only a small fraction of all species is merchantable, it can be considerably smaller.
Roundwood production	Production of wood. Wood in its natural state as felled or otherwise harvested, with or without bark, round, split, roughly squared or in other form (e.g. roots, stumps, burls, etc.). It may also be impregnated (e.g. telegraph poles) or roughly shaped or pointed. It comprises all wood obtained from removals, i.e. the quantities removed from forests and from trees outside the forest, including wood recovered from natural, felling and logging losses during the period, calendar year or forest year. Commodities included are sawlogs and veneer logs, pulpwood, other industrial roundwood (including pitprops) and fuelwood.
Wood removal	The wood removed (volume of roundwood over bark) for production of goods and services other than energy production (wood fuel). Explanatory notes 1. The term removal differs from fellings as it excludes felled trees left in the forest. 2. Includes removal from fellings in an earlier period and from trees killed or damaged by natural causes. 3. Includes removal by local people or owners for their own use.
o.b.	Overbark: Bark included into the volume of a tree.
u.b.	Underbark: Bark excluded from the volume of a tree.

Among the studied countries Switzerland uses the highest d.b.h. threshold value (12 cm) while Italy (2.5 cm), Lithuania (2 cm), Estonia (0 cm), Bulgaria (all trees above 3 m) and Hungary (all trees above 2 m) the lowest (Table 3). The minimum top diameter varies from 0 cm (Austria, Bulgaria, Estonia, Hungary, Latvia, Lithuania, the Netherlands, Portugal, Romania, Spain and Sweden) to 10 cm (Denmark). Traub et al. (1994) reported that the volume of trees below 12 cm d.b.h. comprises 2-3% of the total volume of the Swiss forests. If, for example, the Swiss threshold value (12 cm) is applied in Finnish forests, 13% of the total volume reported according to the Finnish definition would be excluded from the reporting. This result shows that threshold values have more importance in those areas where trees with relatively small dimensions cover a high proportion of the forest, such as in the Nordic and Mediterranean regions. The measuring point of the volume is in some countries at the stump level while the others are using ground level. In the UK, for example, the volume of the stump is included in the stem volume, whereas in Finland and Sweden stump volume is not included. If the UK definitions were used in Finland and Sweden, both countries would gain 5% in volume in their forestry statistics.

In this study national definitions were taken into account as calculations are based on application of Marklund's (1988) biomass functions. If a country had a minimum top stem diameter of 0 cm, tops were not included in the residue potential. Some countries had also included the largest branches in the commercial growing stock. As their proportion was estimated to be minor, all branches were pointed out to wood fuel potential.

Table 3. Trees included in commercial growing stock. Abbreviation d.b.h. refers to diameter at breast height (1.3 meters). Source: Global Forest Resources Assessment 2005

Country	Minimum d.b.h. (cm)	Minimum top stem diameter (cm)	Minimum diameter of branches (cm)	Starting point of volume
Austria	5	0	Not included	Ground
Belgium	7	7	7	Stump
Bulgaria	All trees above 3 m		All included	Ground
Czech Republic	-	7	7	Stump
Denmark	-	10	10	Ground
Estonia	0	0	Not included	Stump
Finland	-	7	Not Included	Stump
France	7.5	7	Not included	Stump
Germany, Greece	-	-	-	-
Hungary	All trees above 2 m		All included	Stump
Ireland	7	7	Not included	Stump
Italy	2.5	3/0 1)	3/Not included 2)	Stump
Latvia	6	0	Not included	Ground
Lithuania	2	0	Not included	Ground
Luxembourg	7	7	7	Stump
The Netherlands	5	0	Not included	Ground
Poland	7	7	7	Ground
Portugal	5	0	Not included	Stump
Romania	8	0	Not included	Stump
Slovakia	7	7	7	Stump
Slovenia	10	7	7	Ground
Spain	7.5	0	Not included	Stump
Sweden	10	0	Not included	Stump
United Kingdom	7	7	7	Ground

1) Pines and broadleaved: 3, Other conifers: 0
2) Pines and broadleaved: 3, Other conifers: Not included

3 Wood biomass potential

3.1 Growing stock

Growing stock, which includes living trees (definition varies between countries), is 19.7 billion m^3 o.b., 16.9 (85.6%) billion m^3 of which is available for commercial use (Table 4). Statistics on commercial growing stock in Germany and Ireland were not available. There is a significant amount of variation in the proportion of commercial growing stock between countries. It ranges between 61% (Bulgaria) to 100% (Belgium and Luxembourg) of the total growing stock. This variation depends not only on legal and economic restrictions but also on differences between national definitions for commercial growing stock.

Annual change rate is used in the calculations as the potential sustainably utilizable surplus of commercial growing stock. This relates to the hypothesis that the growth and removal are equal in forests that are not counted as commercial growing stock. Annual change rate seems to have diminished from the 1990–2000 level to the 2000–2005 level (Table 4). However, if we ignore Germany, which has not reported its annual change rate for the period 2000–2005, the rate has increased by about 28.5 million m^3. Annual change rate is positive in every country studied except in Estonia, where removal is 2.12 million m^3/year more than growth. Romania has achieved a surplus as its annual change rate has increased from 1990-2000 level. Sweden has the largest volume of commercial growing stock with nearly 2.4 billion m^3, but France, Italy and Poland have the greatest annual change rate surplus. Especially in France and Italy the annual change rate surplus has increased significantly from the 1990-2000 level whereas in Bulgaria, Hungary and Slovenia the logging change rate has diminished. The five most remarkable countries; Sweden, France, Finland, Poland and Romania, have about 56% of the total commercial growing stock.

Forest resources in Europe have been increasing during the last 50 years (Kuusela 1994, Gold 2003). In that period the forest cover has increased steadily by about 8%, the average growing stock by about 10%, and the average net annual increment by as much as 25%. The development of forest resources depends on the shifts in the policy and market framework. Forest resources are slow to react to changes in the relationships between society and forestry. The development of average growing stock and increment depend mostly on the age class structure of forests. Age-class structure can be changed significantly by cuttings, afforestation of new forest stands, large-scale calamities and so on. Growing stock further depends on removals (thinnings and final fellings) and the growth in forest stands. Removals are mostly market driven, considering silvicultural constraints. Growth in stands depends on various exogenous factors, such as pollution or climate change.

The increase in forest resources has been a result of changes in land-use history, afforestation of former agricultural land, fellings being less than increment, increased nitrogen deposition, temperatures and atmospheric carbon dioxide concentration (e.g. Spiecker et al. 1996). Afforestation and the establishment of forest plantations have been intensive in many European countries (e.g. Belgium, Denmark, France, Ireland, Portugal, United Kingdom and Poland) after the Second World War (UN-ECE/FAO 2005). The growth rate in plantation forests is higher than in other types of forests and establishment of plantation forests has partly lead to an increase in the average increment in Europe as a whole.

Table 4. Growing stock, commercial growing stock and annual change rate (million m^3 o.b.) in the EU 27. Source: FAO 2006.

Country	Growing stock, million m³	Of which is commercial, million m³	%	Annual change rate 1990 – 2000 million m³	Annual change rate 2000 – 2005 million m³
Austria	1 159	1 132	98	14.1	14.2
Belgium	172	172	100	2.94	2.98
Bulgaria	568	347	61	12.1	8.4
Cyprus	-	-	-	-	-
Czech Republic	736	712	97	7.37	7.36
Denmark	76	58	76	0.94	0.44
Estonia	447	419	94	-	-2.12
Finland	2 158	1 815	84	16.26	17.6
France	2 465	2 305	94	17.5	42.2
Germany	-	-	-	62.2	-
Greece	177	156	88	1.4	1.4
Hungary	337	329	98	3.72	2.37
Ireland	65	-	-	0.74	1.12
Italy	1 447	1 014	70	23.8	31.56
Latvia	599	511	85	9.5	10.6
Lithuania	400	344	86	5.27	5.4
Luxembourg	26	26	100	0.56	0
Malta	-	-	-	-	-
The Netherlands	65	52	80	0.9	0.8
Poland	1 864	1 760	94	25.12	25.66
Portugal	350	232	66	7.5	7.4
Romania	1 347	1 320	98	-0.11	0.18
Slovakia	494	418	85	6.16	6.24
Slovenia	357	326	91	6.12	4.53
Spain	888	689	78	19.8	19.6
Sweden	3 155	2 423	77	24.24	24.24
United Kingdom	340	300	88	4.2	6.4
TOTAL	**19 692**	**16 860**		**272.3**	**238.6**

As the annual change rate has been clearly positive for a long time, an increasing amount of wood has accumulated in the forests, resulting in a denser forest structure and older age class structure. The annual change rate can be regarded as a kind of surplus or reserve that could be used as raw material by the forest industries, or for energy purposes, or left in the forests as is currently the case. An increased use for industrial purposes would require additional demand and markets for wood-based products. Demand for energy is increasing, in particular that of renewable energy and thus wood energy as stated in the EU White Paper (COM 1997). Furthermore, demand for nature protection is increasing. This means that competition for the wood resources is increasing and obviously fulfilling these demands would require compromises. Nevertheless, increased industrial use of wood will result in some of the commercial timber being utilized by the energy sector. The share would depend on the use of wood by the industries (sawmills, chemical and mechanical pulp, different paper grades etc.) as well as the current value of carbon emission trading stocks. In addition, black liquor used for energy production in the forest-based industries equaled 15% of the fellings. If similar shares are applied, more than 30% of the increased fellings would be used for energy production. The use of roundwood directly for energy purposes would depend on the prices of roundwood, sawnwood, pulp, paper and energy. It is difficult to estimate how much of the unutilized increment (annual change rate surplus) could and would be utilized in the future, but it is most likely to be more than today.

3.2 Roundwood production

Roundwood production includes wood biomass that is harvested from the forest and used for commercial wood processing and fuelwood purposes during a year. Roundwood production by country is shown in Table 5. Roundwood production is divided into three main categories: softwood, hardwood, and fuelwood. In addition, softwood and hardwood productions are subdivided into logs and pulpwood. Total roundwood production is shown in the last column of the table. Data are from UNECE Timber Committee Forest Products Statistics 2000–2004 (http://www.unece.org/trade/timber/mis/fp-stats.htm). Data for Malta was not available.

Roundwood production was, on average, 437.1 million m^3 (o.b.) per year in the period 2000–2004. As an average, roundwood production was approximately 3% higher in 2004 than in 2000, although there were also decreases in some countries. Approximately 77% of the production was softwood. Sweden was the largest producer with 75 million m^3, followed by Finland with 61 million m^3. Other big producers were Germany, France and Poland. Roundwood production in these five countries was 268.2 million m^3, which is 61% of the total roundwood production in the studied area.

A substantial share of the roundwood production was wood fuel in Greece (66%) and Italy (65%). The proportion of wood fuel was less than 10% of the roundwood production in Ireland, France, Latvia, the United Kingdom, Germany, Poland, the Czech Republic, Portugal, Slovakia, Finland and Sweden. The largest wood fuel producers, in absolute values, were Sweden, Italy, Finland and Germany. Wood fuel is, by definition, the part of roundwood that will be used as fuel for purposes such as cooking, heating or power production. It includes, for example, wood that will be used for charcoal production and wood chips which are used for fuel and are made directly (i.e. in the forest) from roundwood.

The ratio between fellings and increment in Europe is approximately 70%, varying between countries and regions. The European Forest Outlook Study provides an estimate for the supply and demand of roundwood and forest products from 1960 until 2020 (UN-ECE/FAO 2005). The ratio of fellings to increment has fallen in Western Europe from around 90% in the 1960s to 70% in the last decade, while in Eastern Europe the ratio has fallen from 80% to 70% over the same period. This is far from the situation in Russian Federation where fellings have always been far below increment (around 50%), but the ratio has fallen even further in the last decade to around 20%. The trends in renewable energy and climate change are expected to increase the level of wood removals. The ratio of fellings to increment is expected to increase significantly from 2000 to 2020. The increase is expected to be even over 20% depending predominantly on economic growth and political decisions. The largest changes are anticipated to be in the Baltic countries and south-east Europe where the export and domestic use of wood products will probably increase.

Table 5. Industrial roundwood production in the EU27 (million m³ o.b./a, mean value for years 2000-2004, bark rate 15%). Source: UNECE Timber Committee, Forest Products Statistics 2000-2004.

Country	Softwood				Hardwood					
	Logs	Pulpwood	Other	Total	Logs	Pulpwood	Other	Total	Fuel wood	Total
Austria	10.1	2.6	-	12.6	0.5	0.6	-	1.0	3.6	**17.3**
Belgium	2.2	1.1	0.1	3.4	0.8	0.3	0.1	1.2	0.6	**5.2**
Bulgaria	0.9	0.4	0.1	1.4	0.8	0.7	0.03	1.5	2.4	**5.4**
Cyprus	0.01	-	-	0.01	0.001	-	-	0.001	0.01	**0.02**
Czech Republic	8.8	5.2	0.4	14.4	0.7	0.7	0.02	1.4	1.2	**17.0**
Denmark	0.6	0.3	0.2	1.1	0.1	-	0.1	0.2	0.8	**2.1**
Estonia	3.6	2.3	0.5	6.4	0.7	1.6	0.7	3.0	2.2	**11.6**
Finland	26.8	22.6	-	49.4	1.2	5.7	-	6.9	5.1	**61.4**
France	19.2	7.3	0.2	26.7	8.0	5.5	0.3	13.9	2.8	**43.4**
Germany	29.1	8.6	2.5	40.2	4.5	4.0	1.7	10.2	5.0	**55.5**
Greece	0.3	0.1	0.1	0.5	0.2	0.05	0.04	0.3	1.4	**2.2**
Hungary	0.2	0.3	0.2	0.7	1.6	0.4	1.0	3.0	2.9	**6.7**
Ireland	2.0	0.9	0.1	3.0	0.01	0.02	-	0.03	0.04	3.1
Italy	0.8	0.2	0.3	1.2	1.2	0.5	0.5	2.2	6.2	**9.6**
Latvia	6.1	1.9	0.5	8.5	3.1	2.1	0.1	5.3	1.5	**15.2**
Lithuania	2.1	0.9	0.01	3.0	1.5	0.8	0.01	2.2	1.6	**6.8**
Luxembourg	0.09	0.01	0.03	0.1	0.1	0.1	0.001	0.2	0.02	**0.3**
The Netherlands	0.4	0.1	0.1	0.6	0.1	0.1	0.04	0.2	0.3	**1.1**
Poland	10.5	10.0	1.8	22.2	2.8	4.3	0.5	7.6	2.8	**32.6**
Portugal	2.8	1.5	0.2	4.5	0.1	6.1	0.03	6.3	0.7	**11.4**
Romania	4.5	1.3	0.3	6.1	3.5	1.3	2.2	7.0	3.4	**16.5**
Slovakia	2.0	1.3	0.2	3.6	0.9	2.2	0.1	3.3	0.3	**7.2**
Slovenia	1.0	0.4	0.1	1.5	0.4	0.1	0.2	0.7	0.6	**2.9**
Spain	6.5	2.5	0.6	9.7	2.0	3.7	0.3	6.0	2.2	**17.9**
Sweden	38.8	25.2	0.5	64.5	0.5	3.4	0.1	4.0	6.8	**75.3**
United Kingdom	5.3	2.7	0.4	8.5	0.2	0.2	0.1	0.5	0.3	**9.2**
TOTAL	**184.9**	**99.7**	**9.6**	**294.2**	**35.4**	**45.2**	**8.4**	**89.0**	**54.8**	**437.1**

4 Forest energy potential

4.1 Definition of forest fuel components and estimation of the total potential

Forest fuel potential is calculated based on the data presented in Chapter 3. The potential consists of three main components:

1. Logging residues from the removals of roundwood (branches, needles, top stem wood, off cuts of stem).
2. Annual change rate of growing stock.
3. Stumps and coarse roots of trees (defined separately for the change rate and removals).

To estimate the shares of biomass components (stem & bark, branches, needles, top stem wood and stump wood) trees species were grouped into three species groups: Spruce group (including Picea sp., Larix sp., Abies sp.) Pine group (Pinus sp.) and broadleaved (Beech, Oak, Birch and other broadleaved) (Table 6). Only Finland reported the proportion of removals between these species groups (FRA 2005). Other countries had statistics regarding hardwood and softwood removals in general. As the amount of logged hardwood was known, the proportions of Pine and Spruce group removals were estimated to be a substantial share of the growing stock.

Based on these biomass components, the total theoretical potential of the biomass for energy potential was calculated (Figure 3). Theoretical forest fuel resources were estimated to be 785 million m³ per year, which is over two times (210%) larger than the current removal. Above ground felling residues were 211 million m³ and above ground change rate was 406 (including stems) million m³. Below ground parts of felling residues and annual change rate surplus were together 169 million m³. We assumed that 25% of the total annual change rate surplus could be used for energy production (Figure 4).

Table 6. Proportions of biomass components used in the volume estimation. Above ground biomasses are based on equations presented by Marklund (1988) and volumes of root estimates are based on Eggers (2001)

	Stem + Stembark	Stem wood loss	Branches	Needles	Tops	Total	Stump wood estimation (Nordic and Baltic countries)	Stump wood estimation (rest of Europe)
Spruce group	55%	8%	24%	11%	2%	100%	21.9%	19.1%
Pine group	67.7%	8%	17.7%	4.7%	2%	100%	19.8%	19.3%
Broadleaved group	78.2%	8%	12.1%	--	1.7%	100%	22.4%	14.7%

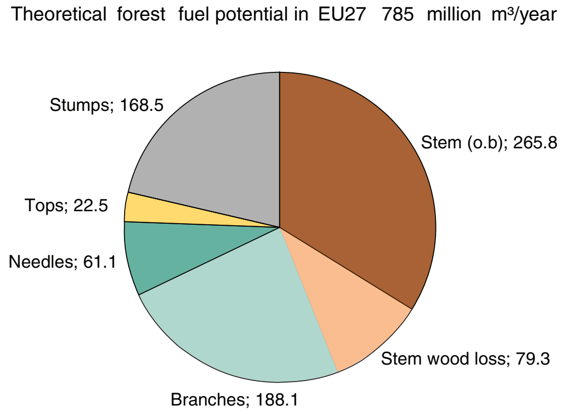


Figure 3. Theoretical forest fuel potential of EU27 (million m³/year). Whole annual change rate surplus is included in the chart.

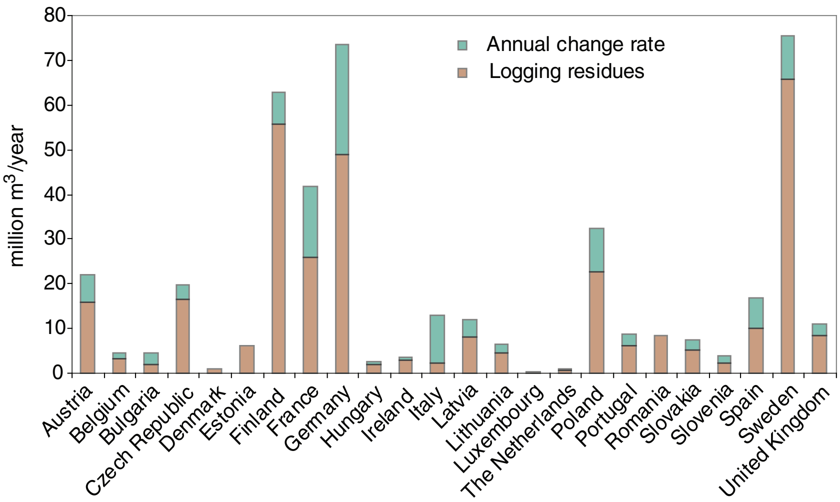


Figure 4. Theoretical forest fuel potential in EU27 (numeric values are presented in Appendix 1). Actual annual change rate surplus use to energy production is assumed to be 25% of the total. (Figure updated 06.02.2008)

According to our calculations the largest biomass reserves are found in Finland, France, Germany and Sweden but also Poland, Austria and Czech Republic have substantial volumes available for energy production (Figure 4). For example Germany, France, Italy, Spain and Poland have a large proportion of annual change rate surplus from total forest fuel potential. This indicates that these countries have significant logging savings that can be used for different purposes.

4.2 Technically harvestable forest fuel potential

The impact of mountains (Table 7 and Figure 5) on the availability of harvestable forest fuels can be assumed to be considerable in countries such as Austria, Greece and Italy. Nevertheless, the impact of mountainous areas on the availability is difficult to estimate. Although mountains constitute about 73% of Austria's territory, the share of forest land available for wood supply is 87% and in rather flat countries such as Poland and the Netherlands it is slightly higher, 93% (Table 7). Also the average annual harvest per unit of forest land (m^3/ha) is much higher in Austria than in France, the Netherlands or Poland. Mountainous was not considered as a factor to reduce the potential of technically harvestable residues in the calculations. It was, however,

used in calculations to extend time used for forwarding and to reduce the amount of harvestable below ground biomass volume. It is evident that mountains impact greatly on the forest fuel harvesting (potentials, costs, etc), however, a more detailed examination was beyond the scope of this study.

Table 7. National area covered by mountain municipalities (Nordregio 2004).

Country	Country Area (1000 km^2)	Mountain Area (1000 km^2)	% of total country area	Forest available for wood supply, % of total forest area
Austria	83.85	61.51	73.4	87.3
Belgium	30.62	1.29	4.2	98.9
Bulgaria	101.74	54.18	53.3	
Cyprus	9.23	4.4	47.6	36.8
Czech Republic	78.79	25.41	32.3	97.3
Denmark	43.62			98.9
Estonia	45.23			95.8
Finland *	326.76	166.08	50.8	94.5
France	637.9	142.12	22.3	95.5
Germany	356.77	52.59	14.7	94.4
Greece	132.22	102.98	77.9	92.1
Hungary	92.48	4.37	4.7	94
Ireland	70.14	7.44	10.6	98.1
Italy	300.59	180.78	60.1	61
Latvia	64.59			83.7
Lithuania	65.03			85.2
Luxembourg	2.59	0.11	4.4	100
Malta	0.22			0
The Netherlands	41.2			92.6
Poland	311.44	16.18	5.2	92.8
Portugal	92.36	36.14	39.1	56.1
Romania	238.4	90.24	37.9	
Slovakia	48.99	30.37	62	84.6
Slovenia	20.27	15.81	78	94.2
Spain	505.21	281.61	55.7	77.6
Sweden **	450	227.7	50.6	77.9
United Kingdom	245.49	62.56	25.5	85.4
Total	**4055.59**	**1419.45**	**35**	

Availability reduction factors were applied when estimating the total technical potential of harvestable forest fuels. It was assumed that 75% of the clear cut areas and 45% of the thinning areas are technically available for supply. The recovery rate was estimated to be 65% in mechanized cutting and 50% in manual cutting. Shares of clear cuts and mechanization degrees are shown in Table 8. The smaller recovery rate in manual cutting results from the fact that residues are scattered over the whole stand whilst in mechanized cutting material can be stacked during cutting. Complementary fellings were assumed to be 25% of the annual change rate surplus (net annual increment – fellings). Stumps were recovered only from the clear cuts of spruce stands. An assumption was made that the maximum harvestable amount of the stumps is 33%, when mountain percentage is zero. The harvestable stump percentage is thereby linearly calculated as [33% - mountain% * 0.33]. The availability of felling residues in the EU27 countries is shown in

Table 8. The harvestable forest fuels totals 186.7 million m³, of which 76.5 million m³ are felling residues from current fellings and 101.6 million m³ are roundwood and felling residues from the annual change rate surplus. Correspondingly the harvestable volume of stumps from current fellings is 7.4 million m³ while the volume of stumps from the annual change rate is 1.2 million m³. The current volume of harvestable residues and stumps without annual change rate surplus is altogether 83.9 million m³ per year. Ecological impacts of whole tree biomass harvesting should also be taken into account when available biomass for energy use is estimated. Stands with poor soils that would become critical with further nutrient loss, steep slopes endangered by erosion and avalanches, and other sensitive sites should be excluded from such calculations. Possible ecological impacts were beyond the scope of this study, but their impact on harvestable volumes was implicitely embedded in the reduction factors.

The largest volumes of available felling residues (excluding stump wood) are in Sweden (18.1 million m³), Finland (15.3 million m³), Germany (8.4 million m³) and France (6.4 million m³). When complementary fellings from the annual change rate surplus and their felling residues are added the available forest fuel resources in these countries is 23-30 million m³.

Figure 5. Mountain areas in Europe defined as mountainous based on topographic criteria (green areas) and climatic criteria (blue areas) (Nordregio 2004).

Table 8. Volumes of available felling residues in EU27 (available residues of annual change rate surplus also include the stem wood).

	Share of timber from clearcuts %	Share of mechanization in cutting %	Share of spruce-group %	Total felling residues (mill. m^3 /a)	Available vol. of felling residues (mill. m^3 /a)	Available vol. of residues from annual change rate surplus (mill. m^3 /a)	Total vol. of stumps from fellings (mill. m^3 /a)	Available vol. of stumps from fellings (mill. m^3 /a)	Available vol. of stumps from annual change rate surplus (mill. m^3 /a)
Austria	18	30	69	10.9	3.0	5.5	4.97	0.05	0.04
Belgium	70	80	40	2.2	0.9	1.1	1.06	0.11	0.02
Bulgaria	70	5	11	1.2	0.4	2.3	0.69	0.01	0.004
Cyprus	-	-	-	-	-	-	-	-	-
Czech Republic	83	40	65	11.2	4.4	3	5.17	0.66	0.05
Denmark	70	50	54	0.6	0.2	0.2	0.32	0.05	0.01
Estonia	73	70	25	3.8	1.4	0	2.42	0.18	0
Finland	71	97	45	35.7	15.3	6.3	20.04	2.11	0.14
France	76	40	19	16.9	6.4	14.2	8.93	0.54	0.15
Germany	5	35	45	32.8	8.4	22	16.02	0.11	0.39
Greece	-	-	-	-	-	-	-	-	-
Hungary	72	15	0	1.2	0.4	0.6	0.76	-	-
Ireland	82	95	74	2.1	0.9	0.4	0.93	0.17	0.01
Italy	20	10	19	1.3	0.3	9.5	0.80	0.002	0.01
Latvia	76	35	17	4.8	1.8	3.4	3.26	0.14	0.03
Lithuania	50	5	23	2.7	0.8	1.7	1.82	0.06	0.02
Luxembourg	70	80	27	0.1	0.03	0.2	0.03	0.003	0.002
Malta	-	-	-	-	-	-	-	-	-
The Netherlands	80	25	13	0.4	0.1	0.3	0.22	0.01	0.001
Poland	44	4	9	14.4	4.2	8.3	8.36	0.10	0.03
Portugal	70	30	0	3.8	1.4	2.2	2.37	-	0.31
Romania	70	1	44	5.6	1.8	0.1	2.85	0.16	0.001
Slovakia	40	4	39	3.4	1.0	2.1	1.69	0.04	0.01
Slovenia	0	6	44	1.5	0.3	1.5	0.72	-	0.01
Spain	70	40	0	6.1	2.3	6	3.81	-	-
Sweden	70	98	43	42.4	18.1	8.4	23.46	2.55	0.2
United Kingdom	80	90	46	5.7	2.5	2.3	2.71	0.31	0.04
Total				**210.8**	**76.5**	**101.6**	**113.4**	**7.4**	**1.2**

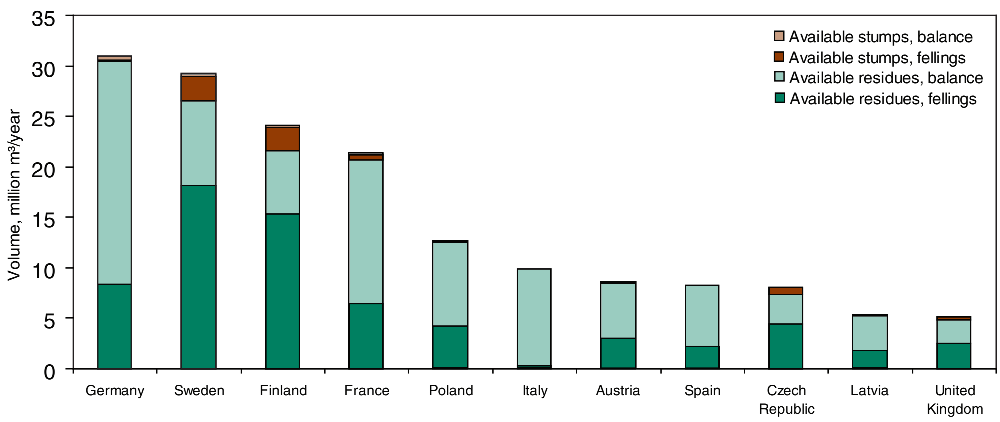


Figure 6. Volumes of available felling residues and stump/root biomass in the top 11 EU countries having the highest available potential.

5 Estimation of the procurement costs for final felling residue chips

Estimation of economical availability of felling residues from final fellings was carried out for the following countries: the Czech Republic, Finland, France, Hungary, Poland, Slovakia, Spain and the UK. The radius of the procurement area around a hypothetical plant is defined by the annual use of forest fuels at the plant and the annual harvestable amount of forest fuels in the environs of the plant. The annual harvestable amount varies considerably in different parts of Europe. This has an impact on the long distance transportation costs in particular. In addition, site conditions and the mix of harvestable fuel can vary considerably within a country. For instance, there are large softwood plantations in south-western France, whereas in central and northern France hardwoods are dominating. Though there are within country differences, this study presents the annual harvestable averages on a country basis.

The availability of felling residues was based on the total potential of the residues from the mechanized final fellings. The above mentioned restrictions of the potential (Chapter 4.2) were applied. The availability of chips from felling residues in each country was expressed in terms of annual availability of fuel (solid volume, m³, of green biomass), around the consumption point (e.g. power, district heating or combined heat and power plant) at a given marginal cost of fuel delivered to the plant. The available felling residues from final fellings in the selected countries are presented in Table 9.

The radius of the procurement area was determined as transport distance along the road network. The long distance transportation winding coefficient was assumed to be 1.3. The winding coefficient was used to reduce the effective area. For instance, if the transport radius was 100 km, the radius of the area from which material was collected was 76.9 km (=100 km / 1.3).

A supply chain based on chipping at the roadside landing is the most common procurement method. It is also used, in this study, in all nine countries to make the results comparable. The material was extracted from the forest to the forest road side using a medium sized forwarder (~12 tons). Chipping took place at the roadside landing by a truck mounted chipper that chipped directly into the truck's container. A truck trailer unit with a maximum weight of 40 tonnes (63.7 m³ loose volume of chips) was used for long distance transportation except in Finland, where maximum allowed weigh is 60 tonnes (110 m³ loose volume of chips).

Table 9. Residues from **final fellings** in selected countries.

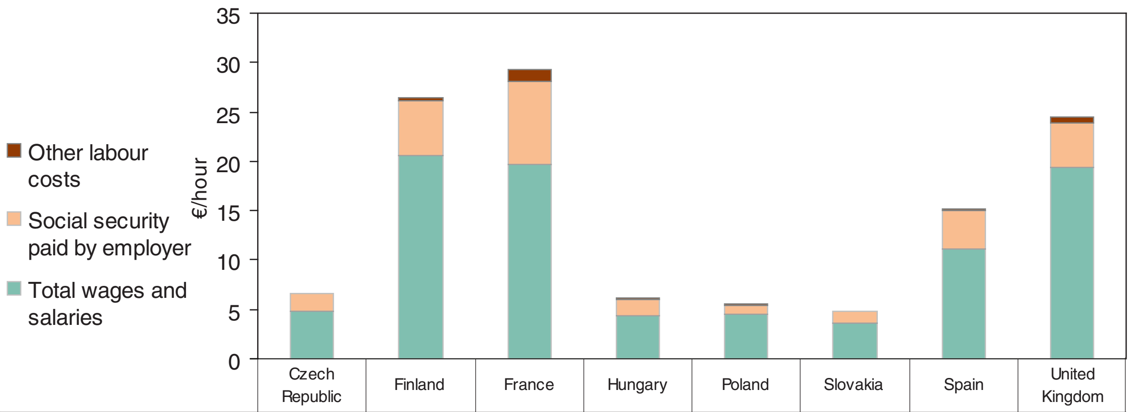
	Logging residues, 1000 m³	Harvestable logging residues, 1000 m³	Country area, 1000 km²	Logging residues m³/km²/a	Solid vol. (m³) of green biomass/ ha² at stand
Czech Republic	9 332	1 820	79	23.07	147.4
Finland	25 376	12 000	338	35.49	51.0
France	12 875	2 511	547	4.59	110.7
Hungary	832	61	93	0.65	97.9
Poland	6 321	123	313	0.39	120.5
Slovakia	1 354	26	49	0.53	147.6
Spain	4 295	838	505	1.66	26.2
United Kingdom	4 563	2 002	245	8.18	78.5

Hourly labor costs and their structures were taken from the Eurostat 2005 statistics (Figure 7). Fuel costs were taken from the statistics of the Finnish Oil and Gas Federation and were the prices from December 2006. All the machines used diesel oil except in Finland, where forwarders can use partially tax free fuel oil. Also the truck mounted chipper units can use fuel oil, which totals roughly 70 % of the total fuel consumption.

The harvesting costs of the chips were calculated with the cost calculator for procurement of logging residue chips developed in the Finnish Forest Research Institute (Laitila 2006). The calculator is based on the results of the National Wood Energy Technology Programme (Asikainen et al. 2001, Ranta 2002).

The hourly costs of the forwarder, chipper and truck were each calculated by the unit cost calculation method (Table 10, Figures 8 and 9). Hourly costs are indicated as $E_{15\text{-}h}$ or gross effective hour which includes delays shorter than 15 min.

Hourly cost structures of a forwarder, chipper and a truck differ considerably between eastern and western Europe primarily due to differences in the labor costs (Figure 8 and Figure 9). Fixed costs are the same in each country because of the assumption of same machine price, operating hours, interest rate and depreciation value (Table 10). Overall costs differ only in transfer costs, because of the different fuel prices and stand structures.



	Czech Republic	Finland	France	Hungary	Poland	Slovakia	Spain	United Kingdom
Other labour costs	0.09	0.32	1.25	0.17	0.18	0.04	0.26	0.60
Social security paid by employer	1.74	5.45	8.40	1.68	0.92	1.14	3.79	4.50
Total w ages and salaries	4.81	20.62	19.64	4.29	4.45	3.62	11.17	19.38

Figure 7. Structure of labour costs in 2005 according to Eurostat.

Table 10. Data for the unit cost calculations.

	Forwarder	Chipper	Truck/trailer
Purchase price, €	242 000	400 000	240 000
Operating hours	2026	2700	3000
Service time, years	8	8	5.1/7.7
Depreciation rate, %	22	20	-
Interest rate, %	6	6	5

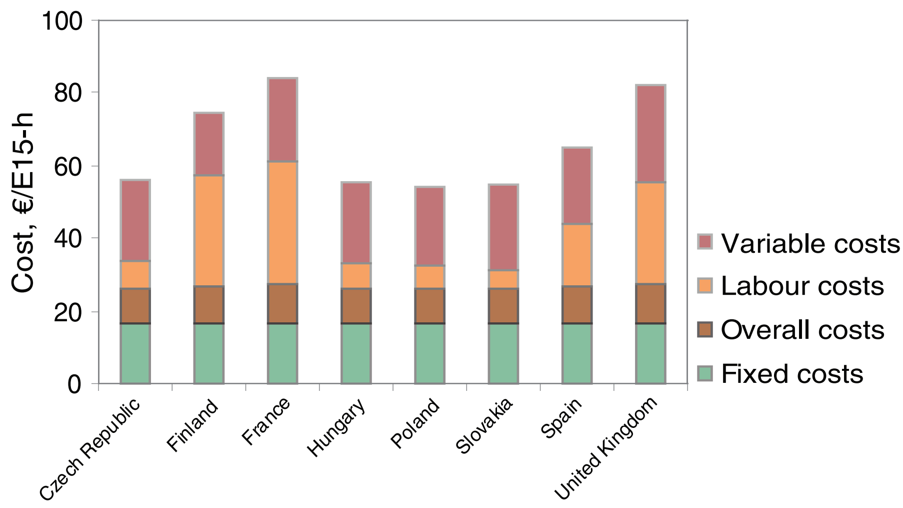


Figure 8. Hourly costs of a forwarder.

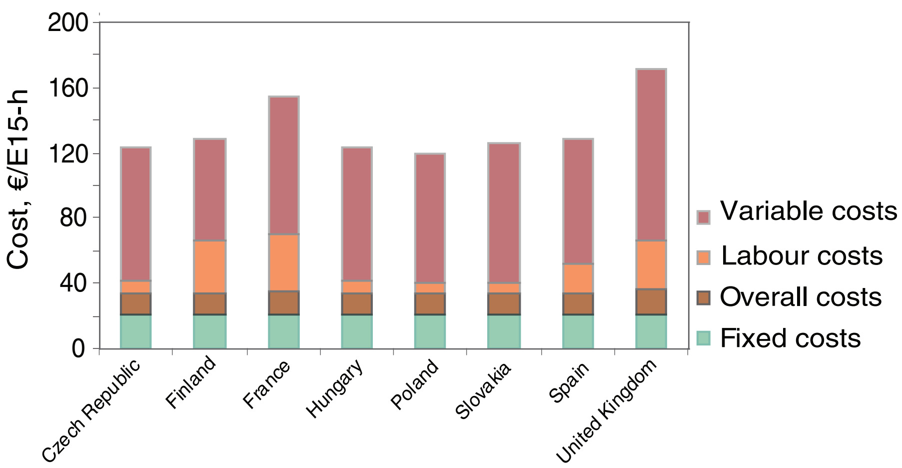


Figure 9. Hourly costs of a chipper.

The supply chain cost calculator calculates the procurement costs of forest chips at the plant according to the stand data and productivity models of harvesting machines (Laitila 2006). The calculator's input values were adjusted to local conditions (Table 11). The accumulation of green biomass from the stand (m³/ha) was derived from the ratio of average tree stand volume per hectare of a country to accumulation values of biomass in Finland (Table 9). The mountainous percentage increased forwarding time according to the formula: [correction factor = 1 + (mountain %*0.35)]. Organizational costs were assumed to be same, 3.6 €/m³ in all the countries. The organizational costs used were the average cost for commercial timber procurement companies in Finland.

The cost of chips at the plant (€/m³ solid) was calculated by summing the harvesting cost of the logging residues at the roadside landing, the chipping cost and the transportation cost. The cost of chips at the plant for different transport distances was calculated by increasing the transporting radius by 10 km increments (Figure 10).

The density of the available chips per annum (m^3/km^2a) was calculated by dividing the available residues from the final fellings by the country area (in France overseas territories were excluded) (Table 9). The quantity of chips that could be harvested from a certain radius was simply determined by multiplying the area by the density of the available chips. When availability and harvesting cost figures are summarized, the cumulative availability of felling residues and their costs delivered to the plant can be estimated (Figure 11, 12 and Table 12).

In the selected countries with a marginal price of 20 €/m^3 (10 €/MWh) a plant is able to get only very small amounts of material except in France and the UK (Table 12), where the price is too low to get any material. When the marginal cost is raised to 30 €/m^3 (15 €/MWh), the plant is able to get the material further than the maximum radius of 200 km in Finland, Hungary, Poland and Slovakia. With a material cost of 30 €/m^3 (15 €/MWh) the plant in the Czech Republic is able to get 1.5 million m^3, while in France it can get 35 200 m^3, in Spain 72 600 m^3 and in the UK 50 400 m^3.

Table 11. Cost data for the supply chain cost calculator.

	Forwarder	Chipper	Transporting	
	€/hour	€/hour	driving €/h	loading/unloading €/h
Czech Republic	55.86	123.83	77.1	34.5
Finland	74.56	128.54	106.0	63.4
France	83.81	154.53	110.53	66.81
Hungary	55.39	123.90	76.8	33.8
Poland	54.03	119.71	74.17	32.91
Slovakia	54.52	126.34	76.97	31.85
Spain	65.16	128.48	86.22	46.70
United Kingdom	82.27	171.86	115.59	59.98

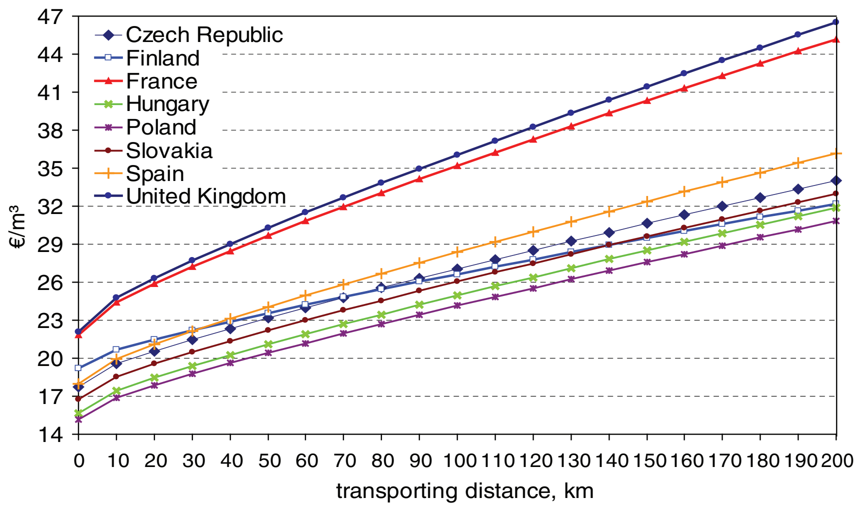


Figure 10. Costs of a chips at the plant, €/m³ by the transporting distance.

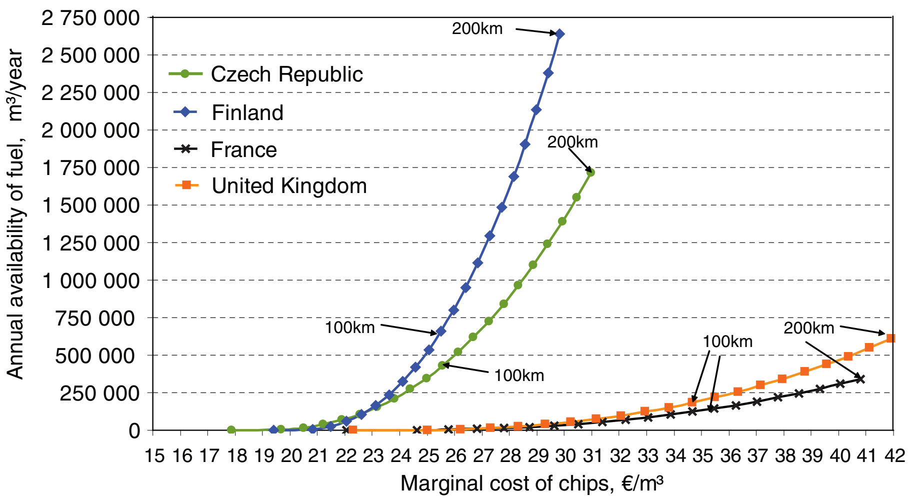


Figure 11. Cumulative availability of felling residues at given marginal costs (cost of fuel delivered at plant) and examples of respective radius of procurement area defined as the distance along the road network. For the higher accumulation countries: the Czech Republic, Finland, France and the United Kingdom.

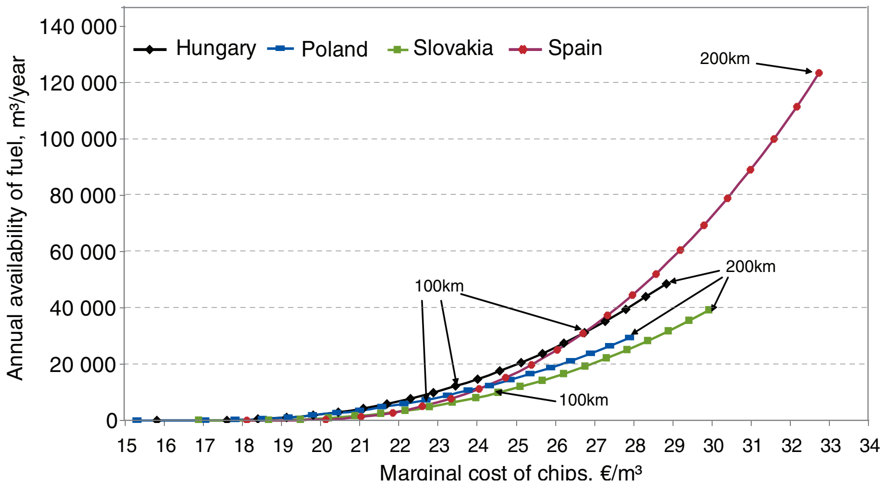


Figure 12. Cumulative availability of felling residues at given marginal costs (cost of fuel delivered at plant) and examples of respective radius of procurement area defined as the distance along the road network. For the low accumulation countries: Hungary, Poland Slovakia and Spain.

Table 12. Availability of felling residue chips at given prices (delivered as chips to mill) and availability of felling residues from procurement areas with the radius (defined as the distance along the road network) of 100 and 200 km.

	Avail. residues at 10€/MWh (20€/m³) 1000 m³	Avail. residues at 15€/MWh (30€/m³) 1000 m³	Avail. residues at radius of 100 km 1000 m³	Avail. residues at max radius of 200 km 1000 m³	Cost range €/m³
Czech Republic	9.3	1548	429	1715	17.88 - 30.97
Finland	2.7	over max radius	660	2639	19.40 - 29.82
France	-	35.2	85	341	22.05 - 40.80
Hungary	2.3	over max radius	12	49	15.80 - 28.83
Poland	2.1	over max radius	7	30	15.30 - 27.89
Slovakia	0.7	over max radius	10	40	16.88 - 29.94
Spain	0.3	72.6	31	123	18.11 - 32.74
United Kingdom	-	50.4	152	608	22.30 - 41.91

6 Concluding remarks

The estimation of the forest fuel potential was based on available and comparable international statistics about forest resources and their utilization in the EU27. The methods and definitions used to provide such data may vary between countries. The net annual increment does not change rapidly over the years whereas annual fellings can vary considerably. This means, that part of the annual change rate surplus moves to utilization and generates felling residues. Thus these changes do not radically affect the total availability of forest fuels. Fellings have been about 70% of the net annual increment. Unutilized increment, i.e. annual change rate surplus in the EU27 is about 238.6 million m³. Nearly 40% of this is in Germany and France alone.

Nikolaou et al. (2003) estimated that forest residue potential in Europe is 34.6 Mtoe. EUBIONET II (Alakangas et. al. 2007) estimated that forest residue potential for energy in the EU27, excluding Bulgaria, Cyprus, Lithuania, Luxembourg, Malta, Romania and Slovenia, is 33.1 Mtoe (193 mill. m³) annually. When this figure is extended to the whole EU27 by using figures acquired in this study the harvestable potential is about 213 mill. m^3 (35 Mtoe). The European Environment Agency (2007) estimated that the forest residue potential from fellings in the EU25 in 2010 will be 14.9 Mtoe and forest energy potential from fellings and complementary fellings will be 42.5 – 52.4 Mtoe, depending the level of environmental constraints. This study's predecessor, Karjalainen et al. (2004), estimated that the annual harvestable potential of forest chips in the EU25 was 140 mill. m³ (24 Mtoe). As mentioned earlier, the updated estimate for the technical potential in EU27 is 187 mill. m³ (36 Mtoe) annually. Comparing in detail the estimates of Nikolaou et al. (2003), Alakangas et al. (2007) and the European Environment Agency (2007) are thus at the same level as presented in this study. The European Environment Agency's (2007) higher estimate of the total potential can be explained by their higher utilization of annual change rate surplus in form of complementary fellings.

All woody biomass resources available for energy production in the above mentioned EU countries were estimated to be 93.8 Mtoe (Alakangas et al. 2007). Total consumption of wood and wood waste in these countries was 58.9 Mtoe, which is about half of the total potential. The current use of forest residues was estimated to be 8.1 Mtoe (24.5% of the potential) (Alakangas et al. 2007).

The methods for calculating the forest fuel volume and procurement costs were the same as in the preceding publication (Karjalainen et al. 2004), except the use of the mountainous factor on stump recovery calculations. Two main factors have caused the increase in available forest energy potential. Firstly there are two new countries in the EU and secondly, an increase in the number of harvesters has raised the mechanization levels.

In Belgium, van Belle et al. (2003) estimated that about 70 000 m^3 of forest chips would be available at the cost range of 15-22 €/MWh (30-44 €/m^3) depending on the supply chain. If the stumpage price and risks were not included (as in this study), the cost was 11-17 €/MWh (22-34 €/m^3).

The production cost of the chips towards transporting distance in the Bialystok area in Poland was roughly 12.5 – 23 €/m³ (20 km – 200 km radius) (Virkkunen and Leinonen 2006), using the comparable supply chain and calculation method. Correspondingly the cost of chips in the surroundings of the city of Zabreh in the Czech Republic was 16-30 €/m³ (Virkkunen 2007). The results in the Banska Bystrica region in Slovakia (Ilavsky et al. 2007) were similar when comparing the procurement cost of logging residue chips from final fellings.

Information about felling methods and mechanization of harvesting is based on various sources ranging from statistical surveys to expert opinions. In most countries the share of mechanization in cutting was based on expert opinion, because no statistical data was available. It was also noted, that operations run by industry are often heavily mechanized but small private forest owners still use manual cutting methods (e.g. in Portugal and Spain). In this study, however, the results are not very sensitive to the estimation of mechanization, because it only effects by 10 %-units in the recovery rate of residues.

The costs and availability of forest chips vary significantly between the countries due to differences in the forest resources, annual harvest and cost structure of machines and especially the mechanization level. It must be kept in mind, that the results are sensitive to changes in cost levels especially in Finland, where change in the cost of chips at plant by 1 € changes the availability by 100 000 – 400 000 m³, whereas in other countries the availability does not change as much (see Figures 11 and 12).

Nationwide estimates give only a general overview of the situation. Within the countries variation in forest resources and infrastructure can be very large. This suggests that more detailed studies should be carried out first in the countries where resources are available and also the infrastructure and technology of energy production could allow substantial and rapid shift from fossil to renewable fuels.

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Appendix 1. Theoretical forest fuel potential in EU27. (Appendix updated 06.02.2008)

Country	LOGGING RESIDUES – (mill. m^3 o.b./ a)						25 % of annual change rate - (mill. m^3 o.b./ a)							**Total, residues & change rate**
	Stem wood loss	Branches	Tops	Needles	Total, above stump	Stumps and Roots	Stem	Stem wood loss	Branches	Tops	Needles	Total, above stump	Stumps and Roots	
Austria	2.14	5.82	0.52	2.37	10.9	4.97	3.04	0.41	1.11	0.48	0.45	5.5	0.66	**22.0**
Belgium	0.48	1.17	0.11	0.41	2.2	1.06	0.66	0.08	0.20	0.10	0.07	1.1	0.13	**4.5**
Bulgaria	0.34	0.63	0.08	0.10	1.2	0.69	1.57	0.17	0.31	0.21	0.05	2.3	0.34	**4.5**
Cyprus	-	-	- -	-	-	- -	-	-	-	-	-	-	-	**-**
Czech Republic	2.20	6.03	0.54	2.46	11.2	5.17	1.62	0.22	0.60	0.27	0.24	3.0	0.34	**19.7**
Denmark	0.12	0.31	0.03	0.12	0.6	0.32	0.10	0.01	0.03	0.01	0.01	0.2	0.04	**1.1**
Estonia	0.91	2.08	0.22	0.64	3.8	2.42	0	0	0	0	0	0	0	**6.3**
Finland	7.59	19.28	1.87	7.00	35.7	20.04	3.90	0.50	1.27	0.12	0.46	6.3	0.95	**63.0**
France	4.03	9.19	0.96	2.77	16.9	8.93	9.42	1.13	2.57	0.27	0.77	14.2	1.85	**42.0**
Germany	6.98	17.66	1.70	6.43	32.8	16.02	13.79	1.76	4.44	0.43	1.61	22.0	2.83	**73.7**
Greece	-	-	- -	-	-	- -	-	-	-	-	-	-	-	**-**
Hungary	0.40	0.64	0.09	0.03	1.2	0.76	0.46	0.05	0.08	0.01	0.003	0.6	0.09	**2.6**
Ireland	0.39	1.10	0.10	0.47	2.1	0.93	0.25	0.03	0.10	0.01	0.04	0.4	0.05	**3.5**
Italy	0.41	0.72	0.09	0.09	1.3	0.80	7.11	0.76	1.34	0.17	0.16	9.5	1.22	**12.9**
Latvia	1.23	2.64	0.29	0.68	4.8	3.26	2.32	0.27	0.57	0.06	0.15	3.4	0.56	**12.0**
Lithuania	0.68	1.45	0.16	0.36	2.7	1.82	1.18	0.14	0.29	0.03	0.07	1.7	0.29	**6.5**
Luxembourg	0.02	0.04	0.004	0.01	0.1	0.03	0.12	0.01	0.03	0.003	0.01	0.2	0.02	**0.3**
Malta	-	-	- -	-	-	- -	-	-	-	-	-	-	-	**-**
The Netherlands	0.10	0.21	0.02	0.05	0.4	0.22	0.17	0.02	0.04	0.005	0.01	0.3	0.03	**0.9**
Poland	3.68	7.86	0.89	1.94	14.4	8.36	5.75	0.67	1.42	0.16	0.35	8.3	1.16	**32.2**
Portugal	1.14	2.07	0.26	0.29	3.8	2.37	1.63	0.18	0.32	0.04	0.04	2.2	0.31	**8.7**
Romania	1.36	3.01	0.31	0.88	5.6	2.85	0.04	0.005	0.01	0.001	0.003	0.1	0.01	**8.5**
Slovakia	0.78	1.82	0.18	0.59	3.4	1.69	1.39	0.17	0.39	0.04	0.13	2.1	0.27	**7.4**
Slovenia	0.33	0.79	0.08	0.27	1.5	0.72	0.98	0.12	0.29	0.03	0.10	1.5	0.20	**3.9**
Spain	1.75	3.38	0.41	0.60	6.1	3.81	4.31	0.48	0.92	0.11	0.16	6.0	0.85	**16.8**
Sweden	8.89	22.86	2.20	8.45	42.4	23.46	5.22	0.67	1.73	0.17	0.63	8.4	1.28	**75.6**
United Kingdom	1.15	3.07	0.28	1.21	5.7	2.71	1.41	0.19	0.50	0.05	0.20	2.3	0.30	**11.1**
TOTAL	47.1	113.8	11.4	38.2	210.8	113.4	66.4	8.1	18.6	2.8	5.7	101.6	13.8	**439.3**

Appendix 2. Machine fuel prices in selected countries.

Consumer prices of liquid fuels €/litre (including taxes) 15.12.2006		
	Diesel oil	Fuel oil / Heating oil
Czech Republic	1	
Finland	1	0.58
France	1.03	
Hungary	1.01	
Poland	0.96	
Slovakia	1.07	
Spain	0.91	
United Kingdom	1.37	