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DIPLOMA THESIS

COST-RESOURCE CURVES OF BIOMASS POTENTIALS IN AUSTRIA AND OTHER CENTRAL EUROPEAN COUNTRIES

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ABSTRACT

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Title: Cost-Resource Curves of Biomass Potentials in Austria and Other Central European Countries

Keywords: Renewable Energy Sources, Biomass, Potentials, Cost-Resource Curves

Biomass is the most important source of renewable energy worldwide. For assessing future developments and options for the enhanced use of bioenergy it is crucial to know the additionally realizable potentials and the costs related to the provision of additional amounts of biomass.

The main objective of this thesis is to provide comprehensive cost-resource curves for biomass in Austria. Therefore, the currently unused potentials of solid biomass have been assessed with respect to technical, ecological and economic conditions.

The result is an additionally realizable short-term potential of 70 PJ per annum. Biomass from forests represents the biggest proportion of this potential. The additional potential of industrial biomass which is currently among the cheapest fractions of biomass is low. The increasing demand for both energy and non-energy purposes of sawdust and industrial wood chips will lead to a significant lack of industrial residues. Still, the importance of wood pellets which are produced from these fractions will keep rising in the near future. The cultivation of energy plants on set-aside land could supply solid biomass with an energy content of approximately 10 to 15 PJ per annum. The cost-resource curves to these potentials provide an insight into the costs which are related to the enhanced utilization of biomass for energy recovery.

Furthermore, the potentials of solid biomass in other central and eastern European countries are being investigated and also used to derive cost-resource curves.

KURZFASSUNG

Author: Gerald Kalt

Title: Cost-Resource Curves of Biomass Potentials in Austria and Other Central European Countries

Schlagwörter: Erneuerbare Energiequellen, Biomasse, Potenziale, Kostenkurven

Die energetische Nutzung von Biomasse ist die weltweit wichtigste aller erneuerbarer Energiequellen. Für die Abschätzung zukünftiger Entwicklungen und der Optionen für eine verstärkte Nutzung von Bioenergie ist es von großem Interesse, welche zusätzlichen Potenziale verfügbar bzw. realisierbar sind und mit welchen Kosten die Nutzung dieser Potenzialen verbunden ist.

Das Hauptziel dieser Arbeit ist die Erstellung detaillierter Kostenkurven für feste Biomasse in Österreich. Dazu wurden die derzeit ungenutzten Biomassepotenziale unter Berücksichtigung technischer, ökologischer und wirtschaftlicher Randbedingungen ermittelt.

Im Rahmen dieser Arbeit wurde das zusätzlich kurzfristig in Österreich realisierbare Potenzial mit 70 PJ pro Jahr abgeschätzt. Forstliche Biomasse stellt etwa die Hälfte dieses Potenzials dar. Das zu erwartende zusätzliche Potenzial industrieller Nebenprodukten, welche momentan zu den billigsten Biomassefraktionen zählen, ist gering. Aufgrund des steigenden Bedarfes an Sägespänen und Hackgut sowohl zur energetischen als auch stofflichen Verwertung, wird voraussichtlich die Nachfrage das Angebot bei weitem übersteigen. Trotzdem ist zu erwarten, dass in den nächsten Jahren zusätzliche Mengen an industriellen Nebenprodukten zur Produktion von Holzpellets verwendet werden. Durch den Anbau von Energiepflanzen könnten jährlich etwa 10 bis 15 PJ an zusätzlicher Bioenergie bereitgestellt werden. Die im Rahmen dieser Arbeit erstellten Kostenkurven geben einen Einblick in die Kosten, welchen mit der Mobilisierung dieser Potenziale verbunden sind.

Die Potenziale in anderen mittel- und osteuropäischen Staaten wurden ebenfalls untersucht und in Kostenkurven dargestellt.

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1 Introduction

Adverse environmental effects of present energy systems, particularly greenhouse gas emissions and the foreseeable depletion of fossil fuels have led to increasing awareness of the importance of renewable energy sources. A shift towards environmentally sound energy technologies is indispensable for reducing greenhouse gas emissions and providing sustainable development. Furthermore, renewable energy sources have an important role to play in improving the security of energy supply by reducing the dependence on imported fossil fuels.

Biomass is the fourth largest energy source worldwide and the predominant renewable energy source accounting for approximately 15 % of the total energy supply. In Austria, biomass is the second most important source of renewable energy. Fuelwood has always been a main energy source for domestic heating and in recent years there was a rapid increase in modern biomass heating systems. It is also of high importance for the wood-working and paper industry and due to regulations about the use of liquid biofuels as additives to fossil fuels, steady increases in the consumption of biodiesel and bioethanol can be expected. Due to Austria's 2002 Eco-Power Act, electricity generation from biomass is also experiencing a significant upturn.

1.1 Objective of this Thesis

Numerous studies about the potentials of biomass have been carried out in recent years. Some concentrate on estimating the theoretically available resources, others deal with the technical feasibility of certain potentials. The main aim of this thesis is to assess the realizable potentials of solid biomass in Austria and illustrate them in detailed cost-resource curves for the time frame 2010 to 2020. These curves give an impression of the costs which are related to the enhanced utilization of biomass. Furthermore, possible future developments of solid biomass and liquid biofuels are assessed.

The enhanced use of biomass will most probably lead to an increase in biomass trade between European regions. Therefore, an objective of this thesis is to summarize and compare the results of other studies about the potentials of solid biomass in other central and eastern European countries. Results of these previous studies are presented in cost resource curves, too.

1.2 Outline

This thesis consists of two parts. The first part investigates the prices, costs and potentials of solid biomass in Austria (chapters 2 to 6). The second part deals with biomass potentials in other central and eastern European countries (chapter 7). **Chapter 2** gives an overview of the importance of biomass for the Austrian energy supply and describes the different fields of utilization. **Chapter 3** deals with forest biomass. The potentials of forest biomass are analyzed and the according provision costs illustrated in cost-resource curves. The utilization of industrial residues (byproducts of the wood-working industry) for energy recovery, possible future developments and additional potentials of this fraction are described in **Chapter 4**. Furthermore, the flow of wood resources for both energy and material use in Austria is analyzed and cost-resource curves derived for different scenarios. The topic of **Chapter 5** is agricultural biomass. In this chapter the available area of arable land for the cultivation of energy crops and short rotation coppice is identified and the possibilities and costs for the agricultural production of solid biomass are analyzed. **Chapter 6** focuses on wood pellets. Recent developments in the production of pellets for domestic heating are illustrated and future developments assessed and illustrated in cost-resource curves.

The second part of this thesis (**Chapter 7**) is a summary of literature about the potentials of biomass in Austria, six of its neighboring countries and Poland. The main focus lies on the new EU member states Slovakia, Slovenia, Hungary, Poland and the Czech Republic. Data about the potentials of biomass stated in literature are compared and possible reasons for difference examined.

Chapter 8 presents the cost-resource curve of the total additional potential of solid biomass in Austria and summarizes the conclusions of this thesis.

1.3 Definition and Classification of Biomass

The term “biomass” comprises all kinds of organic, non-fossil material. This includes all plants and plant-derived material as well as the mass of living biological organisms and animal manure.

The focus of this thesis is on solid biomass. The fractions can be classified according to the sectors that serve as biomass suppliers (Figure 1.1). Forest biomass includes wood logs and wood chips which can be produced from whole trees or felling residues. Industrial biomass consists of different byproducts and residues of the wood-working industry and agricultural biomass includes residues (e.g. straw) and energy plants (short rotation coppice and energy crops). Wood wastes like demolition wood or wooden packages also represent a fraction of solid biomass. Currently, refined wood fuels (pellets and briquettes) are primarily produced from industrial wood chips and sawdust but due to the increasing demand for wood residues, the production of pellets from straw could be an interesting option.

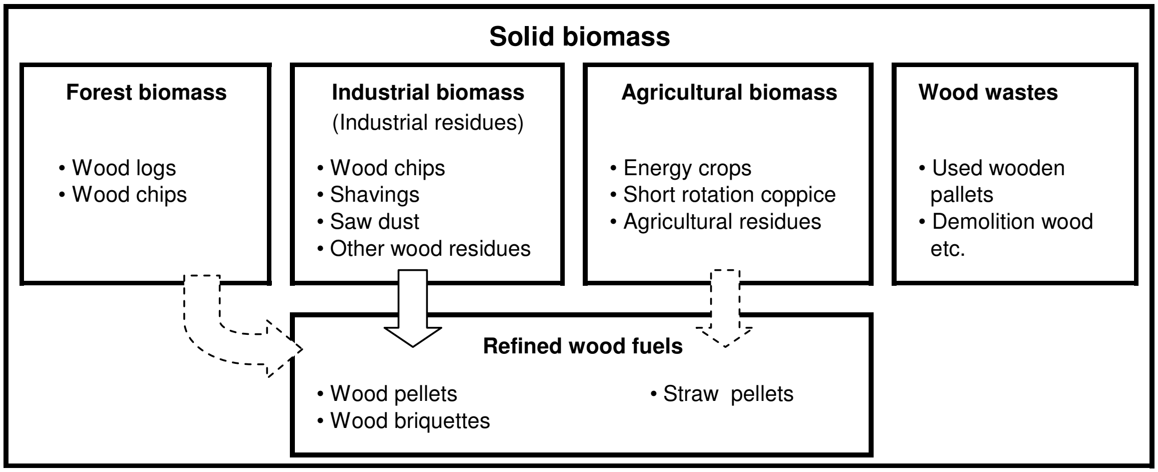

Figure 1.1. Classification of solid biomass.

1.4 Methodology

Cost-resource curves are based on combining data about potentials and costs of various fractions of biomass. Therefore, the methodological approach consists of the following steps:

- Distinguishing the main fractions of biomass resources and their suppliers according to the classification illustrated in the previous chapter (but to a higher level of detail).
- Examining possible methods of provision and identification of the most important impact parameters on the costs (e.g. different harvesting technologies, plant species)
- Assessing the total production costs for each biomass fraction.
- Assessing the potentials for each of these fractions and each parameter setting (e.g. applicability of harvesting).
- Combining potentials and costs to cost-resource curves.
- Deriving conclusions.

The required data originate from previous studies and reports. Concerning forest biomass, the main source of information is the Austrian Forest Inventory which provides comprehensive data about the state of Austria's forests.
The investigations in this thesis focus on Austria. However, investigations on a less detailed level were also carried out for the countries Slovakia, Slovenia, Hungary, Poland and the Czech Republic.

2 Biomass Utilization in Austria

2.1 Primary Energy Mix

The total annual consumption of primary energy in Austria has more than doubled since 1960. Although the consumption of oil has almost remained constant in the last 30 years, Austria has become increasingly dependant on imports of fossil fuels. Figure 2.1 presents the development of gross energy consumption and the shares of imports and domestic energy sources from 1983 to 2003. While the share of domestic raw energy has increased by only 33 %, imports of raw energy showed an increase of almost 85 %. Energy sources which have become more important in the last 30 years include gas and hydro power and there was also an increase in the utilization of biomass and other renewable energy sources.

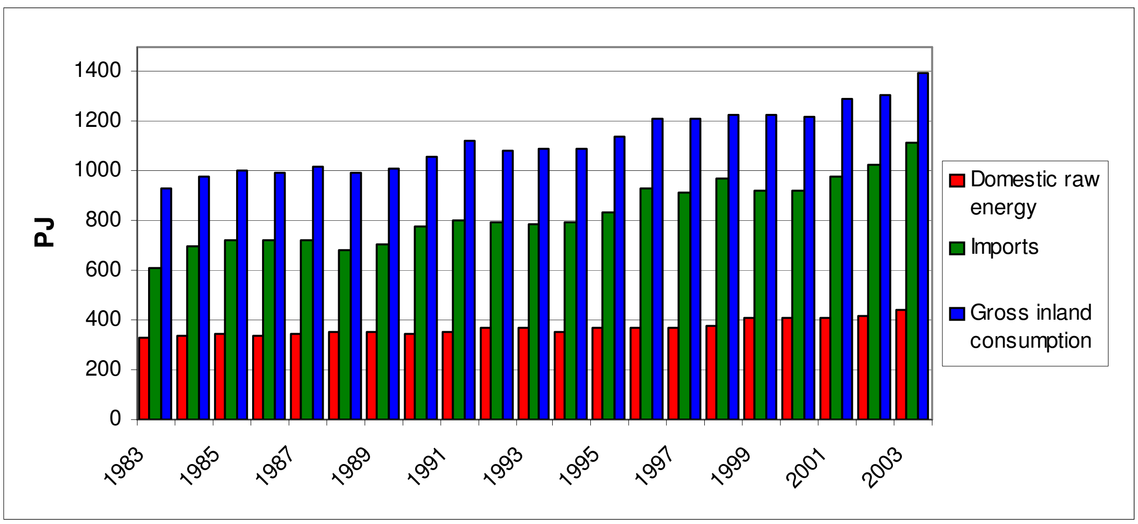

Figure 2.1. Development of energy consumption in Austria.
Source: Statistik Austria 2005.

The total primary energy consumption in 2003 was 1,398 PJ (Figure 2.2). With a share of 42.4 %, oil is still the most important source of energy, followed by gas and coal. Hydropower has the biggest share of all renewable energy sources (9.4 %). The category "Other renewable energy sources" is dominated by biomass (Figure 2.3). The total consumption of renewable energy in 2003 was 300 PJ.

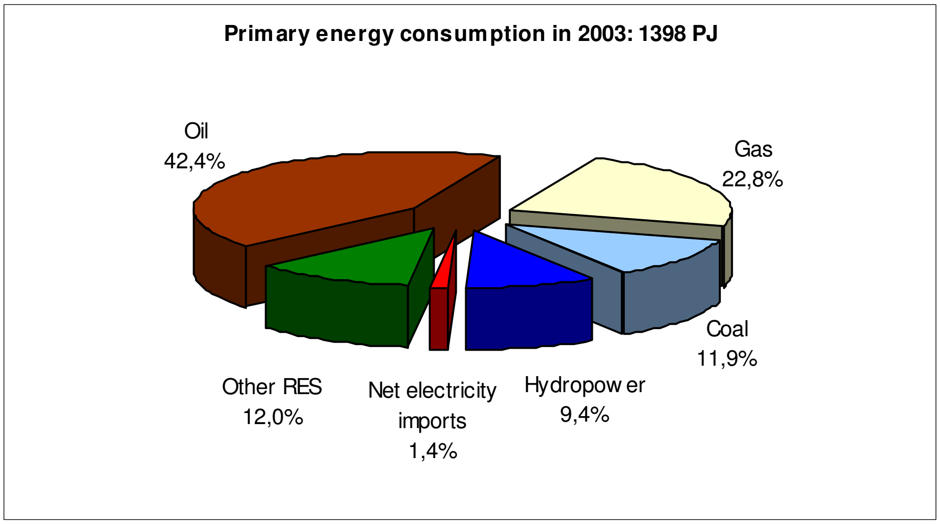

Figure 2.2. Primary energy consumption in Austria in 2003.
Source: Statistik Austria 2005.

The consumption of renewable energy without hydropower ("Other RES") amounted to 168 PJ in the year 2003. About 70 % of this energy quantity was produced with biomass (mainly wood logs, industrial residues and wood chips). Another important source of renewable energy is waste liquor from the pulp industry ("black liquor"). Wastes, landfill and sewage gas accounted for about 11% of "Other RES". The share of wind, solar and geothermal energy is relatively small (only 12 PJ in 2003).

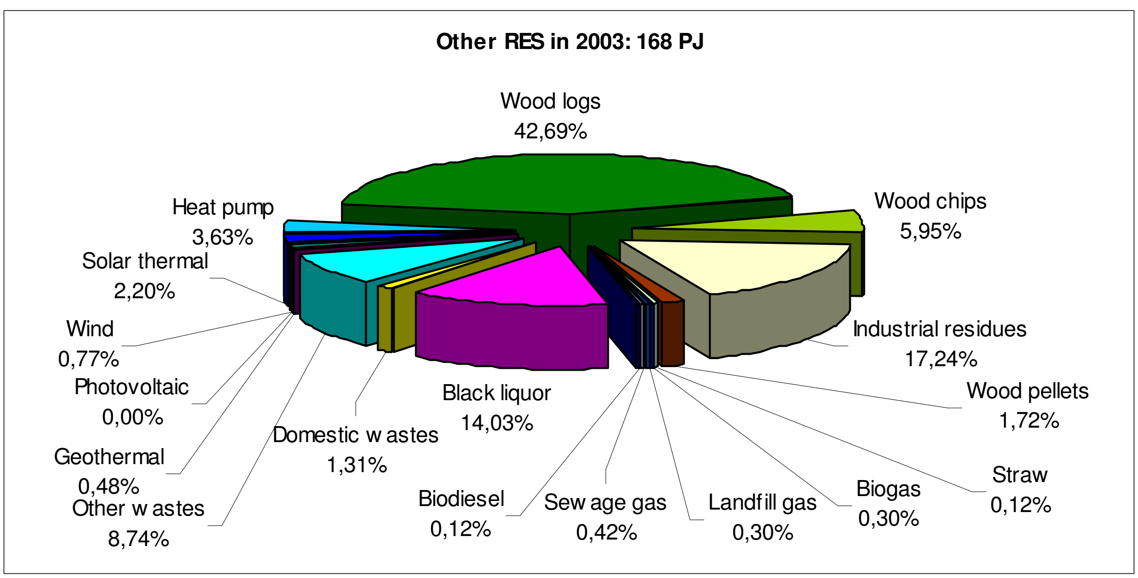

Figure 2.3. "Other RES" in Austria in 2003.
Source: Statistik Austria 2005.

2.2 Biomass Consumption

Since the mid 1970s, the importance of wood as energy source has been increasing steadily. The main factors which have been contributing to this development were rising oil prices, decreasing wood costs due to productivity gains and the use of wood wastes for process heat generation in the wood-working and the paper and pulp industry. In the domestic heating sector an increase in the use of fuelwood could be achieved due to improvements in combustion technologies.

The total consumption of liquid, solid and gaseous biomass in Austria is about 140 PJ/a. The use of wood logs for domestic heating has been extensive by tradition and is still the most important fraction of biomass. In built-up areas fuel wood has widely been replaced by natural gas and fuel oil, but in rural areas it is still of great importance. Figure 2.4 illustrates that the total primary energy production from biomass and wastes has increased by almost 40 % in the last decade. While it was about 100 PJ in 1992, it accounted for more than 140 PJ in 2003.

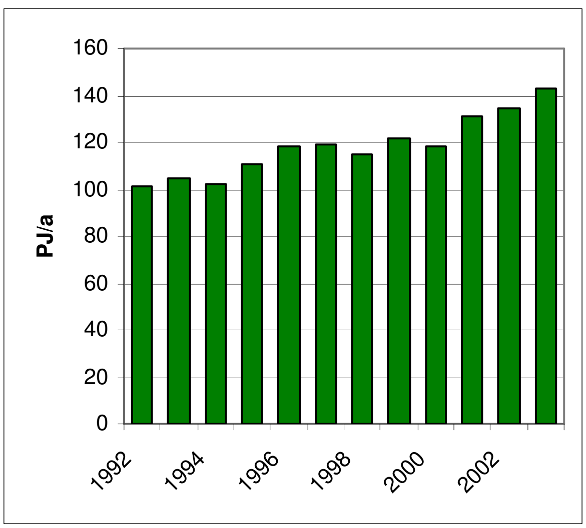

Figure 2.4. Development of the primary energy production from biomass and wastes in Austria.
Source: Eurostat 2005.

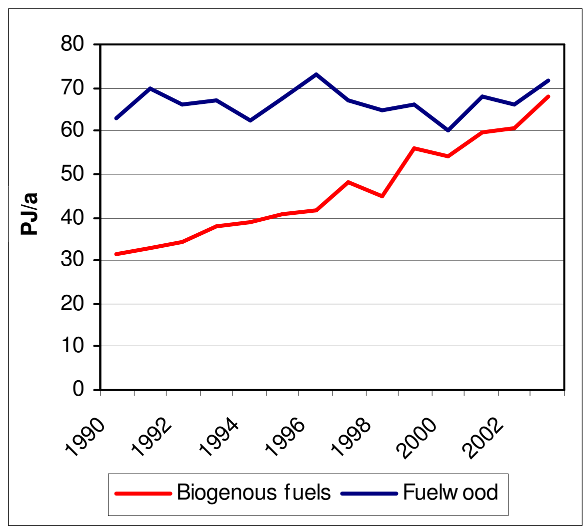

Figure 2.5. Development of consumption of biogenous fuels and fuelwood.
Source: Statistik Austria 2005.

The development of the consumption of biogenous fuels[1] and fuelwood[2] are shown in Figure 2.5. While the consumption of fuelwood has remained relatively

[1] Biogenous fuels include wood chips, industrial residues, bark, refined wood fuels, straw, biogas, landfill gas, black liquor, sewage gas and liquid biofuels.
[2] Wood logs

constant since 1990, the data for biogenous fuels show an increase by more than 100%. The share of biogenous fuels in the total energy consumption has increased from 3% in 1990 to more than 5% in 2003.

Wood chips, industrial residues and bark are used in the wood working industry to cover the internal demand for power and heat, for district heating systems and in smaller boilers for domestic heating. Industrial residues are also required for the production of wood pellets. The share of pellets in the total consumption of biomass is relatively small but there has been an enormous increase in the use of pellet boilers for domestic heating[3]. Figure 2.6 shows the utilization of biomass broken down by type of application. With a share of 60% the use of biomass in small low temperature heating systems is still dominant.

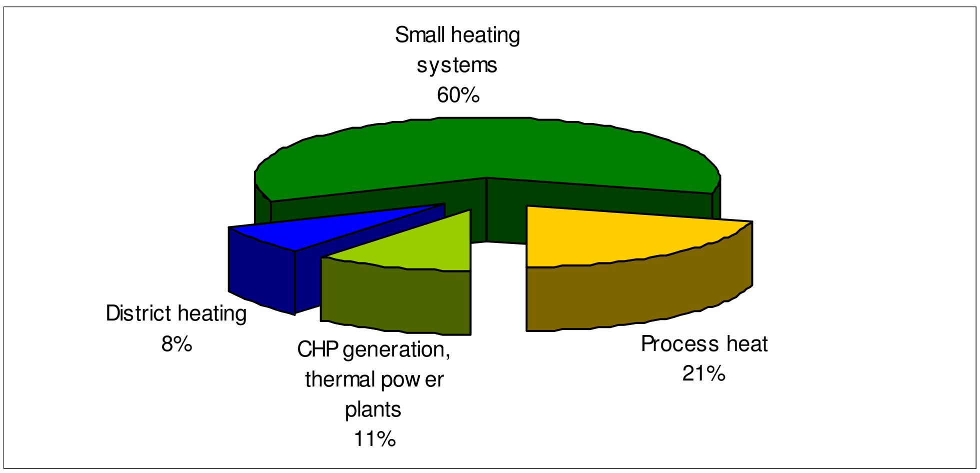

Figure 2.6. Utilization of biomass broken down by application (2001).
Source: AEA 2005.

2.2.1 Domestic Heating

Domestic heating is the most important application of biomass in Austria. Slightly less than 500,000 households (about 17 % of all dwellings) are mainly heated with biomass. Compared to 1980, there was an increase of about 80,000 households, but in 1990 the number was even higher (approximately 616,000). The number of dwellings which are mainly heated with coal has decreased rapidly in the last 20 years, but fossil

[3] See Figure 6.1.

fuels are still dominant in domestic heating (almost 2 million households are mainly heated with oil and gas).

Modern pellet and wood chip heating systems are very promising technologies for the future. In recent years major improvements have been achieved in terms of efficiency and emissions. Emissions of certain air pollutants have been reduced to about one tenth to one hundredth of the average level of the year 1980 [BMWA 2003].

The promotion of pellet-fired installations has been very successful in recent years. Figure 2.7 illustrates the development of new small-scale biomass heating systems (less than 100 kW) in Austria. The first pellet heating systems have been installed in 1997. More than 5,000 were installed in 2003. The number of new wood chip installations has more than doubled since 1989. Still the increase of pellet systems has been exceeding the increase of wood chip installations since the year 2000. The total number of pellet-fired heating systems which have been installed in the period from 1997 to 2004 is more than 28,000.

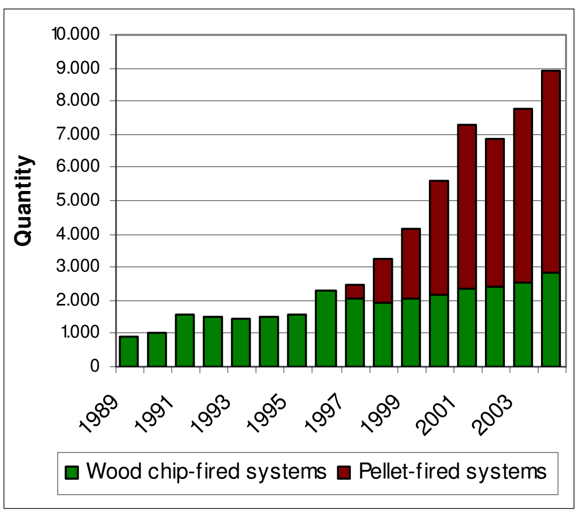

Figure 2.7. Annual increase of biomass heating systems up to 100 kW.
Source: LK 2005.

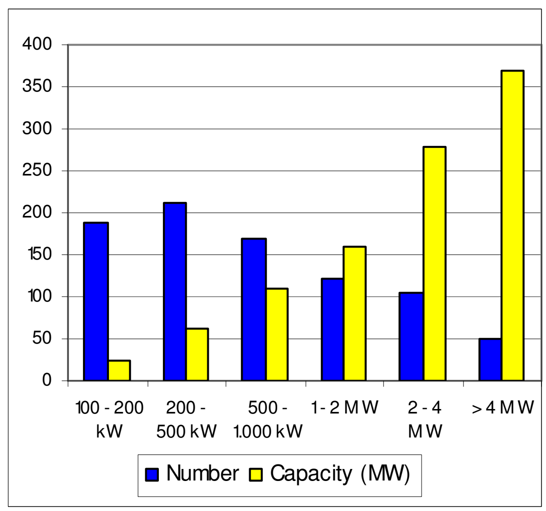

Figure 2.8. Number and capacity of district and local heating systems in 2003.
Source: LK 2005.

The installation of biomass district heating systems in Austria started in the mid-1980s. In the recent past approximately 50 new installations have been registered per annum. By the end of 2003, 843 district and local heating systems with a total capacity of more than 1,000 MW were operational. Most of them are small systems with less than 1 MW but there are also a number of large plants with more than 4 MW. The distribution and their total capacities are shown in Figure 2.8.

2.2.2 Biomass in Industry

About one third of the total biomass consumption is used for the generation of process heat and in combined heat and power plants. The most important branches are the wood-working industry, sawmills and the paper and pulp industry. The used materials are byproducts and wastes like bark, sawdust or waste liquor.

About 17 million solid cubic meters of roundwood are processed to sawnwood annually. The bark is usually separated from other byproducts and used energetically. About 60 % of the input[4] can be processed to sawnwood, the remaining 40 % are byproducts. Bark-free material can either be used for energy production or sold as a raw material for non-energy purposes like paper production. The most important byproduct of the paper and pulp industry which can be used energetically is waste liquor[5]. In 2002, approximately 44 % of the energy required for the production of paper and pulp could be produced from waste liquor and bark[6]. The use of biomass in the paper and pulp industry is the second largest contribution to energy production from biomass in Austria. The third largest contribution comes from the wood processing industry [BMVIT 2005].

2.2.3 Electricity from Biomass

With the 2002 Eco-Power Act, a federally uniform purchasing and payment obligation for "eco-electricity plants" [7] had been introduced. The target is that by 2008 a share of 4 % of the total electricity supply to the end consumer is produced in these plants. In order to facilitate the diffusion of renewable energy, tax incentives, subsidies and supporting schemes for trade and industry have been introduced. These measures created favorable legal framework conditions for an increased generation of electricity from biomass. It is estimated that two thirds of the additionally required quantities of eco-power in 2008[8] could be covered with biomass in an economic way. Therefore, biomass is probably the renewable energy source with the most promising potential.

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[4] Roundwood without bark

[5] Called "black liquor"

[6] See Figure 4.3 in Chapter 4.1.2

[7] Plants run on solar energy, wind, biomass, biogas, landfill gas, sewage gas, geothermal energy and certain kinds of waste, but excluding hydropower

[8] Approximately 1,000 GWh

The total power generation from solid biomass and wastes in 2004 was 313 GWh (Figure 2.9). In the first quarter of 2005, the number of approved plants which generate electricity from solid biomass or wastes with high biogenous share was 155. Many of them are plants of the wood-working industry. About 102 GWh of electricity were generated from gaseous and 18 GWh from liquid biomass in 2004. Figure 2.9 shows that the rapid increase of power generated in biomass plants has continued in 2005. In the first half of 2005 the total amount was almost as high as in the whole year 2004.

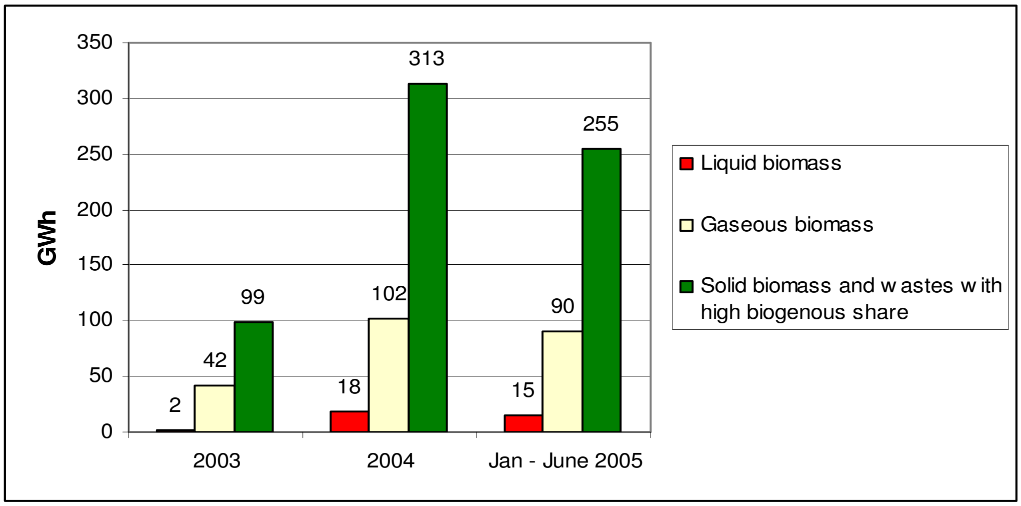

Figure 2.9. Power generation from biomass plants in 2003, 2004 and the first half of 2005.
Source: E-control 2005a.

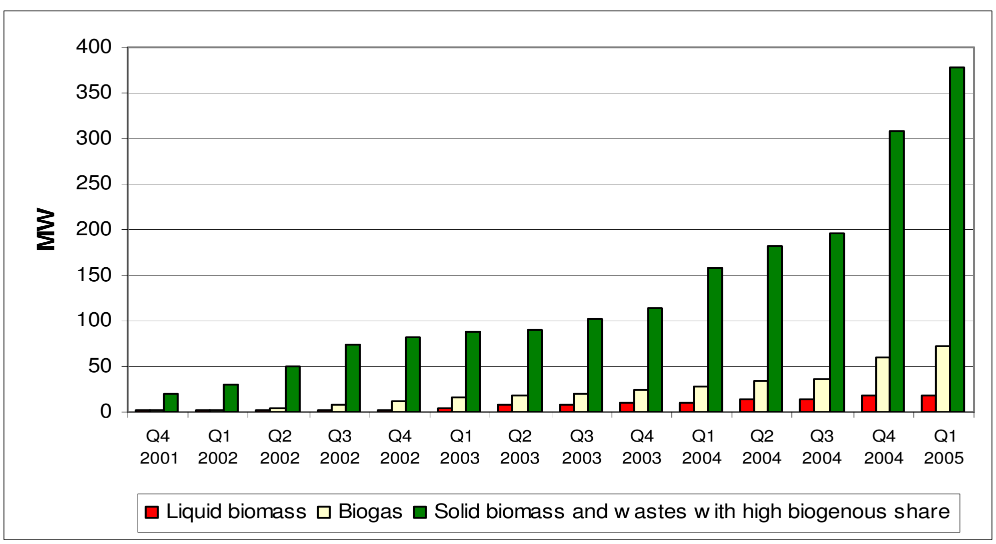

Figure 2.10. Development of the capacity of approved biomass plants in Austria.
Source: E-Control 2005a.

Figure 2.10 shows the development of the capacites of approved biomass plants in recent years. In the first quarter of 2005 their total number was 522, their capacity about 469 MW.

2.2.4 Liquid Biofuels

The biofuel activities in Austria concentrate on biodiesel. The production of biodiesel started in 1991 and especially in recent years, there was a rapid increase in production. The development of biodiesel production in Austria is shown in Figure 2.11. The planned capacity for 2005 is approximately 140,000 tones per annum. Biodiesel is primarily obtained from rapeseed oil, only small quantities are produced from sunflower and waste oil.

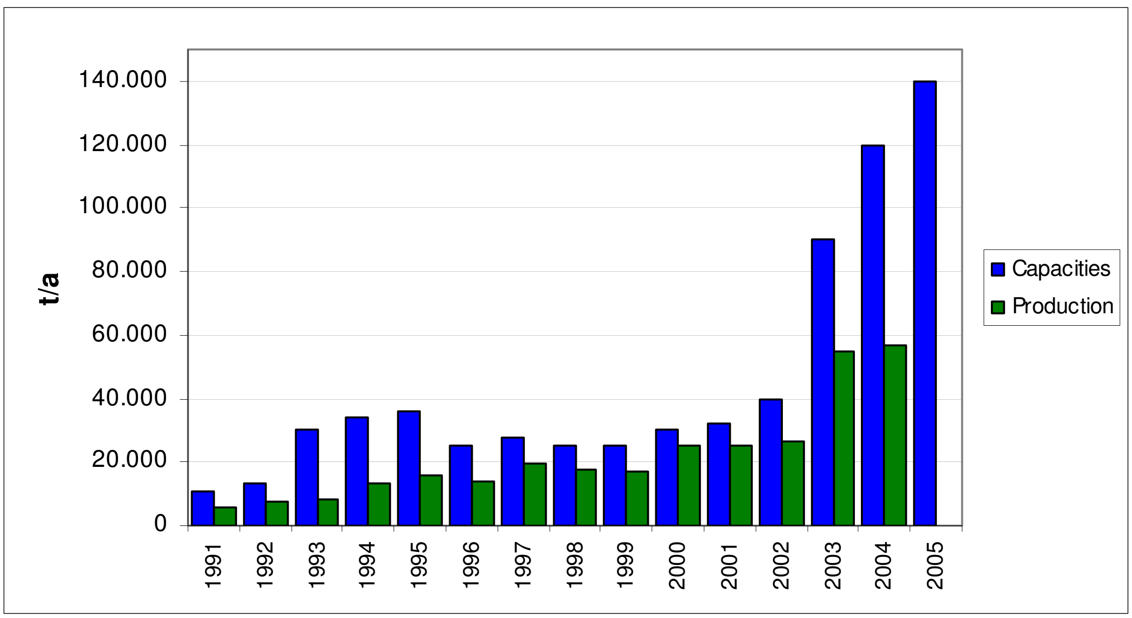

Figure 2.11. Biodiesel production and capacities in Austria.
Source: Krammer et al. 2003, Salchenegger 2004, Handler et al. 2001, AEA 2005.

In accordance with the *Mineralölsteuergesetz* (Mineral Oil Tax Law), fuels produced from biogenic substances are exempt from mineral oil tax. This makes it possible that biodiesel is offered at competitive prices. The blending of up to 2 % biodiesel with diesel is also exempt from tax and there is a tax reduction for the blending of up to 5 % biogenic fuels with petrol. Today biodiesel can be purchased at more than 100 service stations in Austria.

In 1990 first plans for the production of bioethanol were made but could not be realized due to certain economic conditions. Until now there is no bioethanol production in Austria but the first plant with a capacity of 158,000 tons per annum is planned for 2007. There is also increasing interest in the use of pure vegetable oil as fuel for diesel engines or for combined heat and power plants.

With the EU's 2003 biofuels directive targets for the increase of biofuels were defined. The EU targets are a proportion of 2 % biofuels or other renewable fuels by 2005 and 5.75 % by 2010. Austria's plans are more ambitious. Since October 2005 a proportion of 2.5 % is compulsory, a proportion of 4.3 % is planned for October 2007 and 5.75 % for October 2008.

2.2.5 Price Development of Solid Biomass

The Austrian fuelwood price index gives an impression of the price development of solid biomass. The development from 1979 to 2003 is shown in Figure 2.12. The index is composed of the prices of soft and hard fuelwood (each 17.5 %), industrial wood (30 %) and industrial residues (20 % wood chips and 15 % saw dust). For comparison the price indices of fuel oil and electricity are also plotted in this figure.

The fuelwood index reached its highest value in 1981 (1.327) but by 1994 it had dropped to the level of 1979. Since 1994 the index has almost remained constant. The electricity price index showed a significant rise in the years 1979 to 1982 and has stayed quite constant around the value 1.4.
The fuel oil price index was subject to very big fluctuations. It reached its highest value of 2.34 in the year 1985. In the last two years, the price of fuel oil has been rising. This development has probably contributed to the rapidly increasing demand for biomass for domestic heating (e.g. pellets, wood chips).

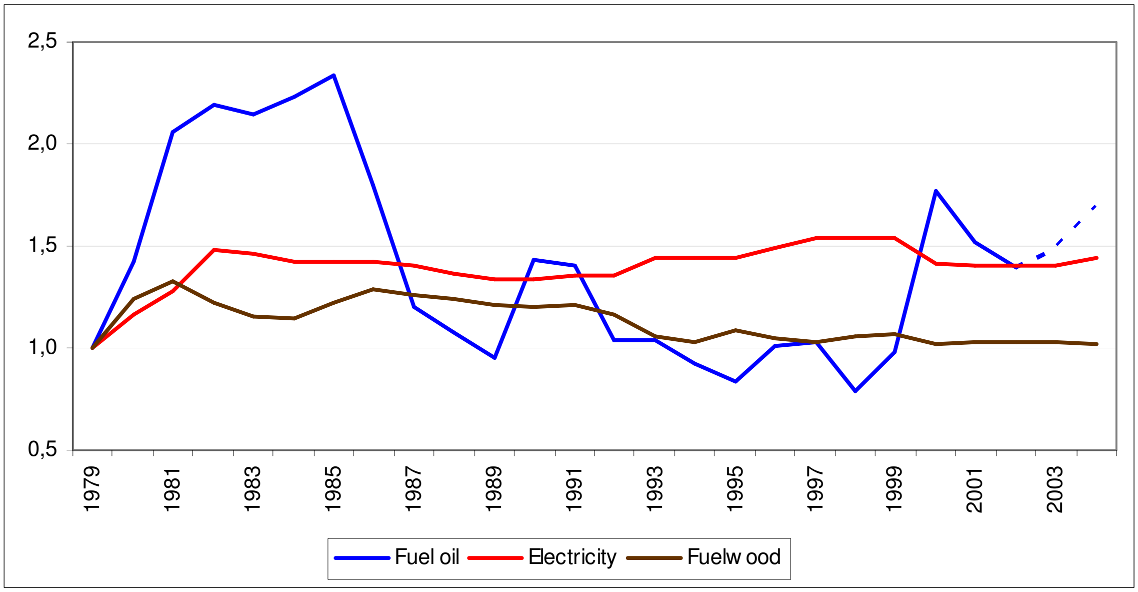

Figure 2.12. Development of fuelwood, electricity and fuel oil[9] price index.
Source: LK 2005.

[9] The values for fuel oil in the years 2003 and 2004 have been calculated from average price increases.

3 Forest Biomass

3.1 Austrian Forests

With a forest area of more than 47 % of the national territory, Austria is one of the most heavily wooded countries in Europe. According to the Austrian Forest Inventory 2000/02 the total forest area is 3.96 million ha. The development of the forest area and its share in the total national territory are illustrated in Figure 3.1. Since the beginning of the Austrian Forest Inventory in 1961 the wooded area has been increasing steadily. The total increase accounted for approximately 270,000 ha. In recent years the annual increment has been decreasing.

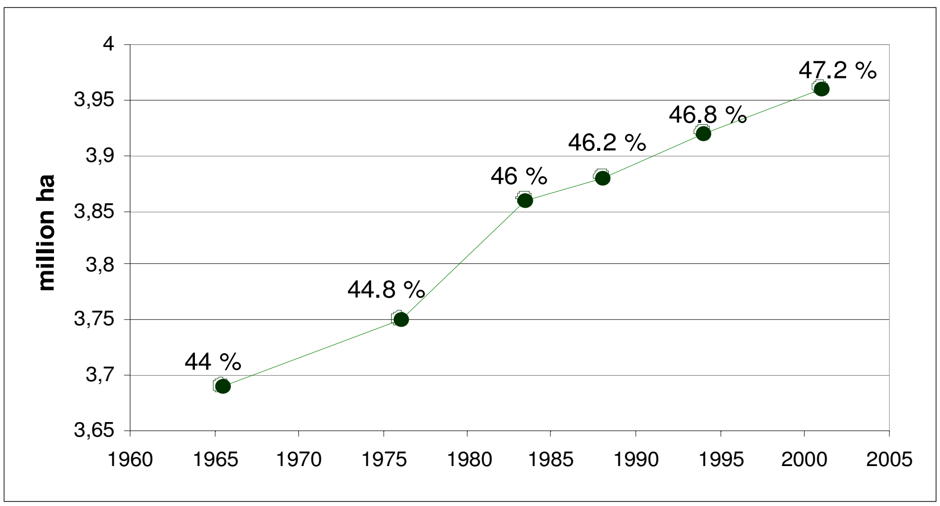

Figure 3.1. Development of the forest area according to the Austrian Forest Inventory. Source: BFW 2004.

3.1.1 Forest Species

The dominating forest species in Austria are coniferous trees (mainly fir, spruce, larch and pine). They account for approximately 80 % of the total stock. The most common broad-leaved tree species are beech, ash, birch and oak. Figure 3.2 shows the shares of the ten most common tree species. In recent years the share of broad-leaved trees has been increasing and it can be assumed that this trend will continue in the near future. The distribution of tree species is quite different in eastern and western provinces. The share of broad-leaved trees is clearly higher in the east of Austria (almost

50 % in Burgenland and more than 30 % in Lower Austria). The share of coniferous trees is highest in Tyrol (about 92 %), followed by Salzburg and Carinthia (approximately 88 %). The total number of trees in Austrian forests is estimated 3.4 billion.

The calorific values of different tree species vary a lot (Figure 3.3). Usually fuelwood is divided into hardwood and softwood. Hardwood includes most broad-leaved trees which have in general a higher density and hardness. Hardwood also has a higher calorific value than softwood. In Figure 3.2, tree species which are counted among hardwood are shown in green color and softwood in blue color.

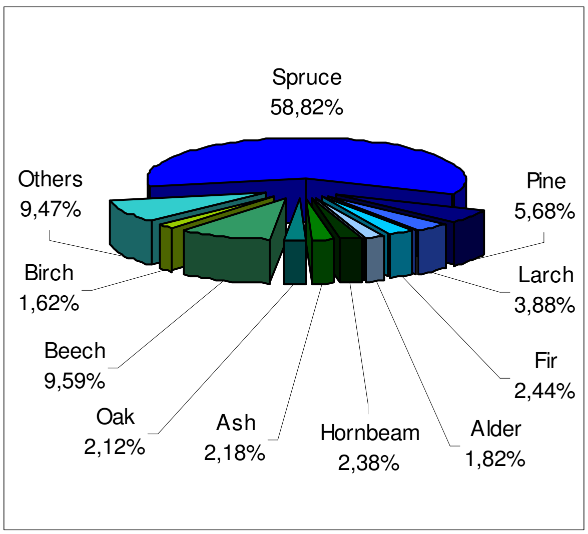

Figure 3.2. Forest species in Austria.
Source: BFW 2005.

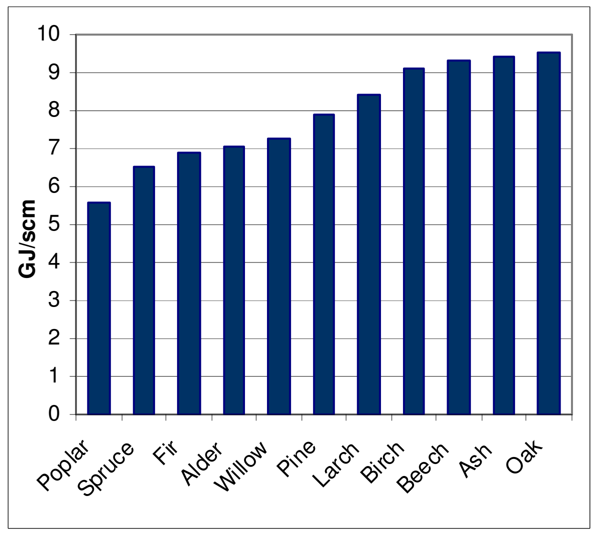

Figure 3.3. Calorific values of different tree species[10].
Source: Regionalenergie Steiermark 2005.

3.1.2 Felling

The development of felling from 1975 to 2004 is shown in Figure 3.4. The total felling has increased from less than 10 million scm in 1975 to more than 16 million scm in 2004. The share of fuelwood in the total felling ranged from 17 to 26 %. From 1975 to

[10] Water content: 20%

In literature the unit m^3 is used both in the sense of solid cubic meters of wood and as a volume unit of wood chips, sawdust etc. However, to avoid any confusion, in this thesis "m^3" is only used in the latter sense. For solid cubic meters the abbreviation "scm" is used. The conversion factors from m^3 to scm are 0.3 to 0.33 for sawdust, 0.35 to 0.4 for wood chips and 0.7 to 0.8 for wood logs.

1996 there was a notable increase in fuelwood but in recent years there is no clear trend noticeable.

In 2004, the total felling accounted for 16.48 million scm without bark. The share of fuelwood was 21.5 %. The biggest share in the total felling was saw log (52.2 %). Small dimensioned wood accounted for 8.6 % and industrial wood for 17.7 % (wood for the production of paper, pulp, chipboards and fiberboards). Austria is the country with the third highest per capita consumption of roundwood in Europe (behind Finland and Sweden).

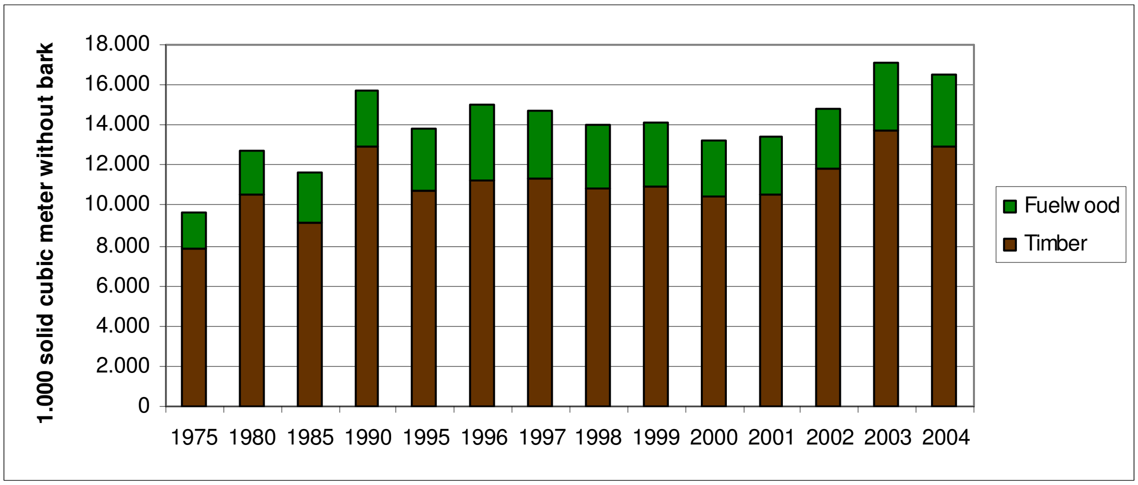

Figure 3.4. Development of felling.
Source: BMLFUW 2005, BMLFUW 2004.

3.1.3 Stock of Wood

The development of the stock of wood in Austria’s forests is illustrated in Figure 3.5. The Austrian Forest Inventory 2000/02 showed a total stock of 1.095 million smc. The increase since the last inventory in 1992/96 was more than 100 million scm. This is partly because of the increase of forest area, but there was also an average stock increase of 30 scm per ha. The increase was highest in small private forests (44 scm/ha), in forests bigger than 1.000 ha and those owned by the *Österreichische Bundesforste AG* the increase was only 10 scm/ha. These numbers indicate that the better part of the unutilized potential is situated in small private forests[11].

[11] See Chapters 3.1.4 and 3.4.1

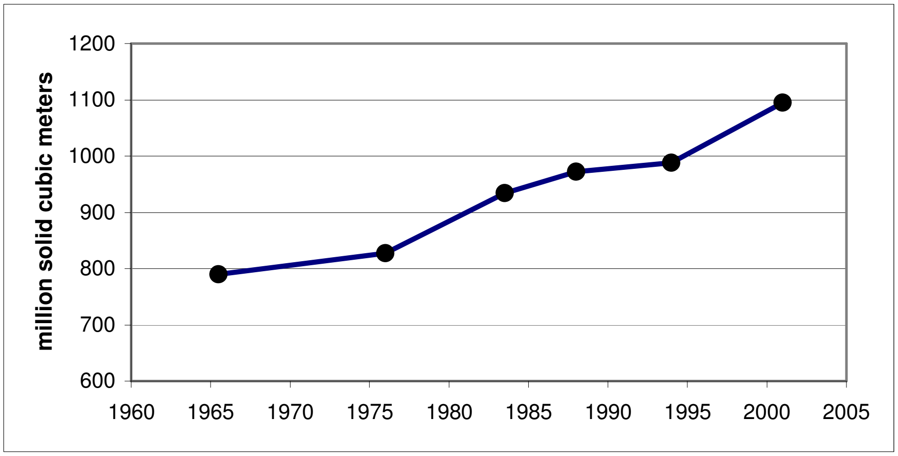

Figure 3.5. Development of stock of wood[12].
Source: BMLFUW 2005.

According to the Forest Inventory 2000/02, there was a significant shift in the age distribution since the previous inventory. The stock of wood with a diameter at breast height (dbh) of more than 50 cm was 32 million scm in 1992/96, in 2000/02 it accounted for 49 million scm. The distribution of tree diameters is illustrated in Figure 3.6. There are slight differences between the distribution in small forests, forests owned by companies and by the ÖBF AG. The share of trees with a smaller diameter (which are usually used as fuelwood or processed to wood chips) is slightly higher in small forests.

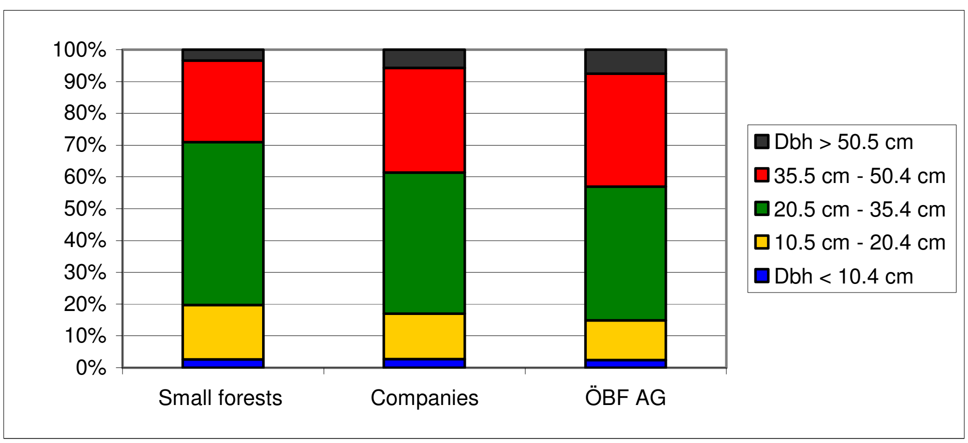

Figure 3.6. Distribution of tree diameters.
Source: BFW 2004

[12] Roundwood only

3.1.4 Forest Ownership

The ownership structure of Austrian forestry is dominated by private owners (Figure 3.7). 50 % are small forests (smaller than 200 ha) which are owned by private persons, mostly farmers who also cultivate agricultural land. The number of these small enterprises is approximately 170,000 but due to structural changes, the number of full-time farmers is decreasing. As a result, the willingness to cultivate the forests is declining. To counteract this development, forestry policies concentrate on supporting communities and cooperation between owners of small forests.

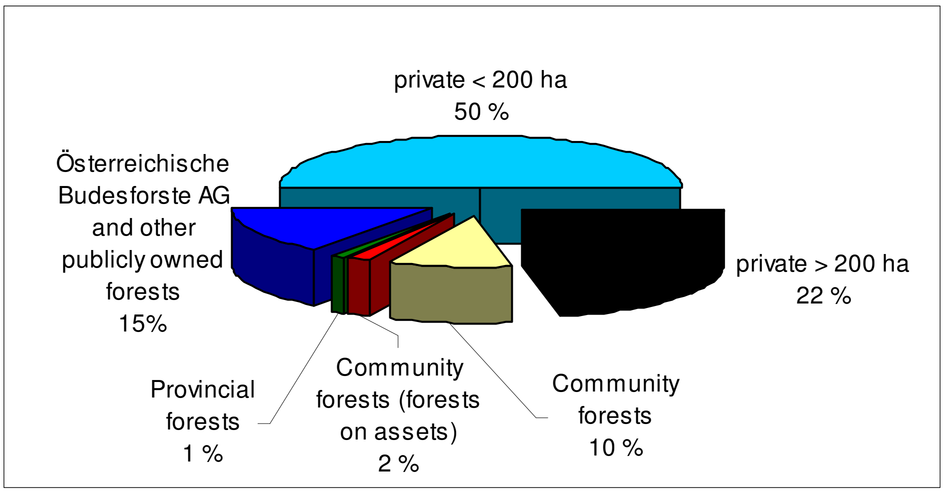

Figure 3.7. Forest ownership in Austria.
Source: BMLFUW 2005

The second half are forests with an area bigger than 200 ha. They are owned by private persons or enterprises (approximate number: 1,400). With a share of 15 % in the total forest area, the *Österreichische Bundesforste AG* is the biggest forest enterprise. The rest is in the possession of provinces and municipalities (13 %).

3.1.5 Slope of Forest Areas

A big share of the forests in Austria is situated on terrain with relatively high slopes (Figure 3.8). Only 38 % of the forest area is located on flat terrain with a slope less than 30 %. This share is drivable with practically every forest machine. A slope of 40 % can be regarded as the upper limit for wheel harvesters and 50 % for crawlers.

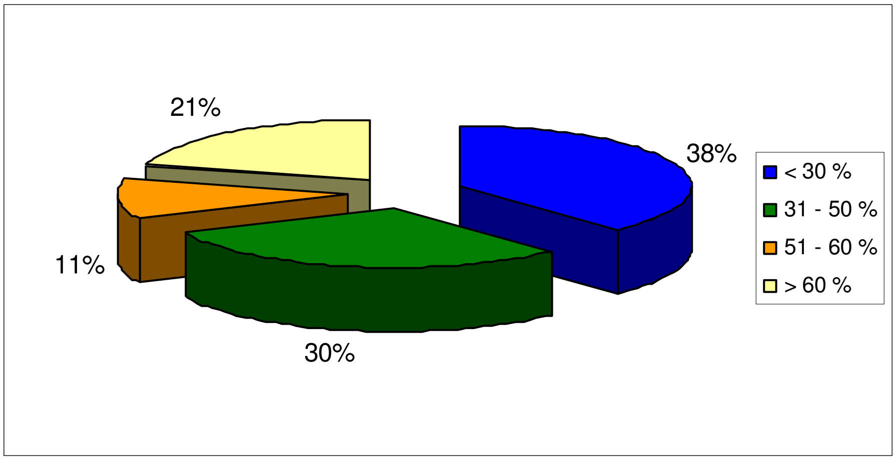

Figure 3.8. Slope of Austria's forest areas.
Source: adopted from [Haneder et al. 2004].

3.2 Potential of Forest Biomass

The total stock of wood according to the Austrian Forest Inventory 2000/02 is 1,095 million scm (see Figure 3.5). The theoretical energy content of this amount is about 8,000 PJ. The actually available potential of forest biomass can be classified in the following categories:

- Roundwood balance
- Wood from thinning
- Forest residues (including stump wood)

3.2.1 Roundwood Balance

In terms of sustainability, the additional potential of forest biomass can be calculated from the roundwood balance[13]. As Figure 3.5 illustrates, the balance has been positive since the beginning of the Austrian Forest Inventory. The net annual increment[14] according to the last inventory is 31.28 million scm/a. The total felling in recent years was about 18.8 million scm. Hence, about 40 % of the annual increment remained unused. The primary energy content of the roundwood balance can be

[13] The difference between net annual increment (NAI) and felling
[14] Gross annual increment minus natural losses

estimated 90 PJ[15]. Due to various conditions the realizable potential is significantly lower. First of all, not all forest land is available for wood supply. 11.9 % of the Austrian forest area is protection forests which are not available. Other forests are not harvestable due to geological conditions (21 % of the forests are located on slopes of more than 60 %). With respect to these restrictions the total potential from roundwood balance was calculated 62.64 PJ/a.

Finally it is also necessary to take economic conditions into account. The estimation of economically harvestable wood resources is probably most problematic. In [Haas et al. 2002] this potential is estimated 27 PJ/a. Own investigations showed an additional economic potential for forest wood chips of about 9.5 PJ/a[16].

3.2.2 Wood from Thinnings

In addition to the roundwood balance, wood from thinnings could be used for energy production. The term "thinning" refers to removing certain trees to provide ideal conditions for the growth of the most useful trees. In recent years thinning has been neglected especially in private forests.

According to the Forest Inventory 2000/02 an amount of 64 million scm should be removed in the course of thinning. This amount cannot be counted to the sustainable potential but represents an additional source of forest biomass. If it was harvested in a space of 20 years the annual potential would be approximately 17.3 PJ. 41 % of the forest areas where thinnings should be carried out have a slope of less than 30 %. Approximately 33 % are situated on slopes between 31 and 50 %, 8 % on slopes between 51 and 60 % and the rest on slopes higher than 60 % [Schaller et al. 2000]. If thinnings are only carried out on slopes less than 60 %, the additional annual potential is reduced to 14.2 PJ.

Besides providing additional biomass, increased thinning would also have positive ecological effects. Too densely wooded forests show a reduced stock increment and increased snow and wind damage.

[15] This estimation only includes trunk wood. Branches, tops, stumps etc. are not included.

[16] See Chapter 3.4.1

3.2.3 Forest Residues

Usually, branches, needles, tops and other parts of the felled trees are not removed from the forest for utilization. These parts are referred to as forest or felling residues. Forest residues are already used for energy production in Austria but the potential is far beyond the current use. The amounts of theoretically available residues are illustrated in Figure 3.9. The total amount which consists of forest residues from current fellings and from the roundwood balance[17] is about 18 million scm. Under the assumption that 25 % of the total residues can be utilized, the energy potential from forest residues is about 30 PJ/a. According to [Schaller et al. 2000], the additional realizable potential is only 5 PJ/a.

If carried out extensively, the ecological impacts of removing forest residues may be significant. In some parts of the trees which are included in forest residues (needles, tops) the greatest concentration of plant nutrient occurs. Extensive removal of these parts results in nutrient loss from the forest and definitely has negative ecological impacts on the forest. Therefore, the utilization of forest residues is often viewed critically in Austria.

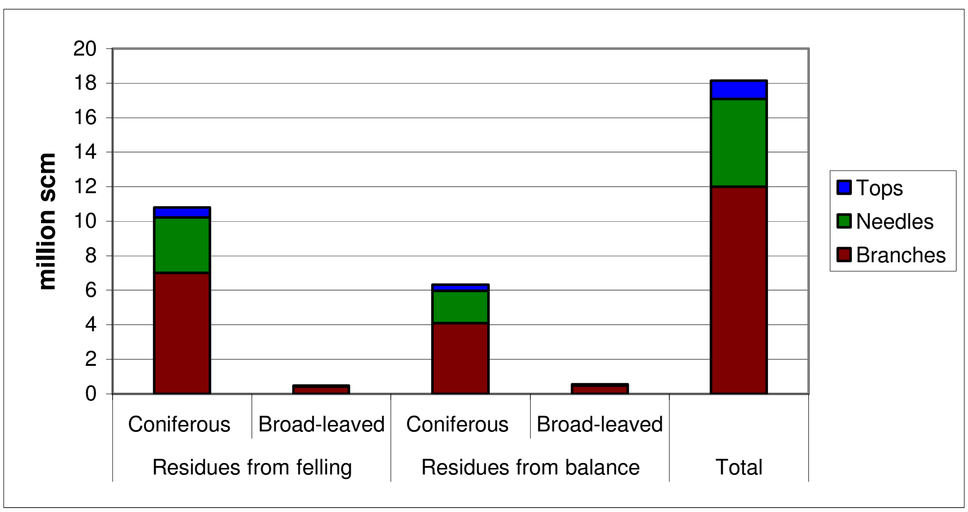

Figure 3.9. Theoretically available forest residues.

In Finland the “bundling technology” has proved to be an effective solution for large scale production of forest chips from felling residues. With dedicated machines the loose forest residues are collected, tightly compressed and tied to bundles of 60 to 70

[17] This amount would only be available if the whole NAI was used.

cm in diameter. The bundles can be transported with standard forwarders or timber trucks and processed to wood chips with stationary or mobile chippers.
The conditions in Austria are slightly different from Finland and first tests in Austria did not meet the expectations [Kanzian 2005]. The main problem is that the use of bundling machines is only cost-efficient if big amounts of felling residues accrue (e.g. at clear-cuttings). Still the bundling technology could be a possibility to increase the use of forest residues and reduce the production costs for wood chips.

According to [Tekes 2004] stumps from regeneration areas could provide a notable amount of fuel. Methods of stump harvesting have been developed in Finland and the first experiences have been promising. With heavy crushers stump wood can be processed to wood chips. The realizable potential of stump wood in Austria according to [Karjalainen et al. 2004] is 200,000 scm/a (approx. 1.5 PJ/a). If this potential will ever be utilized seems questionable.

3.2.4 Potentials of Forest Biomass in Literature

Table 3.1 gives an overview of estimations of Austria's forest potentials stated in different studies. The range of values is quite large but it has to be considered that the potentials are specified differently (e.g. theoretical potential, realizable potential, mid-term potential).

Table 3.1. Overview of potentials of forest biomass in literature.

Potential	Author	Year	Fraction	Value
Theoretical additional potential	Karjalainen et al.	2004	Balance	10,97 million scm/a (80 PJ/a)
			Residues incl. stump wood	15,18 million scm/a (110 PJ/a)
Additional realizable potential	Karjalainen et al.	2004	Balance	2,9 million scm/a (20 PJ/a)
			Residues incl. stump wood	2,9 million scm/a (20 PJ/a)
Theoretically available resources	Nikolaou et al.	2003	Fuelwood	43 PJ/a
			Residues	150 PJ/a
Additional potential 2020	Haberl et al.	2002	Primary forest biomass	37,7 PJ/a
			Bark	4,8 PJ/a
Additional potential	Wörgetter et al.	2001	Forest biomass incl. bark, saw dust	60 PJ/a
Additional potential 2010				36 PJ/a
Mid-term additional potential	Steininger et al.	2003	Fuelwood	44,67 PJ/a
			Forest wood chips	90,47 PJ/a
			Bark	1,62 PJ/a

Theoretically available resources	AFB-net	2001	Domestic Firewood	40 PJ/a
			Residues	150 PJ/a
Additional realizable potential	Haas et al.	2002	Balance	27 PJ/a
			Thinning	18 PJ/a (if harvested in 20 years)
Theoretical potential	Schaller et al.	2000	Balance	4 million scm/a (30 PJ/a)
			Residues	2 million scm/a (15 PJ/a)
			Thinning	2,8 million scm/a (20 PJ/a)
Additional realizable potential	Schaller et al.	2000	Balance	1 million scm/a (7,5 PJ/a)
			Residues	0,7 million scm/a (5 PJ/a)
			Thinning	1,3 million scm/a (10 PJ/a)
Additional Potential	Lechner et al.	2003	Forest wood chips	36,7 PJ/a
			Residues	2-3 million scm (15-22 PJ/a)
Additional potential	Kalt	2005	Balance	62.64 PJ/a
			Residues	5 PJ/a
			Thinning	14.2 PJ/a (if harvested in 20 years)
Additional economic potential[18] (forest wood chips)	Kalt	2005	Balance	9.5 PJ/a
			Residues	5 PJ/a
			Thinning	6 PJ/a

3.3 Prices and Costs of Forest Biomass

3.3.1 Prices of Fuelwood and Wood Chips

Figure 3.10 illustrates the price ranges for soft and hard fuelwood and forest wood chips in Austria's provinces[19]. Forest biomass is most expensive in the western provinces Tyrol and Vorarlberg. In the rest of Austria the price differences for hard fuelwood are marginal. The price ranges are biggest for forest wood chips. In most provinces hard fuelwood is the most expensive and wood chips the cheapest fraction.

[18] The additional economic potentials of forest wood chips are derived from the cost-resource curves (Chapter 3.4.4).

[19] All prices and costs in this thesis are exclusive of VAT. The prices of fuelwood were given in €/scm, those of wood chips in €/t (Burgenland, Lower Austria, Upper Austria and Vorarlberg) or €/m^3 (Carinthia, Salzburg and Styria). The average energy content of hard fuelwood is 7 GJ/m^3, of soft fuelwood 5 GJ/m^3 and of wood chips 2.65 GJ/m^3 (a share of 80 % of softwood and 20 % of hardwood were assumed). The average specific weight of wood chips was assumed 0.167 t/Srm. The original data are presented in the appendix (Table A3.10).

The development of average prices of hard and soft fuelwood is shown in Figure 3.11. In 2004, the average prices of hard and soft fuelwood were 6.15 €/GJ and 5.5 €/GJ respectively. The average price for forest wood chips for heating plants with a capacity of more than 500 kW in 2003 was 5 €/GJ [Golser et al. 2004].

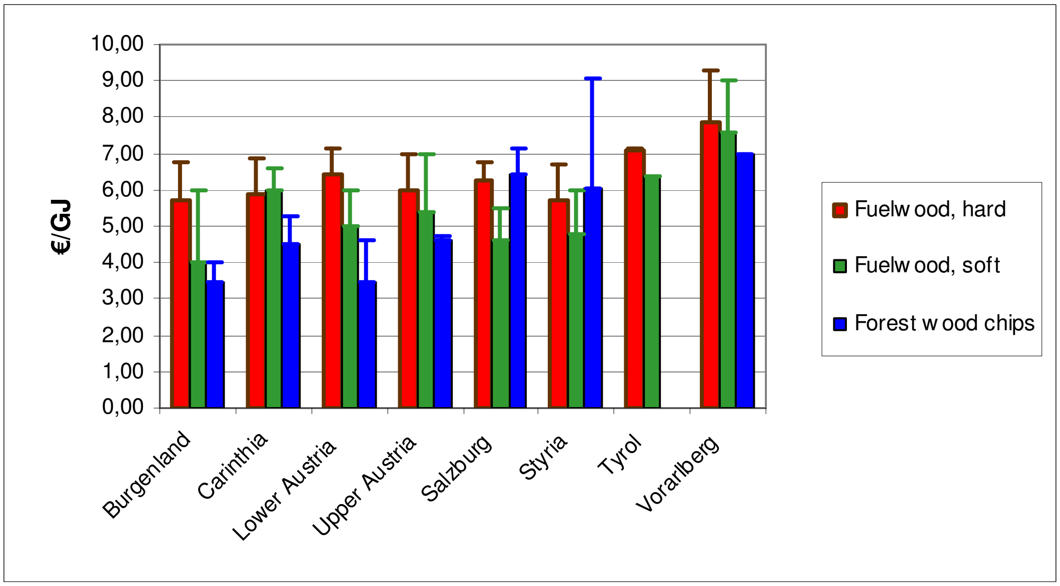

Figure 3.10. Prices for fuelwood and forest wood chips in Austria[20].
Source: Holzkurier 2005.

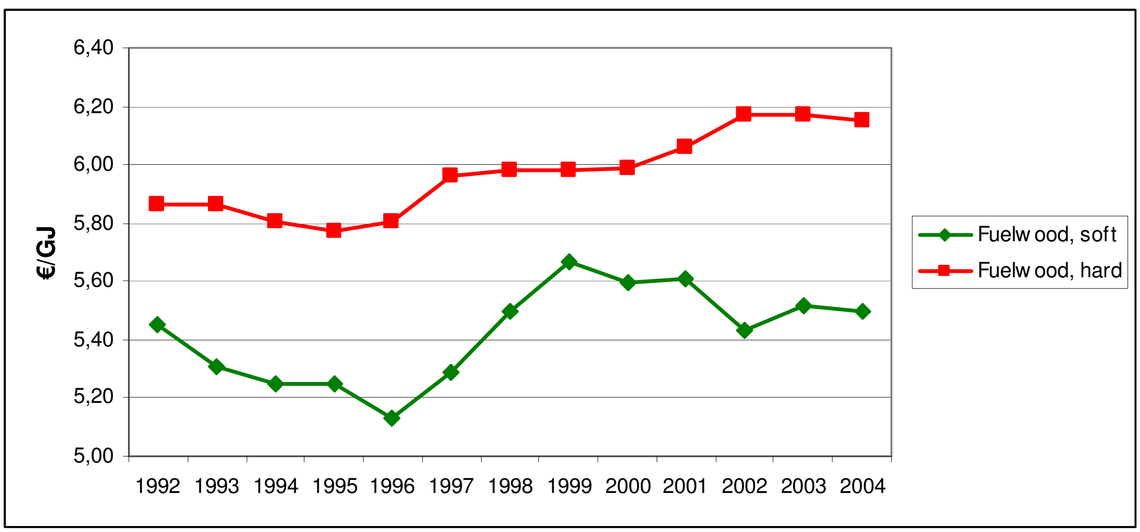

Figure 3.11. Development of average prices for fuelwood.[21]
Source: BMLFUW 2004, BMLFUW 2005.

[20] Prices in April 2005.

[21] See Table F3.11 in the appendix for the original data.

3.3.2 Delivery Costs for Fuelwood

Table 3.2 and 3.3 give an impression of the time needed for felling and removing energy wood and the resulting costs. The costs for the manual felling of trees with different diameters are shown in Table 3.2, Table 3.3 illustrates the costs for removing the wood. The costs have been calculated for two different wage levels (10 and 20 €/h). It is obvious that the costs per solid cubic meter are lower for trees with a bigger diameter.

The first method in Table 3.2 also includes trimming of the stems. Therefore, the costs are significantly higher than for the second method. According to these figures the costs for felling and removing range from 8.8 €/scm[22] to 59.37 €/scm[23] (approximately 0.98[24] to 8.73 €/GJ[25]). Costs for transportation are not included.

According to [BMLFUW 2005] the average costs for felling, removing and transportation in 2002 were 39.01 €/scm for small forests (approximately 4.33 €/GJ for hardwood and 5.74 €/GJ for softwood) and 21.89 €/scm (2.43 €/GJ for hardwood and 3.22 €/GJ for softwood) for forests larger than 500 ha.

Table 3.2. Costs and efficiencies of manual felling.
Source: Schaller et al. 2000.

Description	Conditions	Tree species	Efficiency (scm/h)				Costs (€/scm)			
			dbh 19cm	dbh 27cm	dbh 34cm	dbh 42cm	dbh 19cm	dbh 27cm	dbh 34cm	dbh 42cm
Manual felling, removing branches, trimming	Wood w/bark, slope 30 %	Coniferous	1,19	1,69	2,63	3,23	10,10	6,18	4,58	3,71
							19,33	11,70	8,72	7,12
		Broad-leaved	1,19	1,57	1,94	2,55	10,10	7,70	6,25	4,72
							19,33	14,61	11,85	9,01
Manual felling, removing branches	Wood w/bark, slope 30 %	Coniferous	2,11	3,26	4,12	4,63	5,74	3,71	2,91	2,62
							10,90	7,05	5,60	4,94
		Broad-leaved	2,54	3,18	4,05	5,63	4,72	3,78	2,98	2,11
							9,01	7,19	5,67	4,07

[22] Broad-leaved trees with a dbh of 42 cm, convenient terrain, wage level 10 €/h
[23] Trees with a dbh of 19 cm, rough terrain, wage level 20 €/h
[24] Calculated for hardwood
[25] Calculated for softwood

Table 3.3. Costs and efficiencies of wood removal with tractor.
Source: Schaller et al. 2000.

Description	Conditions	Tree species	Share of drivable area	Efficiency (scm/h)				Costs (€/scm)			
				bhd 19cm	bhd 27cm	bhd 34cm	bhd 42cm	bhd 19cm	bhd 27cm	bhd 34cm	bhd 42cm
Removal w/ tractor, removing remaining branches, storage	Wood w/bark, slope 30 %, distance 300m	Coniferous	1	3,5	6,5	8,8	11,1	19,19	12,28	10,32	8,87
								26,89	17,22	14,46	12,43
			2/3	2,2	4,2	5,7	7,2	24,49	13,08	10,32	8,87
								34,37	18,31	14,46	12,43
			1/3	1,9	3,6	4,9	6,2	28,56	15,19	11,19	8,87
								40,04	21,29	15,62	12,43
		Broad-leaved	1	3,5	5,2	6,7	8,8	15,41	10,54	8,07	6,69
								21,66	14,75	11,26	9,37
			2/3	2,6	3,8	5	6,7	21,22	14,24	10,76	8,14
								29,80	19,91	15,12	11,41
			1/3	2	3	4	5,4	27,03	17,88	13,44	10,10
								37,86	25,14	18,89	14,10

Included wage:	
	10€/h
	20€/h

Figure 3.12 and 3.13 show the results of tests about the costs and efficiencies for felling with harvesters against the diameter at breast height[26]. The costs range from 5.38 €/scm (approximately 0.60 €/GJ[27]) to 25.22 €/scm (3.71 €/GJ[28]). The used harvesters have been divided into small and large machines. The most significant difference to manual cutting is the high efficiency.

[26] Note that removing and transportation are not included.

[27] Calculated for hardwood

[28] Calculated for softwood

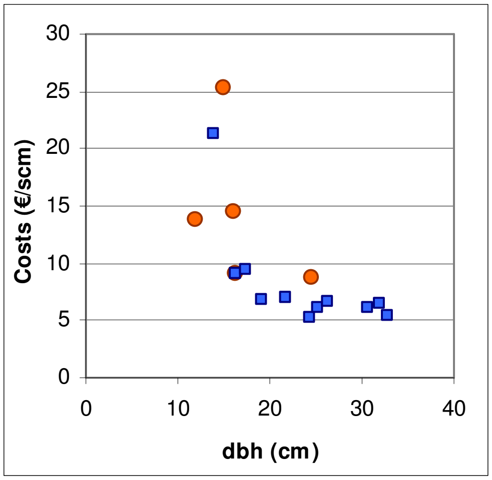

Figure 3.12. Costs for felling with harvesters.
Source: Schaller et al. 2000.

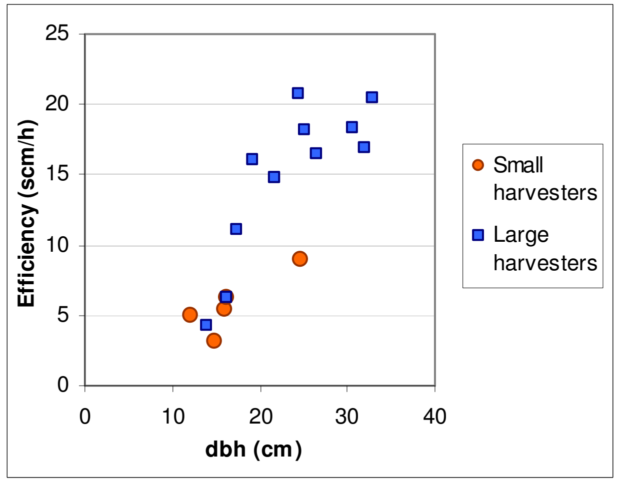

Figure 3.13. Efficiencies of felling with harvesters.
Source: Schaller et al. 2000.

3.3.3 Delivery Costs for Wood Chips

Figure 3.14 shows the results of some tests about the production of wood chips carried out in Austria. The total costs range from 2.67 €/GJ (chipping of forest residues) to 6.67 €/GJ (manual thinning). Because of the higher calorific value of hardwood the wood chip production from broad-leaved trees (e.g. oak, beech) is cheaper than from coniferous trees (e.g. spruce, pine). The average costs according to these tests is about 4.9 €/GJ. The costs include cutting, removing, chipping and transportation.

Table 3.4 gives an overview of different methods for the production of wood chips. The efficiencies (in m^3/h) and costs (in €/m^3) depend on the level of mechanization and the diameter of the trees at breast height (dbh). The costs also depend on the average wage. The recommended field of application for each method is also described in Table 3.4. The total delivery costs range from 7.90 €/m^3 (2.43 €/GJ for hardwood and 3.16 €/GJ for softwood[29]) to 39.10 €/m^3 (12.03 €/GJ for hardwood and 15.64 €/GJ for softwood).

[29] The average energy content of wood chips was assumed 3.25 GJ/m^3 for hardwood and 2.5 GJ/m^3 for softwood.

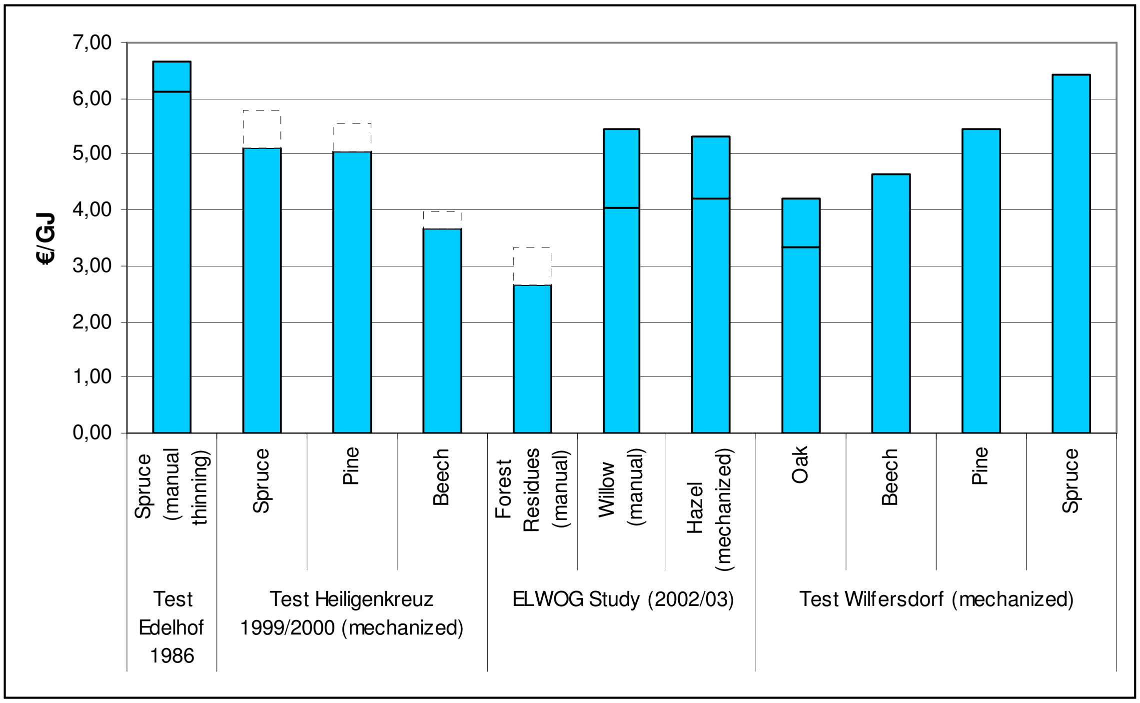

Figure 3.14. Results of wood chip production tests carried out in Austria.
Source: Haneder et al. 2004.

The main advantages of highly mechanized methods are that the efficiencies are significantly higher and that the physical labor is less exhausting. But the costs for the required machines are relatively high and thus, these methods are only favorable for spacious operations.

For methods which are recommended for small private forests it can be assumed that no additional workers need to be employed. The calculative wage rate for these methods has been presumed 10 €/h. The wage rate for employed workers has been assumed 25 €/h. The costs for method 4 and 5 have been calculated for both cases. Costs for transportation are also included in the costs in Table 3.4. For methods which are favorable in small forests (Method 1 to 4), the average distance to the repository has been assumed 5 km, for the others 15 km.

Other differences between the described methods include the quality of the produced wood chips and the damage caused to the remaining stock and the forest soil. Generally, the quality of the wood chips is higher if the wood is not chipped immediately after it was felled. Thus, wood chips produced with method 1 and 6 are of lower quality. The danger of damaging the remaining stock is especially considerable for method 3. The use of highly mechanized methods with harvesters is sparing for the remaining stock but the impact on the forest soil can be heavy.

Table 3.4: Methods for the production of wood chips
Source: adopted from [Wittkopf et al. 2003]

	Description	Field of application	Transport	Efficiency (m3/h)			Cost (€/m3)		
				dbh 10cm	dbh 15cm	dbh 20cm	dbh 10cm	dbh 15cm	dbh 20cm
1	Manual felling w/motor saw, manual removal, chipping in forest	Small private forests, small-scale felling	5 km	1,4	1,6		14,4	12,9	
2	Manual felling, removal w/horse & forwarder, chipping on forest street	Adverse locations, rough terrain, damageable soil	5 km	1,7	2,7		19,4	13,3	
3	Semi-mechanized felling w/winch, removal w/forwarder chipping on forest street	Private forests	5 km	2	2,8	3,5	16,4	12,6	10,9
4	Felling w/winch, removal w/tractor & forwarder, chipping on timber yard	Central timber yard existent or heating plant nearby	5 km	3,6	5,4	6,5	16,8 22,9	11,6 15,2	9,7 12,5
5	Method "Neustadt": felling w/winch and gripper, chipping on forest street	Big area, substantial felling	15 km	4,1	6,1	7,2	13,1 18,6	9,1 12,5	7,9 10,5
6	Semi-mechanized felling with tractor, chipping in forest	Big area, demand for low grade wood chips	15 km	4,7	8,8	12,1	26,2	14,5	10,4
7	Mechanized felling w/harvester, removal w/forwarder, chipping on forest street	Very big area	15 km	3,3	6,9	8,8	39,1	17	12,9
8	Mechanized felling and chipping w/combined harvester/chipper, removal w/shuttle	Vast felling	15 km	5,3	8,5	9,9	25,9	14,5	11,7

Included wage: 10€/h (yellow) / 25€/h (green)

A comparison of the different methods shows that highly mechanized procedures are only favorable for big areas and for the processing of trees with larger diameters. For felling on small-scale (e.g. thinning in small private forests), manual or semi-mechanized felling are the cheaper options.

3.3.4 Costs for Wood Chips in Finland

In Finland an enormous increase in the production and use of wood chips has been achieved in recent years. The production technology is much more mature than in Austria, especially the utilization of forest residues. Although there are significant differences between Austrian and Finnish forestry, the situation in Finland could provide interesting information about possibilities for cost-saving and possible future developments in Austria.

Usually wood chips are produced from small trees or forest residues. Figure 3.15 illustrates typical cost structures of forest wood chip production in Finland. In the production costs of chips from forest residues, costs for felling are not included since residues are regarded as byproduct of roundwood production. The stem volume has a major influence on the costs of "whole-tree chips". According to [Hakkila 2004] the costs for "whole-tree chips" range from about 4.3 to 5 €/GJ for manual cutting and for mechanized cutting from 3.9 to 11.7 €/GJ. Although mechanized cutting of small trees is quite expensive, the average costs for mechanized cutting (approximately 4.2 €/GJ) are slightly lower than the ones for manual cutting (4.6 €/GJ). A comparison with the situation in Austria (Figure 3.14) shows that the costs in Finland are slightly lower. This is probably partly because of the more favorable forestry conditions in Finland, but there also might be some potential for cost-saving in Austria.

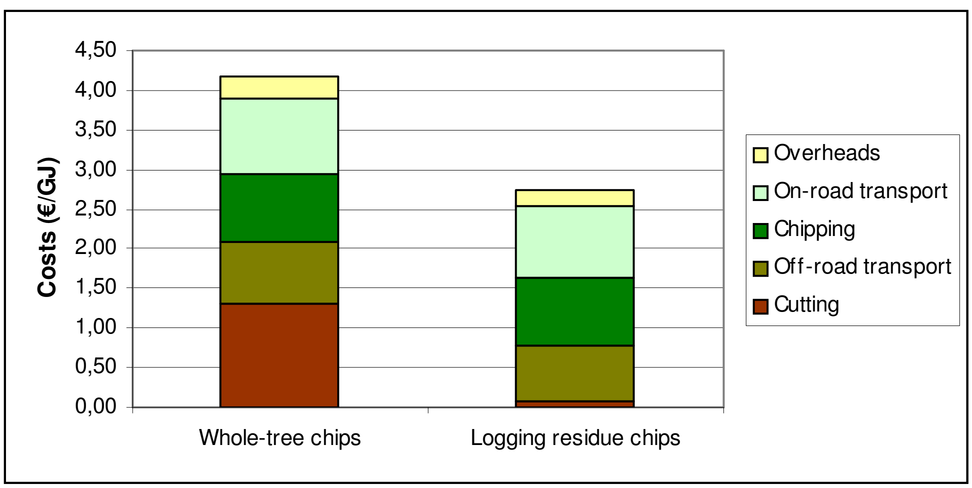

Figure 3.15. Cost structure of forest wood chip production.
Source: Hakkila 2004.

3.4 Cost-resource curves

In the following chapters, information about potentials and costs of forest biomass is combined to cost-resource curves. These figures should give a better impression of the additionally available potential and the costs for its utilization. The following factors have been taken into account:

- **Tree species**: Classification into softwood and hardwood[30].
- **Method of provision** (degree of mechanization): The applied methods have been chosen with respect to the ownership of the forest[31].
- **Tree diameter**: The assumed distribution of tree diameters are based upon results of the Forest Inventory 2000/02.

With regard to developments in the last decade, it does not seem likely that there will be a significant increase in the use of log wood in the near future. Since the cost-resource curves illustrate additionally available potentials, log wood has not been included.

3.4.1 Wood Chips from Balance

Under the assumption that trees with a dbh from 5 to 25 cm are used for wood chip production and that forests on slopes higher than 60 % are not utilized, the annual potential of wood chips from balance is approximately 16.6 PJ. The share of hardwood in the unused increment is about 25 %, 75 % are softwood. The cost-resource curve in Figure 3.16 results from the following assumptions:

- According to the Forest Inventory 2000/02, 84.3 % of the unused increment comes from small private forests and the rest from forests in the possession of companies or the ÖBF AG.
- The assumed distribution of tree diameters is 58 % dbh 20 cm, 22 % dbh 15 cm and 20 % dbh 10 cm.
- The methods of provision (and the according costs) have been chosen from Table 3.4. The assumed distribution is shown in Table 3.5.

[30] The energy content of wood chips from hardwood was estimated 3.25 GJ/m^3 and from softwood 2.5 GJ/m^3.

[31] For the cost-resource curve of wood chips from forest residues, the only factor which has been taken into account is the tree species. There was no information about different methods available. The bundling technology was not taken into account.

Table 3.5. Assumed methods of provision for wood chips from balance[32].

Methods	Small forests	Companies & ÖBF AG	Degree of mechanization
Method 1	25%	-	manual
Method 3	50%	-	semi-mechanized
Method 4	25%	25%	
Method 6	-	25%	mechanized
Method 8	-	50%	

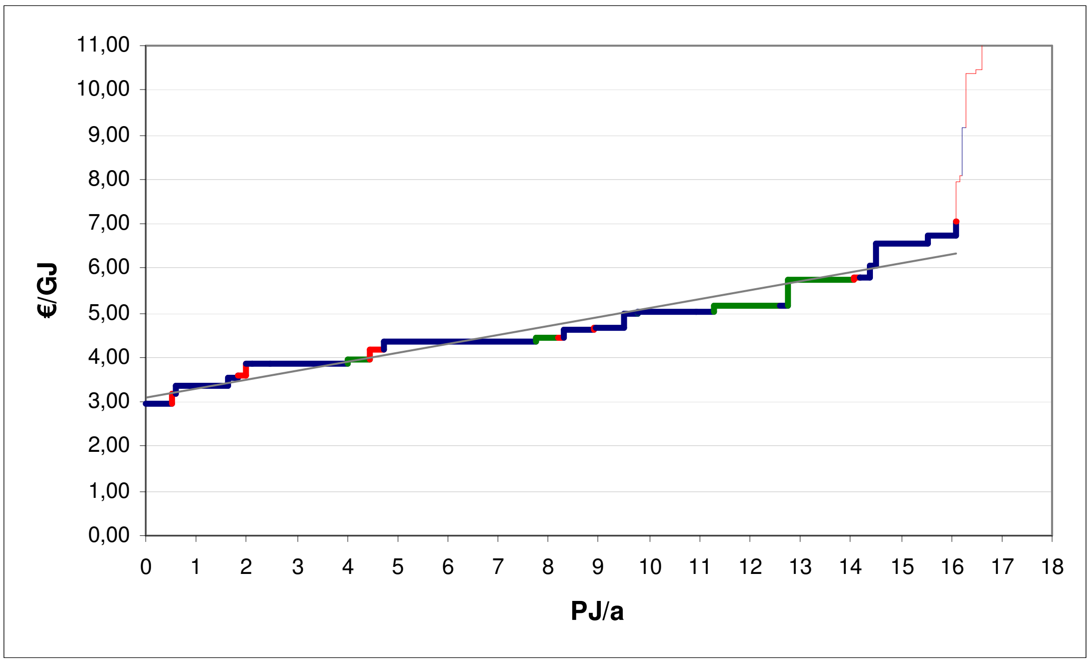

Figure 3.16. Cost-resource curve for wood chips from balance[33].

3.4.2 Wood Chips from Thinnings

The potential of wood chips from thinnings is estimated 14.6 PJ[34]. The assumptions are similar to the ones from the previous chapter but there are slight differences:

[32] See Table 3.4 for the descriptions of the methods.

[33] Especially high costs (thin line) arise from cutting small trees with highly and semi-mechanized methods.

[34] Again it was assumed that only trees with a maximum diameter of 25 cm are used for wood chip production and that thinnings are only carried out on slopes of less than 60 %.

- Based on data from the Forest Inventory 2000/02, the share of softwood has been assumed 80 %.
- According to the Forest Inventory 2000/02, 64.9 % of the thinnings should be carried out in small forests, the rest in forests owned by companies or the ÖBF AG.
- The assumed distribution of tree diameters is 33.3 % for each dbh 20 cm, dbh 15 cm and dbh 10 cm.
- Again the methods of provision (and the according costs) have been chosen from Table 4. The assumed distribution (Table 3.6) is slightly different from the one in the previous chapter.

The resulting cost-resource curve (Figure 3.17) shows marginally higher costs than the curve for wood chips from balance. This is mainly because of the bigger share of trees with diameters from 10 to 15 cm.

Table 3.6. Assumed methods of provision for wood chips from thinnings.

Methods	Small forests	Companies & ÖBF AG	Degree of mechanization
Method 1	50%	-	manual
Method 3	50%	-	semi-mechanized
Method 4	-	50%	
Method 6	-	50%	mechanized

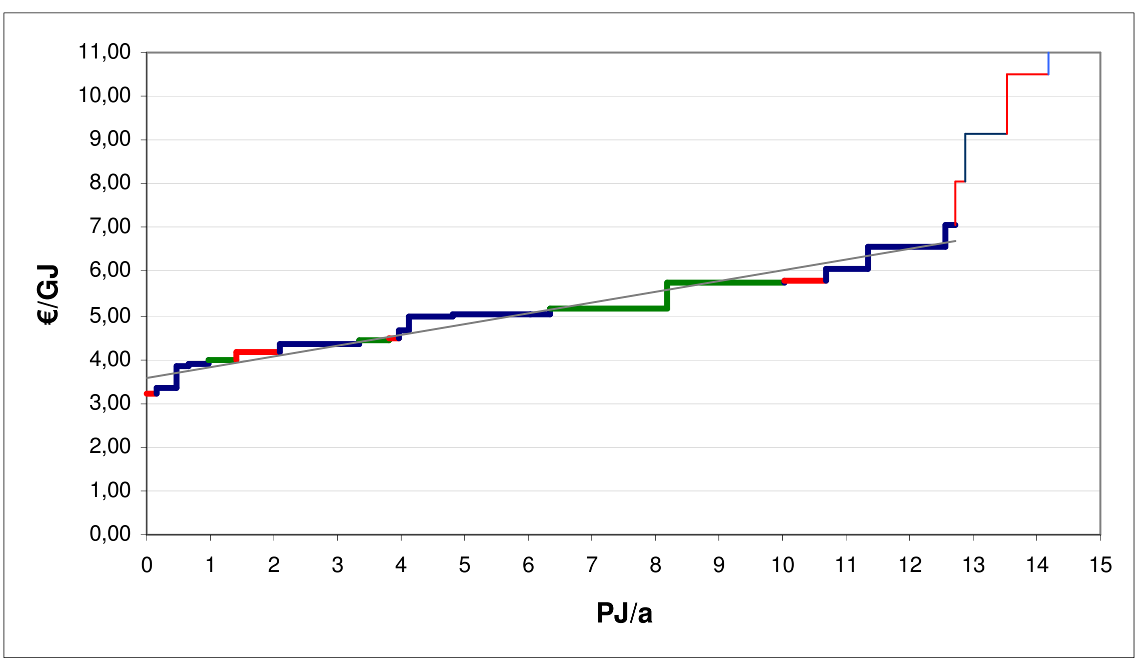

Figure 3.17. Cost-resource curve for wood chips from thinnings.

3.4.3 Wood Chips from Forest Residues

According to [Schaller et al. 2000], the additionally realizable potential of forest residues is about 5 PJ/a. The share of parts of the trees which are included in forest residues is clearly higher for coniferous trees and thus, the share of hardwood has been assumed only 6 %[35]. Based on tests on the production of wood chips from forest residues[36], the production costs have been estimated 8.5 €/m^3. Adopting the bundling technology could possibly lead to cost reductions but from the current point of view it seems unlikely that it will ever be applied in Austria. Figure 3.18 shows the cost-resource curve for wood chips from forest residues.

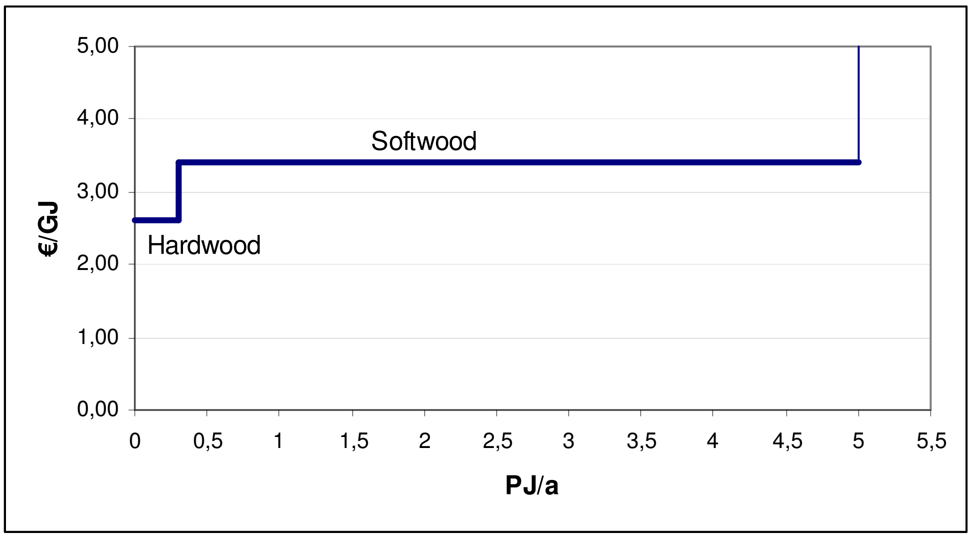

Figure 3.18. Cost-resource curve for wood chips from forest residues.

3.4.4 Total Additional Potential of Forest Wood Chips

The aggregation of the previous curves is the cost-resource curve for the total additional potential of forest wood chips (black line in Figure 3.19). This potential is 35.8 PJ/a (consisting of wood chips from felling residues and trees with a maximum dbh of 25 cm). Additionally, trees with a dbh of more than 25 cm could also be used for the production of wood chips. Their potential is as much as 46 PJ/a and the production costs would probably be less than 3 €/GJ. However, it is more profitable to sell these trees as

[35] See Figure 3.9.

[36] See Figure 3.14.

roundwood. As long as the profit which can be achieved with roundwood is higher than with wood chips, this potential will not be realized. Therefore, opportunity costs have to be considered in the provision costs for wood chips from trees with a dbh of more than 25 cm[37]. The total additional potential of forest wood chips including trees which could be sold as roundwood is 81.84 PJ/a (red line in Figure 3.19).

Assuming that the production of wood chips is profitable at costs up to 5 €/GJ, the additional economic potential is approximately 20 PJ/a. The main barrier for the realization of this potential is probably the fact that the biggest potential is situated in small private forests which are often neglected by their owners. To activate the full potential of Austria's forests it will be essential to overcome this structural barrier.

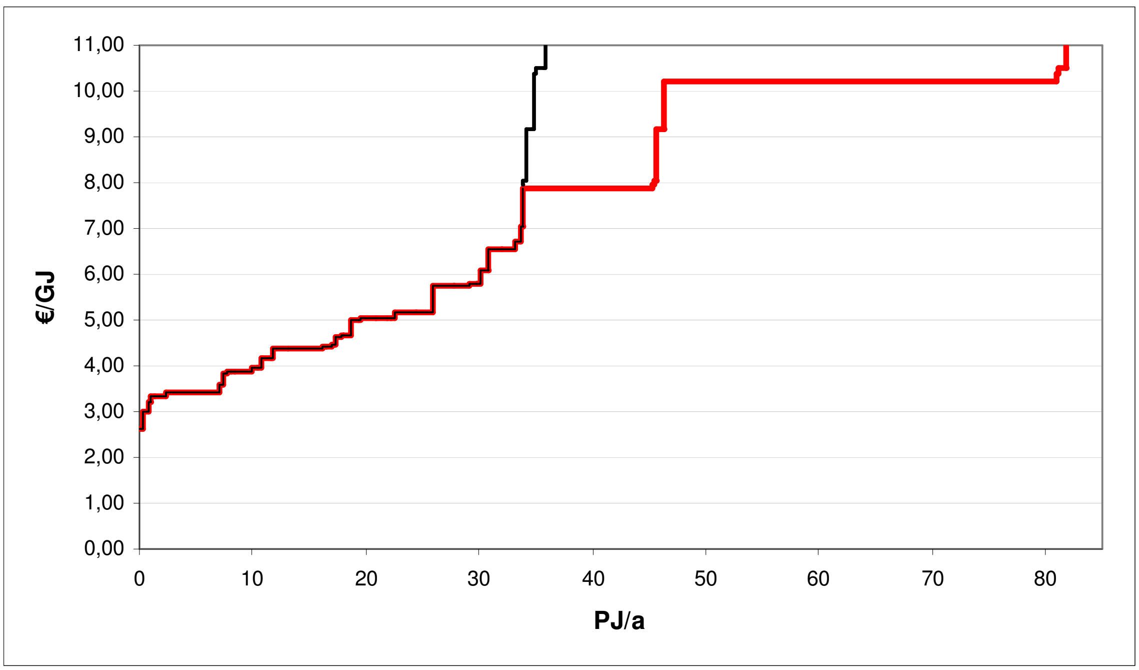

Figure 3.19. Cost-resource curves for the total additional potential of forest wood chips.

[37] The price of roundwood is approximately 70 €/scm. Under the assumption that the costs for felling, removing and transportation remain constant, the resulting provision costs for wood chips including opportunity costs and costs for chipping (2.2 €/m^3) are 25.53 €/m^3 (7.86 €/GJ for hardwood and 10.21 €/GJ for softwood.

4 Industrial Biomass

4.1 Austria's Wood-Working Industry

Approximately 60 % of the total felling of roundwood is used by the sawmill industry. In the year 2004 this was an amount of 11.53 million scm without bark. Additionally 6.8 million scm of roundwood for the production of sawnwood were imported. The development of sawnwood production from 1990 to 2003 is illustrated in Figure 4.1. In the last ten years the production has increased by more than 50 % but since the year 2000 it has remained almost constant at a level of slightly more than 10 million scm/a. Most of the sawnwood originates from coniferous tree species, broad-leaved trees account for approximately 2 %.

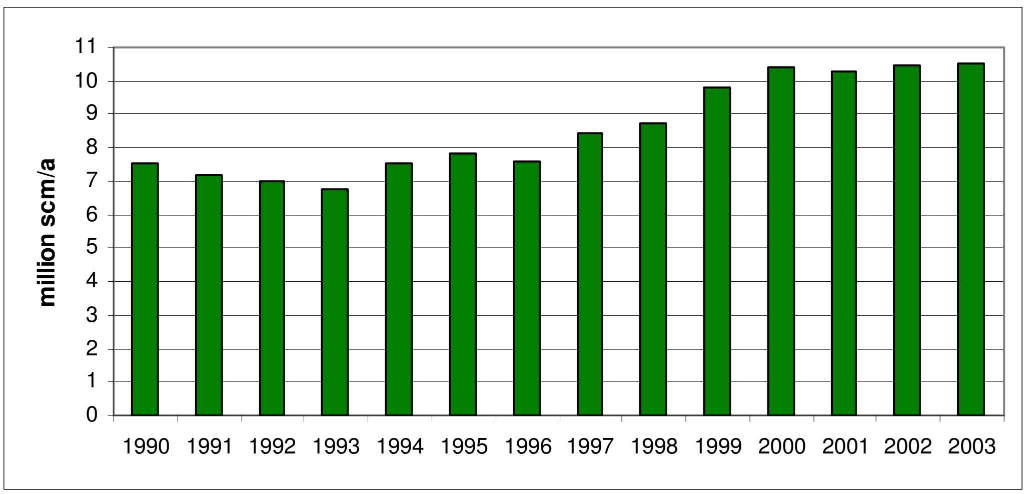

Figure 4.1. Production of sawnwood in Austria.
Sources: Lechner et al. 2003, Rebernig et al. 2002/04.

4.1.1 Industrial Residues

During the production of 1 scm of sawnwood approximately 0.3 m^3 of sawdust and 0.6 to 0.7 m^3 of wood chips accrue. The amount of bark which is usually removed separately accounts for 0.2 to 0.3 m^3 per scm of sawnwood for coniferous trees, for broad-leaved trees it is less.
The amounts of industrial residues which have been produced by the sawmill industry from 1996 to 2003 are shown in Figure 4.2a. Depending on the quality, industrial

byproducts are used for different purposes. Middle-sized wood chips without bark are the preferred raw material of the paper and pulp industry, residues of poor quality, sawdust, shavings and bark are mainly used for energy production or sold to the chip- and fiberboard industry. Sawdust and shavings can also be processed to wood pellets. In 2004, about 300.000 tons of pellets were produced in Austria. According to estimations the total production in 2010 could amount to 1 million tons (about 2.65 million scm of wood will be required for this amount of pellets)[38].

The total amount of energy produced from industrial residues in 2003 was 31.9 PJ (including 2.9 PJ from wood pellets)[39]. The total energy content of the domestic production of industrial byproducts is shown in Figure 4.2b. The biggest share of the produced industrial residues was used for the production of paper and pulp (about 3.24 million scm in 2003) or processed to chip- or fiberboards (estimated 2.6 million scm in 2003).

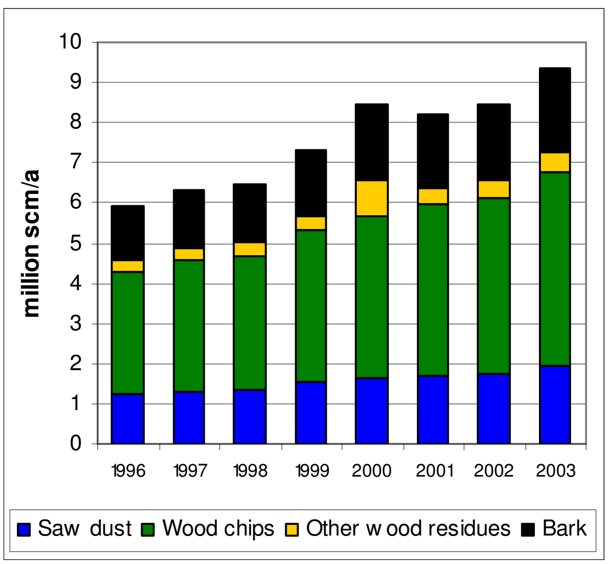

Figure 4.2a. Development of the production of industrial residues.
Sources: Lechner et al. 2003, Rebernig et al. 2002/04, own estimations.

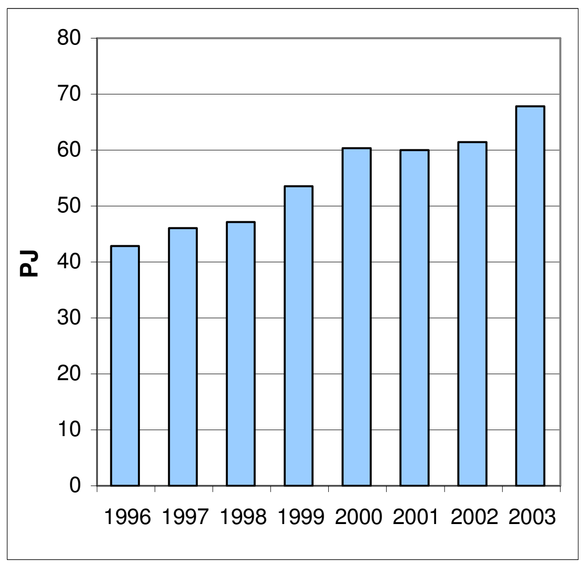

Figure 4.2b. Total energy content of the produced industrial residues.
Sources: Lechner et al. 2003, Rebernig et al. 2002/04, own calculations.

[38] See Chapter 6.3

[39] See Figure 2.3

4.1.2 Paper and Pulp Industry

Approximately 50 % of the raw materials processed by the paper and pulp industry are industrial residues. The consumption of wood resources in recent years is illustrated in Figure 4.3. More than 90 % of industrial residues come from Austrian sawmills[40] and more than 70 % of the roundwood originate from Austrian forests[41]. Thus, the paper and pulp industry consumes more than half of the produced industrial residues without bark.

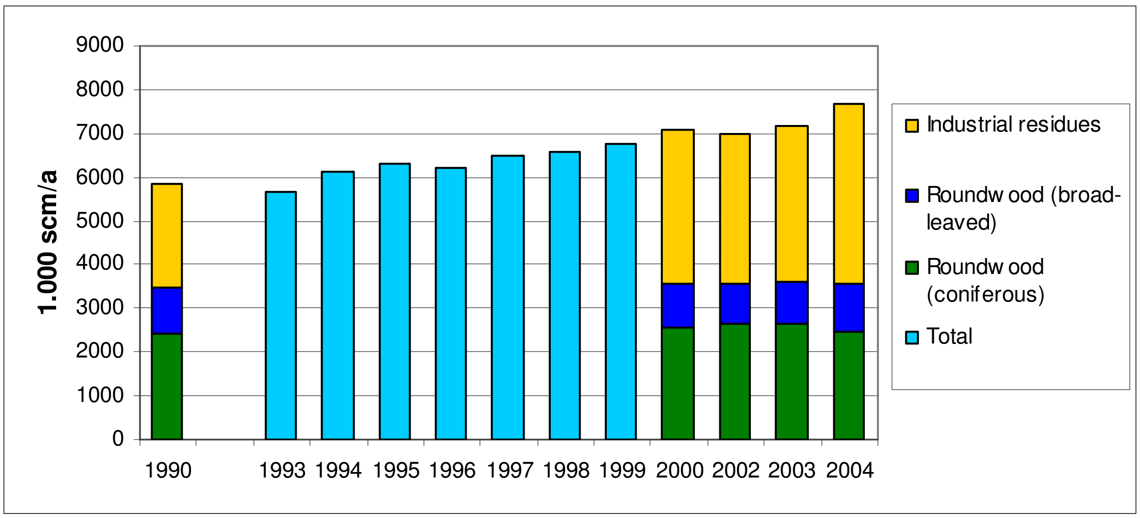

Figure 4.3. Wood resources consumed by the paper and pulp industry.
Source: Austropapier 2004, Schachenmann 2003.

The paper and pulp industry is the industrial sector with the biggest contribution to energy production from biomass in Austria. The most important energy source is waste liquor from paper production ("black liquor") which contains dissolved lignin and can be incinerated to generate electricity and process heat. In 2004, an energy quantity of more than 24 PJ was produced from black liquor. Smaller amounts of energy were produced from bark (2.9 PJ) and sludge (1.2 PJ). The contribution of other biomass fractions and biogas was less than 100 TJ. The share of biogenous fuels in the total fuel consumption was approximately 44 %. Figure 4.4 shows the total energy production from biomass in paper and pulp industry in recent years.

[40] In the year 2004, 3.81 million scm came from the domestic wood-working industry and 281.000 scm were imported.
[41] The total amount of roundwood in 2004 was 3.58 million scm; 981.000 scm of roundwood were imported.

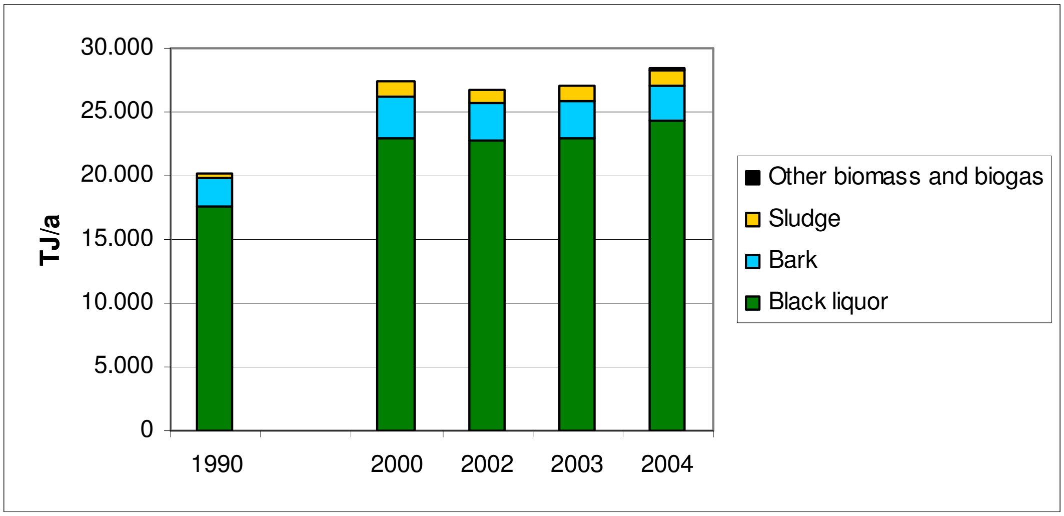

Figure 4.4. Energy production from biomass in the paper and pulp industry.
Source: Austropapier 2004.

4.1.3 Chipboard and Fiberboard Industry

In recent years the wood consumption of the chipboard and fiberboard industry has increased to approximately 4 million scm/a. The biggest share is industrial byproducts (sawdust and other wood residues; each about 40 %), the share of roundwood accounts for approximately 20 %. Figure 4.5 shows the development of wood consumption from 1993 to 2002.

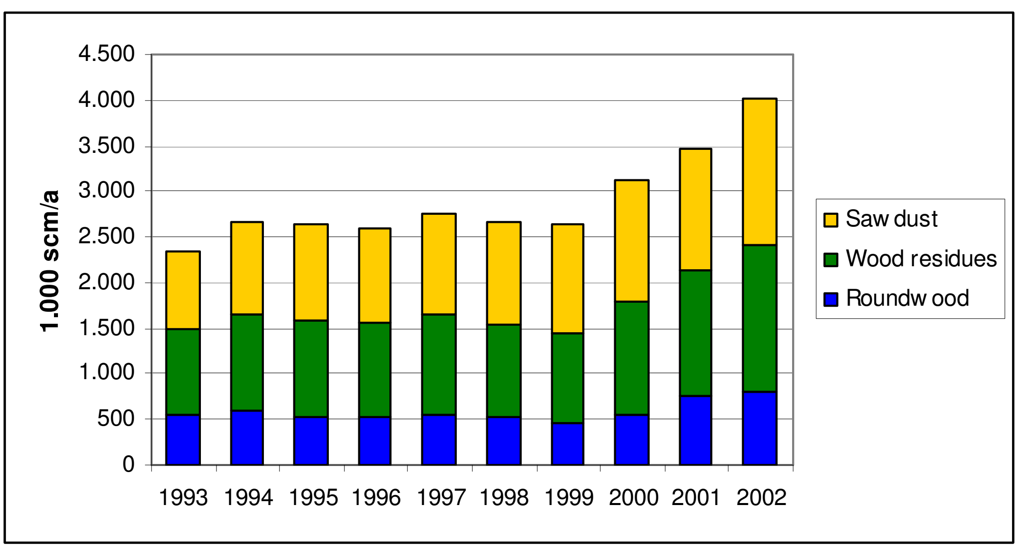

Figure 4.5. Wood consumption of the chipboard and fiberboard industry.
Source: Lechner et al. 2004, Schachenmann 2003.

About 25 % of the total wood consumption is imported. The share of imported wood residues has been slightly more than 10 % and the share of imported roundwood more than 70 % in recent years.

4.1.4 Flow of Resources

Figure 4.6 illustrates the flow of wood resources[42] in 2003. According to [BMLFUW 2004] the utilized amount of roundwood in 2003 was 17.06 million scm without bark. The total amount of felling residues is estimated 10 scm. The energy content of this amount is about 72 PJ. Approximately one third of the felling residues are actually utilized[43]. The share of fuelwood in the total amount of roundwood from felling was about 20 %, 62 % was used by the sawmill industry and the rest by the paper and pulp industry or processed to chipboards and fiberboards.

The sawmill industry produced 10.5 million scm of sawnwood and 7.25 million scm of industrial residues in 2003[44]. About 1.5 million scm of bark were used in sawmills to generate heat and electricity (12 PJ). Approximately half of the industrial residues were wood chips with or without bark, one quarter sawdust and the rest bark. 3.3 million scm of saw dust and wood chips without bark were sold to the paper and pulp industry. 0.5 million scm of industrial residues were used for the production of wood pellets. The rest was used for energy production (14 PJ).

The paper and pulp industry processed an amount of 7.24 million scm of wood in 2003. The biggest share were industrial residues (3.24 million scm), roundwood from domestic sources accounted for 2.6 million scm. Additionally, 1.04 million scm of roundwood and 0.36 million scm of industrial residues were imported. About 3 PJ of energy were produced from bark by the paper and pulp industry.

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[42] Exports of roundwood and industrial residues and stock-keeping are not considered in this figure. Some values are estimates.

[43] There is no reliable data about the use of forest residues but it is estimated about 25 PJ/a.

[44] Note that bark is included in “industrial residues” but not in “felling”.

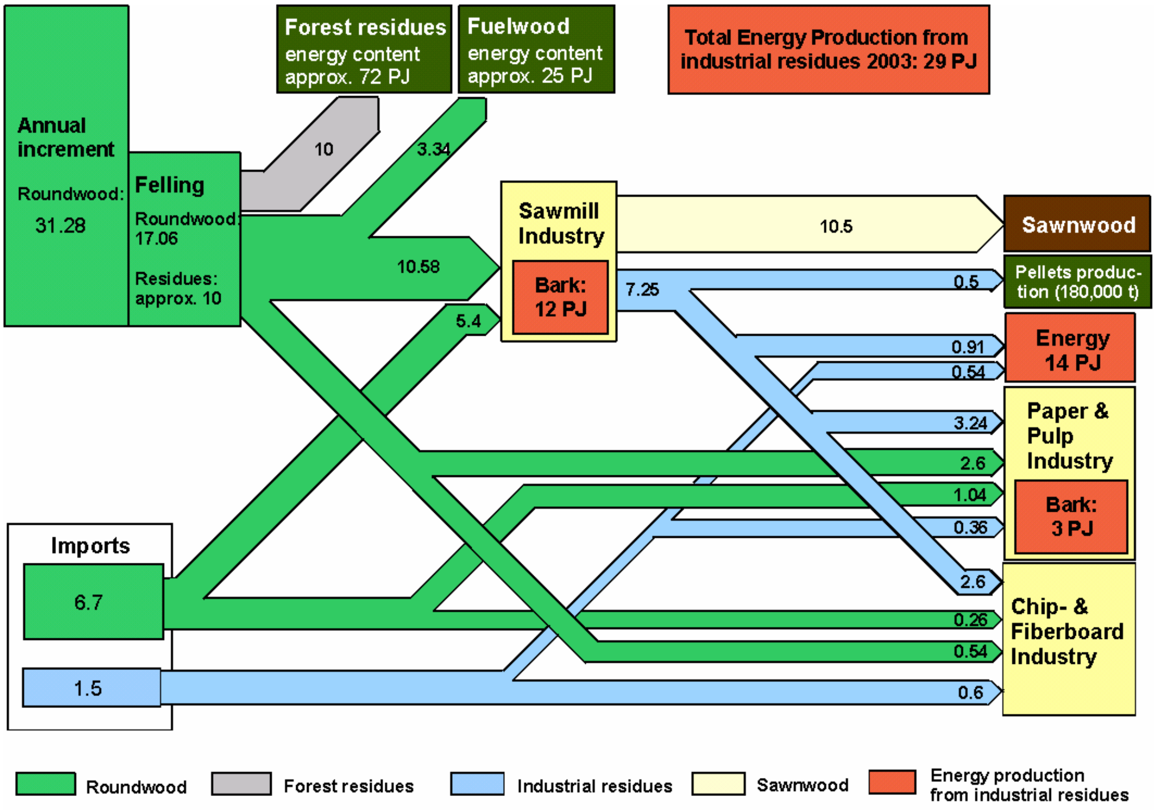


Figure 4.6. Flow of wood resources in 2003.[45]
Sources: BMLFUW 2004, Austropapier 2004, Rebernig et al. 2004, Schwarzbauer 2005a.

4.2 Potentials of Industrial Biomass

4.2.1 Estimation of Future Developments

Since industrial residues are byproducts of the sawmill industry and saw dust and wood chips are important raw materials for the paper, pulp and board industries, the future potentials of industrial biomass depend on many factors. Of course, the main factor is the development of the industries but price developments and subsidies for biomass plants could also influence the distribution of the materials.

The demand for roundwood in Austria has been increasing steadily in the last decades. In recent years the demand has been increasingly met with imports. The development of roundwood imports from 1997 to 2004 is shown in Figure 4.7. But the

[45] The unit is million scm if not stated otherwise.

demand in the neighboring countries is also rising (especially in the Eastern European Countries) and thus, a rapid increase in the domestic roundwood production will probably be necessary.

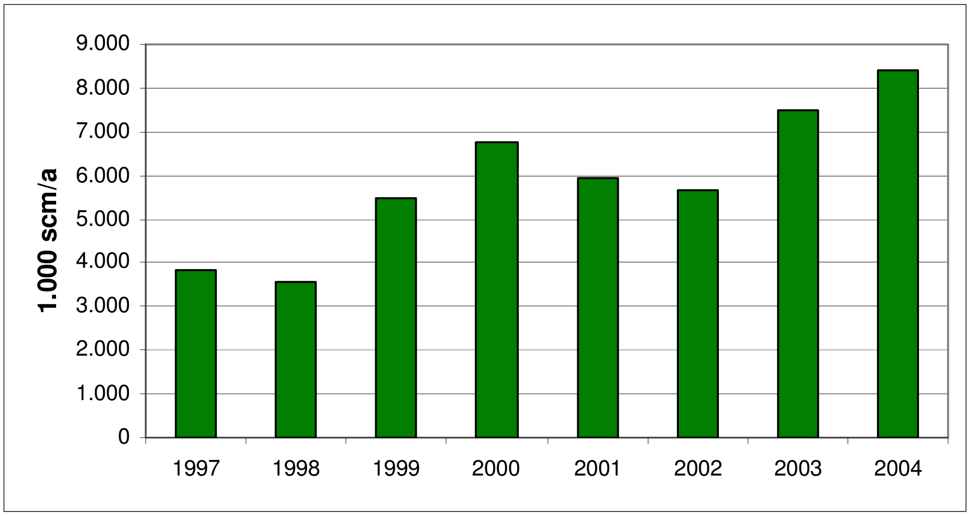


Figure 4.7. Development of roundwood imports.
Source: Schachenmann 2003, Holzkurier 2005.

According to [Schachenmann 2003], the additional wood demand of the paper, pulp and board industries in 2010 will be approximately 3.5 million scm. The sawmill industry is also likely to increase its production which would cause further demand for roundwood but would also mean that more industrial byproducts become available.

The trends of the wood consumption and production of the industries are illustrated in Figure 4.8. The development of sawnwood production shows that the growth of the sawmill industry in recent years was far beyond the growth of the other industries. If this trend continues in the near future, there will be enough industrial residues available to meet the demands of both the paper and pulp industry and the board industry. The supply of roundwood for the sawmill industry will probably be more problematic.

However, according to this trend analysis there will be notable additional amounts of industrial residues available for energy production. Based on the trends from 1993 to 2002 (see Figure 4.8), estimates about the future development of the industries [Schachenmann 2003] and the trends from 1955 to 1995 [Haberl et al. 2002], the additionally available amounts of solid industrial byproducts were calculated. Table 4.1 shows the presumed developments of the industries and the resulting additional potentials of industrial residues.

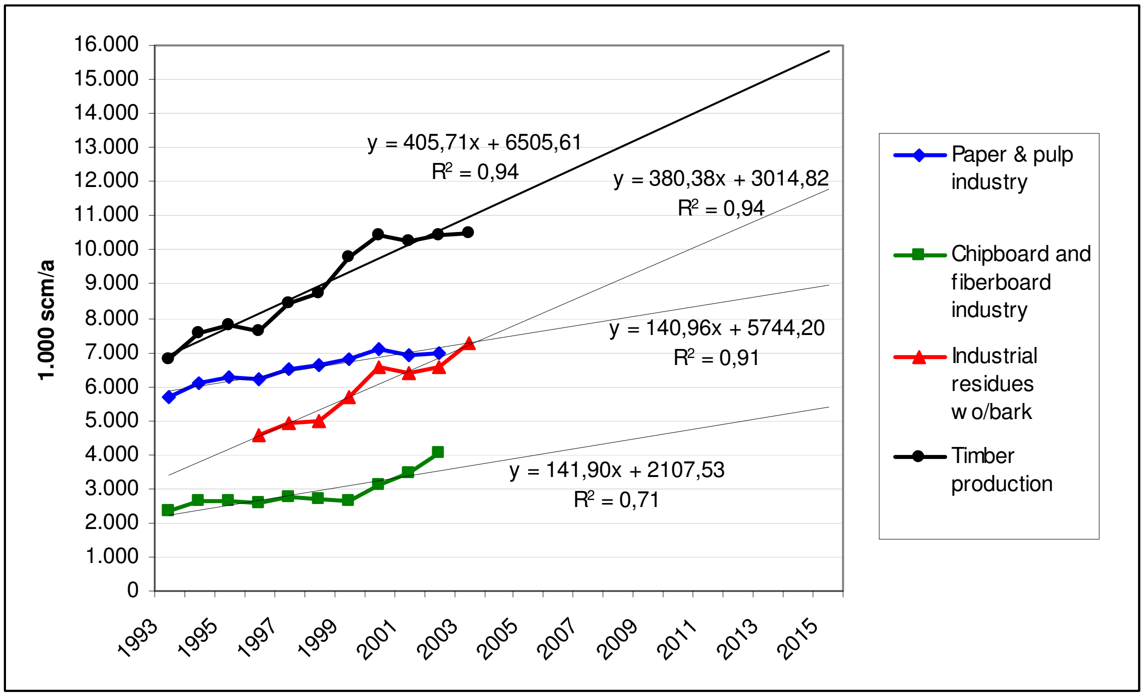


Figure 4.8. Development and trends of the sawmill industry (sawnwood production and industrial residues) and wood consumption of the paper and pulp and board industry.
Sources: Austropapier 2004, Schachenmann 2003, Lechner et al. 2004, Rebernig et al. 2002/04.

For the scenarios in Table 4.1, the following assumptions were made:

- During the production of one solid cubic meter of sawnwood, 0.62 scm of byproducts accrue.
- The imports and exports of industrial residues remain constant (base year: 2002).
- The share of industrial residues in the total wood consumption of the paper and pulp industry is assumed 50 % and of the board industry 80 %[46].
- The average energy content of 1 scm of industrial residues is 7.1 GJ.

The additional potentials of industrial residues in 2010 according to these scenarios range from 2.33 PJ/a to 11.93 PJ/a. However, the value of 2.33 PJ/a seems to be most realistic since it is based on expert estimations. In addition to this potential, bark could provide an energy quantity of about 1.46 to 2.58 PJ.

[46] Average values in recent years

It should be mentioned that all these estimations are based on the assumption that the distribution of industrial residues will not change significantly in the near future. But major changes in the near future can not be ruled out. For example, it is possible that the increasing production of wood pellets will lead to a significant lack of cheap raw material for the paper production.

Table 4.1. Scenarios about the availability of industrial residues.
Sources: Schachenmann 2003, Haberl et al. 2002, own calculations[47].

Scenario	Year	Sawnwood production (1.000 scm/a)	Wood demand (1.000 scm/a)		Additionally available residues (1.000 scm/a)	Additional annual potential of residues (PJ)	Additional annual potential of bark (PJ)
			Paper & pulp industry	Board industry			
Trend 1993 - 2003	2010	13.500	8.200	4.700	728	5,18	1,46
	2015	15.800	9.000	5.400	1.203	**8,57**	**2,58**
Estimate [Schachenmann 2003]	2010	13.500	9.000	4.700	328	**2,33**	**1,46**
Trend 1955 -1995	2010	13.000	7.600	3.500	2.475	11,93	1,22
	2020	14.000	8.500	4.000	2.249	10,32	1,70

These are definitely optimistic estimations. From the current point of view it seems especially questionable that the production trend of the sawmill industry will continue. [Schwarzbauer 2005] assumes that the sawnwood production will grow between 1.1 and 2.1 % per annum[48], while for the board industry he estimates an increase in production of 1.8 to 3.1 % and for the paper industry 2.7 to 4.8 %. If these forecasts are correct, there will not be any additional amounts of industrial residues available for energy production unless there is a significant increase in imports. Schwarzbauer estimates that the annual net import will be between 1.53 and 1.78 million scm in 2010 and between 2.25 and 3.43 million scm in 2020. In the years 1996 to 2000, the average net import of industrial residues was 0.83 million scm.

[47] Only the estimations about developments of the industries have been adopted from these sources.
[48] Depending on the economic growth

4.2.2 Potentials of Industrial Biomass in Literature

Table 4.2 gives an overview of the potentials of industrial residues stated in different studies.

Table 4.2. Overview of potentials of industrial biomass in literature.

Potential	Author	Year	Fraction	PJ/a
Theoretically available resources	Nikolaou et al.	2003	Industrial residues	50,72
Mid-term additional potential	Steininger et al.	2003	Pellets (industrial byproducts)	8,11
			Bark	1,62
			Wood chips	10,30
Additional realizable potential	Haas et al.	2002	Industrial residues	3,00
			Industrial residues (ambitious)	20,00
			Bark	1,00
Additional potential 2020	Haberl et al.	2002	Industrial residues & wood wastes	1,60
Theoretically available resources	AFB-net	2001	Solid ind. byproducts	50,00
Additional potential 2010	Rathbauer	2000	Forest Biomass & industrial res.	34,90
Additional potential	Lechner	1998	Industrial residues & bark	1,60
Additional potential 2010	Kalt[49]	2005	Industrial residues	2,33
			Bark	1,46
Additional potential 2015			Industrial residues	8,57
			Bark	2,48

4.3 Prices of Industrial Biomass

4.3.1 Wholesale Prices

Figure 4.9 shows the development of domestic wholesale prices of industrial wood chips and saw dust from January 2001 to July 2005. With a current price of 3.6 €/m^3, sawdust is clearly cheaper than wood chips. The current price of industrial wood chips without bark is 7.8 €/m^3, wood chips with bark are slightly cheaper (7.6 €/m^3). The prices of other wood residues are not plotted in Figure 4.9 since they have stayed constant in the considered period (wood residues without bark: 10.6 to 13.3 €/m^3, with

[49] Optimistic estimations

bark: 5.8 to 7.6 €/m^3). The current wholesale prices of industrial residues in €/GJ are shown in Figure 4.10. “Other wood residues” are the cheapest fuel but usually have to be processed to wood chips which causes further costs.

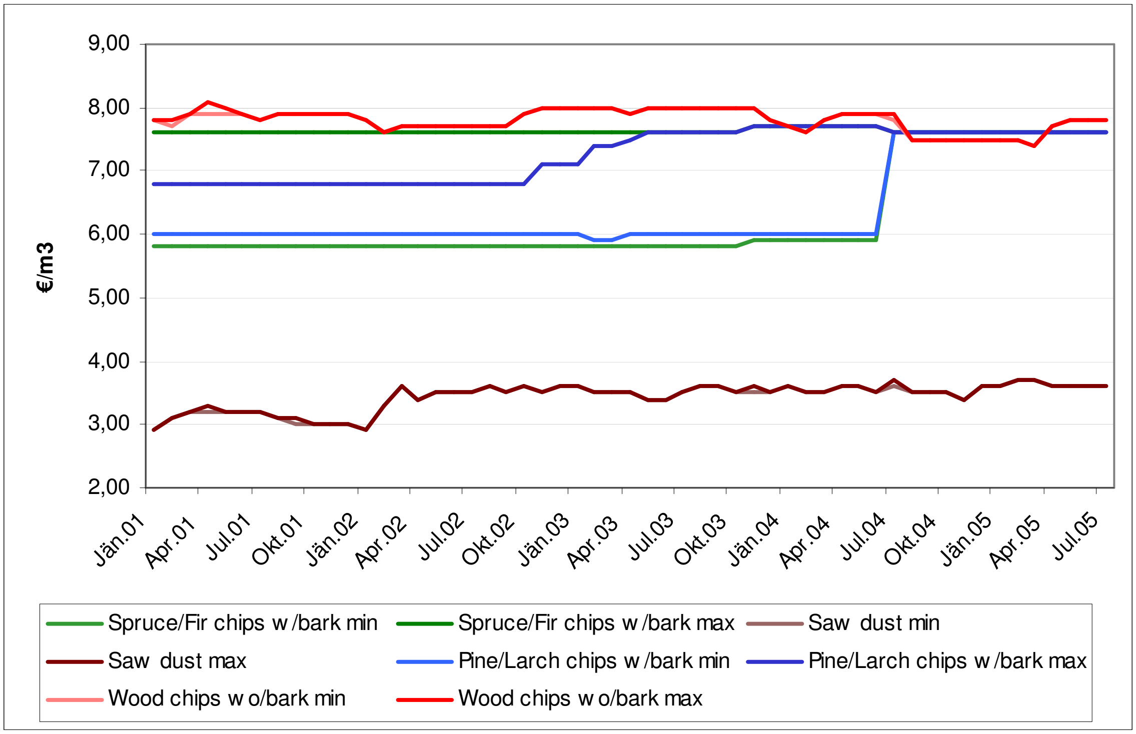


Figure 4.9. Wholesale price development of industrial residues.
Source: Holzkurier 2005.

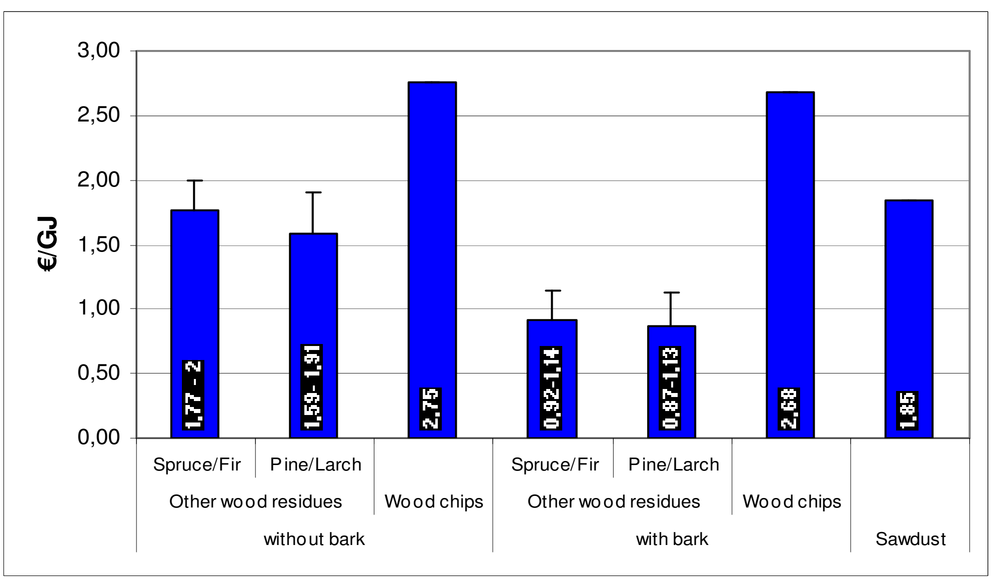


Figure 4.10. Wholesale prices of industrial residues in €/GJ.
Source: Holzkurier 2005, own calculations.

4.3.2 Fuel Prices

The prices of industrial residues stated in literature are significantly higher than the wholesale prices given in the previous chapter (Figure 4.11). According to most sources, there are also big differences between prices of wood chips with and without bark. In the price for "other wood residues" costs for chipping are included.

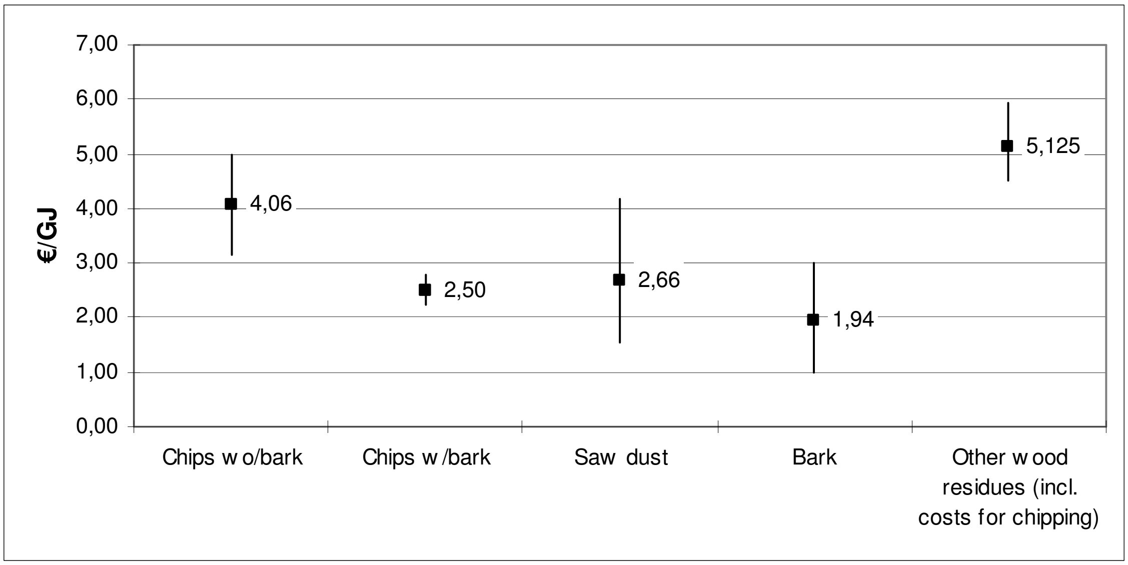


Figure 4.11. Prices of industrial residues.
Source: Schachenmann 2003, Golser et al. 2004, Streißelberger 2004.

4.4 Cost-resource Curves

4.4.1 Additional Potential in 2010

The cost-resource curves in Figure 4.12 are based on the scenario "Estimate [Schachenmann 2003]", described in Table 4.2. The additional potential of bark[50] is estimated 1.46 PJ/a and of wood chips, sawdust and other industrial residues 2.33 PJ/a.

The black curve ("Curve B") is based on the assumption that only the cheapest fractions of industrial residues are used for energy production (bark, wood chips with bark and sawdust). The more expensive fractions like wood chips without bark and most of the additional amounts of sawdust are used for the paper, pulp or board production.

[50] It was assumed that bark is only used for energy production.

The curve in red color (“Curve A”) includes all kinds of industrial residues. For this curve it was assumed that the additionally available amounts of cheaper fractions are also used for other purposes (e.g. wood chips with bark for the production of boards) and that the same share of each fraction is used for energy production.

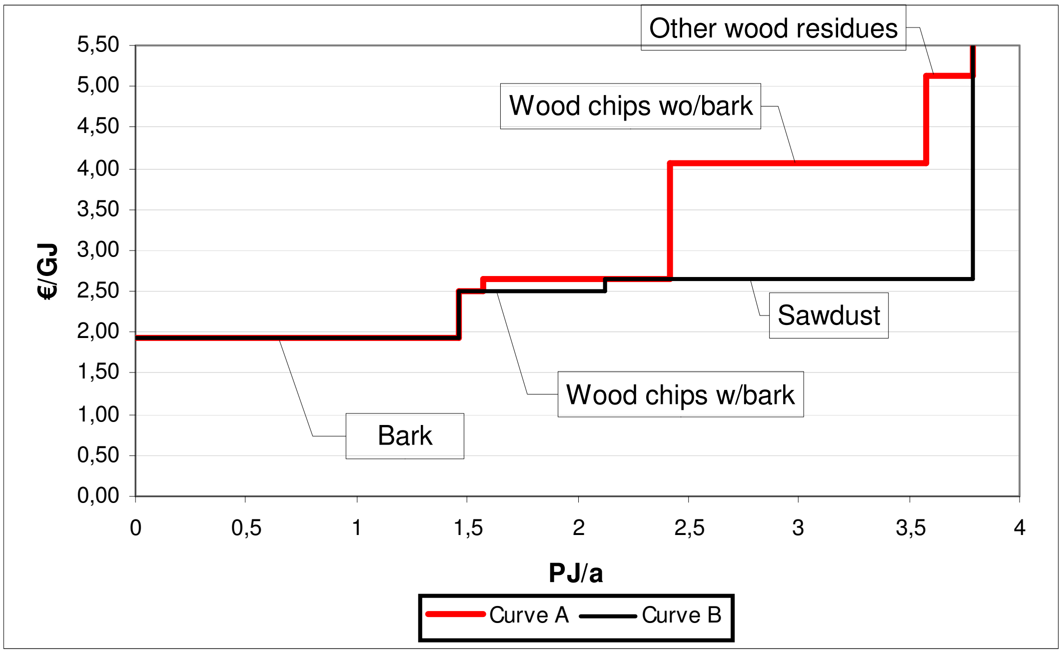


Figure 4.12. Cost-resource curve for additional potential of industrial biomass in 2010.

4.4.2 Additional Potential in 2015

The scenario “Trend 1993-2003”[51] which was used for the cost-resource curve of the additional potential in 2015 (Figure 4.13) presumes a slower growth of the paper and pulp industry. Therefore, increased amounts of sawdust are available for energy production. The additional potential of bark in this scenario is 2.58 PJ/a and the total additional potential of industrial biomass 11.15 PJ/a. Again, “Curve A” includes all fractions and “Curve B” only the cheapest fractions of solid industrial biomass.

[51] See Table 4.2

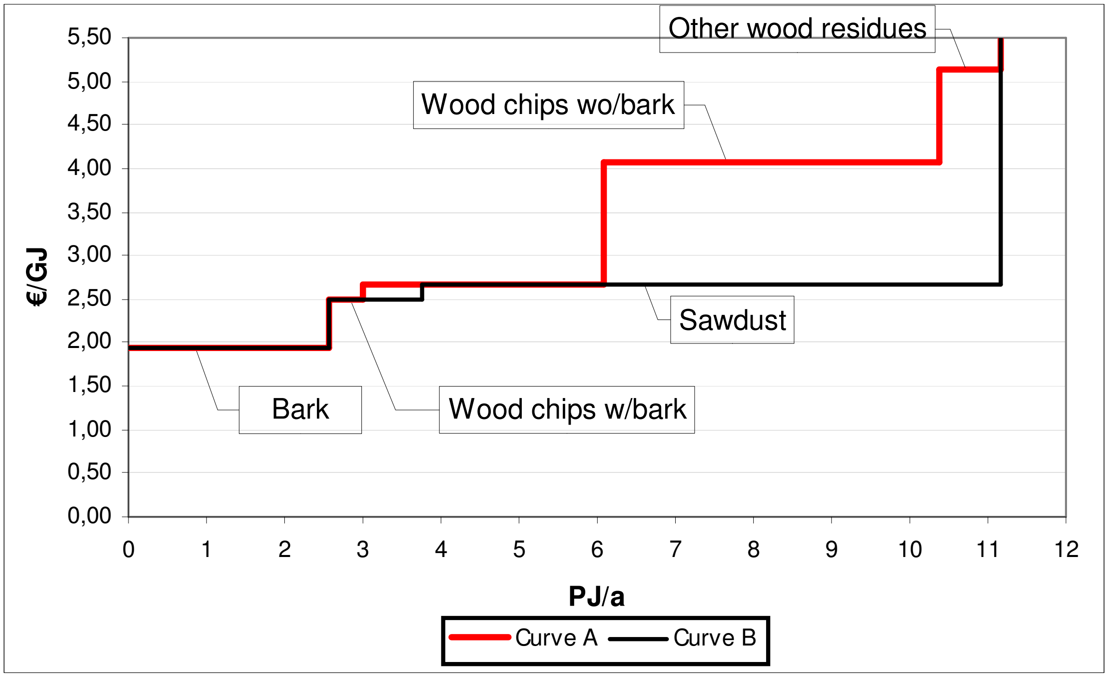


Figure 4.13. Cost-resource curve for additional potential of industrial biomass in 2015.

4.4.3 Summary

The production trends of the involved industries indicate that there will be additional amounts of industrial residues from domestic sawnwood production available for heat and electricity generation in the near future. Estimates of the total additional potentials resulting from a trend analysis are 6.64 PJ for 2010 and 11.15 PJ for 2015.

However, experts predict a different development. [Schachenmann 2003] believes that the paper and pulp industry will grow significantly faster than recent trends indicate. The resulting potential of additionally available industrial biomass for the year 2010 would be only 3.79 PJ/a.

With regard to biomass potentials, estimates of [Schwarzbauer 2005] are even more pessimistic. According to his prognoses, the demand for industrial residues will be far beyond the domestic production and thus, big amounts will have to be imported to meet the increasing demand.

5 Agricultural Biomass

5.1 Agricultural Production in Austria

5.1.1 Cereals

In 2004, about 5.3 million tons of cereals[52] were produced in Austria. Compared to 2003, there was an increase of more than 1 million tons. The average production in the last ten years was approximately 4.7 million tons. Besides maize, wheat and barley are the most important types of corn. With a share of about 32 % in the total cereal production, the amounts of wheat in 2004 were slightly higher than those of maize (31 %). Barley accounted for approximately 19 %, the shares of other types of corn such as rye, oat and triticale were less than 5 % (Figure 5.1).

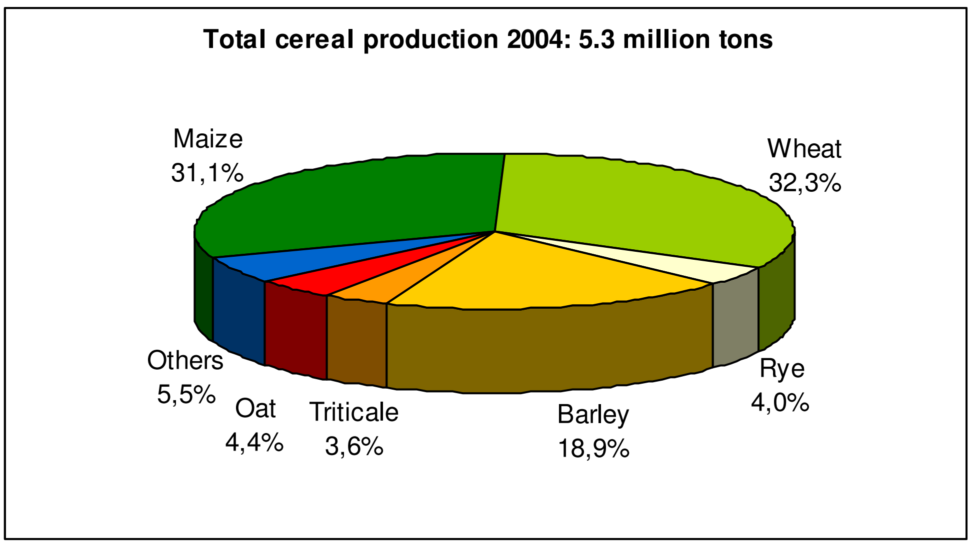


Figure 5.1. Cereal production in 2004 broken down by types of corn.
Source: Eurostat 2005.

The average production of straw in the last ten years was slightly more than 2 million tons. The development of cereal and straw production from 1990 to 2004 are presented in Figure 5.2.

[52] Including wheat, barley, maize and other cereals

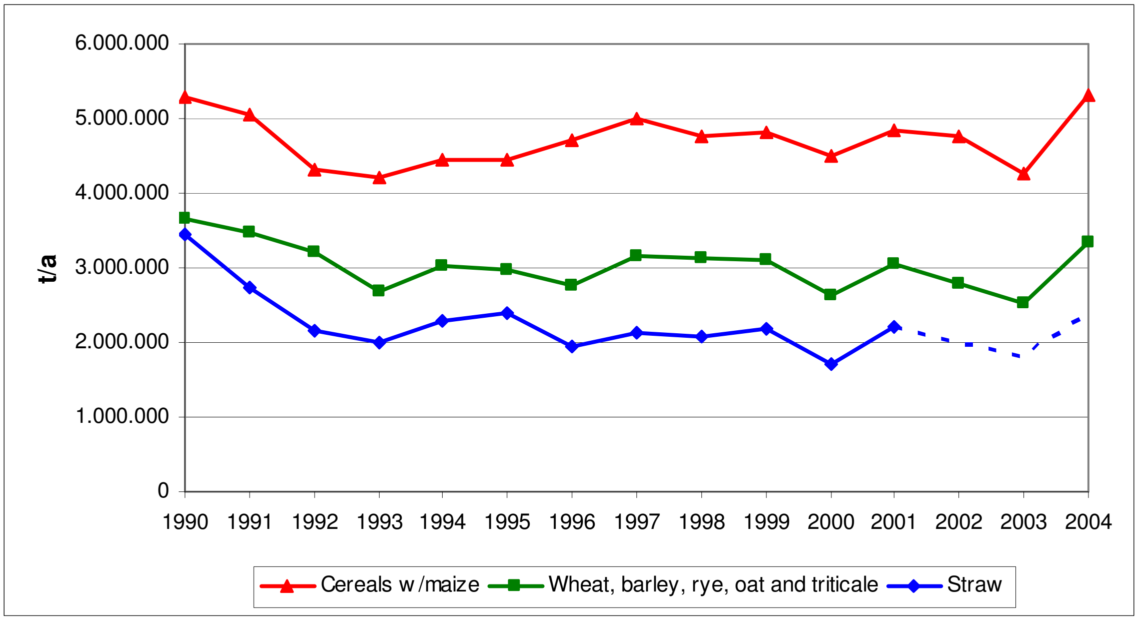


Figure 5.2. Development of cereal and straw production in Austria.[53]
Source: Eurostat 2005 (cereals), Lechner et al. 2003 (straw)[54].

5.1.2 Oilseeds

The developments of rapeseed, sunflower and the total oilseed production[55] are presented in Figure 5.3. In 2004, the total amount accounted for approximately 250.000 tons. Even though the area for rapeseed has been decreasing rapidly from 2002 to 2004, rapeseed is still the most important of all oilseeds in Austria. Figure 5.3 illustrates that the annual yields of sunflower are virtually constant while the yields of rapeseed are subject to big fluctuations[56].

[53] The water content of cereals is 15 to 20 % if not stated otherwise.

[54] The amounts of straw for the years 2002 to 2004 were calculated from the production of cereals without maize. The assumed average ratio of straw and cereals is 1:1.4.

[55] Other oilseeds include soybeans, cotton-seed and peanuts.

[56] According to data from [Eurostat 2005], the average yield of rapeseed was only 1.76 t/ha in 2003. In 2004 it reached the record value of 3.42 t/ha.

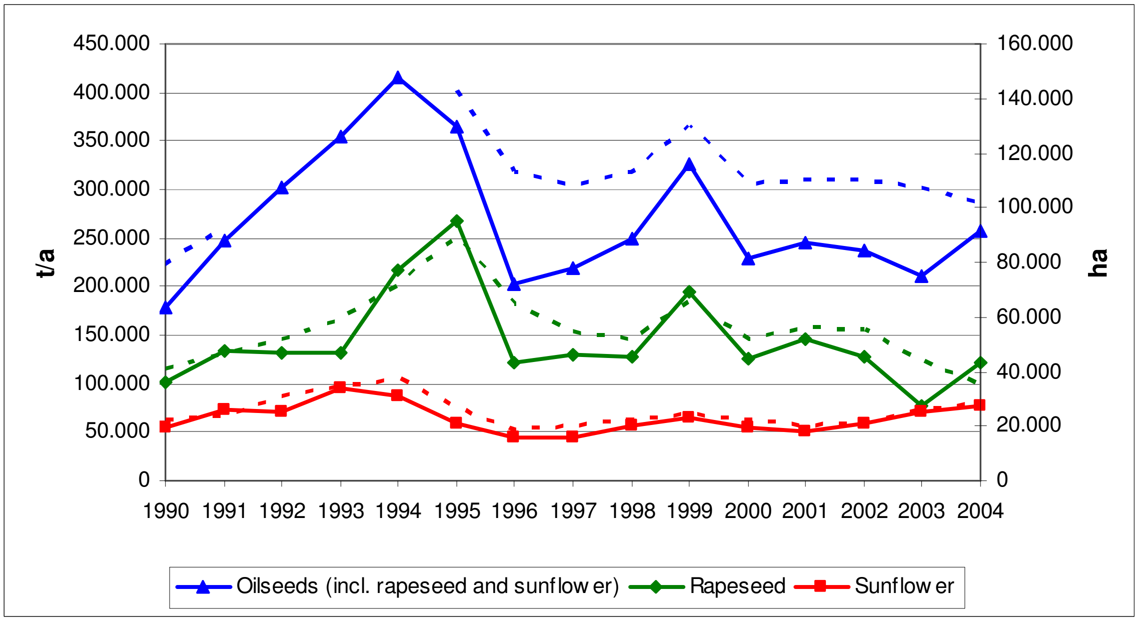


Figure 5.3. Development of oilseed production[57] and production areas[58].
Source: Eurostat 2005.

5.1.3 Industrial Crops

Industrial crops refer to crops which are not used for food production. They include oilseed crops (e.g. rape seed, sunflower, poppy) for the production of biodiesel, fibre crops (e.g. hemp, flax) for purposes like the production of textiles, paper or energy use, carbohydrate crops (e.g. potato starch, maize starch) and plants for pharmaceutical uses.

The agricultural plant production of crops used as renewable resources for industrial purposes is based on EU regulations and supported by the European Union. Industrial crops can be cultivated on set-aside land[59], but this possibility has been used

[57] Continuous lines

[58] Dashed lines

[59] Set-aside lands are fertile lands currently in excess as a result of the European regulations for food production or left fallow for proper soil management. Farmers above a certain size have to leave a certain percentage of their total cultivated area fallow. (The percentage of set-aside land was fixed by the Common Agricultural Policy reform of 1992 to a default value of 17.5 %. In 1993/94 the rate was reduced to 15 % and in 1997/98 there was a further reduction to 5 %. For the following years the rate was increased to 10 %.) Farmers receive a payment per hectare

quite sparsely in recent years (as Figure 5.4 illustrates). In 2002, the share of utilized set-aside land was only 12.5 %. The total set-aside land was slightly more than 100,000 ha from 1999 to 2002.

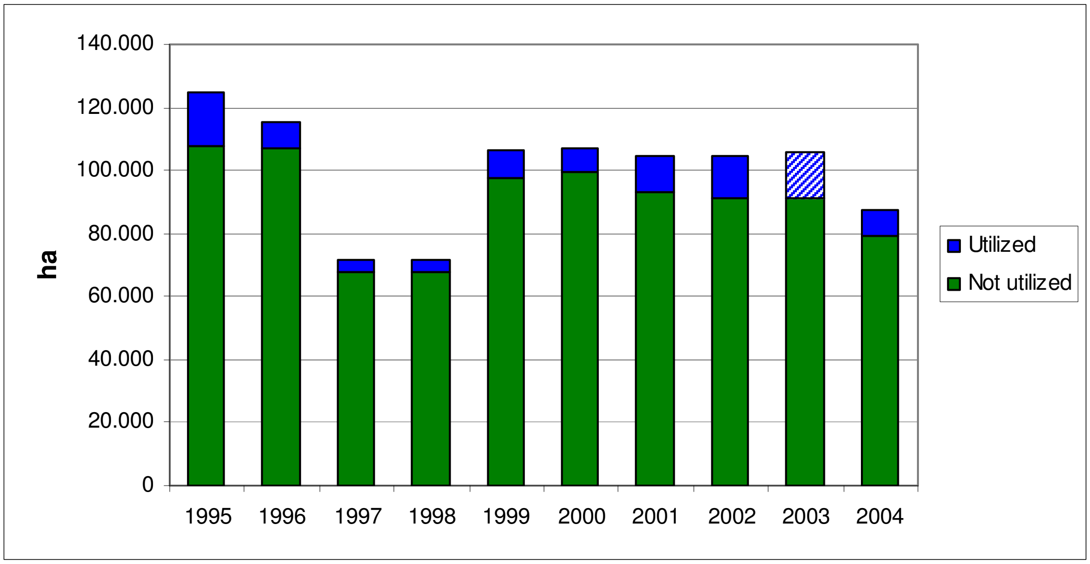


Figure 5.4. Development of set-aside land[60].
Sources: Handler et al. 2003, Ruckenbauer 2004, BMLFUW 2004a.

Figure 5.5 illustrates that the predominant crop on set-aside land is rapeseed. The share of rapeseed on set-aside land in the total area used for the cultivation of rapeseed has increased from about 5 % in 1998 to almost 28 % in 2002. About 85 % of the total rapeseed production for non-food purposes is used for biodiesel. The rest is used for non-energetic purposes such as hydraulic fluids or lubricants [Handler et al. 2003].

The second biggest share in industrial crops on set-aside land has sunflower. The total area for the cultivation of sunflower has remained relatively constant in recent years but there was a significant increase of sunflower on set-aside land. About half of the sunflower oil from set-aside land is used for biodiesel.

fallow land for compensation of the decrease in income. The regulations allow the cultivation of non-food crops on set-aside lands. Cultivation of energy crops like rape and sunflower could generate additional income, thereby increasing the feasibility of energy crops.

[60] There was no data available about the utilized set-aside land in 2003. The total set-aside land in 2002 was 105,940 ha. For 2004 the rate was reduced to 5 % because of the low production in 2003 [BMLFUW 2004a].

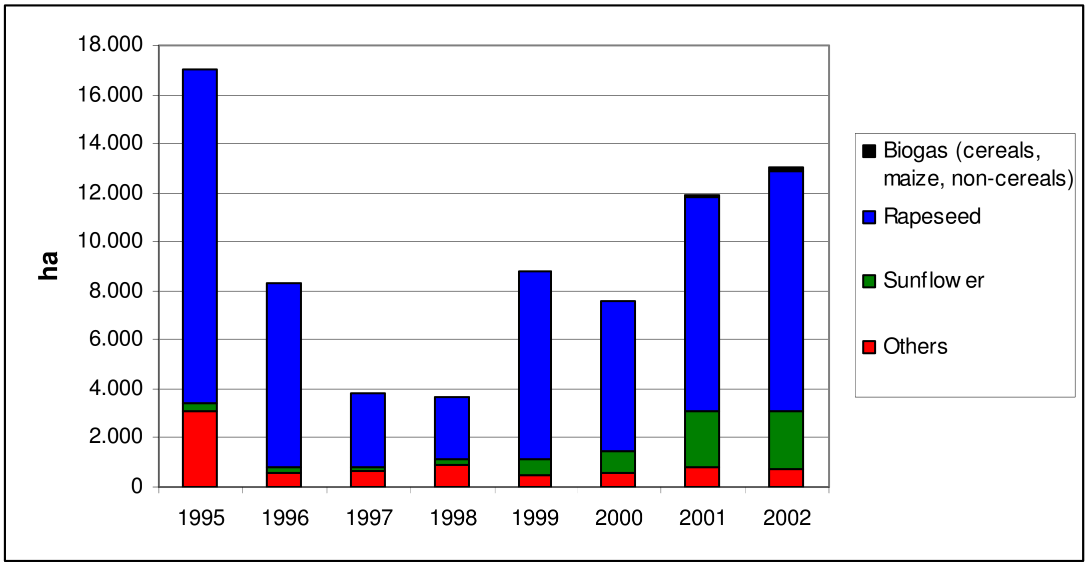


Figure 5.5. Area of industrial crops on set-aside land, 1995-2002.
Sources: Handler et al. 2003, Ruckenbauer 2004.

5.2 Resources of Solid Agricultural Biomass

The resources of solid agricultural biomass can be divided into agricultural residues, energy crops and short rotation coppice. With energy crops the raw materials for the production of liquid biofuels (oilseeds for biodiesel and cereals, maize etc. for bioethanol) and biogas (e.g. cereals, maize) are also included in this chapter.

5.2.1 Agricultural Residues

Agricultural residues refer to all kinds of plant material that are byproducts of crop production. They include the parts of plants that remain after a crop has been harvested and separated. Agricultural residues can be classified into primary residues which are the result of farm level activities (e.g. straw, stalks, corn stover) and secondary residues which result from processing (e.g. sugar beet pulps, cotton mill wastes). With an average annual production of about 2.1 million tons, straw is definitely the most important and most promising of all agricultural residues in Austria.

5.2.2 Energy Crops

Energy crops include a variety of plants which can be used as fuel. With the EU regulations about the cultivation of industrial crops on set-aside land[61] the necessary legal conditions for the production of energy crops on arable land have been created. Currently, the most important energy crops in Austria are oil plants for the production of biodiesel. Still, most of the raw material for the production of biodiesel has to be imported, mainly from Hungary [EVA 2004]. Due to regulations about the use of liquid biofuels[62], the importance of oilseeds and also of cereals for the production of bioethanol will definitely rise in the near future.

There is also the possibility to use cereals (e.g. wheat, triticale) or grasses (e.g. Miscanthus, Switchgrass) as fuel for heating plants. The main advantage of cereals is that both production and combustion technologies are well known. Concerning energy grasses, there are still problems related to harvesting and combustion technologies.

5.2.3 Short Rotation Forestry

Short rotation forestry refers to the practice of planting fast-growing trees such as willow, poplar or robinia in evenly spaced rows on cultivated land. The trees are harvested with dedicated machines in rotation cycles between three and ten years and processed to wood chips. Numerous tests about short rotation coppice have been carried out in Austria and some of the results were quite promising. Still rotation forestry has not proceeded beyond test stage in Austria. The area used for the cultivation of short rotation coppice has remained almost constant since 1995 (about 1,300 ha).

Due to the possible lack of industrial residues in the near future, short rotation coppice could become an important source for wood chips. In Scandinavia, wood chips from willow plantations are already used as a fuel for heating plants. The main barrier for the widespread cultivation of short rotation coppice is probably the fact that long-term commitment of farmers is required. Apart from that,

[61] Council Regulation (EC) No 1782/2003

[62] See Chapter 1.2.4

5.3 Potentials of Agricultural Biomass

5.3.1 Potential of Straw

The theoretically available potential of straw is about 2.1 million tons (approximately 30 PJ/a)[63]. Most of it is used for animal feeding or bedding or ploughed back into the soil for fertility purposes. According to [Pastre 2002], an annual amount of 512,000 tons (7.4 PJ) could be used for energy production in Austria. Estimations in other studies reach up to 14 PJ/a[64]. However, as a result of EU Directives about adequate livestock husbandry, bigger amounts of straw will be demanded by livestock owners in the near future. According to [EVA 2003], no additional potential of straw for energy production can be expected unless types of corn with a higher share of straw are cultivated. Still, for this report an additional potential of 5 PJ/a is assumed.

In 2003, about 14,000 tons of straw were used energetically (approximately 200 TJ). The pelletisation of straw has been tested for several years now but there are still technical problems related to the combustion of straw pellets[65]. However, the combustion of straw and straw pellets is likely to become more important in the near future.

5.3.2 Potentials of Energy Crops and Short Rotation Coppice

Estimates on the potentials of solid agricultural biomass are based on the area of arable land available for the production of energy plants. Since the planned set-aside rate for the near future is 10 %, the total set aside land can be estimated 105,000 ha. Based on its utilization in recent years and under the assumption that there will be a slight increase in the production of industrial plants for non-energetic purposes on set-aside land, the additionally available area for the production of energy crops and short rotation coppice can be estimated 90,000 ha.

Figure 5.6 illustrates that the yields of energy crops are significantly lower than those of short rotation coppice. Under the assumption that the total available area is used for the production of short rotation coppice, the energy potential is about 16 PJ/a. However, it is more likely that in the near future a bigger share of the available area is

[63] The calorific value of cereal straw with a water content of 15 % is 14.5 GJ/t.

[64] See Table 5.1

[65] See Chapter 6

used for energy crops. If 40 % of the available set-aside land is used for short rotation coppice and 60 % for energy crops, the additionally available potential is 10.27 PJ/a (6.35 PJ/a from short rotation coppice and 3.92 PJ/a from energy crops).

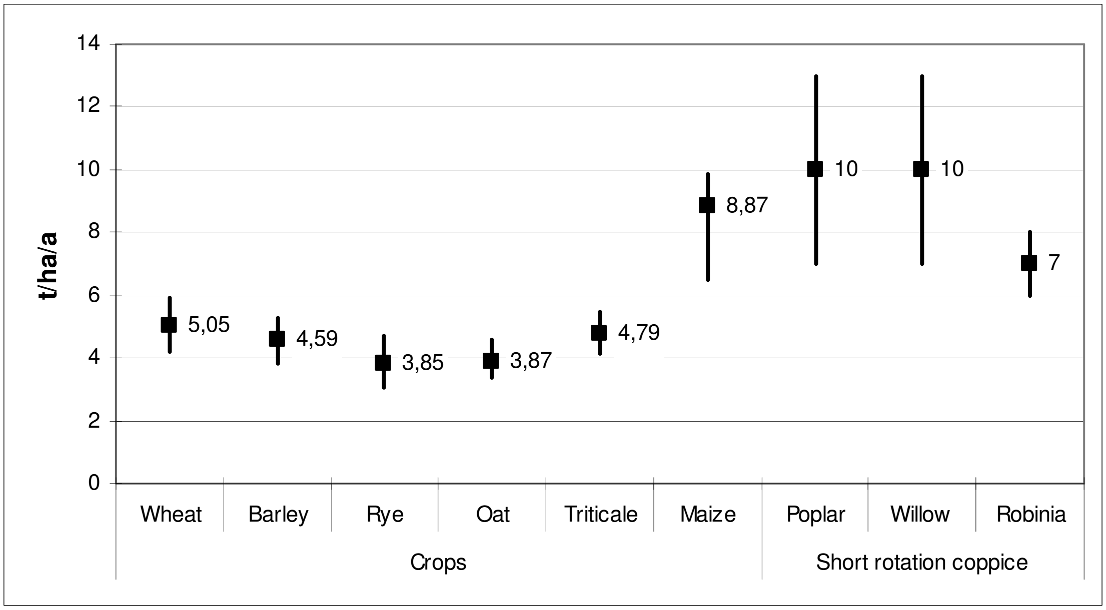


Figure 5.6. Yields of different crops and short rotation coppice.
Source: Eurostat 2005 (crops[66]), Traupmann et al. 2004 (short rotation coppice[67]).

5.3.3 Potentials of Agricultural Biomass in Literature

Table 5.1 gives an overview of potentials of agricultural biomass stated in literature. Estimations for biodiesel and bioethanol potentials are presented in Table 5.2 and Table 5.3.

Table 5.1. Overview of potentials of solid agricultural biomass in literature.

Potential	Author	Year	Fraction	PJ/a
Available potential	Passalacqua et al.	2004	Agricultural residues	12,00 (841.000 t)
Theoretically available resources	Nikolaou et al.	2003	Agricultural residues	9,00

[66] The values for crops are the lowest, highest and average values from the last 15 years (water content: 15 – 20 %).
[67] Yields in tons dry substance

Mid-term additional potential	Steininger et al.	2003	Straw	14,00
Additional realizable potential	Haas et al.	2002	Straw	12,00
			Short rotation coppice	25,00
Additional potential 2020	Haberl et al.	2002	Agricultural residues incl. straw	3,50
Available resources	Pastre	2002	Straw	7,40 (512.000 t)
Additional realizable potential 2010	Rathbauer	2000	Agricultural residues	8,30
			Energy crops	2,90
			Short rotation coppice	0,70
Additional technical potential 2010	Wörgetter et al.	1998	Agricultural residues	15,23
			Energy crops	24,98
			Short rotation coppice	6,00
Additional potential	Kalt	2005	Straw	5,00
			Energy crops	0,65 – 3,92
			Short rotation coppice	6,35 – 14,30

Table 5.2. Overview of estimations of biodiesel potentials in literature.[68]
Source: Haas et al. 2002.

Potential	**Author**	**Year**	**t/a**	**PJ/a**
Technical potential	ÖBI	2000	283.000	10,00
Realizable potential			80.000	3,00
Technical potential	TERES II	1996	155.000	5,80
Technical potential 2005	Schnitzer	1995	210.000	7,90
Technical potential 2050			350.000	13,00
Realizable potential	Kopetz	2000	190.000	7,00
Realizable potential 2020	Haberl et al.	2001	150.000	5,50
Technical potential	Neubarth et al.	2000	140.000	5,20
Realizable potential	Clement et al.	1998	50.000	1,90
Technical potential	Haas et at.	2002	150.000	5,50

[68] The calorific value of biodiesel is about 37.5 GJ/t.

Table 5.3. Overview of estimations of bioethanol potentials in literature.[69]
Source: Haas et al. 2002.

Potential	Author	Year	t/a	PJ/a
Theoretical potential	Steinmüller et al.	1997	1.000.000	25,20
Technical supply potential (Sugar beet)	Neubarth et al.	2000	600.000	15,70
Technical supply potential (Wheat)			240.000	6,20
Technical potential	TERES II	1996	220.000	5,80

5.3.4 Prospects for Liquid Biofuels

Due to the EU biofuels directive and its implementation in Austria[70], big additional amounts of crops for the production of liquid biofuels will be required. According to recent press releases Austria's first bioethanol plant will be operational in the middle of 2007. The planned annual production of bioethanol is about 150,000 tons, the required crops are 388,000 tons of wheat, 81,000 tons of maize and 48,000 tons of sugar beet sap. The total arable land needed for the cultivation of these amounts is about 80,000 ha[71].

In addition to 150,000 tons of bioethanol, about 450,000 tons of biodiesel will be required to reach the "5.75 %–target" in 2008 (and about 480,000 tons in 2010) [Tretter 2004]. An area of approximately 400,000 ha, which is far beyond the available area, would be necessary to produce the amounts of rapeseed which are required for this amount of biodiesel. Despite the increasing demand for oilseeds for biodiesel production, the area used for the cultivation of rapeseed has been decreasing in recent years and the production area for sunflower has remained relatively constant[72]. The additional demand was mostly met with imports[73]. These developments indicate that there will probably be no significant increase in the production of oilseeds in Austria in the near future.

69 The calorific value of bioethanol is about 26 GJ/t.

70 See Chapter 1.2.4

71 Own estimate

72 See Figure 5.3

73 The net imports of oilseeds (including oilseeds for food production) have risen from 126,000 tons in 1996 to 163,000 tons in 2004 [AMA 2005]. It can be assumed that most of this increase was used for the production of biodiesel.

5.4 Production Costs for Crops and Short Rotation Coppice

5.4.1 Production Costs for Crops

Figure 5.7 shows the production costs for different crops in 2004 according to [AMA 2005]. The costs for cereals like wheat, barley or rye are about 100 €/t. According to [Jauschnegg 2002], wheat has a slightly higher calorific value (14.8 MJ/kg) than barley (14.7 MJ/kg) and triticale (14.2 MJ/kg). There was no data available for other cereals. For further calculations, the calorific value of cereals is assumed 14.5 MJ/kg. Hence, if cereals are used as fuel for heating plants, the fuel costs are approximately 6.90 €/GJ. The costs for maize are clearly higher (9.10 €/GJ). Taking into consideration the set-aside payment of 45 €/ha, the costs are reduced to 6.3 €/GJ for cereals and 8.8 €/GJ for maize.

The use of cereals as fuel is only reasonable in boilers with a capacity of more than 30 kW [74]. Apart from that, it is more economic to use the grain for food and only the straw for heating.

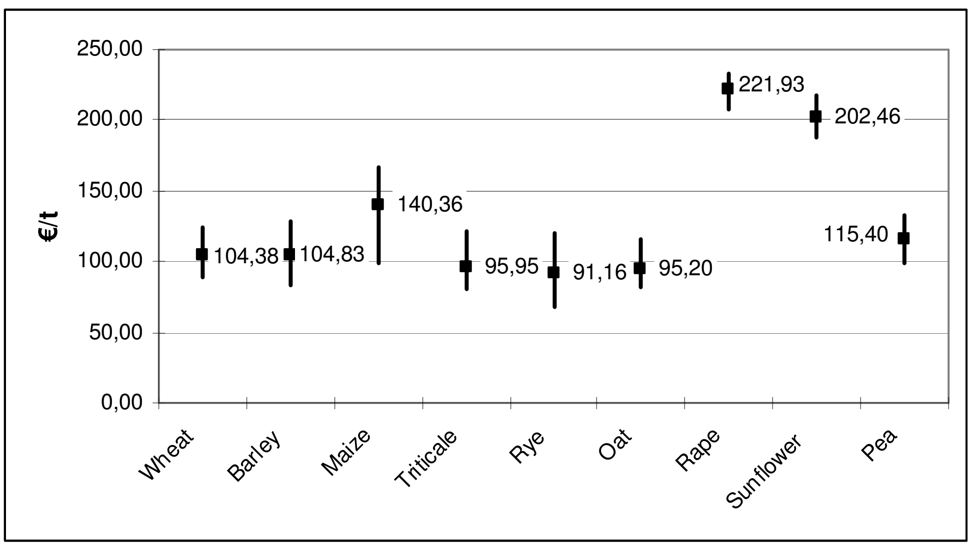


Figure 5.7. Production costs for crops in 2004.[75]
Source: AMA 2005.

[74] [Jauschnegg 2002] calculated the full costs for cereal-fueled heating plants and compared them with the costs for oil, gas, wood chip and pellet heating systems. The result was that the use of cereals as fuel is only cost-effective at a heating load of at least 30 kW and if the cereal is available at the producer price. This situation has possibly already changed due to rising prices for fossil fuels.

[75] The water content is 15 – 20 %. Straw is not included.

5.4.2 Production Costs for Short Rotation Coppice

The most expansive activity during the production of wood chips from short rotation coppice is harvesting. Various methods ranging from manual felling to fully mechanized harvesting with dedicated machines have been tested. The results of studies recently carried out in Germany are presented in Table 5.4. The main differences concern costs for machines and equipment, the quality of the produced wood chips and the physical strain on workers. Mechanized harvesting methods are clearly better in terms of efficiencies[76] and costs.

Table 5.4. Harvesting methods of short rotation coppice.
Sources: Burger et al. 2005, Schmidt 2005.

Method	**Advantages**	**Disadvantages**	**Recommended field of application**
Manual	+ No expensive equipment required + Internal labor possible (farmers)	- High physical strain - Low efficiency - High costs - High water content of wood chips	Small areas (about 1 ha), small-scale heating plants
Manual felling, collecting with tractor	+ High utilization ratio of chipper + Internal labor possible (farmers)	- High physical strain (felling) - Expensive machines required - High water content of wood chips	Areas up to 5 ha, small-scale heating plants or district heating systems
Harvester/bundler	+ Low physical strain + High utilization ratio of chipper + Low water content of wood chips (trees dry before chipping)	- Expensive machines required - High transportation costs for harvester/bundler - Low availability of technology - High costs for logistics	Large areas, suitable for any heating system
Direct-chip harvesting	+ Low physical strain + Lowest costs	- Low availability of technology - Low-quality wood chips (inhomogeneous, coarse)	Medium to large areas, large heating/cogeneration plants

[76] The efficiency of "Direct-chip harvesting" is 7.6 t/h, the one related to manual harvesting only 2 t/h [Burger et al. 2005].

The harvesting costs for each method are illustrated in Figure 5.8. “Direct-chip harvesting” is by far the cheapest method but due to the low quality of the wood chips it is only suitable for the supply of large heating or combined heat and power plants. Another problem concerning highly mechanized methods is that the availability of the required machines is relatively low. Manual harvesting is the most expensive method but since no dedicated machines are required and the whole work can be carried out by farmers, it is a reasonable option for the supply of rural small-scale heating plants.

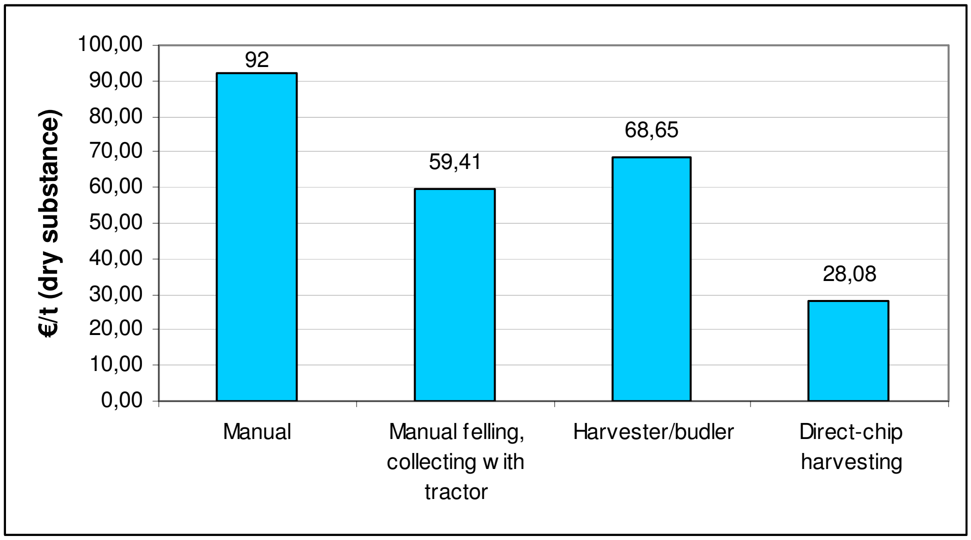


Figure 5.8. Harvesting costs for short rotation coppice.
Sources: Schmidt 2005, Burger et al. 2005.

The costs for establishment according to [Burger 2005] are 1,324 €/ha (the costs for the cuttings account for about 900 €/ha, the rest are costs for herbicides and labor costs). According to [Textor 2005], the one-off fixed costs are significantly higher (3,254 €/ha). The costs for logistics/transportation can be assumed 15 €/t for a distance of 30 to 50 km[77].

Based on these data, the total production costs for wood chips from short rotation coppice have been calculated. The results are presented in Figure 5.9. Under consideration of various conditions[78], the utilization of harvesters/bundlers is the most expensive option, but according to [Schmidt 2005] the quality of the produced wood chips is highest.

[77] See [Textor 2005]

[78] See footnote to Figure 5.9

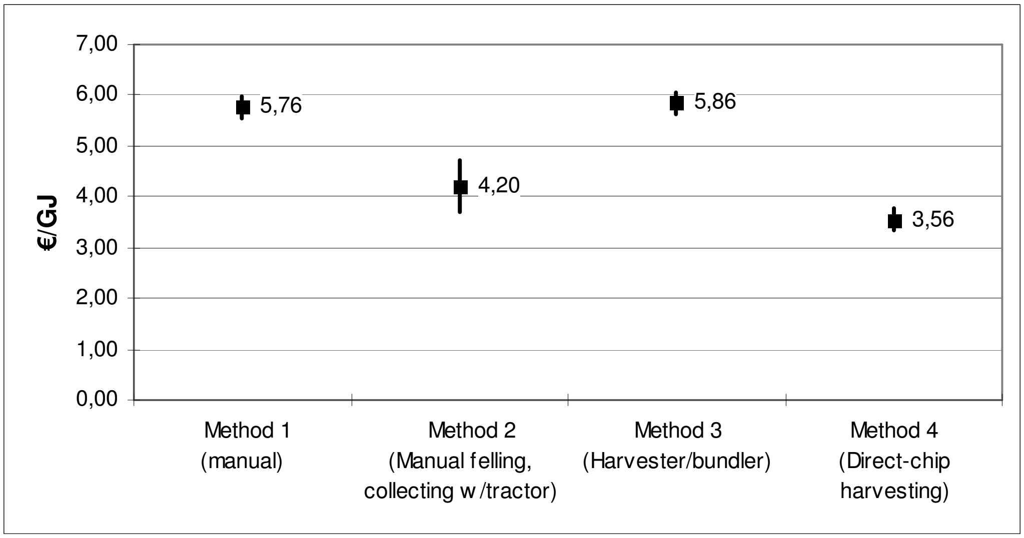


Figure 5.9. Total production costs for wood chips from short rotation coppice[79].

5.5 Cost-resource Curves

Figure 5.10 shows three different cost-resource curves for solid agricultural biomass including straw, short rotation coppice and energy crops (cereals). The curves are based on scenarios which differ in the shares of set-aside land used for the production of energy crops and short rotation coppice. For Scenario 1, which is most likely for the near future, it was assumed that 60 % of the set-aside land is used for energy crops and the rest for short rotation coppice. For Scenario 2 the share of crops was assumed 40 % and for Scenario 3 only 10 %. Due to higher yields and calorific value of short rotation coppice, the total potential is highest for Scenario 3 (about 20 PJ/a).

Although the costs of the different methods of wood chip production from short rotation coppice vary widely, each of them has its advantages and is favorable under certain conditions. It was assumed that each method has an equal share of 25 %.

[79] Lower costs for logistics/transportation have been presumed for manual methods (5 €/t for the methods 1 and 2) since these methods are assumed to be applied by farmers who produce wood chips for the supply of their own small-scale heating plants.
Highly mechanized methods (3 and 4) are assumed to be applied by companies which have to lease arable land from farmers. Thus, additional leasing costs of 150 €/ha were included.

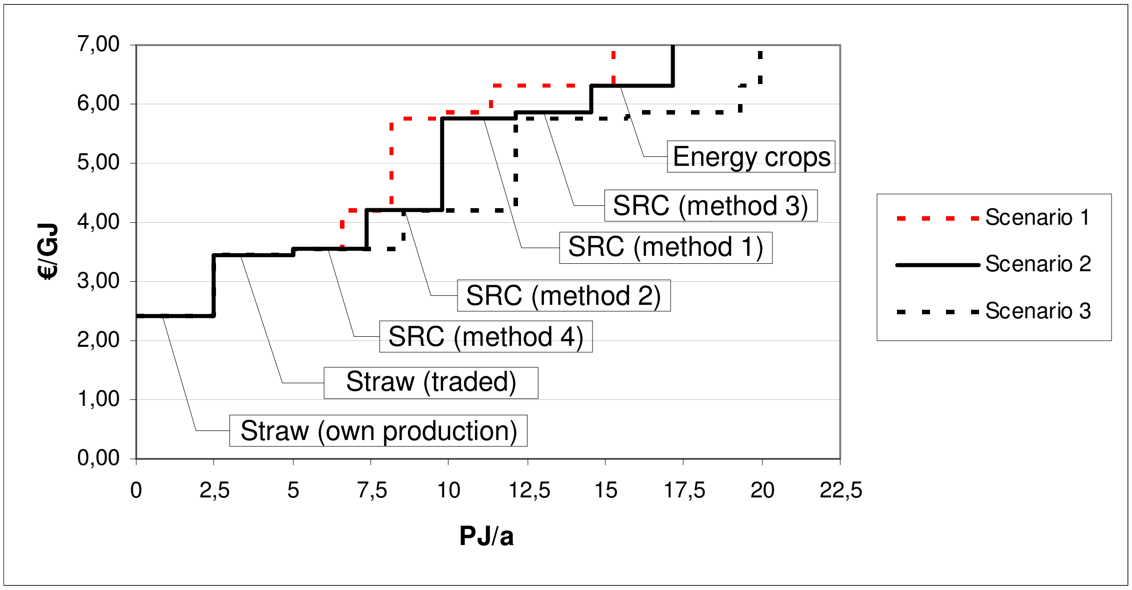


Figure 5.10. Cost-resource curves for the additional potential of solid agricultural biomass.[80]

[80] The potentials can be regarded as realizable until 2010 to 2020. Scenario 1 is probably the most likely for the near future.

6 Pellets

6.1 The Use of Pellets in Austria

In recent years there was an enormous increase in the use of wood pellets as high quality biomass fuel in Austria and Europe. Compared to other wood fuels, the main advantages of pellets are the low moisture content and the increased density which result in reduced costs for transportation and storage and easier handling. Furthermore, the homogenous composition facilitates automatic control and makes more efficient combustion possible. Modern pellet boilers have efficiency ratings of 80 to 85 % and hardly produce any ash. The major disadvantage of pellets is the relatively high cost for the pelleting process, increasing the price of the end-product.

Figure 6.1 shows the development of cumulated installed pellet boilers with a maximum capacity of 100 kW in Austria. In 1997, the number of installed boilers was slightly more than 400, until 2004 it had increased to approximately 28,000.

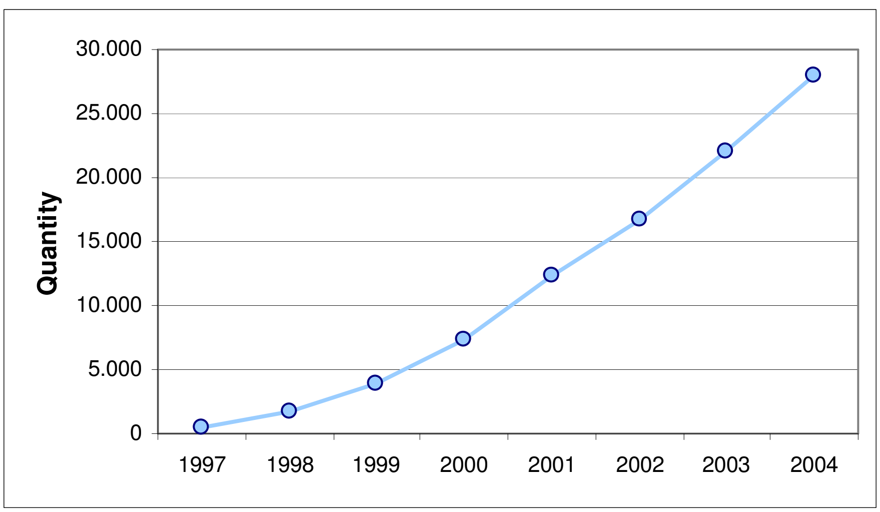


Figure 6.1. Development of installed pellet boilers (<100 kW).
Source: European Pellet Centre 2005, LK 2005.

6.1.1 Standards for Pellets

Wood pellets are standardized compressed wood pieces with a cylindrical form, 4 to 10 mm in diameter and a density of at least 1 kg/dm^3. The calorific value of pellets from Austrian producers is at least 18 MJ/kg (5 kWh/kg), the ash content has to be less

than 0.5 % and the moisture content less than 12 %. These and further specifications are defined in the Austrian standard ÖNORM M 7135 (briquettes and pellets). According to [Pigaht et al. 2005], the existence of this standard has been highly important in the development of the Austrian pellet market and has also gained importance in neighboring countries, such as Slovakia, Italy, Germany and the Czech Republic.
There are also standardization activities on a European level. In CEN/TC 335 “Solid Biofuels” 28 European standards for solid biofuels will be established. These standards will be valid throughout Europe. Some of them are already published.

6.1.2 Production

Pellets can be produced from a variety of raw materials. Today mostly sawdust, wood chips and wood shavings are used but it is also possible to use natural waste wood, forest residues or agricultural residues (“agri-pellets”). In the near future, other raw materials are likely to become more important because the competition with the paper and board industry and the increasing demand for pellets will probably lead to a lack of industrial residues. Figure 6.2 shows the development of pellet production in Austria. Between 20 and 30 % of the annual production was exported in recent years.

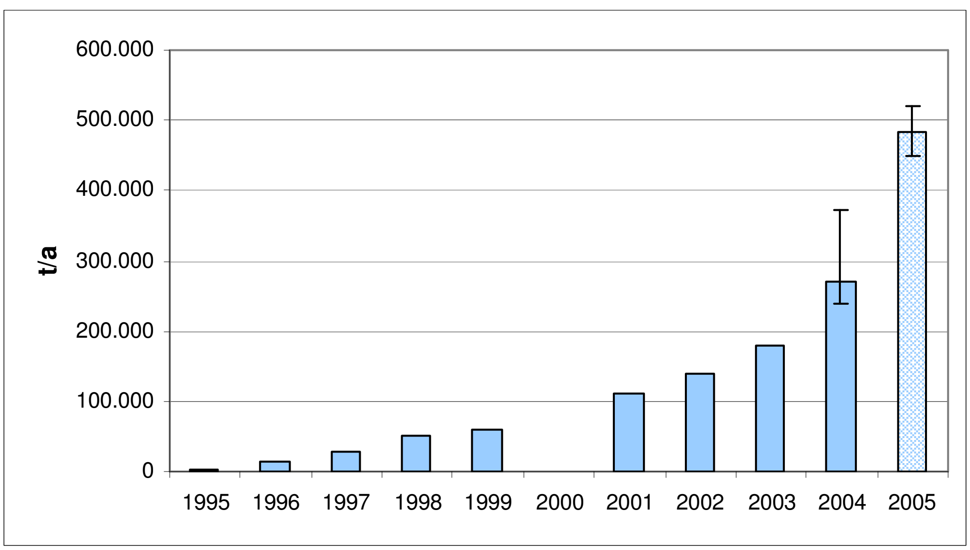


Figure 6.2. Development of pellet production in Austria[81].
Sources: European Pellet Centre 2005, Öhlinger et al. 2001, Haas et al. 1998, Pigaht et al. 2005, Timber-online 2005.

[81] There was no data available for the year 2000. The discrepancies for 2004 and 2005 originate from different data in literature.

6.1.3 Agri-Pellets

The use of agricultural residues for pellet production could be a possibility to counteract the future shortage of woody raw materials. Agricultural residues include all plant material that remains after a crop has been harvested and separated (e.g. stalks, straw, peanut shells, sugar beet pulps). For pellet production, the most interesting among all agricultural residues is definitely straw. Straw can be pelletised without major difficulty. Generally, the same pellet mills are used for straw and wood pelleting, but some manufacturers emphasize that the use of straw could reduce the wear parts lifetime by up to 20 % [Passalacqua 2004]. Because of the low moisture content, the total energy requirement for pelleting straw is even lower to the one related to wood. But the energy content is slightly lower[82] and there are still several technical problems related to the combustion of agri-pellets.

The main problems of agri-pellet combustion are emissions, corrosion and deposit formation. Another problem is the increased disposal of ashes which are produced in high quantities. These problems can be overcome with different techniques, ranging from agricultural practices (leaching of straw in the field) to combustion equipment design (such as flue gas cleaning systems or combustion control systems). The latter are only applicable cost-effectively in bigger plants and thus, from the current point of view pellets made from agricultural residues should be used primarily in medium or large scale combustion plants while wood pellets are favorable for small-scale combustion units.

The main technological challenges concerning the use of straw pellets are the production of a high quality fuel and technological improvements for small-scale combustion devices. Apart from economic aspects, the agri-pellet market for small-scale use will develop only if equipment manufacturers develop suitable combustion solutions [Passalacqua 2004].

[82] The net calorific value of straw pellets is about 15.5 MJ/kg (4.3 kWh/kg).

6.2 Prices and Costs of Pellets

6.2.1 Price of Wood Pellets

The current prices of wood pellets range from 151 to 225 €/t, depending on the purchase quantity. The price development since 2003 is illustrated in Figure 6.3. There was no reliable data about average prices before the third quarter of 2003 available, but data from different producers indicate that the prices have decreased by about 20 % from the beginning of 2002 to 2005[83]. These data also show that prices for pellets are significantly higher in winter than in summer.

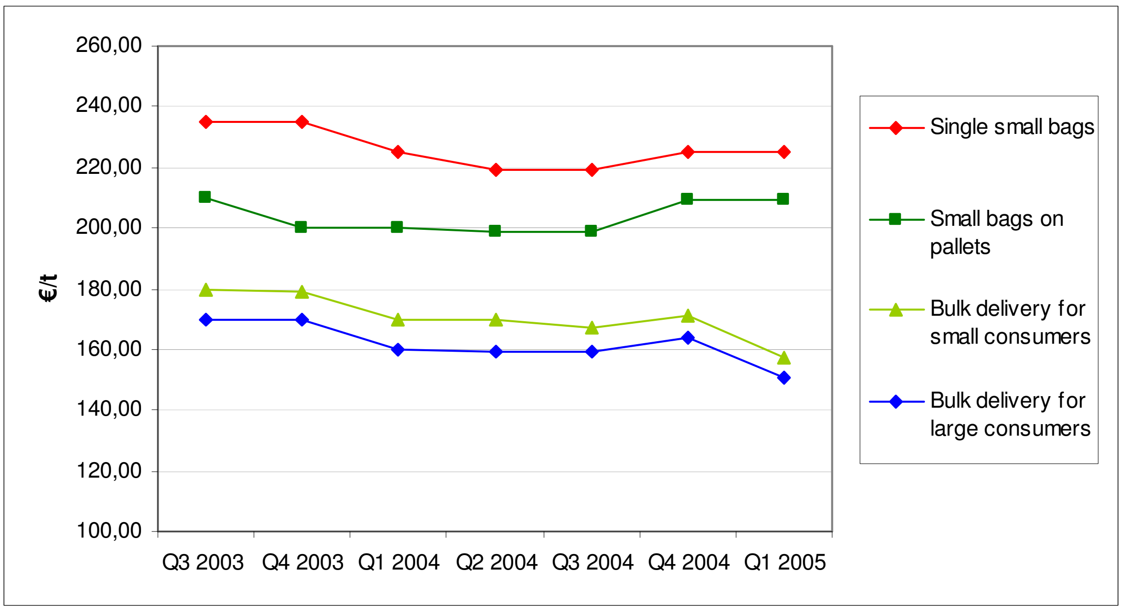


Figure 6.3. Price development of wood pellets.
Source: European Pellet Centre 2005.

6.2.2 Production Costs for Wood Pellets

The production costs for wood pellets are mainly influenced by the raw material costs. Wet raw materials are cheaper but additional costs for drying arise. Figure 6.4 shows the cost ranges for each step of the production process. The costs for the raw material and drying can cause up to one third of the total production costs. Another important factor is the annual operation time of the plant. According to [Thek et al. 2002],

[83] [ProPellets 2005], [ESV 2005]

at least three shifts per day, five days per week is necessary for an economic production of wood pellets.

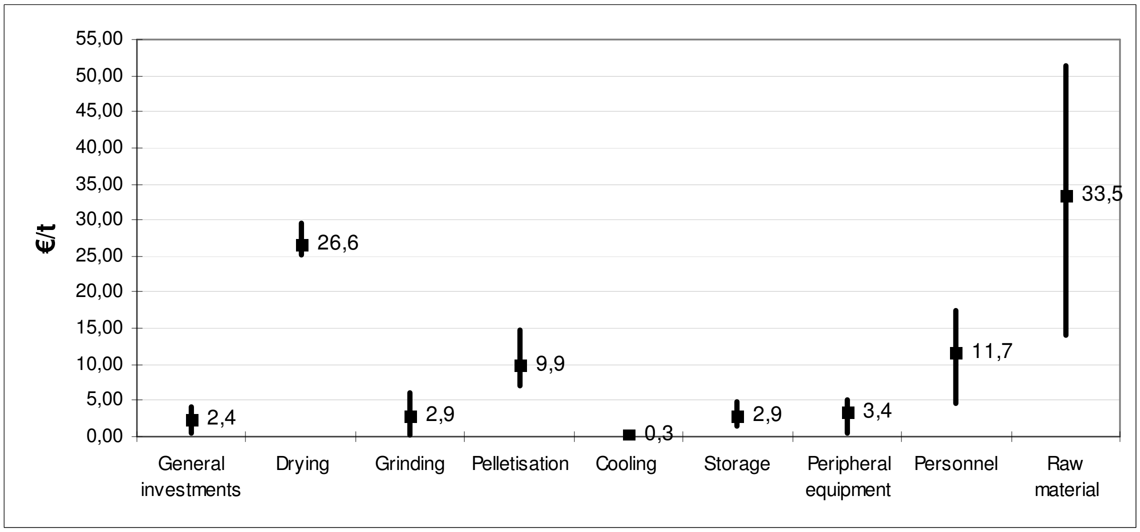


Figure 6.4. Costs for pellet production.
Source: Thek et al. 2002.

In 2001, the average production costs in Austria were between 73.5 and 94.6 €/t (4.1 to 5.3 €/GJ) for plants with drying and between 52.2 and 81.3 €/t (2.9 to 4.5 €/GJ) for plants without drying. The raw material for about 55 to 58 % of the total pellet production was wet and 42 to 45 % dry residues[84] [Hahn 2002]. Because of the rapid increase in production capacities[85], it is possible that the average costs are already lower today[86].

According to [Pastre 2003], the production costs for straw pellets are quite similar to the ones for wood pellets. In [Passelacqua et al. 2004] production costs between 94 and 164 €/t (6.06 to 10.58 €/GJ) are stated. The average production costs in Denmark, where a small market for straw pellets already exists[87], are 135 €/t.

[84] The total amount of sawdust in 2001 was about 4 million tons.

[85] In 2001, the production capacities were about 130.000 t/a. The planned capacities for 2005 are about 500.000 t/a.

[86] In Sweden, which has by far the biggerst pellet production capacities in Europe, the costs are considerably lower than in Austria. This is partly because of the cheaper price of electricity but according to [Thek et al 2002] the main factors are the larger plant capacities and an efficient heat recovery system from the dryers applied in Sweden.

[87] The “Amager plant” in Denmark, an old coal-fired plant with a capacity of 136 MW has been converted to be fired with straw pellets.

6.3 Possible Future Developments

Figures 6.1 and 6.2 illustrate that there was an enormous increase in the utilization of wood pellets in Austria in recent years and their importance will definitely continue to rise in the near future. The developments of pellet production, domestic consumption, exports, installed pellet boilers and possible trends for the year 2010 are illustrated in Figure 6.5. According to estimations of experts, the annual pellet production could amount to one million tons in the year 2010 [Timber-online 2005]. Thus, the trend shown in Figure 6.5 is probably not likely to occur.

If the trend of new annual installations continues, there will be as much as 90,000 pellets boilers installed in Austria in 2010. With an average annual consumption of 6.5 tons of pellets, the demanded amount will be slightly less than 600,000 t/a (about 10.5 PJ/a). Hence, 40 % of the total production could be exported. In recent years, this proportion was slightly more than 20 %.

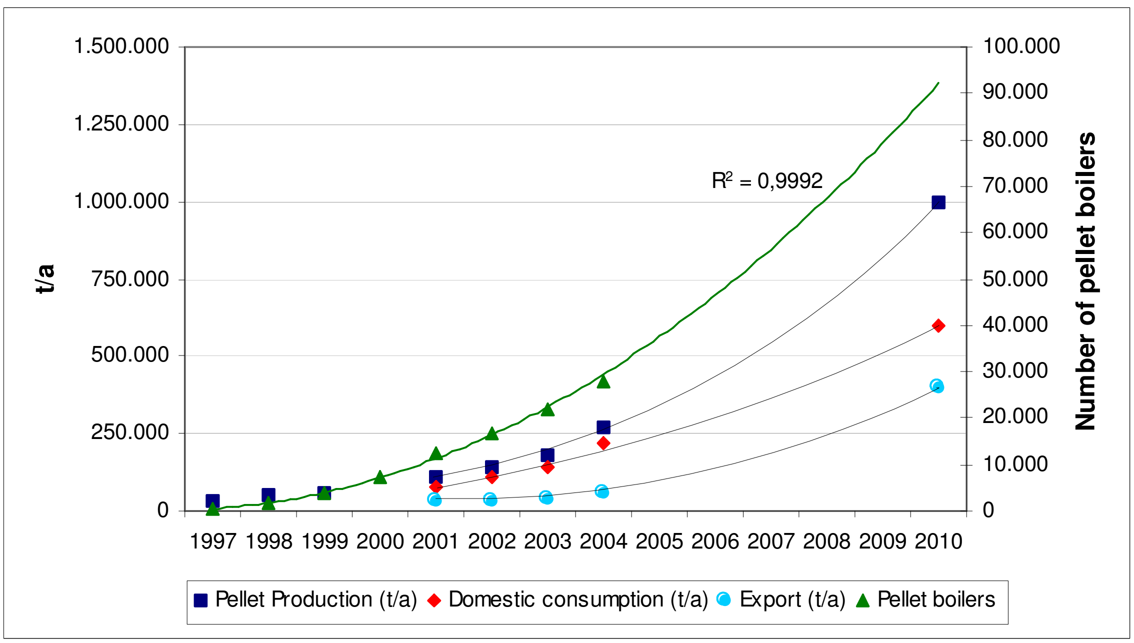


Figure 6.5. Developments of pellet production, domestic consumption, exports and installed pellet boilers and possible trends.

Sources: European Pellet Centre 2005, LK 2005.

The amount of industrial residues which is required to produce one million tons of pellets can be estimated 8 million m^3 (2.65 million scm)[88]. This will be about 30 to 40 % of the total production of industrial residues without bark. In 2001 this proportion was only 4.5 % and in 2003 about 9 %. These data indicate that big additional amounts of industrial byproducts will have to be imported, otherwise there will be an obvious lack of sawdust and industrial wood chips for non-energy purposes like paper and pulp production. Other possible prospects would be a rapid increase in felling or major advances in the production and small-scale combustion of straw pellets.

6.3.1 Cost-Resource Curve

The cost-resource curves in Figure 6.6 are based on the following assumptions:

- For the total available potential the planned production for 2010 was chosen (1 million tons). The production in the base year 2002 was 140,000 tons and thus, the additional potential is about 13.7 to 15.5 PJ[89].
- There will be slight reductions in the production costs[90].
- The included costs for transportation are 10 €/t.
- For the red curves it was assumed that there is a strong trend towards straw pellets and that additional amounts of industrial residues from the domestic sawmill industry are available for pellet production[91]. Furthermore, it was presumed that the production costs for agri-pellets can be reduced to 80 €/t. Still, as a result of the lower calorific value of straw pellets, the costs in €/GJ are clearly higher than for wood pellets.
- The black curves are based on the assumption that straw pellets will not be utilized in the near future and that sufficient amounts of industrial residues can be made available to satisfy the demands of pellet producers[92]. For the dashed curve it was presumed that the costs for the raw materials remain constant.

[88] According to [Lechner et al. 2003], 8 m^3 of sawdust are required for the production of 1 ton of pellets.

[89] The energy potential of the planned production of 1 million tons depends on the share of agri-pellets, which have a lower calorific value than wood pellets.

[90] The assumed average production costs for wood pellets are the lower values mentioned in [Thek et al. 2002].

[91] The amounts are derived from the scenarios “Estimate [Schachenmann 2003]” (continuous line) and “Trend 1993 – 2003” (dashed line) in Table 4.2.

[92] This could mean that the available amount of residues for non-energy purposes is reduced by up to 1.5 million scm.

However, in consideration of the increasing demand for industrial residues and the need for more imports, it seems more likely that in the near future the costs of raw materials for the pellet production will rise significantly. For the continuous curve in black color[93] a price increase of 1 €/GJ was assumed.

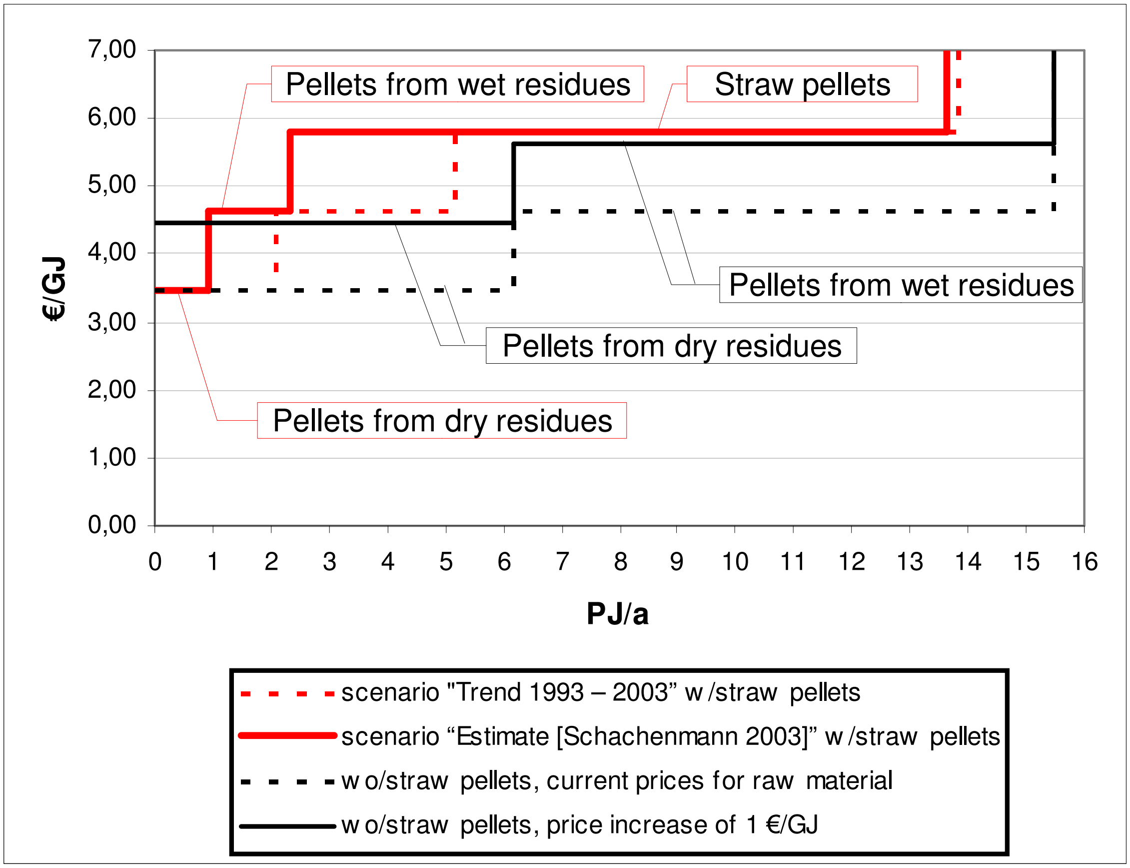


Figure 6.6. Cost-resource curves for the additional potential of pellets.

[93] It is the author's opinion that the continuous black curve represents the most likely scenario.

7 Utilization and Potentials of Biomass in Other Central European Countries

7.1 Primary Energy Production

Figure 7.1 presents the development of primary energy production[94] from biomass and wastes in central European countries in the years 1992 to 2003 according to [Eurostat 2005]. All kinds of solid (e.g. fuel wood, wood chips, saw dust), liquid (e.g. biodiesel, bioethanol) and gaseous biomass (e.g. landfill gas, biogas) and wastes which can be used for energy production are included. Since 1992 there was a notable increase in the utilization of biomass and wastes in all considered countries.

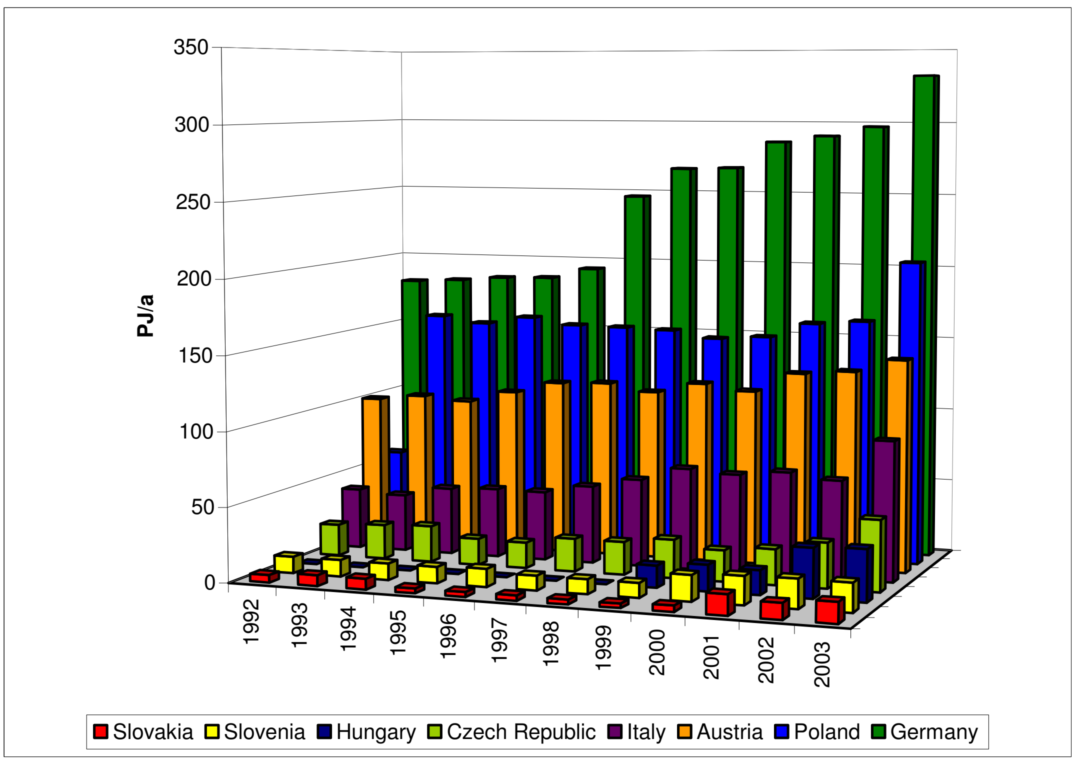


Figure 7.1. Primary energy production from biomass and wastes.
Source: Eurostat 2005.

The share of solid biomass in the data in Figure 7.1 is quite different from country to country. In Italy and Poland it is virtually 100%, whereas in Germany and the Czech

[94] The amount of primary energy is the heat produced during incineration or the energy content of the produced fuel.

Republic it is only about 65% (i.e. the share of liquid and gaseous biomass and wastes is relatively high in these countries). In Austria, Hungary, Slovenia and the Slovak Republic the share of solid biomass is between 80 and 90 %[95] [EarthTrends 2005].

7.2 Solid Biomass

7.2.1 International Studies

In this chapter, the results of international studies on potentials of solid biomass and their current use in the countries Austria, Germany, Hungary, Italy, Slovenia, Slovakia, Poland and the Czech Republic will be presented and compared. The data originate from the following studies:

- The final report to Task 2 of the Altener Programme's AFB-net[96], titled "Export and import possibilities and fuel prices of biomass in 20 European countries" [AFB-net 2001]
- The study "Biomass availability in Europe" by Nikolaou, Remrova and Jeliazkov [Nikolaou et al. 2003]
- The study "Estimation of Energy Wood Potential in Europe" carried out by the Finnish Forest Research Institute [Karjalainen et al. 2004]
- The Staff Working Document "The share of renewable energy in the EU" of the Commission of the European Communities [Commission of the EC 2004]
- The second interim report to the study "Strategies for the sustainable use of biomass in Europe" [97] by the Institute for Energy and Environment in Leipzig [Thrän et al. 2005]

The total available amounts of biomass for energy recovery and the most important types of biomass are quite different from country to country. This is mainly because of the different land use in each country but it should also be mentioned that different ways of estimating the resources can cause discrepancies.

[95] These data refer to the year 2001.
[96] Altener is a programme of the European Commission that is focused on the promotion of renewable energy sources. The AFB-net is the European Bioenergy Network. One of its special tasks was on export and import possibilities and fuel prices.
[97] The original title in German is „*Nachhaltige Biomassenutzungsstrategien im europäischen Kontext*".

7.2.1.1 Final Report of the Altener Programme's AFB-Net

In the final report of the Altener Programme's AFB-net [AFB-net 2001] which was published in January 2001, biomass is classified into the following categories: forest residues, industrial by-products, industrial black liquors, domestic (residential) firewood, wood wastes, refined wood fuels, other biomass resources and peat. The data was collected by carrying out a questionnaire among the AFB-net partner countries. Since many countries had problems in collection the necessary information and some data seemed unreliable, other available information sources have been used. These include other EU projects, different reports and proceedings of seminars on biomass field.

Forest residues include wood chips from all kinds of forest resources like tree tops and branches and other wood fractions which are not used as raw material for non-energy purposes. **Industrial by-products** include sawdust, bark, wood chips and other clean byproducts from forest industry. Contaminated fractions cannot be used for energy production. **Industrial black liquors** are liquid byproducts from pulp industry, which are normally used as fuel in boilers. Black liquors are not included in this report. The category **domestic (residential) firewood** includes wood logs and chopped firewood which is used for heating in private houses and in smaller district heating plants. **Wood wastes** include different fractions of wood residues like demolition wood, wooden packages or pallets. Waste paper which is used for energy production is also included in this category. **Refined wood fuels** are wood pellets, briquettes and other such wood fuels. **Other biomass resources** include short rotation coppice, energy grasses, straw and agricultural wastes. **Peat** is an important energy source especially in Nordic countries. It could also be used as a biomass resource in Poland.

The available resources of biomass are presented in Figure 7.2 and their use for energy production in 1999/2000[98] in Figure 7.3. The unit of the given data is PJ per annum. Hungary and the Czech Republic were not included in the AFB-net countries.
As already mentioned, the share of each fraction is very different from country to country. Naturally, in heavily wooded countries like Austria and Slovenia, forest residues and domestic firewood are most important. With a percentage of 58%, the share of domestic firewood is conspicuously high in Italy. Since these countries also have large wood-working industries, solid industrial by-products also make an important contribution to the biomass resources. In Germany, Poland and Slovakia, the category "Other biomass resources" is dominating. This category means mainly straw and energy plants.

[98] The data collection started in June 1999 and ended in spring 2000. As Figure 7.1 shows, there was an increase in the utilization of biomass in almost every country since 2000.

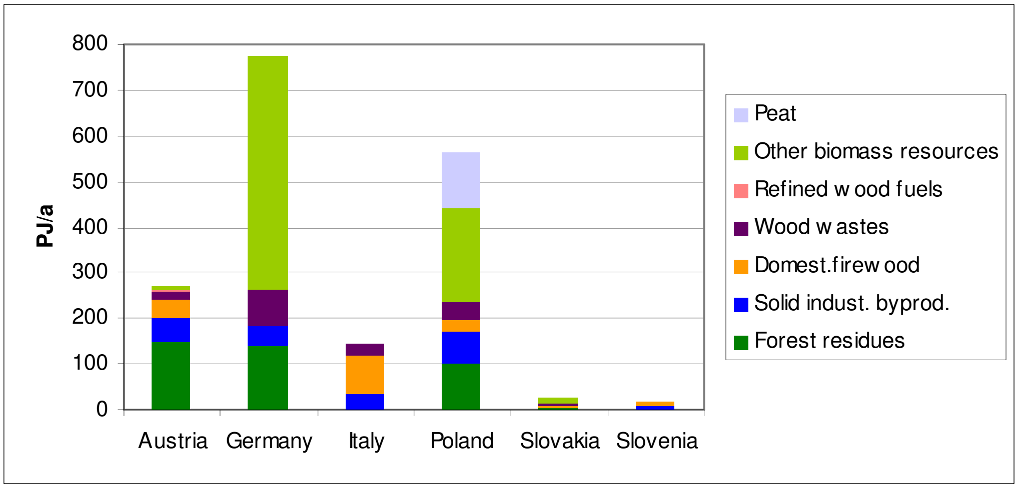


Figure 7.2. Available resources of solid biomass in central European countries according to [AFB-net 2001].

The current use of biomass also differs a lot from country to country. Domestic firewood is the only fraction which is used in every country and it also the one which is used most exhaustively. There is no country where less than 70% of the available resources of firewood are actually used.

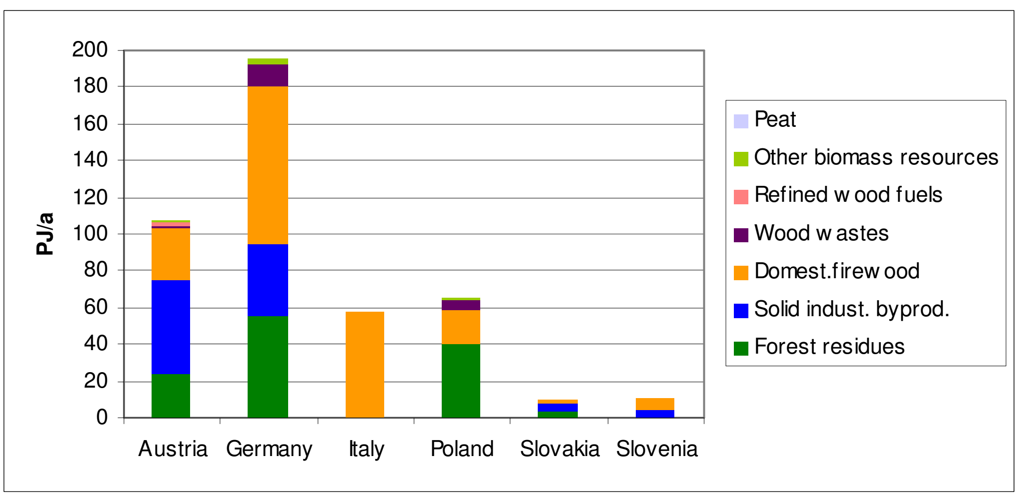


Figure 7.3. Energy use of solid biomass in central European countries in 1999/2000 according to [AFB-net 2001].

The use of solid industrial byproducts is very important in Germany and Austria, while in Italy and Poland this fraction is not used at all. The use of forest residues is already quite common in the countries where they are available, but there are still remarkable additional potentials.

The share of wood wastes which is used for energy production is relatively low in every country except for Slovenia where the whole potential of wood wastes is used (0.1 PJ/a). In Germany and Poland, about 15% of all available wood wastes are used.
Figure 7.2 and 7.3 illustrate that there is an enormous additional potential of straw, short rotation coppice and agricultural wastes ("other biomass resources") in Germany and Poland. In Germany, the amount of energy which could be produced with this fraction is more than 500 PJ/a and in Poland more than 200 PJ/a. Another 122 PJ/a could be produced by using peat for energy recovery in Poland.

Figure 7.4 shows the fuel prices of different biomass types. Generally, the fuel prices for large plants are lower than for smaller ones. However, the data presented in Figure 7.4 are average prices for different plant sizes and "subtypes" of biomass fractions.

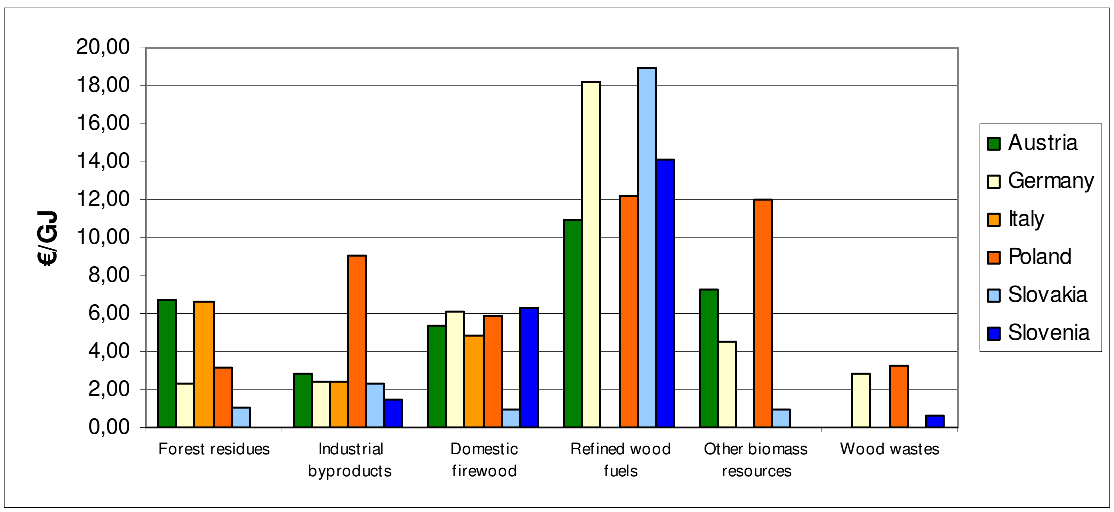


Figure 7.4. Fuel prices of different biomass fractions.
Source: AFB-net 2001.

7.2.1.2 Biomass Availability in Europe

The general approach of the study "Biomass availability in Europe" [Nikolaou et al. 2003] was to collect data from literature. In the cases where no data were found own estimates based on commonly used methodologies were used. Estimations on crop residues were based on the cultivated area or the agricultural production for each crop in each country.

In this study biomass resources are classified according to fuel quality and supply sector (similar to the classification used in this thesis). The categories are agriculture (agricultural residues and energy crops), forestry (fuel wood and forest residues), industry (dry and wet industrial residues), wastes (regulated and non-regulated) and "parks and gardens" (urban wood and cut grass). The study also includes resources for liquid biofuels, livestock waste, black liquor, landfill waste and sewage sludge. These resources are left out of this report.

Resources from forestry are divided into **fuel wood** and **forest residues**. **Industrial residues** consist of waste wood from wood processing industries, remains of food crops processing etc. **Agricultural residues** include a wide range of plant material which is produced along with crops and other agricultural products. Examples are straw, orchard prunings, corn stems and cobs. **Energy crops** include perennial grasses and short rotation coppice. Demolition wood, urban wood and resources from parks and gardens are summarized in the category "**wastes**".

The results of this study represent available resource potentials in consideration of estimated, realistic limits (technical, physical, environmental etc.). The available potentials of solid biomass are shown in Figure 7.5. For some countries there is no data about forestry byproducts and data on potentials of energy crops is missing entirely. Figure 7.6 present data on the current use[99] of biomass.

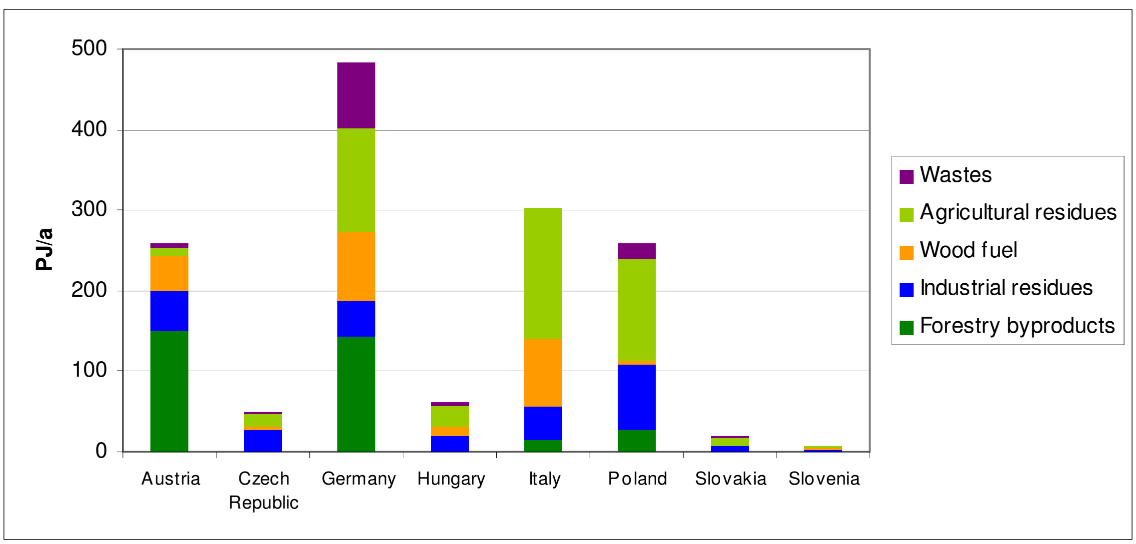


Figure 7.5. Theoretically available resources of solid biomass in central European countries according to [Nikolaou et al. 2003].

[99] The reference year for all data is the year 2000 and when this was not possible the year for which the most recent data were reported. No data before 1995 were used.

Concerning the current use of biomass, the results of this study widely correspond with [AFB-net 2001]. The fraction of biomass which is most commonly used is wood fuel. In Austria and Germany, virtually all the resources of industrial residues are actually used while in some other countries they are not used at all. There are enormous potentials of forestry byproducts and agricultural residues which are not utilized yet.

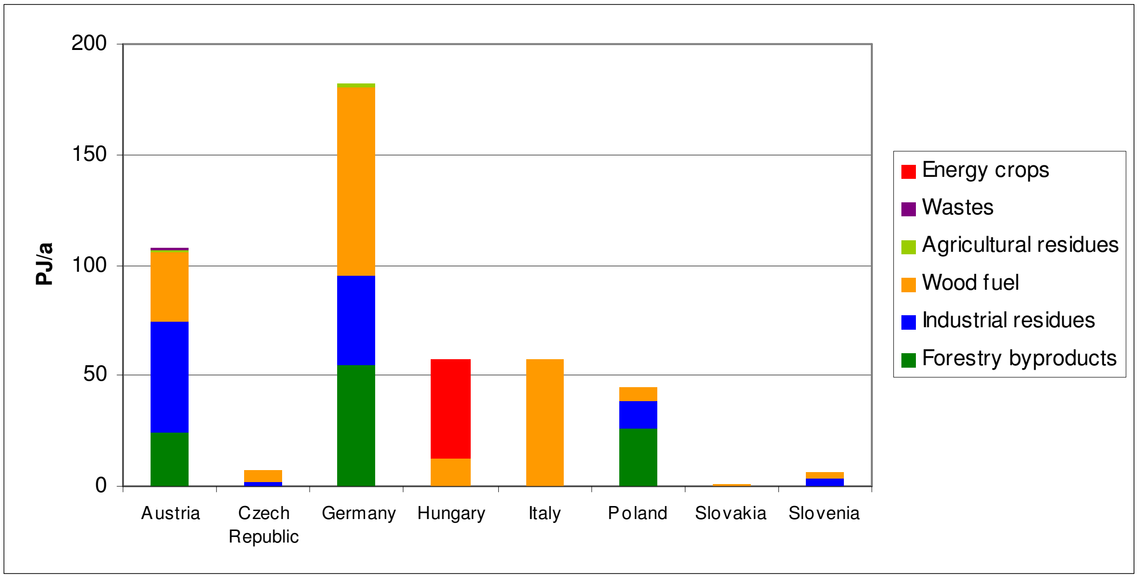


Figure 7.6. Current use of solid biomass in central European countries according to [Nikolaou et al. 2003].

This study also includes an analysis of the delivery cost of the different biomass fractions[100]. The total costs consist of production, transportation and other costs (such as storage, handling etc.). The cost for the fractions wood fuel, forestry byproducts, industrial and agricultural residues and energy crops are presented in Figure 7.7.

The cost differences between the countries are considerable for every fraction. The cheapest sort of solid biomass is industrial residues. The most expensive fraction is energy crops. With more than 18 €/GJ the costs for energy crops are exceedingly high in Slovenia. On average, solid biomass is cheapest in Austria, followed by Italy and the Czech Republic. According to this study it is most expensive in Slovenia.

[100] All costs refer to the year 2000.

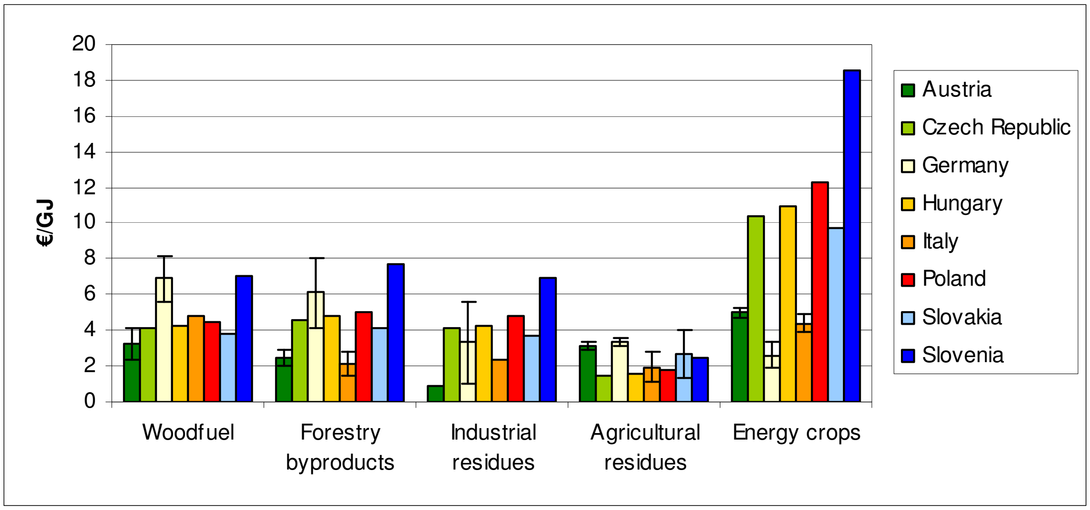


Figure 7.7. Delivery cost for solid biomass.
Source: Nikolaou et al. 2003

7.2.1.3 Estimation of Energy Wood Potential in Europe

The aim of this study [Karjalainen et al. 2004] was to estimate the wood energy potential of the 25 European countries that were members of the European Union from the beginning of May 2004 (EU25). It has been divided into the estimation of roundwood balance and felling residues available for wood supply. Roundwood balance is the difference between net annual increment (NAI)[101] and fellings and represents the unutilized increment which could be used for energy production. The estimations of roundwood balance for central European countries are illustrated in Figure 7.8. In all of the considered countries the balance is clearly positive. The highest NAI on forest available for wood supply among these countries has Germany (89 million scm/a) and the lowest Slovenia (6.1 million scm/a). But in relation to the current use, the roundwood balance is highest in Slovenia (62%) and relatively low in the Czech Republic (21%), Poland (23%) and Austria (29%).

[101] NAI = gross annual increment minus natural losses (insect attacks, fire etc.)

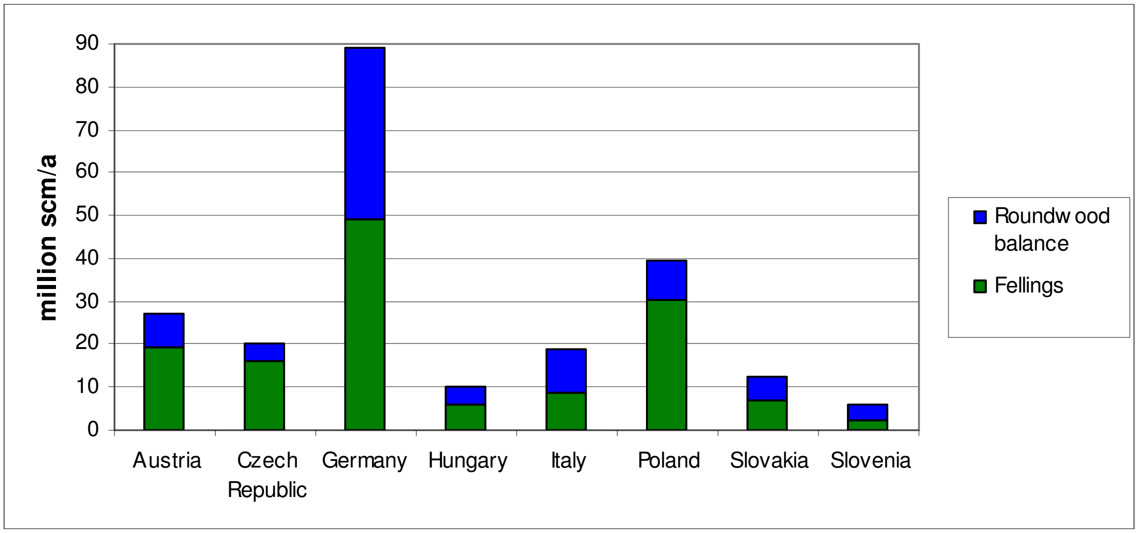


Figure 7.8. Net annual increment of roundwood (sum of fellings and roundwood balance) in the considered countries102.
Source: Karjalainen et al. 2004

The volume estimations of available felling residues and roundwood balance in this study were used to calculate the theoretical energy potential of forest biomass in the considered countries[103] (Figure 7.9). In addition to felling residues and unutilized increment, stump wood[104] has also been taken into account.

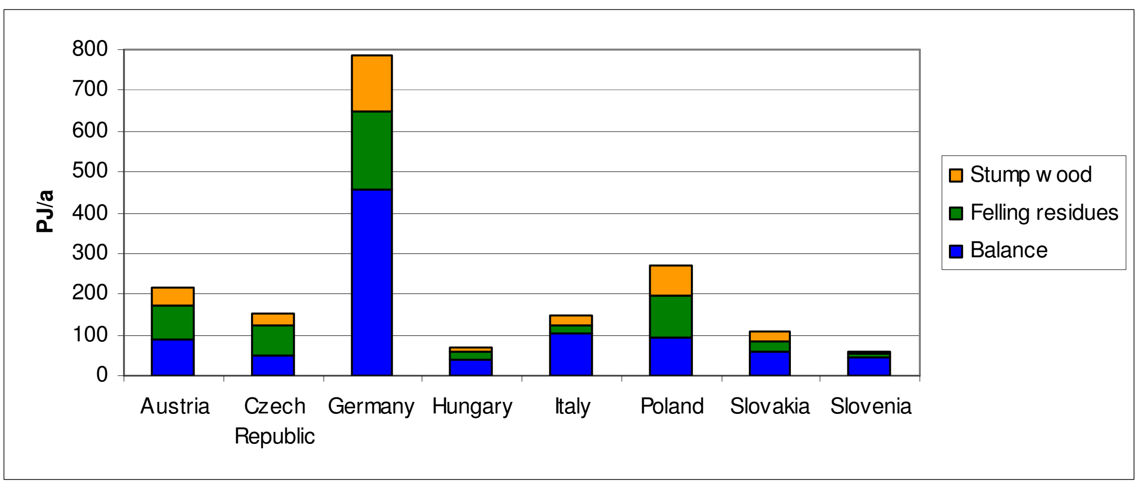


Figure 7.9. Theoretically available wood fuel potentials.
Source: Karjalainen et al. 2004, own calculations.

[102] The data for Austria originate from the last but one Forest Inventory in 1992/96 and therefore does not correspond with the data in Chapter 3.2.1.
[103] It was assumed that the average energy content of 1 scm is 7.2 GJ.
[104] Stumps and coarse roots of trees

To arrive at more realistic estimations of the available fuel potential (realizable potential) various restrictions have been taken into account. For example it was assumed that 75% of clear cuts and 45% of thinnings are technically available for supply, that 20% of stump wood from clear cuts is harvestable and that additional fellings account for 25% of the unutilized increment. The resulting potentials are illustrated in Figure 7.10. They are about 20 to 30% of the theoretically available potentials.

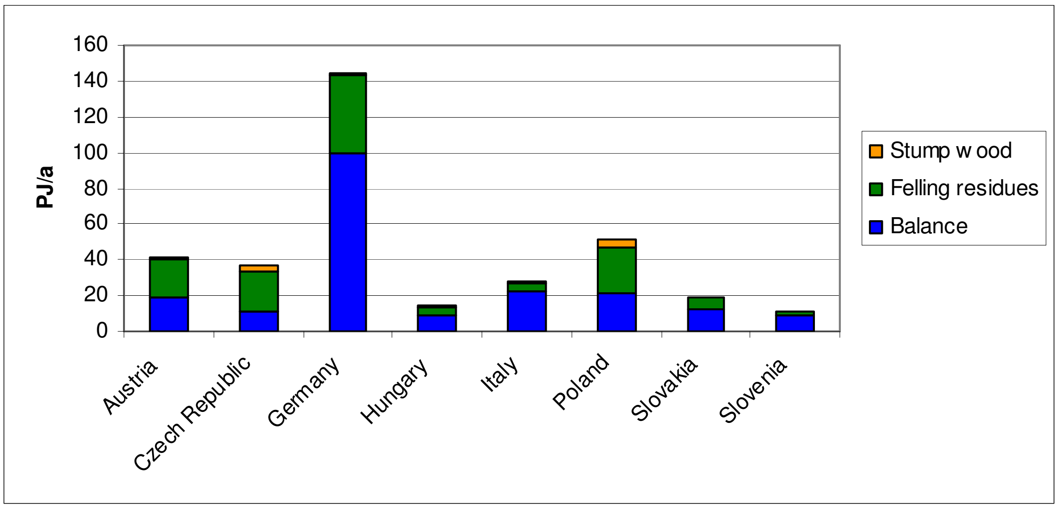


Figure 7.10: Estimations of available forest fuel potentials (realizable potentials).
Source: Karjalainen et al. 2004, own calculations.

7.2.1.4 The Share of Renewable Energy in the EU

This Staff Working Document of the Commission of the European Communities was published in May 2004 and gives an overview of the different situations of RES in the EU countries. It is a report on electricity and heat produced from renewable sources. Therefore, data on potentials and current use of biomass from this document are separated into heat and electricity. Furthermore, “Biomass electricity” is separated into “solid biomass electricity” and “biowaste electricity” and “Biomass heat” into “grid” and “non-grid” but these classifications are left out in this report.

The data on potentials and current use of biomass from this document are presented in Figure 7.11. The current use (achieved potentials) for heat and electricity production is shown in green and the additional potentials in blue color. The additional potentials are specified as mid-term potentials.

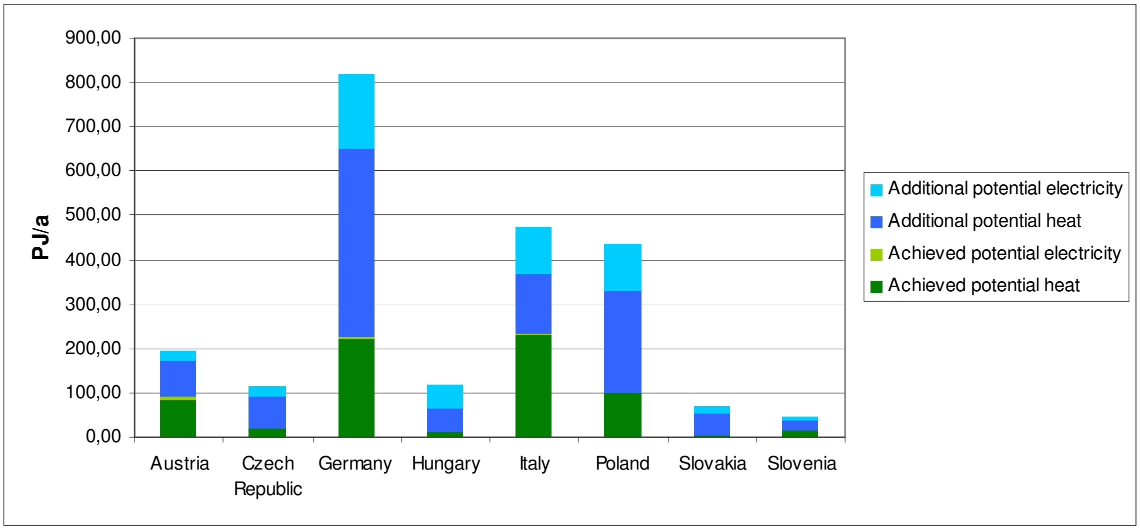


Figure 7.11. Mid-term potentials and current heat and electricity production from biomass according to [Commission of the EC 2004].

The share of the achieved potential in the total potential is quite different from country to country. In Austria and Italy it is about 50%, mainly because of the extensive use of biomass for heat generation. According to this document biomass is used for electricity production in Austria, the Czech Republic, Germany, Italy and Slovenia. The total electricity production is less than 4 TWh/a.

Figure 7.11 illustrates that biomass is mainly used for heat generation in the considered countries. The additional potentials for both heat and electricity production are remarkable for every country.

7.2.1.5 Strategies for the Sustainable Use of Biomass in Europe

The second interim report to the study “Strategies for the sustainable use of biomass in Europe” includes estimations of the technical potentials of forest biomass in the EU 28. The estimations are based on the current use of fuelwood[105] and the roundwood balance. In this study, the share of residues in the total felling was estimated 12.5 %. The results (Figure 7.12) are specified as technical potentials[106].

[105] In this study the term “fuelwood” is used for the share of felling which is currently used as fuel.

[106] From the author’s point of view “theoretically available potentials” would be a more appropriate specification.

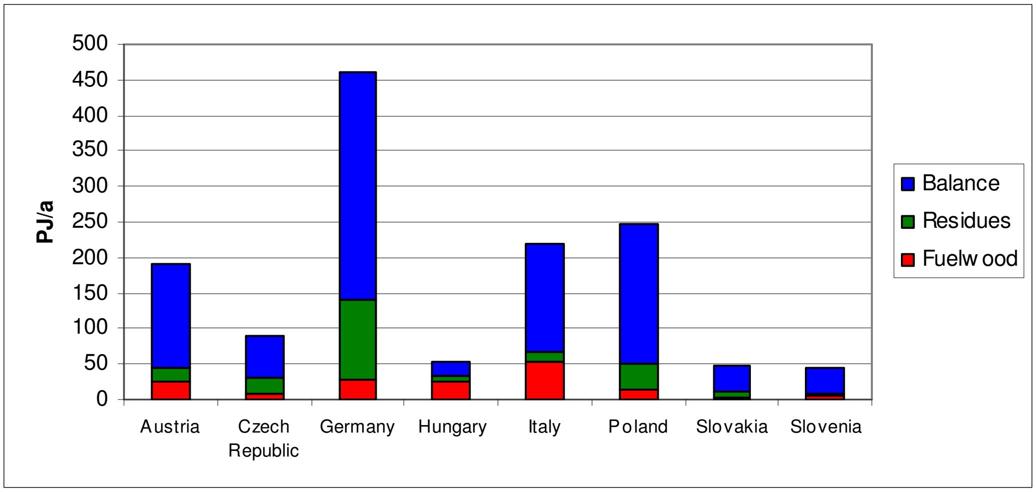


Figure 7.12. Technical potentials of forest biomass[107].
Source: Thrän et al. 2005, own calculations.

7.2.1.6 Remarks

The results of the presented studies show some remarkable discrepancies. To a certain extent, this can definitely be ascribed to the fact that different methods of assessing the potentials were applied. The data in [AFB-net 2001] and [Nikolaou 2003] have partly been collected from literature and thus, it can be assumed that the potentials stated in these studies are based on inconsistent assumptions and general conditions.

A main problem for comparisons and interpretations is that sometimes it is not clear which assumptions have been made for assessing the potentials. Furthermore, some of the data do not give much insight into the future development of biomass energy because economic conditions are not considered. For example the energy content of the annual production of industrial residues does not have much significance. It is necessary to consider the demand for non-energy purposes of industrial residues to get an impression of the amounts available for energy production.

With regard to forest biomass, the study "Estimation of Energy Wood Potential in Europe" [Karjalainen et al. 2004] provides the most consistent and probably most reliable data. In most other studies the potentials of forest biomass seem to be highly underestimated for some countries (e.g. Slovenia, Slovakia, Hungary).

[107] It was assumed that the energy content of 1 ton of dry substance is 18.5 GJ.

7.2.2 Country Profiles

The following chapters give short descriptions of the utilization of biomass in the countries Slovakia, the Czech Republic, Slovenia, Hungary and Poland. The resources of solid biomass in these countries are described more detailed and estimates of the potentials are illustrated.

7.2.2.1 Slovakia

The Slovak Republic has minor oil and gas reserves. It is heavily dependant on imported oil, gas, coal and nuclear fuel, mainly from Russia. The current share of renewable energy sources is relatively low. The primary energy demand of the Slovak Republic in the year 2003 is illustrated in Figure 7.13.

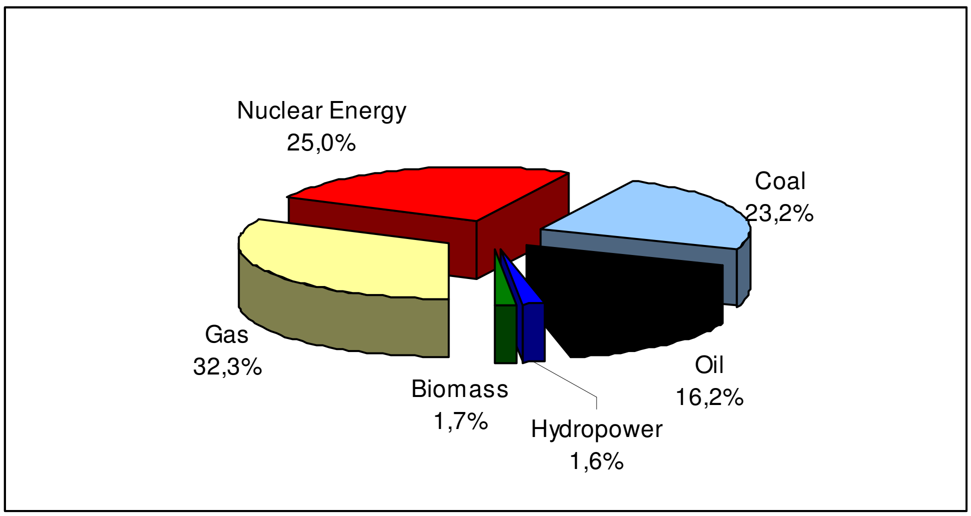


Figure 7.13. Primary energy demand of the Slovak Republic in 2003.
Source: enerCEE 2005.

The potential of renewable energy in the Slovak Republic is quite high and a gradual increase in its utilization is expected [enerCEE 2005]. Besides hydropower, biomass is the most important and probably most promising source of renewable energy. Today there are a high number of municipalities which are heated with relatively old district heating systems that will have to be replaced in the near future. Most of them are fired with imported fossil fuels. To replace these systems with biomass heating systems would result in a significant increase in the utilization of biomass.

About 41 % of the national territory is forest land and 35 % are used for farming. Still, biomass from forestry and agriculture is scarcely used for energy production but a commercial breakthrough is expected in the near future. Table 7.1 presents the short-term potentials of forest, industrial and solid agricultural biomass of the Slovak Republic according to [Viglasky et al. 2005].

Table 7.1. Short-term biomass potentials of the Slovak Republic.
Source: Viglasky et al. 2005.

Forest biomass	**Current forests**	**PJ/a**
	Timber	1,91
	Residues in forest deposits	0,31
	Residues in handling deposits	0,39
	Wood from cutting	0,10
	Stumps	0,15
	Wood fuel	3,42
	Small timber processing plants	
	Lump residues	0,78
	Sawdust, planner residues	0,39
	Fast growing timber	
	Short rotation coppice	4,13
Total forest biomass		11,57
Industrial biomass	Residues	8,50
Agricultural biomass	Energy crops	25,00
Total		**45,07**

A comparison with the results of the international studies in the previous chapter shows that the data about potentials of solid biomass in the Slovak Republic differ a lot. Figure 7.14 gives an overview of the potentials stated in literature. Estimations of the total potential of solid biomass range from 19 PJ/a[108] to 67 PJ/a. However, an energy potential of 45 PJ/a seems to be a realistic value for the near future. In the most recent study by [Ilavský 2005] a value of 57.2 PJ/a is stated (consisting of 16.9 PJ/a from forest, 28.6 PJ/a from agricultural and 11.7 PJ/a from industrial biomass).

Most studies agree that in the Slovak Republic agriculture is the sector which could provide the biggest amount of biomass. In [Viglasky et al. 2005] it is estimated that in the very long term the total energy potential from energy crops for the production of solid, liquid and gaseous fuels can be as much as 200 PJ/a.

According to most recent sources the current use of biomass is about 12.7 PJ/a.

[108] Note that in the study by [Nikolaou et al. 2003] the potentials of forestry byproducts and agricultural residues in Slovakia are not included.

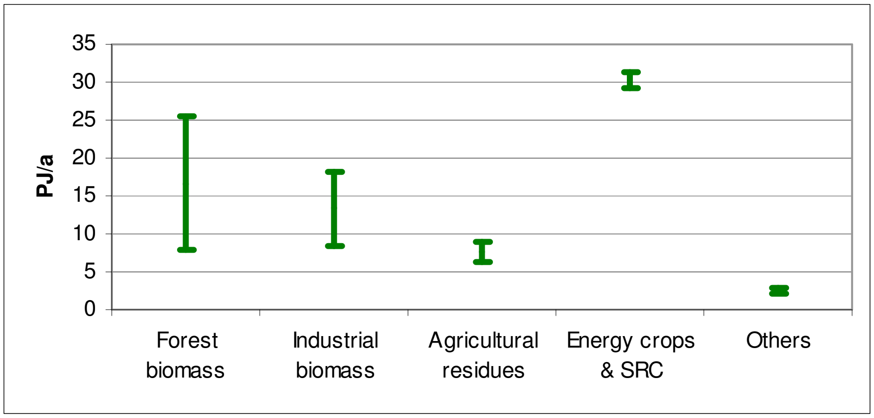


Figure 7.14. Ranges of the potentials of solid biomass in Slovakia stated in literature.
Sources: AFB-net 2001, Nikolaou et al. 2003, Viglasky et al. 2005, Soltes 2005, Karjalainen et al. 2004, Jääskeläinen et al. 1999, Zsolt 2005, Ilavský 2005.

7.2.2.2 Czech Republic

The share of renewable energy sources in the Czech Republic is low. The most important sources of energy are coal resources located mainly in Northern Bohemia, followed by imported oil and gas (Figure 7.15).

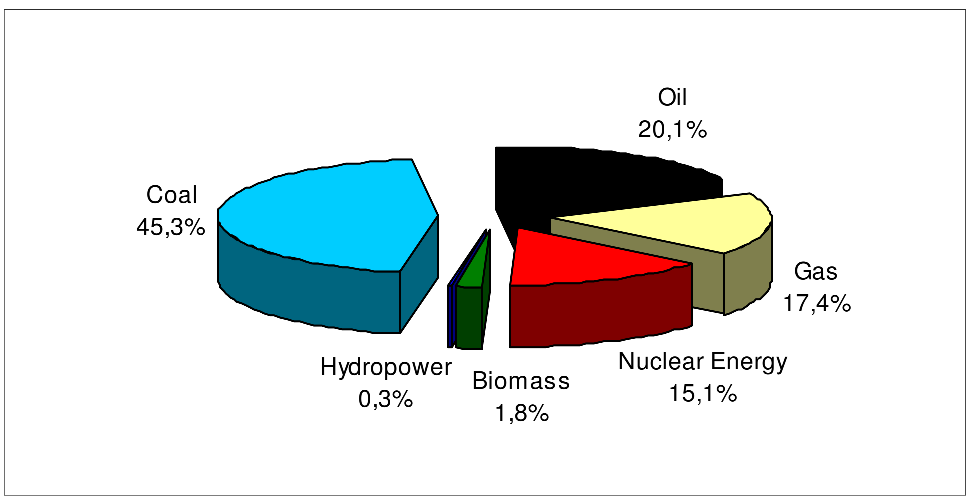


Figure 7.15. Primary energy demand of the Czech Republic in 2003.
Source: enerCEE 2005.

In recent years, there was an enormous increase in the use of biomass for energy production but it is still far from the potential. In 1995 the total energy production from biomass accounted for 11.5 PJ, four years later it had risen to 19.7 PJ.

About two-thirds of the current use of bioenergy is low temperature heat generation consumed in private households. There are about 35,000 biomass boilers. Most of them are fired with wood chips or wood logs and there is also a smaller number of pellets boilers. There were also some district heating systems installed in the last ten years which are fired with wood chips or straw.
Biomass is also used in the industry. There are approximately 80 large biomass boilers and 30 waste wood boilers in the wood processing industry.

The commercial production of energy crops is just at the beginning but it is expected to grow rapidly in the near future. In 2004 about 1,250 ha of arable land have been used for the production of energy crops. The use of biodiesel has already been subsidized for more than ten years, with the result that the biodiesel market is already quite advanced in the Czech Republic. The current production capacities account for approximately 75,000 t/a.

The data about the current use and the available potentials of solid, liquid and gaseous biomass which are shown in Table 7.2 were presented by Jakubes at the International Slovak Biomass Forum 2005 [Jakubes 2005].

Table 7.2. Use of biomass in the year 2003 and potentials for 2010 in the Czech Republic.[109]

Source: Jakubes 2005.

PJ/a	Use 2003	Potentials 2010
Firewood, waste wood, other solid biofuels	37,2	32,8 - 39,3[110]
Cereal straw	0,04	6 - 22,4
Rapeseed straw	0,2	9,7 - 12,2
Energy crops	~ 0	6 - 22,5 (63)
Biodiesel	2,66	4,2 - 9,2
Bioethanol	~ 0	9
Biogas	1,7	4,7 - 7 (21,8)
Total	**41,8**	**72,4 - 121,6 (176,9)**

Figure 7.16 gives an impression of the available potentials of solid biomass in the Czech Repubilic. The data are mainly based on [Jakubes 2005], so they can be interpreted as the available potentials in the year 2010. The category with the biggest range of values is definitely "energy crops". However, since 40 % of the country area is

[109] The estimations of the potentials originate from the "National Energy Efficiency Study 1999" (lower estimate) and the non-governmental organization *CZ Biom* (higher estimate).

[110] According to [Jakubes 2005] this potential is possibly underestimated.

arable land, energy crops could definitely become an important source of biomass in the Czech Republic.

The total short-term potential of solid biomass can be estimated about 100 PJ/a. On very long term, extensive use of energy crops and forest biomass could provide a total energy amount of more than 200 PJ/a.

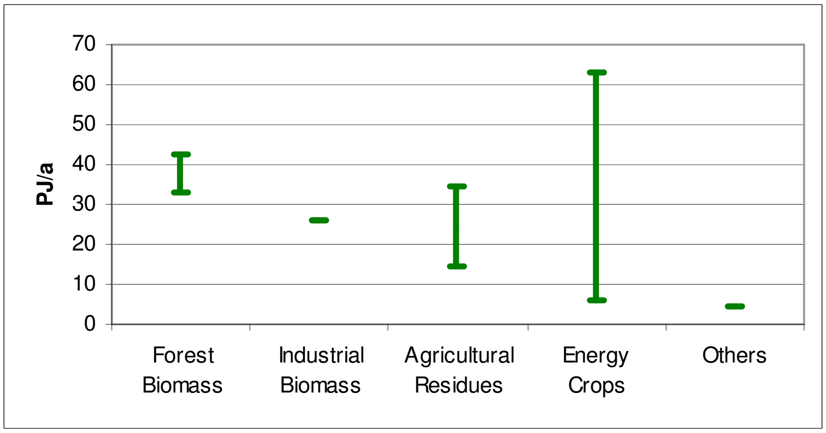


Figure 7.16. Ranges of the potentials of solid biomass in the Czech Republic stated in literature.
Sources: Nikolaou et al. 2003, Karjalainen et al. 2004, Jakubes 2005, enerCEE 2005.

According to [Knapek et al. 2005], the biomass market in the Czech Republic is not fully developed yet. To some extent it still has regional character and as a result, the price ranges of different fractions of solid biomass are relatively big (Figure 7.17).

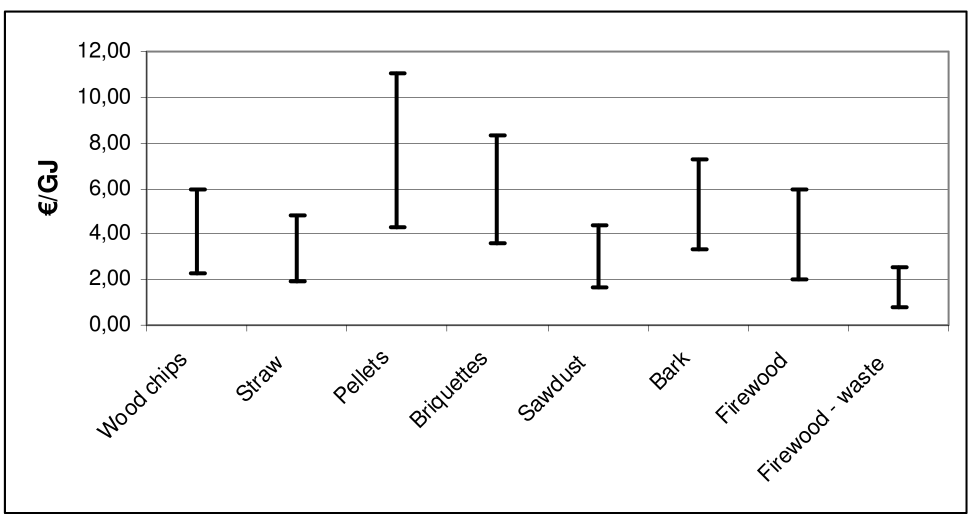


Figure 7.17. Price ranges of solid biomass in the Czech Republic in 2004.
Source: Knapek et al. 2005.

7.2.2.3 Slovenia

Slovenia is a heavily wooded country with about 57 % of the land area covered with forests. The share of renewable energy in the primary energy balance is about 11 %, about 6.9 % coming from biomass (Figure 7.18). Fuelwood and forest residues are especially important for domestic heating. The number of households using wood as only source of energy is decreasing but there is a notable trend towards new biomass technologies with higher efficiencies and lower emissions.

There are only few bigger biomass users in Slovenia: six district heating systems, five combined heat and power generation plants and 35 biomass systems in industry [Krajnc 2005].

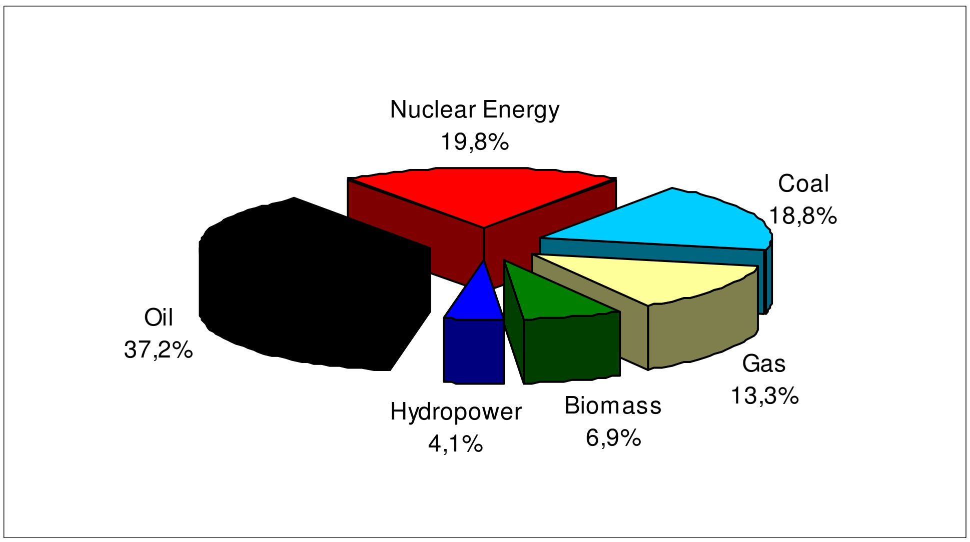


Figure 7.18. Primary energy demand of Slovenia in 2003.
Source: enerCEE 2005.

Besides fuel wood and wood residues from forestry, industrial byproducts are an important source of energy. Approximately 700,000 m^3 of industrial residues are produced every year. About 50 % of these are used by wood processing companies to cover their internal power and heat demand, the rest is mostly sold on markets.

Biomass from agriculture is currently not used for energy production in Slovenia. No data about the potential of energy crops was found in literature but the available area of arable land is definitely modest. Own estimations of the short term potential of energy crops are 1.75 PJ/a[111].

[111] The area which could be used for the production of energy crops is 178.226 ha. It was assumed that on short term 7 % of this area could be dedicated to the production of energy

Figure 7.19 illustrates the ranges of estimated potentials of solid biomass in literature. Forest biomass has by far the biggest potential in Slovenia. About 30 PJ/a seems to be a realistic estimation of the total potential of solid biomass in Slovenia.

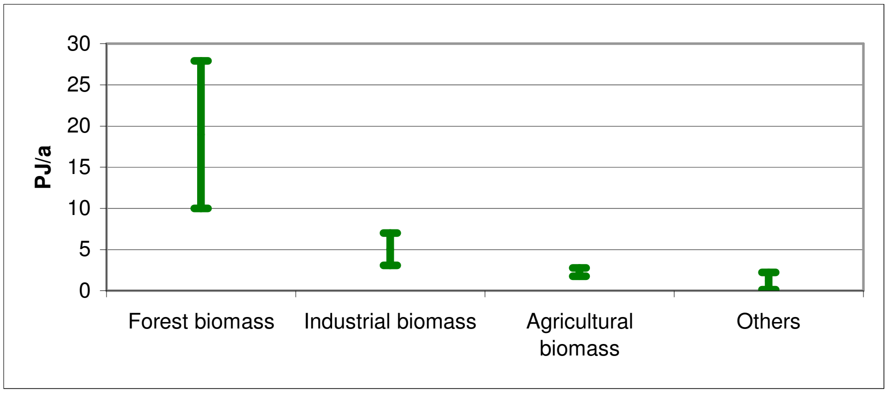


Figure 7.19. Ranges of the potentials of solid biomass in Slovakia stated in literature. Sources: AFB-net 2001, Nikolaou et al. 2003, Karjalainen et al. 2004, Krajnc 2005, Al-Mansour 2005.

7.2.2.4 Hungary

With a share of 46 % in the total primary energy demand, gas is Hungary's most important source of energy (Figure 7.20). But the domestic production of natural gas is decreasing and Hungary is becoming increasingly dependant on imports.

The current utilization of biomass and hydropower accounts for only 1.7 % of the total energy demand but renewable energy sources are getting a more and more important role in the national energy-policy [Vityi 2005]. By the year 2010, 3.6 % of electric energy[112] and 6-7 % of the total energy consumption is planned to come from renewable sources. Biomass already accounts for the largest share of Hungary's RE consumption and it is likely to become even more important in the near future.

crops, that the average yield is 10 t of dry substance per hectare and that the energy content is 3.9 MWh/t.

[112] Today the ratio of electric power from RES is 0.7%.

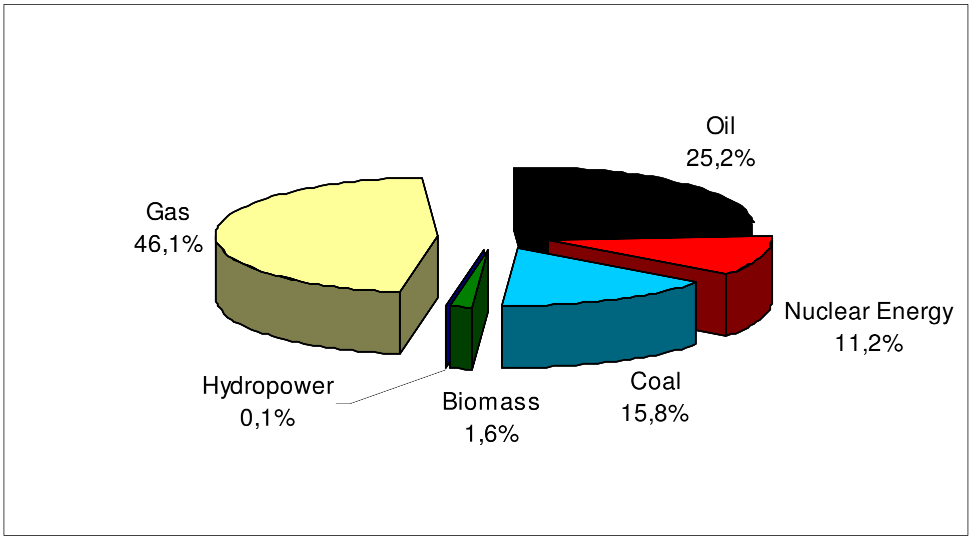


Figure 7.20. Primary energy demand of Hungary in 2003.
Source: enerCEE 2005.

Just like in most other central European countries, domestic heating with fuelwood is the predominant use of biomass in Hungary. Additionally, forest residues and industrial byproducts are used to cover the energy demand in sawmills and for the production of briquettes. Nearly 40 % of the total felling is used for energy purposes.

In the year 2000, the installed capacity of biomass boilers accounted for about 500 MW [enerCEE 2005]. The better part was fueled with industrial wastes (300 MW) or forest residues (175 MW). The rest was fueled with agricultural wastes. The total use of solid biomass in the year 2000 was 14.8 PJ.
In the last five years the most important development concerning biomass energy took place in the generation of electrical energy. Between 2003 and 2005 three coal-fired power plants with a total capacity of 100 MW switched to wood chips.
According to [Nikolaou et al. 2003], energy crops with an energy content of 44.17 PJ were utilized in the year 2000. However, this data seems unreliable. According to [enerCEE 2005], no energy crops were used to produce electricity or heat in 2000.

The total potential of solid biomass without forestry byproducts and energy crops according to [Nikolaou et al. 2003] is about 62 PJ/a. Since 52.2% of the county area is arable land [enerCEE 2005] the potential of energy crops can be considered to be significant. The potential of solid biomass according to [Vityi 2005] is presented in Table 7.3.

Table 7.3. Potentials of solid biomass in Hungary.
Source: Vityi 2005.

	PJ/a
Wood	
Fuel wood	20 - 22
SRC	30 - 32
Forest residues	5 - 7
Industrial residues	1,5 - 2
Plants	
Agricultural residues	10 - 12
Other plant byproducts	30 - 50
Energy crops	30 - 40
Wastes	
Food production	3 - 5
Domestic wastes	6 - 9
TOTAL	**135,5 - 179**

In [Commission of the EC 2004] Hungary's mid-term biomass potentials are separated into electricity and heat production. The total biomass potential according to this report is approximately 117 PJ/a. Biomass electricity accounts for 50.5 PJ/a (48 PJ/a from solid biomass and 2.5 PJ/a from biowaste). The amount of biomass heat is about 66.5 PJ/a.

The ranges of potentials stated in literature are illustrated in Figure 7.21. Both forestry and agriculture could provide significant amounts of solid biomass. The current use of biomass in Hungary accounts for approximately 28 PJ/a.

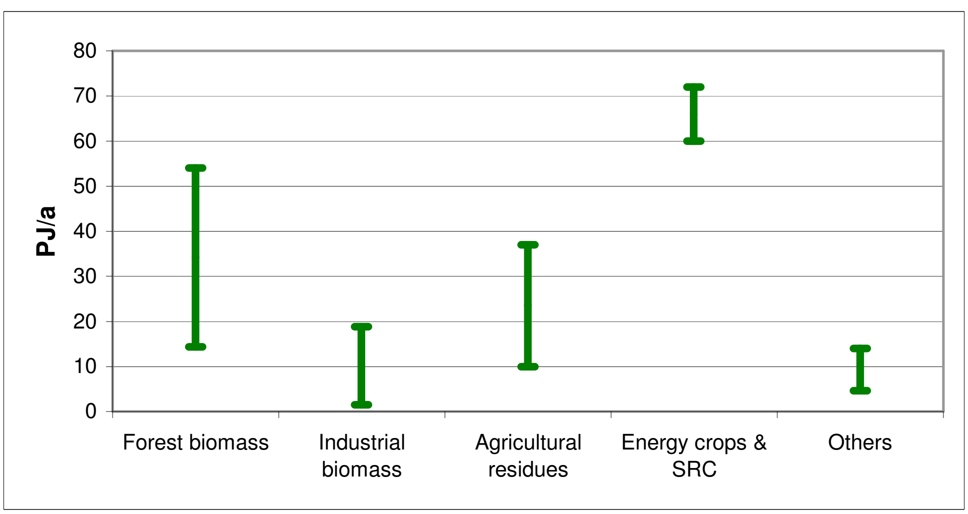


Figure 7.21. Ranges of the potentials of solid biomass in Hungary stated in literature.
Sources: Nikolaou et al. 2003, Karjalainen et al. 2004, Vityi 2005.

7.2.2.5 Poland

Since there are substantial coal reserves in Poland, coal has a dominant role in energy supply (Figure 7.22). But due to outdated mining equipment and unfavorable geological conditions, coal production is becoming more and more difficult and economically inefficient. As a consequence, coal prices have been rising in the past few years which resulted in a notable increase in the consumption of biomass.

Biomass is by far the most important renewable energy source and is considered to be the most promising renewable energy for both heat and power generation in Poland. In recent years important developments in energy production from fuelwood, felling residues and agricultural byproducts have taken place. Biomass has been used to replace coal as a fuel for individual and industrial heating plants as well as combined heat and power plants and district heating systems which are very common in Poland. In the year 1999, about 70 % of the total heat demand in the municipal sector was covered with district heating systems. In rural areas individual boilers are more common. Since there are big resources of both biomass and coal, Poland has good preconditions for co-combustion of biomass with coal.

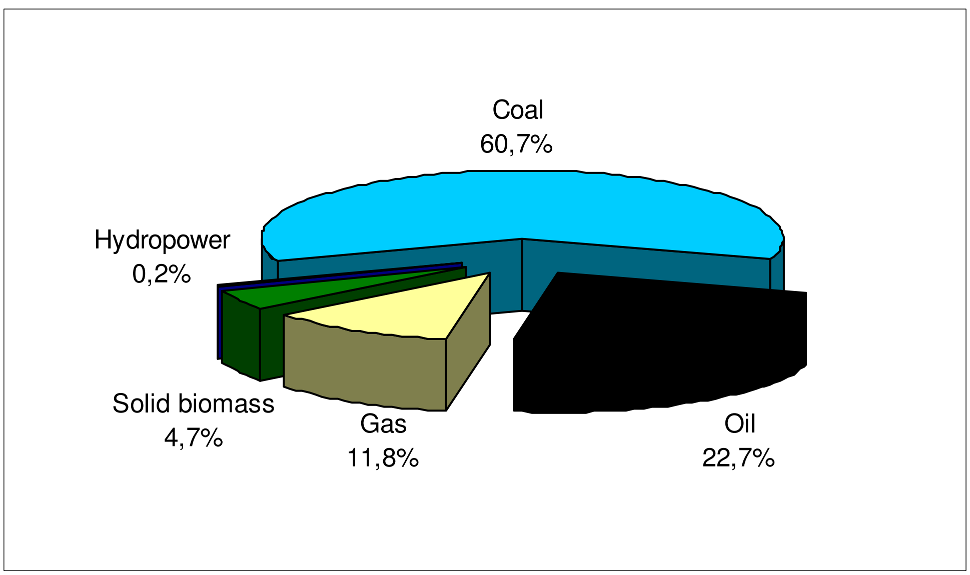


Figure 7.22. Primary energy consumption of Poland in 2003.
Source: enerCEE 2005.

The technical potentials and utilization of biomass according to [Scholwin et al. 2005] are presented in Table 7.4. Fuel wood is clearly the most important fraction, followed by waste wood and industrial residues. With an estimated potential of more than 250 PJ/a agriculture could possibly provide the biggest amounts of solid biomass in Poland (straw, hay and energy crops).

Table 7.4. Technical potentials and use of biomass in Poland.
Source: Scholwin et al. 2005.

PJ/a	Technical Potential	Use in 2002/03
Straw	114	1,5
Hay	10	0,0
Fuel wood	230	104,0
Industrial residues	29	24,0
Waste wood	43	29,0
Energy crops	130	0,3
Prunings	16	1,1
TOTAL	**572**	**159,9**

An overview of Poland's biomass potentials stated in different studies is presented in Figure 7.23. Although the data about potentials of energy crops and short rotation coppice differ a lot, all studies agree that agricultural biomass has the biggest potential.

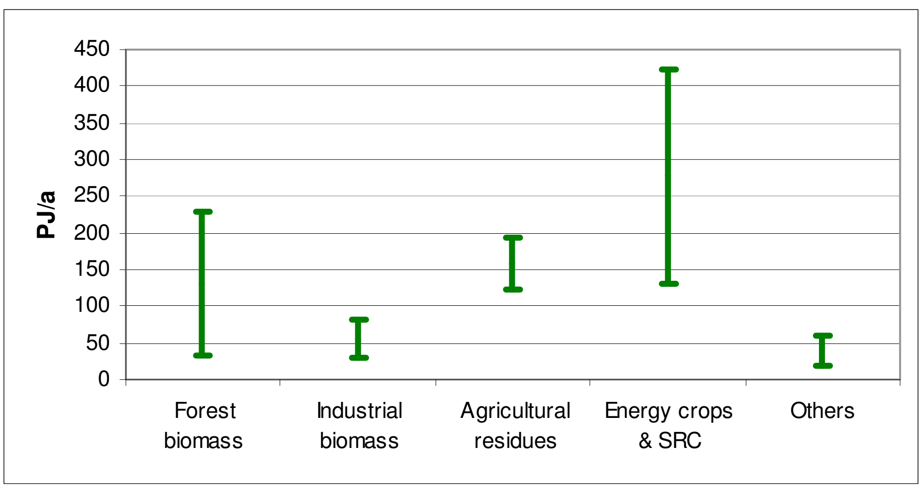


Figure 7.23. Ranges of the potentials of solid biomass in Poland stated in literature.
Sources: AFB-net 2001, Nikolaou et al. 2003, Karjalainen et al. 2004, Scholwin et al. 2005, Rogulska et al. 2005, Jääskeläinen et al. 1999.

7.2.3 Cost-resource Curves

The following figures show short-term cost-resource curves for the Czech Republic, Hungary, Poland, Slovakia and Slovenia. These curves illustrate the available resources of solid biomass and their delivery costs[113]. The potentials can be regarded realizable until 2020. The fractions of biomass which have been taken into account are fuelwood, forestry byproducts, industrial residues, agricultural byproducts and energy crops. There was no data about the costs of short rotation coppice available, so this fraction is not included. In all of the considered countries agricultural byproducts are the cheapest and energy crops the most expensive fraction. Fuelwood is always cheaper than forestry byproducts.
In the Czech Republic, both the costs for industrial residues and for fuelwood are 4.1 €/GJ. In the other countries there are slight differences; in Hungary and Poland fuelwood is cheaper, in Slovakia and Slovenia industrial residues.

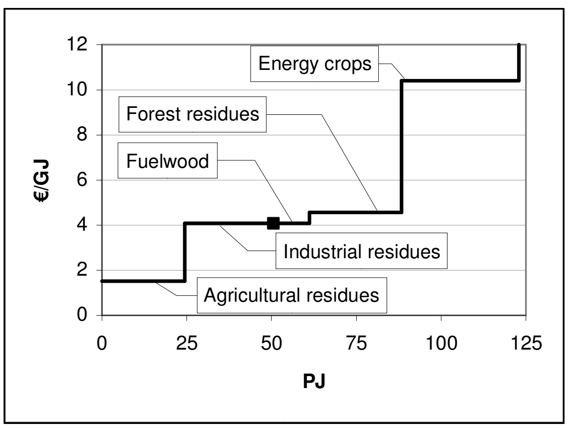


Figure 7.24a. Cost-resource curve for the Czech Republic.

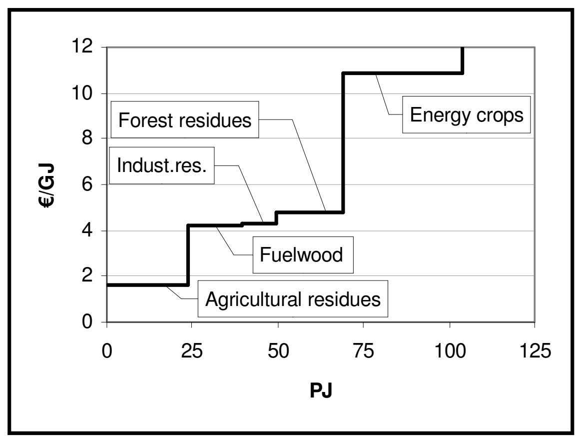


Figure 7.24b. Cost-resource curve for Hungary.

[113] The potentials are average values from literature, the delivery costs have been adopted from [Nikolaou et al. 2003].

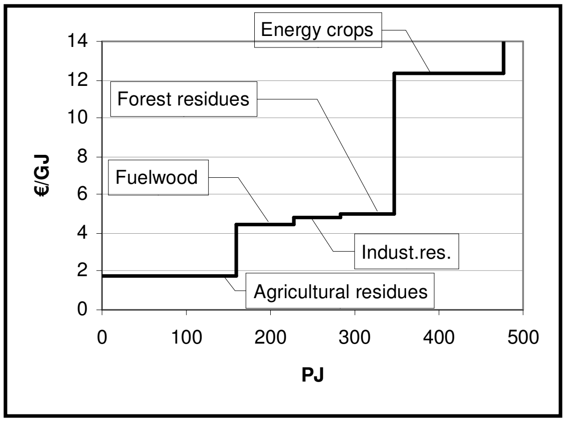


Figure 7.24c. Cost-resource curve for Poland.

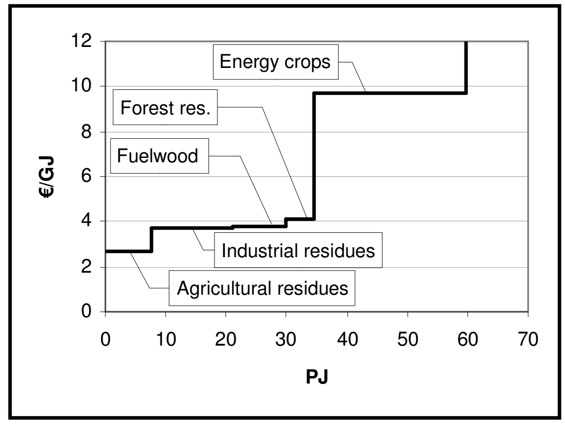


Figure 7.24d. Cost-resource curve for Slovakia.

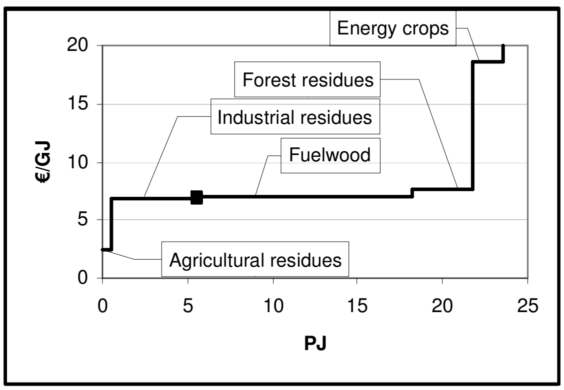


Figure 7.24e. Cost-resource curve for Slovenia.

7.2.4 Summary

The data about potentials of solid biomass differ a lot. However, by comparing different studies it is possible to get an idea of the dimensions of available biomass resources. The ranges of estimates of the total potential of solid biomass stated in different studies are illustrated in Figure 7.25.

The specifications of the data which have been included in this summary are various. Common specifications were “short-term potential”, “potential for 2010” or “technical potential”. To get a better idea of the available resources of biomass, the higher values can be interpreted as theoretically available or medium- to long-term potentials and the lower values as short-term realizable potentials.

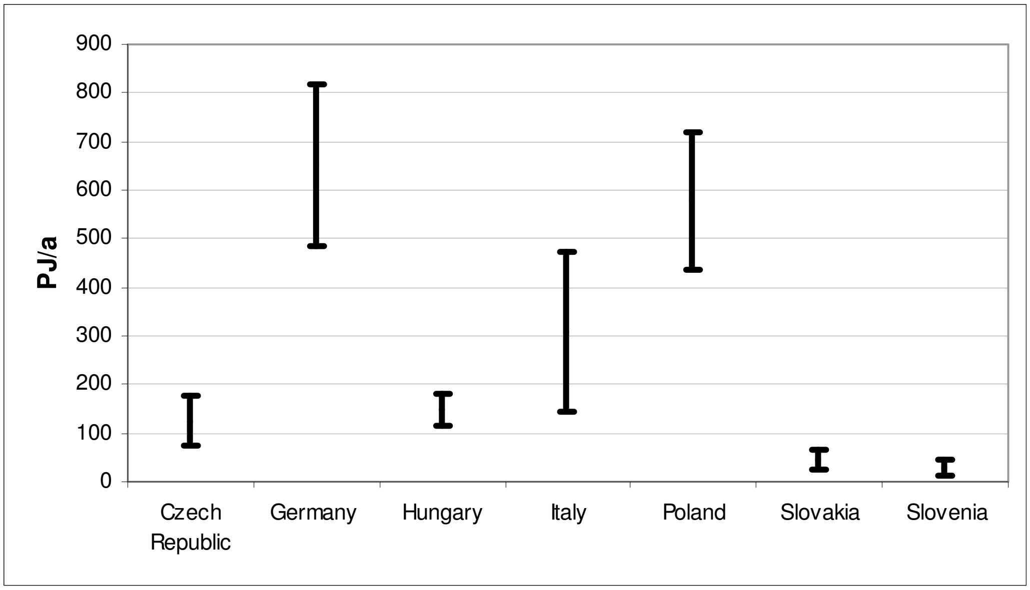


Figure 7.25. Summary of the total potentials of solid biomass stated in different studies. Sources: AFB-net 2001, Nikolaou et al. 2003, Commission of the EC 2004; *Czech Republic*: Jakubes 2005 ; *Hungary*: Vityi 2005; *Poland*: Scholwin et al. 2005, Rogulska et al. 2005; *Slovakia*: Viglasky et al. 2005, Soltes 2005, Jääskeläinen et al. 1999; *Slovenia:* Krajnc 2005.

7.3 Liquid Biofuels

Biodiesel and bioethanol can be produced from a variety of raw materials. In Europe, the main crops for the production of biodiesel are rape and sunflower. Waste cooking oils are also used to a limited extent. For the production of ethanol virtually any source of carbohydrates can be used. The main crops for the industrial production in Europe are wheat and sugar beet. Ethanol can be used in blends with petrol or pure for dedicated engines. In France and Spain, it is increasingly transformed to ether (ETBE) and used as an additive to petrol.

7.3.1 Biodiesel Production and Capacities in the EU

Biodiesel has become a fast-growing renewable liquid biofuel within the European Community. Figure 7.26 shows the development of biodiesel production from 1992 to 2004. Since 1992, rape seed and sunflower biodiesel production has highly increased. In 2004 the total production in the EU amounted to almost 2 million tons per year.

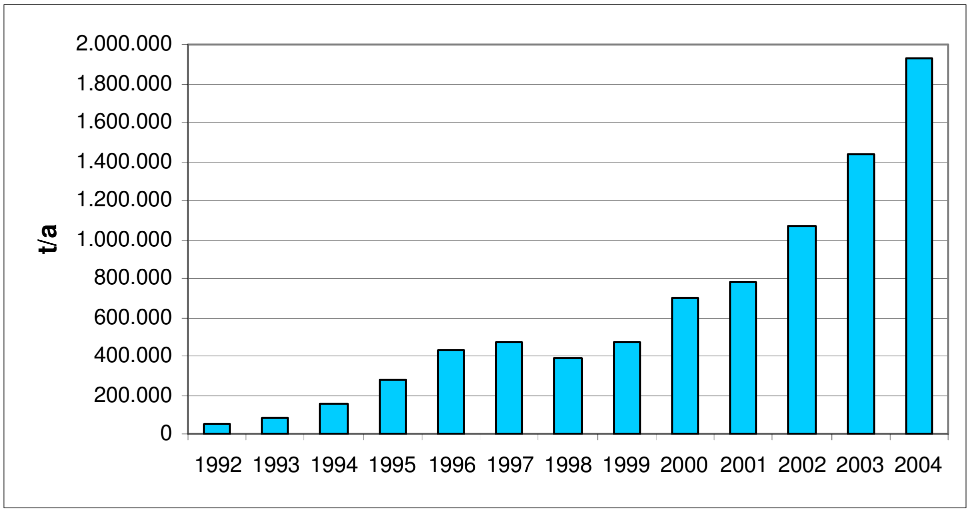


Figure 7.26. Total biodiesel production in the EU.
Source: EBB 2005.

The following figures show the development of biodiesel production and capacities in the Czech Republic, Germany, Italy and Slovakia. For Germany and the Czech Republic the consumption of biodiesel is also plotted. These data illustrate that Germany and the Czech Republic are net-importers of biodiesel. Austria, on the other hand, has been exporting biodiesel in recent years. There is was no data available about the production capacities in the Czech Republic.

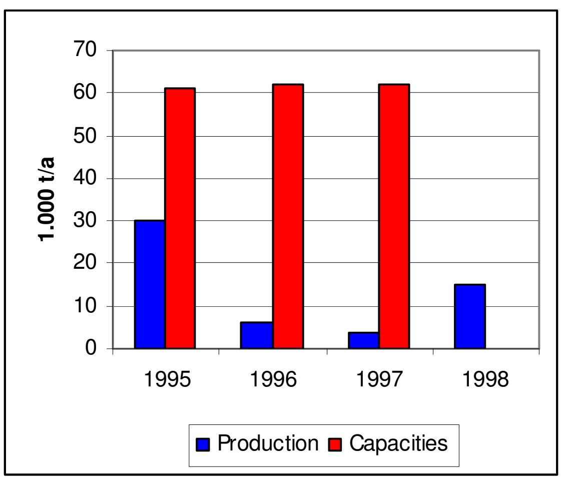


Figure 7.27a. Development of biodiesel capacities and production in Slovakia.

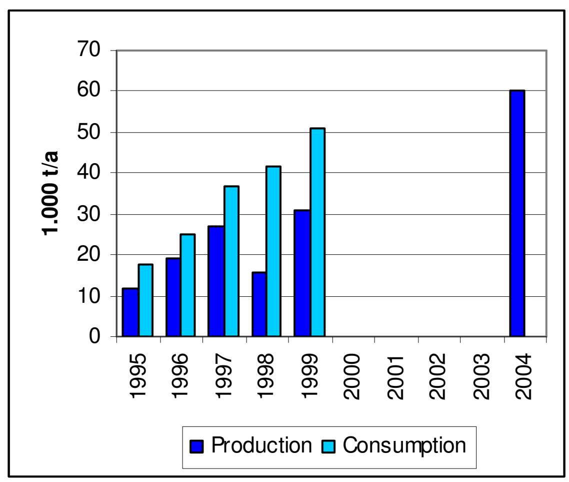
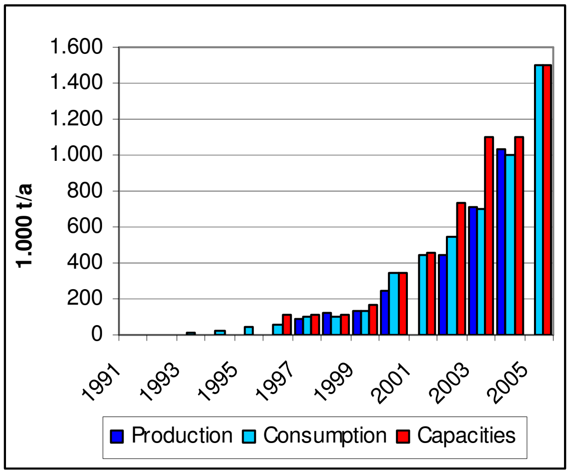


Figure 7.27b. Development of biodiesel production and consumption in the Czech Republic



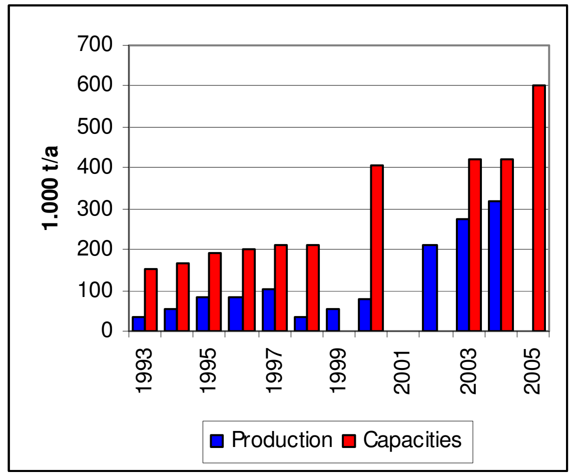


Figure 7.27c. Development of biodiesel capacities, sales and production in Germany.

Figure 7.27d. Development of biodiesel capacities and production in Italy.

Sources: EBB 2005, Eibensteiner et al. 2000, UFOP 2005.

There is no production of biodiesel or other biofuels in Slovenia. In the year 2002, 5,179 tons of rape seed for the production of biodiesel were produced in Slovenia but the entire amount of rape seed and collected waste food oil was exported to Austria [Al-Mansour 2005]. There is also no production of biodiesel in Hungary. In Poland, small amounts are produced on a pilot scale and some projects are in the development phase.

The planned biodiesel production capacities in European countries for 2005/06 are presented in Figure 7.28. Germany has by far the biggest capacities, followed by Italy and France. In Austria there are already production capacities for more than 100,000 tons of biodiesel per year, the planned capacity for 2005/06 is 140.000 t/a. The total planned capacities in Europe are more than 3.7 million t/a. With an average harvest of 1.4 t/ha, about 2.65 million ha of agricultural crop land will be required to produce this amount of biodiesel.

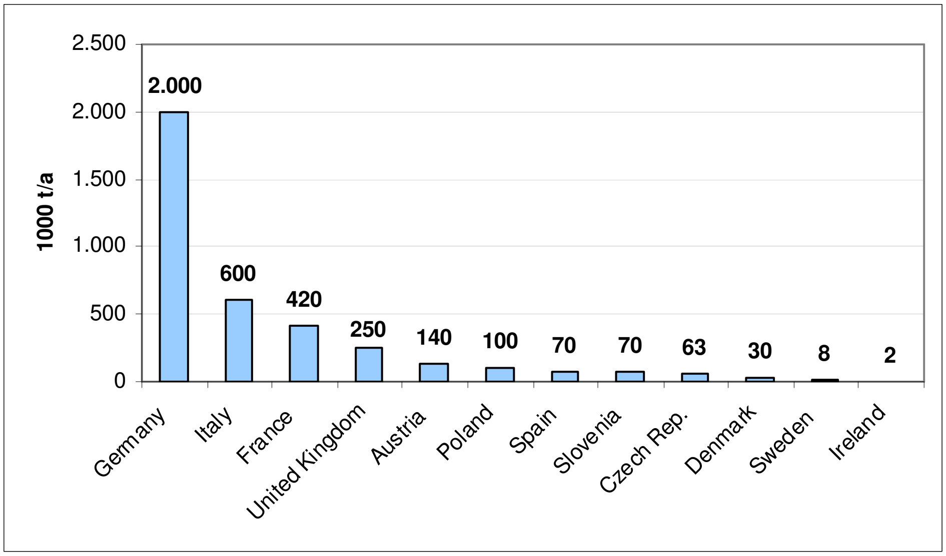


Figure 7.28. Planned biodiesel production capacities in Europe for 2005/06.
Source: UFOP 2005

7.3.2 Costs of Energy Crops for Biodiesel Production

The European biodiesel production is heterogeneous. There are different production technologies and different raw materials being used. The production costs of oil seeds which can be used for the production of biodiesel are also quite different from country to country. They are illustrated in Figure 7.29a.

The average annual yields per hectare are shown in Figure 7.29b. It is clear that the crop yield has a major influence on the total production costs of biodiesel. The production costs in countries with relatively high yields like Austria and Germany are significantly lower than in the Czech Republic, Hungary or Poland. With regard to average yields, Slovakia has relatively low and Slovenia high production costs. The data for Italy seem to be highly questionable; especially the exceedingly high value of the production costs, since Italy is one of the main producers of biodiesel in Europe.

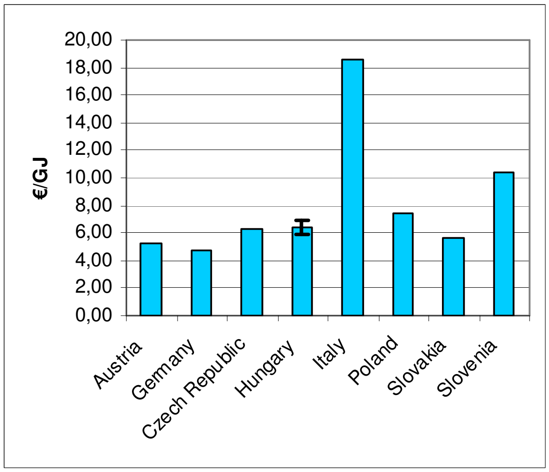


Figure 7.29a. Production costs of oil seeds for biodiesel.
Source: Nikolaou et al. 2003, Austria: Tretter 2004, Germany: UFOP 2005a

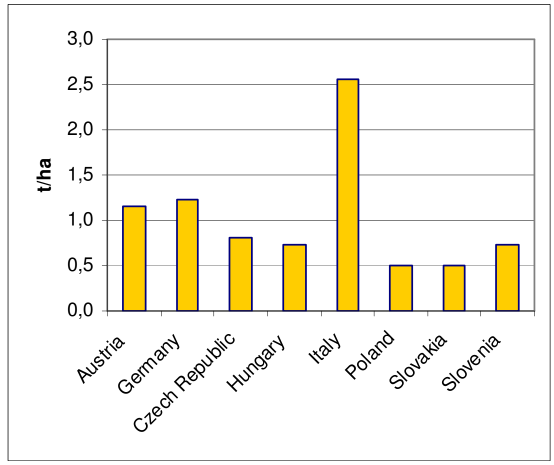


Figure 7.29b. Annual biodiesel yields per hectare.
Source: Nikolaou et al. 2003

7.3.4 Bioethanol and ETBE Production and Capacities in the EU

France, Spain and Sweden are the only European countries with a significant production of bioethanol/ETBE. In 2002, about 90,500 tons of ethanol were produced in France and about 80,000 tons in Spain. In these countries, ethanol is usually transformed to ETBE. The ethanol production in Sweden was approximately 50,000 tons. These data and the production capacities are illustrated in Figure 7.30.

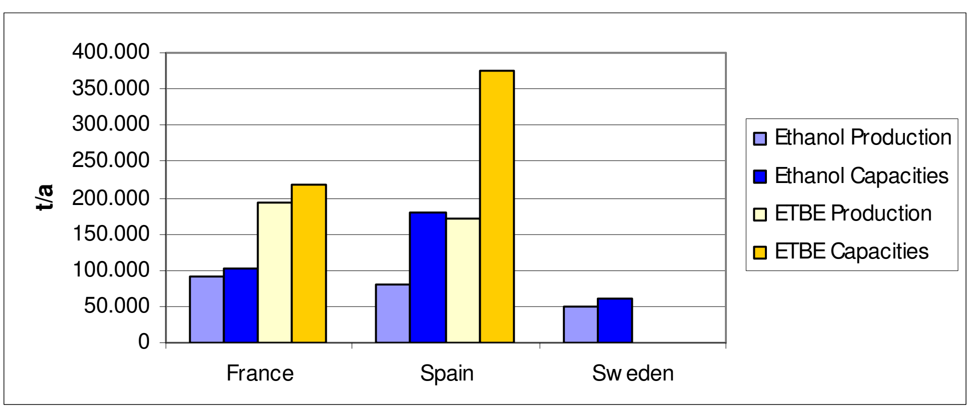


Figure 7.30. Ethanol and ETBE production and capacities in Europe in 2002.
Source: Eubionet 2003.

7.3.3 Potentials of Liquid Biofuels

Potentials of liquid biofuels depend on the arable land suitable for the cultivation of energy plants. In Austria an area of about 200,000 ha is suitable for the production of rape seed. With a yield of 3 to 3.5 tons of rape per hectare, approximately 200,000 to 230,000 t of biodiesel could be produced per year [Eibensteiner et al. 2000]. The potential of biodiesel in the Czech Republic is estimated between 4.2 and 9.2 PJ/a (112,000 to 246,000 t/a). The potential in Slovakia is estimated 11 PJ/a [Ilavský 2005].
In Germany, the area suitable for the production of rapeseed is about 2 million ha. Provided that half of this area is used for food rape oil, the potential of biodiesel in Germany is 1.4 to 1.9 million tons per year[114]. With this amount about 5 to 7 % of the fossil diesel consumption could be substituted [Eibensteiner et al. 2000].
According to [Vityi 2005], the potential of biofuels in Hungary is approximately 4 to 6 PJ/a. The available arable area which could be used for the cultivation of rape seed in Slovenia is estimated between 6,000 and 7,000 ha [Al-Mansour 2005]. Between 6,000 and 8,000 t of biodiesel could be produced on this area.

Figure 7.31 illustrates the production of liquid biofuels in 2002 and the mid-term potentials according to [Commission of the EC 2004]. The production data stated in this paper do not fully accord with the data from other sources presented in the previous chapters and the potentials are considerably higher than estimates in most other studies.

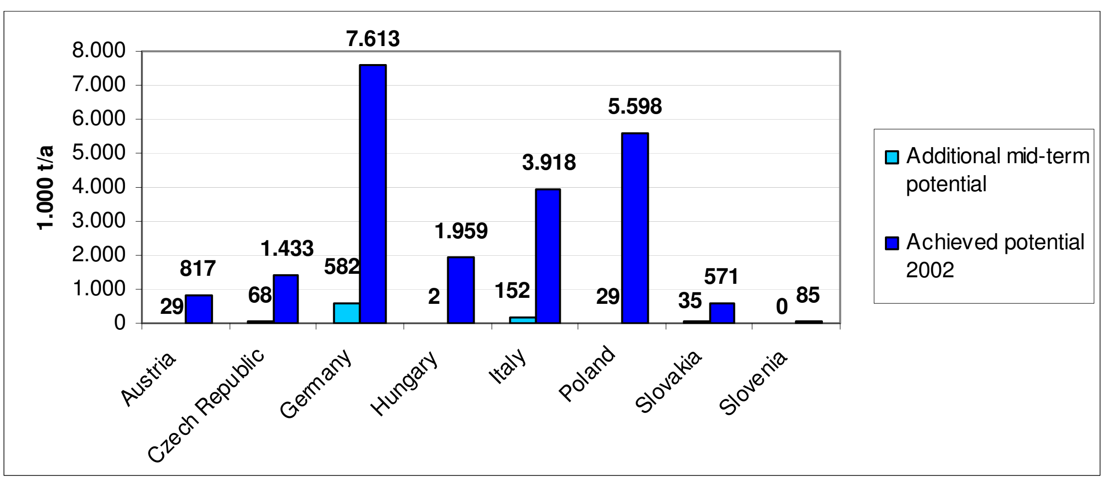


Figure 7.31. Mid-term potentials of liquid biofuels and production in central European countries in 2002.
Source: Commission of the EC 2004

[114] Since the planned capacities for 2005/06 amount to 2 million tones per year, this potential is possibly underestimated.

8 Conclusion

The main objective of this study was to assess the additionally realizable potentials of solid biomass in Austria and to illustrate them in cost-resource curves. Figure 8.1 shows a comparison of the results of this study with estimates stated in literature[115].

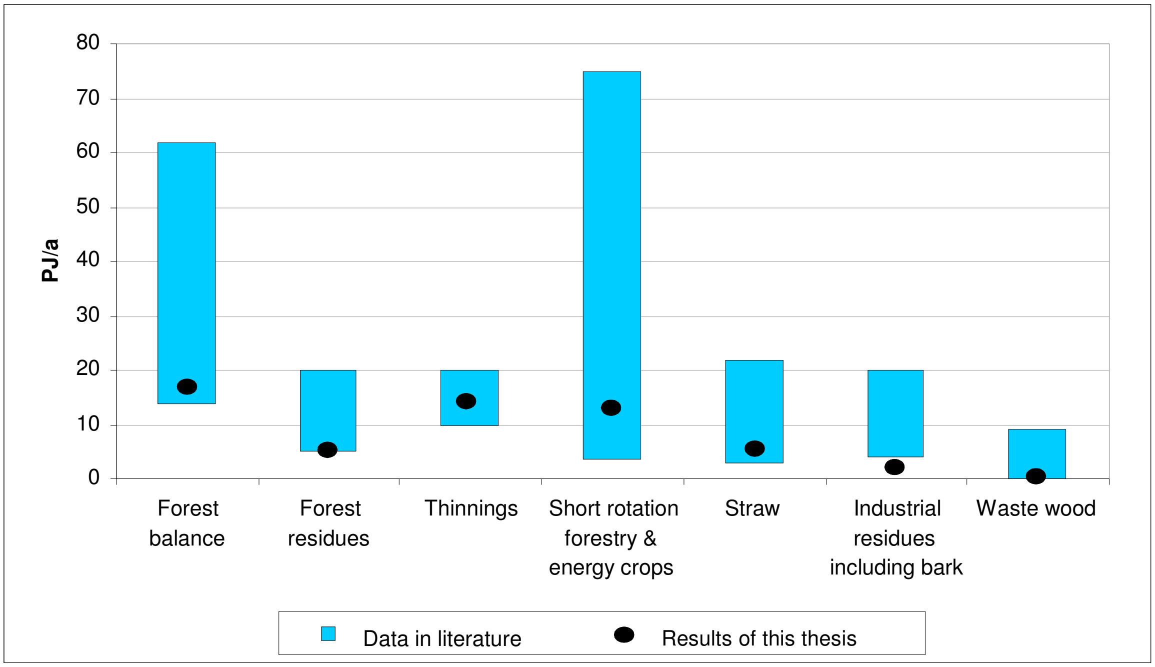


Figure 8.1. Additionally realizable potentials of solid biomass in Austria – Comparison of the results of this thesis with data in literature.
Sources: See Tables 3.1, 4.2 and 5.1, Haas et al. 2002, own calculations.

The cost-resource curve for the total potential of approximately 70 PJ/a is illustrated in Figure 8.2. The main conclusions that can be derived from this figure are:

- Additional amounts of **cheap biomass** (provision costs of less than 3 €/GJ) will account for **less than 5 PJ/a.** These fractions are bark from the increased production of the sawmill industry, additional amounts of straw and forest wood chips from felling residues and trees harvested under most favorable conditions.
- From 5 to 68 PJ of additional bioenergy the **provision costs** will **increase almost linearly.** This increase can be approximated very well by a straight line. (The coefficient of determination R^2 has a value of 0.973.)

115 It has to be pointed out that the results of this thesis are additionally realizable potentials whereas “data in literature” also include estimates declared as “additional technical potentials”, which have clearly higher values.

- The **biggest additional potential** comes from **forest biomass** (**36 PJ/a**). The provision costs for forest wood chips range from less than 3 €/GJ to more than 10 €/GJ, depending on harvesting technologies, tree diameters and tree species.
- The realizable short-term potential (until 2010 to 2020) of **agricultural energy plants** is about **10 to 15 PJ/a**. The provision costs for wood chips from short rotation coppice are highly dependant on the applied method of harvesting. (The total production costs range from 3.60 to 5.90 €/GJ.)
- With an additional potential of **15.5 PJ/a**, **wood pellets** account for more than 20 % of the total additional potential. Due to the rapidly increasing number of pellet boilers in Austria, this potential is probably most likely to be utilized in the next 5 to 10 years. It has to be noted that the value of the pellets potential originates from the expected production in Austria in the year 2010. For achieving this potential, a shift of industrial byproduct utilization from industrial use (paper and board industry) to pellet production will occur. Only small amounts of additionally available industrial byproducts (less than 2.5 PJ in 2010) can be expected from the growth of the sawmill industry.
- Assuming that an additional amount of 40 PJ of bioenergy will be required in 2010, the price for biomass would theoretically account for 5 €/GJ.

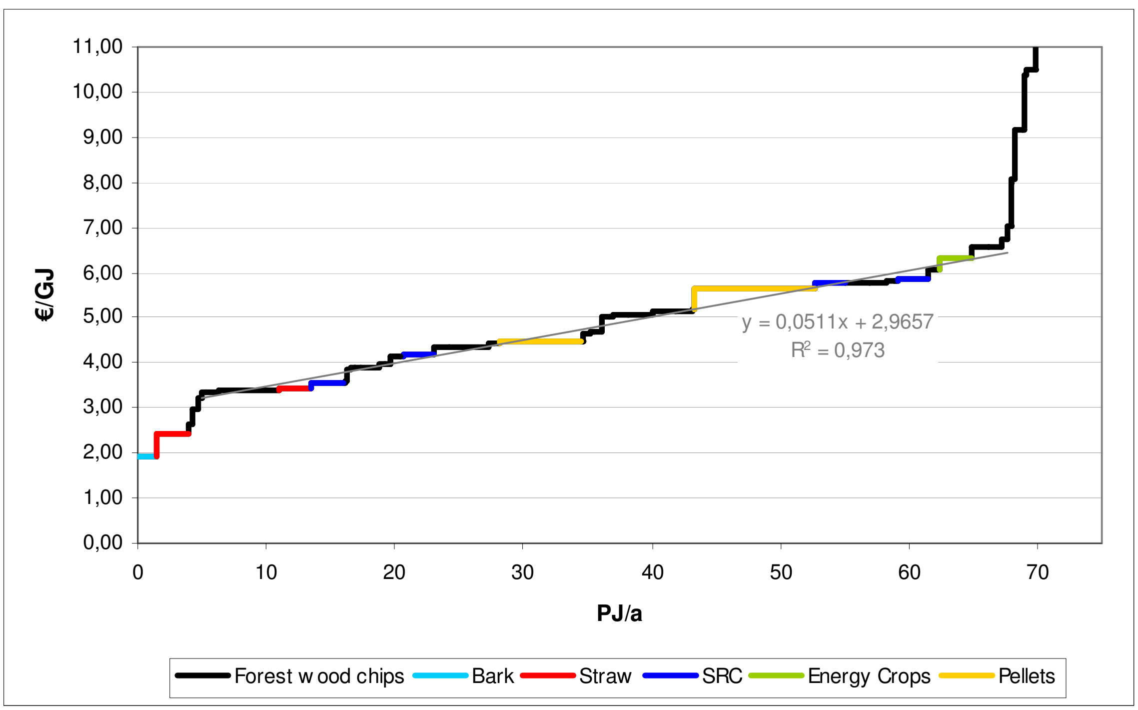


Figure 8.2. Cost-resource curve of the additionally realizable potential of solid biomass[116].

[116] This curve is based on the following assumptions: Only trees with a maximum diameter of 25 cm and felling residues are used for wood chip production. The additional potential of bark is

Although it was assumed that only small trees and felling residues are used for the production of wood chips, forest biomass represents the biggest potential of solid biomass. The main problem concerning its realization is probably the ownership structure of Austria's forests. The biggest share of Austria's forests are small forests in the possession of private persons (mostly farmers) and their willingness to cultivate the forests seems to be decreasing since most of the unutilized stock increment is situated in private forests. For the activation of the full potential of forest biomass it will be essential to overcome this structural barrier, for example by supporting the foundation of forest communities. Rising prices for fossil fuels will possibly lead to additional demand for wood fuels and increasing awareness of the additionally available potential of forest biomass.

Due to the increasing demand for industrial residues for both energy and non-energy purposes, it can be assumed that major changes in the distribution of sawdust and industrial wood chips will occur. In the year 2010, about 30 to 40 % of the domestic production of this fraction will be required for the production of wood pellets. In the year 2003 this share was less than 10 %. Hence, it seems likely that the price of industrial residues will rise in the near future, that increasing amounts will have to be imported and that the domestic felling will rise.

Due to higher yields and lower production costs short rotation coppice is preferable to energy crops. Still it can be assumed that activities will concentrate on energy crops in the near future. The main barriers concerning short rotation coppice are the required long-term commitment of farmers and the lack of dedicated machines for highly mechanized harvesting. Although in other countries the technological know-how for highly mechanized harvesting of short rotation coppice exists, in Austria it has not yet

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derived from the scenario "Estimate [Schachenmann 2003]" (Table 4.1). For the additional potentials of agricultural biomass, Scenario 2 from Figure 5.10 was chosen (40 % energy crops, 60 % short rotation coppice). For this scenario it was presumed that that there will be no increase in the production of oilseeds for biodiesel. The potentials of pellets are based on the assumption that enough industrial residues for the production of 1 million tons of wood pellets can be made available and that the price for the raw material will increase by 1 €/GJ. Because of the technical barriers of straw pellets, they are not included in this curve. According to [Lechner et al. 2003], all available amounts of waste wood are already used for energy or non-energy purposes and therefore, it is also not included in this curve. However, a higher level of non-energy use of biomass could lead to additional amounts of waste wood for energy purposes after the period of its original use. But this higher amount of waste wood would definitely not appear in the period investigated in this thesis (2010-2020).

become broadly available and applied. Energy crops, on the other hand, have the advantage that production and harvesting technologies are well known and their importance for the production of liquid biofuels and biogas will definitely rise.

The results of this thesis show that Austria has still high amounts of currently unused biomass potentials. However, in the view of successful promotion strategies and political targets for the enhanced use of biomass the competition for cheap biomass fractions will further increase. In order to prepare the path for the role of biomass in a future sustainable energy system, two strategies will be important: First, the efficient and economical use of biomass and second to overcome barriers for mobilizing additional biomass potentials in a cost effective and ecologically sound manner.

9 Appendix

9.1 References

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9.2 Data Tables

The following tables show the data to the figures in the chapters 2 to 7.

Table F2.1. Development of energy consumption in Austria.

Source: Statistik Austria 2005.

PJ/a	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993
Domestic raw energy	330	340	346	339	347	353	353	345	356	366	370
Imports	606	696	719	722	722	678	703	775	801	796	787
Gross inland consumption	934	976	1.003	995	1.019	997	1.011	1.056	1.126	1.084	1.093

PJ/a	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Domestic raw energy	355	369	365	371	375	410	411	413	417	438
Imports	792	836	929	912	973	925	925	980	1.029	1.118
Gross inland consumption	1.088	1.140	1.212	1.212	1.229	1.225	1.218	1.288	1.306	1.398

Table F2.4. Development of the primary energy production form biomass and wastes in Austria.

Source: Eurostat 2005.

	1992	1993	1994	1995	1996	1997
1.000 toe	2.419	2.504	2.449	2.636	2.824	2.853
PJ	101,28	104,84	102,54	110,37	118,24	119,46

	1998	1999	2000	2001	2002	2003
1.000 toe	2.739	2.910	2.819	3.140	3.204	3.420
PJ	114,68	121,84	118,03	131,47	134,15	143,20

Table F2.5. Development of annual consumption of biogenous fuels and fuelwood in Austria.

Source: Statistik Austria 2005.

PJ/a	1990	1991	1992	1993	1994	1995	1996
Biogenous fuels	31,26	32,88	34,07	37,99	38,99	40,51	41,68
Fuelwood	63,12	69,96	65,98	67,18	62,39	67,35	73,29

PJ/a	1997	1998	1999	2000	2001	2002	2003
Biogenous fuels	47,94	44,71	55,73	54,17	59,65	60,52	67,78
Fuelwood	67,21	64,88	65,94	60,23	68,15	66,11	71,79

Table F2.7. Annual increase of biomass heating systems up to 100 kW in Austria.
Source: LK 2005.

	1989	1990	1991	1992	1993	1994	1995	1996
Wood chips	892	1.036	1.548	1.501	1.443	1.479	1.579	2.280
Pellets	0	0	0	0	0	0	0	0
Total	892	1.036	1.548	1.501	1.443	1.479	1.579	2.280

	1997	1998	1999	2000	2001	2002	2003	2004	Total
Wood chips	2.027	1.913	2.058	2.149	2.344	2.392	2.558	2.855	30.054
Pellets	425	1.323	2.128	3.466	4.932	4.492	5.193	6.077	28.036
Total	2.452	3.236	4.186	5.615	7.276	6.884	7.751	8.932	58.090

Table F2.10. Development of the capacity of approved biomass plants in Austria.
Source: E-Control 2005a.

MW	Q4 2001	Q1 2002	Q2 2002	Q3 2002	Q4 2002	Q1 2003	Q2 2003
Solid biomass and wastes with high biogenous share	19,22	30,65	49,73	74,02	81,77	87,86	90,85
Liquid biomass	1,02	1,02	1,02	1,55	1,84	3,36	8,30
Biogas	1,55	2,51	4,72	7,49	12,13	16,52	17,44

MW	Q3 2003	Q4 2003	Q1 2004	Q2 2004	Q3 2004	Q4 2004	Q1 2005
Solid biomass and wastes with high biogenous share	102,15	114,34	157,53	181,14	196,58	307,56	378,84
Liquid biomass	8,63	10,35	10,57	13,90	14,08	17,29	18,79
Biogas	19,72	24,09	28,30	34,18	36,70	59,88	71,31

Table F2.11. Biodiesel production and capacities in Austria.
Sources: Krammer et al. 2003, Salchenegger 2004, Handler et al. 2001, AEA 2005.

t/a	1991	1992	1993	1994	1995	1996	1997	1998
Capacities	11.000	13.000	30.000	34.000	36.000	25.000	27.500	25.000
Production	5.900	7.500	8.300	13.400	15.900	13.800	19.400	17.650

t/a	1999	2000	2001	2002	2003	2004	2005
Capacities	25.000	30.000	32.000	40.000	90.000	120.000	140.000
Production	16.900	24.900	24.900	26.440	55.000	57.000	

Table F2.12. Development of fuelwood, electricity and fuel oil price index in Austria.
Source: LK 2005.

	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
Fuel oil	1,000	1,426	2,056	2,195	2,144	2,228	2,340	1,798	1,204	1,081	0,954	1,431	1,405
Fuelwood	1,000	1,238	1,327	1,222	1,152	1,140	1,222	1,289	1,263	1,241	1,214	1,198	1,213
Electricity	1,000	1,167	1,276	1,479	1,458	1,427	1,427	1,427	1,406	1,365	1,333	1,333	1,354

	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Fuel oil	1,036	1,036	0,921	0,839	1,011	1,029	0,791	0,976	1,767	1,523	1,392		
Fuelwood	1,167	1,060	1,025	1,085	1,050	1,031	1,060	1,070	1,023	1,026	1,028	1,033	1,023
Electricity	1,354	1,438	1,438	1,438	1,490	1,542	1,542	1,542	1,411	1,406	1,400	1,400	1,445

Table F3.1. Results of the Austrian Forest Inventories.
Source: Austrian Forest Inventory 2000/02.

Period	Area (ha)	Share (%)	Stock (million scm)
1961/70	3,69	44,0	790
1971/80	3,75	44,8	827
1981/85	3,86	46,0	934
1986/90	3,88	46,2	972
1992/96	3,92	46,8	988
2000/02	3,96	47,2	1.095

Table F3.10. Prices for fuelwood and forest wood chips in Austria.
Source: Holzkurier 2005.

	Fuelwood, hard (€/m^3 with bark)		Fuelwood, soft (€/m^3 with bark)		Forest wood chips (€/t)		Forest wood chips (€/m^3)	
	low	high	low	high	low	high	low	high
Burgenland	40,0	47,3	20,0	30,0	55,0	64,0		
Carinthia	41,0	48,0	30,0	33,0			12,0	14,0
Lower Austria	45,0	50,0	25,0	30,0	55,0	73,0		
Upper Austria	42,0	49,0	27,0	35,0	73,0	75,0		
Salzburg	44,0	47,5	23,2	27,6			17,0	19,0
Styria	40,0	47,0	24,0	30,0			16,0	24,0
Tyrol	49,5	50,0	32,0	32,0				
Vorarlberg	55,0	65,0	38,0	45,0	110,8	110,8	18,5	18,5

Table F3.11. Development of average prices for fuelwood in Austria.
Sources: BMLFUW 2004, BMLFUW 2005.

	Price (€/m^3 with bark)		Price (€/GJ)	
Year	**Soft**	**Hard**	**Soft**	**Hard**
1992	27,25	41,06	5,450	5,866
1993	26,53	41,06	5,306	5,866
1994	26,23	40,62	5,246	5,803
1995	26,23	40,41	5,246	5,773
1996	25,65	40,62	5,130	5,803
1997	26,45	41,71	5,290	5,959
1998	27,47	41,86	5,494	5,980
1999	28,34	41,86	5,668	5,980
2000	27,98	41,93	5,596	5,990
2001	28,05	42,41	5,610	6,059
2002	27,17	43,20	5,434	6,171
2003	27,57	43,21	5,514	6,173
2004	27,49	43,07	5,498	6,153

Table F3.14. Results of wood chip production tests carried out in Austria.
Source: Haneder et al. 2004.

		Costs			
		€/MWh		€/GJ	
		low	high	low	high
Test Edelhof 1986	Spruce (manual thinning)	22,00	24,00	6,11	6,67
Test Heiligenkreuz 1999/2000 (mechanized)	Spruce	**18,40**	20,80	**5,11**	5,78
	Pine	**18,20**	20,00	**5,06**	5,56
	Beech	**13,20**	14,30	**3,67**	3,97
ELWOG Study (2002/03)	Forest Residues (manual)	**9,60**	12,00	**2,67**	3,33
	Willow (manual)	14,50	**19,60**	4,03	**5,44**
	Hazel (mechanized)	15,10	**19,10**	4,19	**5,31**
Test Wilfersdorf (mechanized)	Oak	12,00	**15,20**	3,33	**4,22**
	Beech	**16,75**		**4,65**	
	Pine	**19,60**		**5,44**	
	Spruce	**23,10**		**6,42**	

Table F4.1. Production of sawnwood in Austria.
Sources: Lechner et al. 2003, Rebernig et al. 2002/04.

	1990	1991	1992	1993	1994	1995	1996
scm/a	7.522.500	7.160.100	7.019.600	6.779.300	7.538.400	7.813.700	7.600.000

	1997	1998	1999	2000	2001	2002	2003
scm/a	8.450.000	8.737.000	9.785.000	10.404.000	10.262.000	10.455.000	10.514.000

Table F4.2a. Development of the production of industrial residues in Austria.
Sources: Lechner et al. 2003, Rebernig et al. 2002/04, own estimations.

scm/a	1996	1997	1998	1999	2000	2001	2002	2003
Saw dust	1.224.600	1.306.000	1.334.100	1.518.000	1.617.000	1.703.733	1.750.133	1.933.333
Wood chips	3.061.500	3.265.000	3.335.250	3.795.000	4.052.500	4.259.334	4.375.334	4.833.334
Other wood residues	306.150	326.500	333.525	379.500	924.250	425.933	437.533	483.333
Bark	1.324.385	1.414.830	1.459.204	1.661.270	1.767.642	1.842.588	1.892.769	2.090.900
Total	5.916.635	6.312.330	6.462.079	7.353.770	8.361.392	8.231.588	8.455.769	9.340.900

Table F4.3. Wood resources consumed by the Austrian paper and pulp industry.
Sources: Austropapier 2004, Schachenmann 2003.

1.000 scm/a	1990	1993	1994	1995	1996	1997
Roundwood	3.459					
coniferous	2.438					
broad-leaved	1.021					
Industrial residues	2.397					
Total	5.856	5.677	6.119	6.299	6.227	6.487

1.000 scm/a	1998	1999	2000	2002	2003	2004
Roundwood			3.576	3.571	3.587	3.582
coniferous			2.572	2.633	2.662	2.489
broad-leaved			1.004	938	925	1.093
Industrial residues			3.518	3.429	3.596	4.113
Total	6.596	6.773	7.094	7.000	7.183	7.695

Table F4.4. Energy production from biomass in the Austrian paper and pulp industry.
Source: Austropapier 2004.

TJ/a	1990	2000	2002	2003	2004
Black liquor	17.592	22.887	22.718	22.916	24.239
Bark	2.292	3.315	2.933	2.923	2.916
Other biomass and biogas					86
Sludge	316	1.173	1.085	1.232	1.183
Total	20.200	27.375	26.736	27.071	28.424

Table F4.5. Wood consumption of the Austrian chipboard and fiberboard industry.
Sources: Lechner et al. 2004, Schachenmann 2003.

scm/a	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Total	2.335	2.659	2.634	2.584	2.746	2.670	2.634	3.123	3.466	4.029

Table F4.7. Development of roundwood imports to Austria.
Sources: Schachenmann 2003, Holzkurier 2005.

Scm/a	1997	1998	1999	2000	2001	2002	2003	2004
Roundwood	3.850	3.543	5.473	6.781	5.944	5.664	7.496	8.401
Industrial residues	2.187	2.269	2.429	2.327	2.328	2.977	1.722	1.362
Total	6.037	5.812	7.902	9.108	8.272	8.641	9.218	9.763

Table F5.1. Cereal production in Austria broken down by types of corn (2004).
Source: Eurostat 2005.

	Maize	**Wheat**	**Rye**	**Barley**	**Triticale**	**Oat**	**Others**	**Total**
t/a	1.653.746	1.718.825	213.478	1.006.742	192.558	235.685	294.239	5.315.273
%	31,1%	32,3%	4,0%	18,9%	3,6%	4,4%	5,5%	100,0%

Table F5.2. Development of cereal and straw production in Austria.
Sources: Eurostat 2005 (cereals), Lechner et al. 2003 (straw).

t/a	1990	1991	1992	1993	1994	1995	1996	1997
Cereals w/maize	5.289.750	5.044.859	4.322.591	4.206.457	4.435.936	4.452.053	4.708.652	5.008.712
Straw	3.450.000	2.750.000	2.150.000	2.000.000	2.300.000	2.400.000	1.950.000	2.120.000
Cereals wo/maize	3.669.512	3.473.497	3.204.421	2.681.969	3.015.290	2.978.390	2.757.917	3.167.031
Area under cereals (ha)	948.018	923.541	837.704	825.037	821.404	807.656	833.037	848.087

t/a	1998	1999	2000	2001	2002	2003	2004
Cereals w/maize	4.771.551	4.806.496	4.490.206	4.833.794	4.757.312	4.263.775	5.315.273
Straw	2.090.000	2.180.000	1.700.000	2.200.000			
Cereals wo/maize	3.125.261	3.106.556	2.638.555	3.056.021	2.789.409	2.537.986	3.350.086
Area under cereals (ha)	839.626	809.662	829.872	824.312	814.098	809.800	815.768

Table F5.3. Development of oilseed production and production areas in Austria.
Source: Eurostat 2005.

t/a	1990	1991	1992	1993	1994	1995	1996	1997
Rapeseed	101.527	132.875	132.352	131.396	217.069	267.600	120.757	129.084
Sunflower	54.848	72.110	71.830	94.936	87.689	57.984	43.661	43.899
Oilseeds (incl. rapeseed and sunflower)	178.749	246.778	302.382	355.255	415.481	365.744	203.349	219.205

t/a	1998	1999	2000	2001	2002	2003	2004
Rapeseed	128.374	194.265	125.353	146.525	128.647	77.720	120.815
Sunflower	56.853	64.066	54.960	50.566	58.476	71.010	77.925
Oilseeds (incl. rapeseed and sunflower)	248.936	325.374	229.022	245.195	237.515	210.130	256.719

ha/a	1990	1991	1992	1993	1994	1995	1996	1997
Rapeseed	40.844	46.880	52.007	59.090	71.402	89.246	64.904	54.897
Sunflower	22.111	23.808	30.670	34.482	37.299	26.915	18.983	19.954
Oilseeds (incl. rapeseed and sunflower)	79.097	92.828				142.769	113.276	108.420

ha/a	1998	1999	2000	2001	2002	2003	2004
Rapeseed	52.086	65.768	51.762	56.098	55.383	44.035	35.284
Sunflower	22.096	24.249	22.336	20.329	21.381	25.748	28.988
Oilseeds (incl. rapeseed and sunflower)	112.872	129.764	108.531	110.613	110.499	107.650	101.637

Table F5.4. Development of set-aside land and its utilization in Austria.
Sources: Handler et al. 2003, Ruckenbauer 2004, BMLFUW 2004a.

Ha	1995	1996	1997	1998	1999	2000	2001	2002
Sunflower	351	261	162	209	689	929	2.275	2.318
Rapeseed	13.592	7.471	3.058	2.563	7.630	6.095	8.652	9.771
Others	3.067	548	622	916	468	558	849	759
Total set-aside land	125.018	115.340	71.846	71.482	106.366	107.030	104.824	104.471

Table F6.1. Development of installed pellet boilers (<100 kW) in Austria.
Sources: European Pellet Centre 2005, LK 2005.

	1995	1996	1997	1998	1999	2001	2002	2003	2004	2005
Number of pellet boilers			425	1.748	3.876	7.342	12.274	16.766	22.000	28.023
Pellet production (t/a)	2.500	15.000	29.000	50.000	60.000	110.000	140.000	180.000	270.000	484.000

Table F6.3. Price development of wood pellets in Austria.
Source: European Pellet Centre 2005.

€/t	Q3 2003	Q4 2003	Q1 2004	Q2 2004	Q3 2004	Q4 2004	Q1 2005
Single small bags	235,00	235,00	225,00	219,00	219,00	225,00	225,00
Small bags on pallets	210,00	200,00	200,00	199,00	199,00	209,00	209,00
Bulk delivery for small consumers	180,00	179,00	170,00	170,00	167,00	171,00	157,00
Bulk delivery for large consumers	170,00	170,00	160,00	159,00	159,00	164,00	151,00

Table F6.5. Developments of pellets production, domestic consumption and exports in Austria.
Source: European Pellet Centre 2005.

1.000 t/a	1995	1996	1997	1998	1999	2001	2002	2003	2004	Estimate for 2010
Pellet Production	3	15	29	50	60	110	140	180	270	1.000
Domestic consumption						80	110	140	220	600
Export						30	30	40	60	400

Table F7.1. Primary energy production from biomass in European countries.
Source: Eurostat 2005.

PJ	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**
Austria	101,28	104,84	102,54	110,37	118,24	119,46
France	513,07	505,04	452,45	478,74	505,45	467,56
Germany	181,21	182,80	185,36	186,20	193,40	246,20
Italy	40,82	38,60	45,09	46,69	46,43	52,17
Slovakia	4,94	7,20	7,16	3,18	3,18	3,43
Czech Rep.	21,31	23,11	24,37	17,84	17,42	22,07
Slovenia	11,14	11,05	11,01	11,01	12,02	9,80
Hungary	0,00	0,00	0,00	0,00	0,00	0,00
Poland	58,12	159,02	154,84	159,99	155,59	155,09

PJ	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**
Austria	114,68	121,84	118,03	131,47	134,15	143,20
France	479,54	470,28	484,81	494,15	466,18	504,78
Germany	266,38	267,30	285,97	290,37	296,98	332,11
Italy	58,66	68,00	65,82	69,21	65,57	93,66
Slovakia	3,10	3,06	4,19	13,73	10,89	13,86
Czech Rep.	22,19	25,71	20,85	23,78	30,19	47,23
Slovenia	9,71	9,76	17,17	18,84	19,47	19,26
Hungary	0,00	14,70	17,42	16,12	32,87	34,21
Poland	154,25	149,56	151,82	162,20	164,67	205,92

Table F7.2. Biomass resources in Central European Countries according to [AFB-net 2001].

PJ/a	Forest residues	Solid indust. byprod.	Domest. fire-wood	Wood wastes	Refined wood fuels	Other biomass resources	Peat	Total
Austria	150	50	40	18	3	9	0	**270,00**
Germany	142	40	0	81	0	511	0	**774,00**
Italy	0	36	83	24	0	0	0	**143,00**
Poland	101	68	26	40	0	205	122	**562,00**
Slovakia	6	0,1	3	3	0,1	13	0	**25,20**
Slovenia	2	7	8	0,1	0	0	0	**17,10**

Table F7.3. Current energy use of biomass in Central European Countries according to [AFB-net 2001].

PJ/a	Forest residues	Solid indust. byprod.	Domest. fire-wood	Wood wastes	Refined wood fuels	Other biomass resources	Peat	Total
Austria	23,8	51,6	27,9	0,7	3	0,3	0	**107,30**
Germany	55	40	85	12	0	4	0	**196,00**
Italy	0	0	57,6	0	0	0	0	**57,60**
Poland	39,8	0	18,4	6,2	0	0,8	0	**65,20**
Slovakia	3,8	3,3	2,7	0,03	0,06	0,04	0	**9,93**
Slovenia	0	4,1	7,1	0,1	0,002	0	0	**11,30**

Table F7.4. Fuel prices of different biomass fractions according to [AFB-net 2001].

€/MWh	Austria	Germany	Italy	Poland	Slovakia	Slovenia
Forest residues	24,12	8,43	23,69	11,41	3,96	:
Industrial by products	10,40	8,55	8,60	32,65	8,30	5,20
Domestic firewood	19,50	22,07	17,32	21,24	3,60	22,70
Refined wood fuels	39,45	65,60	:	43,96	68,40	50,80
Others	26,01	16,42	:	43,20	3,30	:

Table F7.5. Theoretically available resources of solid biomass in Central European Countries according to [Nikolaou et al. 2003].

PJ/a	Wood fuel	Forestry byproducts	Industrial residues	Agricultural residues	Energy crops	Wastes	Total
Austria	43	150	50,72	9	:	7	**259,72**
Czech Republic	5,4	:	26	14,3	:	4,7	**50,40**
Germany	85	142	45,67	130	:	81	**483,67**
Hungary	12,39	:	18,8	25,9	:	4,66	**61,75**
Italy	83	15,48	41,22	163,29	:	0	**302,99**
Poland	6	26	82	125	:	20	**259,00**
Slovakia	1	:	7	9	:	2	**19,00**
Slovenia	2,54	:	3,1	1,01	:	0,81	**7,46**

Table F7.6. Current use of solid biomass in Central European Countries according to [Nikolaou et al. 2003].

PJ/a	Wood fuel	Forestry byproducts	Industrial residues	Agricultural residues	Energy crops	Wastes	Total
Austria	30,9	23,8	51	1	0	1	**107,70**
Czech Republic	4,77	:	2,1	0,09	0	0	**6,96**
Germany	85	55	40	2,5	:	0	**182,50**
Hungary	12,39	:	0	0	44,17	0	**57,09**
Italy	57,6	0	0	0	0	0	**57,60**
Poland	5,91	26,33	12,5	0,18	0,02	0	**44,94**
Slovakia	1	:	0	0	0	0	**1,00**
Slovenia	2,54	:	3,3	0	0	0	**5,84**