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Biomass based energy intermediates boosting biofuel production

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Deliverable

Feedstock costs

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Publishable Summary

The conversion technologies Fast Pyrolysis, Catalytic Pyrolysis and Hydrothermal Carbonisation studied in the BioBoost project apply a broad feedstock spectrum of lignocellulosic fuels from dry to wet. Suitable biomasses occur in various waste and residue streams from agriculture (straw, surplus manure), forestry, land management, food processing and settlement (waste wood, organic municipal waste). In order to cover the whole value chain the biomass cost determination was included. However as the primary focus of the project is on the conversion technologies and the overall concept of remote bioenergy intermediates for final energy commodity production in central facilities, the costs have been determined based on published information. In the assessment chain, the biomass cost report receives information on available amounts as input from the biomass potential assessment (WP1 Task 1) and contributes to the logistic- (WP4) and the overall techno-economic assessment (WP5).

In general, results on biomass provision costs are that

- Wastes are more economic than residues and may generate an income for the conversion process;
- Dry feedstock is more expensive than wet;
- Ash-rich feedstock is more economic than low-ash biomass

Straw collection was assessed as difference to leaving it on the field in terms of fertilizer withdrawal and replacement costs, baling and bale chasing technology and efficiency and implications of field size, straw amount and labour costs. Applying the most efficient technology as condition for the supply of several ten- to hundred-thousand tonnes to decentral conversion plants leads to straw costs free field side stack between €31 and €39 per tonne. This is in contrast to average prices between €20 and €180 per tonne recorded in 2011.

The harvest of forestry residues thinning wood, slash and stumps was presented with the example of the advanced countries Sweden and Finland, complemented by information on the forestry in the other European countries and wood chip prices free forest road. Prices are between about €25/odt (oven dry tonne) for low quality residues and €80 to €100 for high quality wood chips.

A versatile system of a forestry mulcher coupled to a round baler was described for cases, where the focus is on cost effective management instead of biomass harvest as e.g. in landscape maintenance, clearing of road side green or power line tracks, pruning residues, … The rough cut, round-baled biomass air-dries in road side stacks and respective chips cost between €66 and €81/odt, depending on the terrain biomass density and forwarding distance.

Organic wastes from municipalities or food processing have a waste yard gate fee of €-60 to €-20 per tonne (€-200/odt at 70% moisture) to cover the costs for composting, depending on the system and purity of the waste; Incineration is typically more expensive.
Waste wood has gate fees typically between €-60 per tonne of contaminated or treated wood up to €15 per tonne of untreated wood, but depending also on the region and the season.

Europe has regions, where the manure from livestock rearing exceeds the amounts which may be land-spread. In these surplus regions between €5 and €25 per tonne are paid for the manure removal, either to processing plants or to areas of low cattle density.

Lignocellulosic energy crops as e.g. willow or poplar SRC, Miscanthus or cardoon are typically priced in the upper end of the comparable commodities *wood chips* and *straw* according to their combustion properties. The harvest of Miscanthus and switchgrass in late winter / early spring 7 month after the cereal straw harvest saves storage costs of about €10/t.

Residues from flour mills, breweries, distilleries, juice, sugar or starch production and oil mills are often valuable animal feeds, but may have high additional costs for conservation in case the local demand is less than the production. If suitable for animal nutrition the residues may have a value of up to €180/t and in case of oil seed residues up to €390/t.

An overview on the results of the cost assessment for the countries of the consortium members is shown below:

	Austria	Finland	Germany	Greece	The Netherlands	Poland
Commodity	**€/t free field side/forestry road/waste yard or producer**					
Straw (minimal costs)	35	34	32	38	34	36
Straw (price)	80 to 180	n.a.	160	144	144	n.a.
Forestry residues (price)	30 to 80	25 to 80	30 to 80	(30 to 80)*	30 to 80	30 to 80
Organic municipal waste (gate fee)	-15 to -60					
Surplus manure (price)	-	-	-10**	-	-15 to -25**	-
Waste wood (gate fee)	-60 to -25	-60 to -25	-60 to -25	-60 to -25	-60 to -25	-60 to -25
Land scape & road side management (price)	66 - 81					
Food processing residues (price)	0 to 180	0 to 180	0 to 180	0 to 180	0 to 180	0 to 180
Energy crops (price)	80	80	80 to 160	80 to 150	80 to 150	80

* theoretical price, no harvester, forwarder and chipper available; **In parts of the country; n.a.: not available; -: no surplus manure

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Introduction

The BioBoost project studies the conversion of biomass with three different technologies, Fast Pyrolysis, Catalytic Pyrolysis and Hydrothermal Carbonisation. The design fuels of the pathways are straw for Fast Pyrolysis, wood for Catalytic Pyrolysis and bio waste for Hydrothermal Carbonisation. For the pyrolysis processes, the feedstock has to be dry or dried to about 15% water content, the Hydrothermal Carbonisation is a wet process, fuels below 70% water content have to be wetted. Any of these processes requires oil-, starch- or sugar-crops; lignocellulosic biomass of waste, residues or energy crop nature is fine. This broad feedstock spectrum is possible as an intermediate energy carrier with improved logistic performance is produced for conversion to a final energy product, either in a large, central plant or in small plants, where it may be used with high efficiency.

Accordingly, the BioBoost cost assessment studies various available residue and waste streams from agriculture, forestry, land management, food processing and settlement in order to minimize environmental concerns and the competition to food production. The spectrum is completed with perennial, lignocellulosic energy crops, which have low soil quality or water requirements, a low or nil fertilizer demand and may be harvested up to 30 years after establishment of the plantation.

The envisaged remote biomass conversion plants require fuel on a scale of several 10,000 to 100,000 tonnes per year. These are significant amounts which may not be mobilized with presently available equipment in every region. However, it is expected that the most economic machinery and processes will be used for the biomass supply in order to keep the bioenergy prices competitive.

The cost assessment is based on published information. It is a prerequisite in order to build the logistic model along the complete value chain in WP4 and to assess the socio-economic and environmental impacts of the value chain in WP6.

The agricultural residue straw

Straw is a residue of agricultural production. Usually the term ‘straw’ is used in relation to small grain cereals like wheat, rye, barley, oats and rice. Other European crops include maize (stalk and cob), oil plants like rapeseed and sunflower, legumes like pea, bean, soy bean and lupine and potatoes. The straw may be removed from the field for use as animal fodder and bedding, mushroom substrate, soil cover (e.g. tulip frost protection), energetic use or as building material. Otherwise it is chopped and left on the field as feed for soil dwelling organisms, which remineralise it together with the stubbles and roots to maintain the soil fertility.

The costs for straw removal are calculated as difference to leaving it on the field. They are composed of costs for fertilizer replacement, baling, bale collection and stacking on field side. Usually the fertilizer value is restricted to the main nutrients nitrogen, phosphor and potassium which is sometime extended to micro nutrients as magnesium, sulfur and if necessary includes an alternative source for humic substance as manure or compost. Costs for fertilizer spreading have to be added, costs for straw chopping to be deducted. The other costs consist of fix and variable costs for tractor, baler, bale collector and/or stacker and wages. The variable costs depend on the distance from yard to field (or field to field), the field size, fuel, lubricants and repair.

Fertilizer replacement demand

When the straw is baled and used outside the holding also some fertilizer is removed from the field. It has to be replaced by mineral or organic fertilizers for the next crop in comparison to chopping the straw for decomposition on the field. The primary nutrient elements are nitrogen (N), phosphor (P, reported as P_2O_5) and potassium (K as K_2O), secondary nutrients include magnesium (Mg as MgO), sulfur (S) and organic carbon (Corg).

Comparison of straw removal to chopping leads to credits of 100% for phosphate, magnesium and sulfur. For potassium it is 50 % as it is partially leached out. With nitrogen it is more difficult: In former times straw was preferably burned in the Mediterranean countries as its decomposition does not increase but reduced the residual nitrogen amount. The actual German fertilization regulation considers straw decomposition on the field as neutral for the N-fertilization demand of the following crop. That means the ~5 kg N per tonne of straw is not deducted from the total N-fertilizer application of the following crop. Actually, the organic carbon and nitrogen of the straw are converted to humic substances commonly referred to as ‘soil Corg’.

Soil organic carbon is beneficial for water retention, erosion protection, ion exchange capacity (fertilizer retention), root-ability (soil compaction) and highly contributes to soil fertility required for good crop growth. Some of these properties are due to the soil dwelling (micro-)organisms, which constantly feed on soil Corg and remineralise it to (mostly) CO_2 and N_2. Thus, soil Corg has to be refueled by regular input of fresh organic matter. The required amount depends on soil, grown crops, fertilization intensity and cultivation technology. Its origin may be harvesting residues (e.g. straw, beet leaves), intertillage crops (e.g. mustard) or organic fertilizer like farm yard manure or slurry as shown in the table below.

Table 1: Effect of crop cultivation, harvest residues and manure on the humic substance pool (soil organic carbon) in the soil. Source: German regulation on direct payment obligations[1].

Crop	Humic substance demand [kg Corg/ha*a]
Beet (sugar or fodder), potatoes	-760
Maize (silage, grain)	-560
Cereals, oil seeds	-280
Grain leguminous	+160
Forage crops (grass, leguminous)	+600
Inter tillage crops	+120
Inter tillage crops as green manure (2 t_{dm}/ha)	+280
Maize and cereal straw [t, 86 $\%_{dm}$]	+100
Beet leaves [t, 10 $\%_{dm}$]	+8
Yard manure [t, 35$\%_{dm}$]	+56
Yard slurry [t, 8$\%_{dm}$]	+9

The importance of organic matter for the soil fertility is accounted in the direct payment obligations, which is a prerequisite for farmers to receive subsidies ('direct payments'). So farmers are obliged to sustainability. For the sake of simplicity it is assumed in this assessment that the humic substance demand of cereal cropping is covered with the respective amount of straw. This is achieved by leaving 2.8 t/ha on the field as shown in the table above. On the second thought, this is less dramatic as a good part of the Corg demand is usually covered by chaff and straw brittle occurring in harvesting and baling. Modern combines and balers lead to a straw harvesting efficiency of around 66 %. A typical German wheat yield of 8 t/ha is related to 6.4 t/ha straw (average straw/grain-ratio: 0.8) of which 1/3 or 2.13 t/ha are technically not recoverable and left on the field. If not removed, the straw would increase the soil organic carbon with all subsequent benefits its content in N and Corg should usually be valorized. However, there is also a 'too much' of straw, which may lead to an increased need for fungicide applications.

[1] http://www.landwirtschaftskammer.de/landwirtschaft/ackerbau/pdf/tabellen-humus.pdf

Fertilizer content in straw

The amount of fertilizer in the straw is quite variable, depends on species and breed, precipitation and salt availability, and may change on a site between the years. An overview for wheat is shown in the following figure:

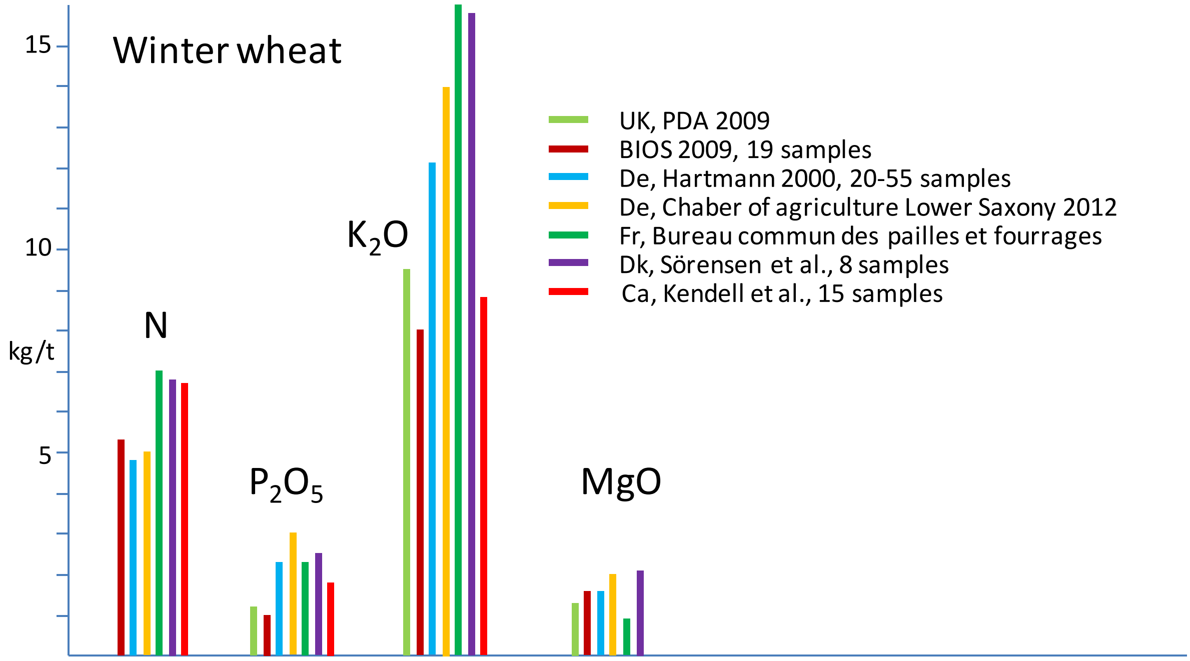

Figure 1: Average content of fertilizers in wheat samples of different origin.

A Canadian study[2] made a broad approach and analysed the fertilizer content in straw of winter wheat on 4 fields per site located in 20 different counties of Southern Ontario over 2 years. Nitrogen ranged from 4.9 to 9.7 %, P_2O_5 from 0.4 to 1.5 and K_2O from 3.3 to 15.6 kg/t straw in the years 2009 and 2010. The variation of the average between the years was not significant (p=0.05), the variation across the sites was up to 40% for N and P_2O_5 and up to 60% for K_2O.

Generally, the claimed value of P_2O_5 and K_2O content of the straw might be overestimated. The straw CHP in Ely, UK, observed that the amounts of phosphate and potassium in the firing ash were lower than expected; In case of K_2O by around 60 % of what agronomists and the fertilizer guideline indicated[3].

As publically available data on the fertilizer content of winter wheat straw are limited in number and geographic distribution and have a considerable site and management-specific footprint the following averages are used in this study: N – 7 kg/odt; P_2O_5 – 2 kg/odt; K_2O – 15 kg/odt; MgO – 2 kg/odt. It is expected that these values match or overestimate the real content in most cases. The straw of the less abundant cereals barley, triticale and rye contains 4 to 6 kg/odt more K_2O; rape straw has nearly a doubled NPK content compared to wheat. An adjustment of the fertilizer part of the straw value seems reasonable if straw supply from certain regions is long term contracted. The analysis of P_2O_5, K_2O and MgO cost around €20 per sample[4]

[2] Katie Kendell, Characterizing agricultural residues nutrient properties and removal variation in Ontario 2012. Master thesis.
[3] Profi-UK, 1/2009 p.66-69 To chop or not to chop www.krone.de/media/ldm/pdf/profi_090211.pdf
[4] Institut für Futtermittel 2013 http://www.lufa-nord-west.de/data/documents/Downloads/IFF/wirtschaftseigene.pdf

Mineral fertilizer type and price
Fertilizers are global commodities, the production is mostly outside the EU and has a high level of concentration. In a trade union as the European Community the price should mostly depend on transport costs, store keeping and retailing and on the individual form of the fertilizer element.

N-fertilizers for example are all based on ammonium, which is produced in an energy intensive process from air and natural gas or coal. Ammonium may be the cation of salts like phosphate (MAP mono-ammonium phosphate, 11-52-0[5] or DAP di-ammonium phosphate, 18-46-0), sulfate (21-0-0-24S) or nitrate, which is an oxidized N-compound with high plant availability (ammonium nitrate 33-0-0 or CAN 26-0-0+12Ca). Reaction of ammonium with CO_2 leads to urea (46-0-0).

P-fertilizers are based on acid treatment of phosphate rock ore. The most common phosphate fertilizers are the above mentioned binary DAP and MAP coming with some nitrogen and triple super phosphate (TSP, 0-45-0). The past knew also super phosphate (0-18-0) and Thomaskali of e.g. 0-10-20+MgO+Na+S, the milled slag of a now unused blast furnace process.

K-fertilizers are made from potassium salt, which precipitated and formed beds when water evaporated in ancient land-locked ocean basins. It comes as potassium muriate (MOP, KCl, 0-0-60), potassium sulfate (0-0-50+18S) for chlorine-sensitive crops or various mixtures with magnesium, sodium or sulfur.

The price of fertilizers depends on the price of energy (production costs) and food (fertilizer demand) and is increasingly variable as shown in the figure below. Farmers start to reduce the risk of high purchase prices by buying in several batches, off-season or when the price seems to be low.

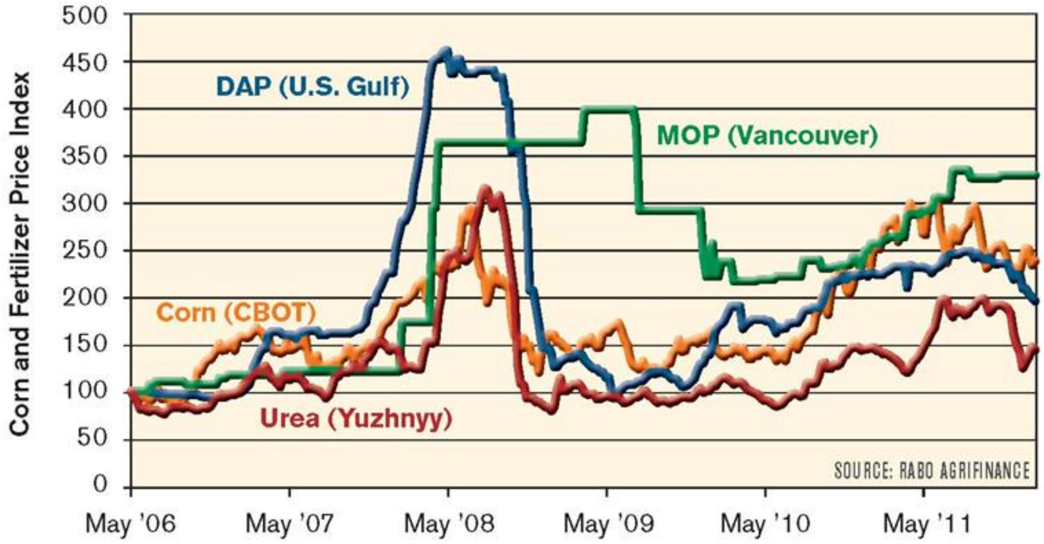

Figure 2: Variability of fertilizer prices (DAP, MAP and urea) and agricultural products (corn). Copyright: Ed Clark, AG WEB / Farm Journal[6]

[5] The content of fertilizers is declared as % of the major elements N, P_2O_5 and K_2O in the nomenclature of x-y-z plus eventual additional elements, e.g. 12-5-12+6 MgO+6 S

[6] www.agweb.com/assets/1/6/MainFCKEditorDimension/p%2037%20Fertilizer%20Carries%20Reduced%20Inventory%20-%20Chart.jpg

The fertilizer prices for this biomass cost assessment are retrieved from EUROSTAT, which lists the price of diverse fertilizers as input to agricultural production of the member states on a yearly base[7]. However, this is not a straight forward process as some entries are inconsistent, relate to rarely used (more expensive) fertilizers or to bagged instead of bulk products:

- For the year 2011 the product ‘Ammonium nitrate (26 % N, in sacks) - prices per 100 kg of nutritive substance’ has 12 entries in two classes: 8 are from € 95 to € 145 and 4 are between € 26 and €42. Between the prices is roughly a factor of four. The reason may be in the term ‘nutritive substance’, which may be understood as N or the ammonium nitrate: The high price entries reported the price of 100 kg N by normalizing the 26 % N containing fertilizer, the other reported the price of 100 kg ammonium nitrate i.e. of 26 kg N. As adaptation, the supposed whole product prices were normalized to the fertilizer element (N, P_2O_5, K_2O) and cross-checked by calculation of and comparison to the price of compound fertilizers.
- The average price of different N-fertilizer compounds and trading units (bulk, sacked) ranged from €0.9/kg N for urea to €1.2/kg N for bagged ammonium nitrate of 26% N in 2011 (see table below). Bagged fertilizer is considered incompatible to modern machinery (several tonnes capacity) and more expensive than bulk ware.
- The reported P_2O_5 fertilizers are triple-superphosphate and superphosphate. The latter is outdated and cost on the EU-average €1.49/kg P_2O_5, which is 149% of the more common variety TSP (EU-average €1.00/kg P_2O_5. However, the most traded P-fertilizer is DAP (18-46-0) with a world production of over 20 million tons per year compared to 13 million tons MAP and 5 million tons TSP. In the season 2010/11 DAP cost around € 0.73 per kg P_2O_5 in Lower Saxony, Germany, which is 20 % less than the € 0.92 to be paid for TSP.
- Concerning data gaps some countries never reported fertilizer prices or stopped it in the past.

[7] EUROSTAT database for inputs to agricultural production http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=apri_ap_ina&lang=en

Table 2: Prices [€/kg] of different fertilizer in the EU states. Source: EUROSTAT

Country	N					P2O5		K2O	
	urea	AN26% bulk	AN26% bag	AN33% bag	AS	TSP	SP	chloride	sulphate
Austria	0,87	1,12						0,67	
Belgium			1,15		1,05		1,39	0,48	0,96
Bulgaria	0,74			0,86	1,16	0,85		1,01	
Cyprus	1,02		1,62	1,12	1,67	1,33			1,80
Czech Republic	0,83		1	0,73	0,90		2	0,68	1,02
Denmark									
Estonia				1					
Finland			1,30						
France	1,05	1,09		1,16	1,03	1,01		0,66	
Germany		1							
Greece	1,04		1,31	1,15	1,38	1,02	1,78		1,12
Hungary	0,71			0,87			1,35	0,63	1,05
Ireland			0,92					0,78	
Latvia				0,91			1,78	0,6	
Lithuania	0,74		1,30	0,89	1,26	1,3	1,04	0,73	
Luxembourg		1,07				0,99		0,76	
Malta									
Netherlands	0,86	1,07	1,19			0,96	1,49	0,6	0,93
Poland	0,83			0,97		0,96	1,28		0,86
Portugal	1,10		1,45		1,54		1,54	0,79	
Romania	0,81		1,18	1,13					
Slovakia	0,80	1			0,62		1,5		0,94
Slovenia	0,94		1,18						
Spain	0,85		1,15	1,10	1,15	0,66	1,20	0,70	1,16
Sweden			0,95						
United Kingdom	1,18			1,10		1,04		0,65	
Average	**0,90**	**1,06**	**1,20**	**1,00**	**1,18**	**1,00**	**1,49**	**0,68**	**1,09**
sd	0,14	0,05	0,19	0,14	0,31	0,20	0,28	0,12	0,28

Taking into account further uncertainties as the scale of order (bag vs. some tonnes bulk vs. full truck loads), the seasonal variability (spring more expensive), market competition and that some important commodities are not covered, it seems appropriate to use European averages for this assessment. For N a 1:1-mixture of urea and ammonium nitrate is assumed leading to **€0.95/kg N**. For phosphate the **€1/kg P2O5** of TSP is a conservative estimate for the occurred costs. Concerning potassium only 10% of the world production is as sulfate usually for chlorine-sensitive cultures. This is usually of no concern for cereals but possibly to other crops of the rotation, so this ratio is used leading to a **€0.72 per kg K2O**.

Baling

Balers pulled and powered by tractors pick up the straw swath left by the combine, eventually cut or chop it and put it in the bale chamber, where it is pressed and baled with twine or a net.

Round balers entered the market in the 1970ies. The bales usually have an axial width of 1.2 m and may have a diameter of up to 2 m. The rolling straw agglomeration and the net binding make round bales quite resistant to rain and water uptake from the ground, which affects only the outer layer of the bale if stored on the round side (axial). The maximum straw bale density is usually between 110 and 140 kg/m³ but the storage density is lower (around 23%) due to gaps between the round bales.

Large square balers emerged in the late 1970ies and are sometimes called 'Hesston'-balers after one of its inventors. They have typical bale chamber dimensions of 0.7 to 1.3 m height, up to 1.2 m width and may produce bales of up to 3 m length. The maximum bale density for standard balers is approximately 120 to 160 kg/m³. The bale density might be increased by cutting or chopping of the straw down to a theoretical length of 20 mm[8], respectively, depending on the number of knifes in the feeder. Fine cutting usually reducers the mass throughput and increases the fuel consumption by around 30%. Chopping makes even smaller pieces and additionally splits the straw. The fuel consumption increases by a further 20% (~180% compared to plain baling[9]). The chopper is installed in front of the pick-up and blows the straw in, with the consequence of higher bale stability.

Recently, balers with extra high pressing density were introduced to increase the loading capacity of a 40 t truck up to the weight limit of about 27 t. The bales have a 20 to 30 % higher density, which means the amount of straw of a 120x130 cm bale is put in a 120x90 bale. Long distance transport of straw may be carried out with dedicated platform trucks with dimensions of 2.4 x 7.2 m with a platform height of 1.1 m (loading height: 2.9 m) of the truck and 2.4 x 8.4 with a platform height of 0.8 m (loading height: 3.2 m) of the trailer. These can take 45 to 47 bales of the 120x90 format or 26 to 27 of the 120x130 format.

High bale density requires as rule of the thumb 45 rams of the compression piston per 2.4 m bale. A lower number of rams i.e. a higher straw throughput usually results in lower bale density. For example the Krone 1290 HDP high speed baler (shown in the figure below) makes 45 rams per minute and has thus a theoretical throughput of 30 t/h or one bale per minute. The measured performance of such a baler in a field test was 50 seconds per 235 cm bale in a single lane and 50 bales per hour with turning on headland. The HDP-bale density with 17% moisture (bit wet) straw was 220 kg/m³. In a direct comparison bales of a conventional 1290 baler had a density of 165 kg/m³ (25% less). The power requirement is 180 to 220 kW depending on the terrain, which is 30 to 60 % more than the 140 kW for a conventional press. The price was €152,000 in 2005[10].

Figure 3: A large square baler of the 120 by 90 cm bale dimension and a high straw bale density of above 200 kg/m³ as build by several manufacturers. Copyright: Krone

The Claas 3200 FC has a bale dimension of 120x70 cm and a theoretical throughput of 45 t/h in dry straw (5% moisture)[11]. The bale density was 165 kg/m³, with the straw cut to about 25 mm length. The tractor power requirement is up to 180 kW depending on the terrain. The price is around €167,000 in 2011.

[8] Krone XC for big bales, 26 knives = 44 mm. Krone pre-chop 88 knives, 21 mm; Claas fine cut 49 knives, special cut is a 90 knive roto-chopper
[9] Land und Forst 4.7.2012: Gras- und Stroherente: Richtig verdichten für gute Qualität
[10] Wilmer H: Ballen wie Briketts. profi 10/2005 p30-31
[11] Wilmer H: Feinster Schnitt, Profi 4/2011 p28-33

The figures below show the dependence of the baling costs (€/t) from the straw density on the field (t/ha) and the area of a rectangular, 2:1 edge length field, assuming a distance of 4 km from holding to field and 2 km field to field, using a standard density baler and a 140 kW tractor according to KTBL, a German society for agricultural assessment[12].

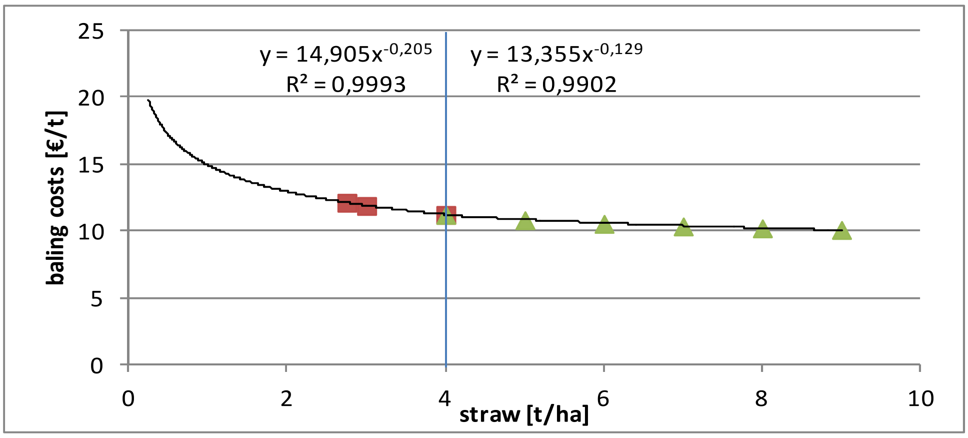

Figure 4: Dependence of the large square baling costs [€/t] from the straw density [t/ha] on a field of 5 ha, 7 m swath width at a fuel price of 0.9 €/l. The straw costs were calculated on base of the equations for densities below 4 t/ha (top left) and above 4 t/ha (top right).

Average field size

According to the figure below baling on a 1 ha field cost 25% (or €2.75) more per tonne straw than on a 10 ha plot (calculated using the tool from KTBL, see above). Baling (or generally machine) costs are power functions of the area, at least up to about 10 ha.

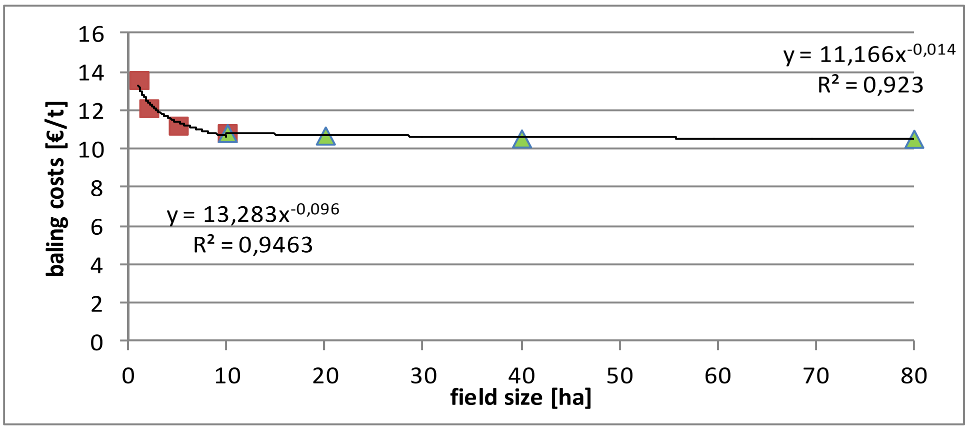

Figure 5: Dependence of the large square baling costs [€/t] from the field size [ha] with 4 t/ha straw, 7 m swath width at a fuel price of 0.9 €/l. Areas larger than 10 ha have a nearly linear rate.

Coherent information on the average field size in the EU is not publically available. However, it is recorded due to the obligation of farmers to report cultivated areas and crops. For some member states (or entities within) respective information (shown in the table below) was published usually in the context of agricultural or environmental studies. However, the minimum size of areas eligible for the application for direct payments is 0.1 ha, which leads to the inclusion of 'every last edge', which dilutes the average field size. Optimal for the purpose of the project would be the average size of fields cropped with cereals. This is available only for Belgium.

[12] KTBL, Feldarbeitsrechner http://www.ktbl.de/index.php?id=850

Table 3: Various information on the average field size in countries or regions.

Region	Size [ha]	Comment, date, sources
Belgium	2	average size of cereal fields, max size 58 ha, std dev 2.25[13]
DE Mecklenburg-Pomerania,	70	Average field size, 1998 (Schäuble[14])
DE: MVP, BRA, SNA, SN, TH		15% of agricultural area in fields >100 ha; in good areas 20 – 50 ha size, in unfavorable areas 5-20 ha (Schäuble)
DE: Schleswig-Holstein	4 ha	1/4 of counties 2-3.5; 2/3 3.5-5 ha; Ostholstein 5.6 ha as of 1998 (Schäuble)
DE: Lower Saxony	2.28	Average field size 2001[15]. 1999: Weser-Ems: 17/18 counties 2-3.5 ha arable land; 1/18 <2 ha; Hannover-region: 63% communities 2-3.5 ha; 3.3 % >5 ha average size of arable plots (Schäuble)
DE: Harburg county	7.5	Estimated average field size cultivated by the regional machinery cooperative, 2009[16]
DE, Hessia	~0.9	75% of hessian communities have averages <1 ha, largest community has av. 2 ha. (Schäuble)
	1.36	for cash-cropped arable land. Data from requests for direct payments, HDLGN 2004 retrieved from Engelhardt 2004[17]
DE: Northrhine-Westphalia	~2.5	43% of communities 1-2 ha; 52% 2-3.5 ha; 1% 3.5-3.9 ha. 1999 (Schäuble)
DE: Rhineland-Palatinate	~1.3	33% of communities <1 ha; 54% 1-2 ha; 0.2% >5 ha. 1999 (Schäuble)
DE, Saarland	~1.8	1 cm'ty 4.9 ha; 4 with 2-2.3 ha, 47 with <2 ha. 1999 (Schäuble)
DE, Baden-Württemberg		Oberschwaben, Hohenlohe plain with averages between 5 and 11 ha; averages <2 ha in Black Forest, Swabian Alb and Stuttgart communities. 1999 (Schäuble)
DE, Bavaria	1.5	Average of arable land 1999 (Schäuble). Parcels >5 ha have a share of 3.7 % of the total agricultural area
	1.73	Average of arable land 2010 [18]
Ireland	5.2	weighted average for arable land[19]
UK, England	7.5 3	Average of areas claimed under the arable area payment scheme. Range 3.5 to 9 ha over the 46 counties. 2000 Average of areas declared but no grant claimed. 2000[20]

[13] Gabrielsen Campling Landscape parameters: Parcel sizes from the Land Parcel Identification System http://archives.eionet.europa.eu/irena/library/04sirenasexpertsmeetings/landscape_biodiversity/presentation_lpisppt/download/1/Presentation%2003%20-%20LPIS.ppt.
[14] Schäuble 2007 Nutztausch auf Pachtbasis als neues Instrument der Bodenordnung http://137.193.200.7:8081/doc/86058/86058.pdf
[15] http://literatur.vti.bund.de/digbib_extern/bitv/zi036477.pdf
[16] http://www.maschinenringe.org/content/ackerbau-%E2%80%93-vollkostendeckung-ohne-fl%C3%A4chenpr%C3%A4mie
[17] Engelhardt 2004 Auswirkungen von Flächengröße und Flächenform auf Wendezeiten, Arbeitserledigung und verfahrenstechnische Maßnahmen im Ackerbau. http://geb.uni-giessen.de/geb/volltexte/2005/2254/pdf/EngelhardtHeiko-2005-02-22.pdf
[18] http://www.lfl.bayern.de/publikationen/daten/informationen/p_41901.pdf
[19] Deverell 2009 Our national landscape: Limitations and opportunities for bioenergy crop production http://www.ucd.ie/bioresources/bulletin/BRC_ECB_Feb2009.pdf
[20] Gabrielsen Campling Landscape parameters: Parcel sizes from the Land Parcel Identification System http://archives.eionet.europa.eu/irena/library/04sirenasexpertsmeetings/landscape_biodiversity/presentation_lpisppt/download/1/Presentation%2003%20-%20LPIS.ppt.

Denmark	4	4 ha average field size acc. direct payment request in 2008[21]
Romania	30	average field size of legal entity farms in 2010, of which 30% operate less than 5 ha[22]
Bulgaria	0.6	0.3 ha in average in the Smolya, to 3 ha in Dobrich. 2003[23]
Hungary	32 9	average size of physical blocks usually containing some to several fields acc LPIS average field size[24]
Portugal	~18	Av. size, range ~1 to 115 ha, see fig 7, sample 2001[25]
Poland	1.4	Of 379 NUTS3 10 have averages of 5-9.3 ha; 70 of 2-5 ha[26]
Czechia	20	Average field size 2008[27]
Austria	0.85	average field size 2010 excl. alms[28]
Greece	0.7	Average parcel size 2000[29]
Cyprus	0.69	Average field parcel size, range 0.29 to 2.1 ha. 2009[30]

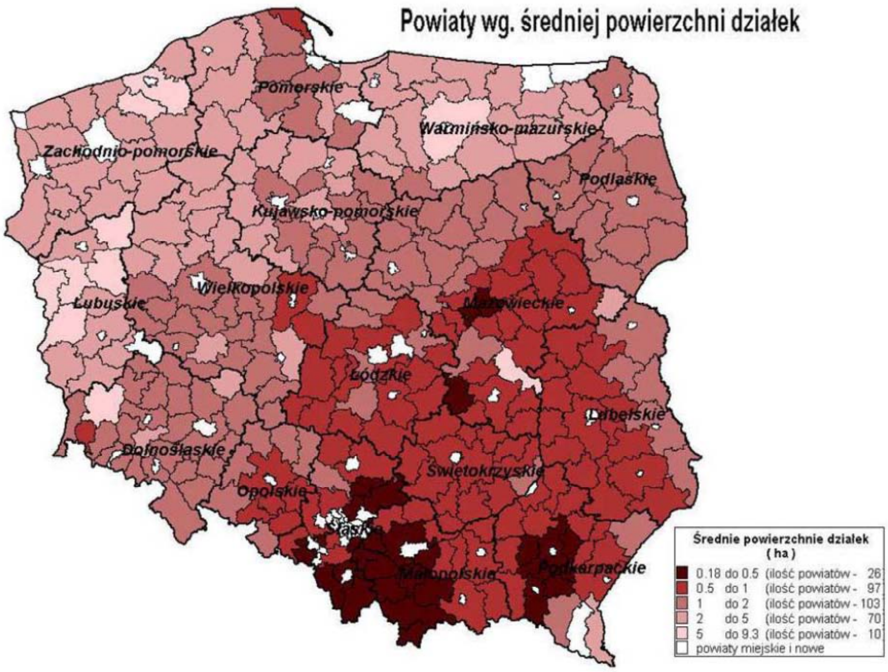

Figure 6: Field size in Polish NUTS3. Averages range from 0.18 – 0.5 ha (dark) to 5 - 9.3 ha (light). White: no data. Copyright: Jolanta Orlinska, Jacek Jarzabek, ARMA Poland

21 http://www.eea.europa.eu/soer/countries/dk/soertopic_view?topic=biodiversity
22 http://www.iamo.de/fileadmin/uploads/forum2012/presentations/day1/SessionC/C2_Voicilas_P.pdf
23 http://www.ceps.eu/book/institutional-factors-affecting-agricultural-land-markets
24 http://www.ceryc.eu/download/Study_Support_for_young_farmers_in_the_EU.pdf
25 http://agrienv.jrc.it/publications/pdfs/agri-ind/CH5IACS_LUCAS.pdf
26 http://mars.jrc.ec.europa.eu/mars/content/download/919/5752/file/4_T6_Orlinska__LPIS_INSPIRE_ARMA_PL.pdf
27 http://eagri.cz/public/web/file/10574/RDP_November_2008.pdf
28 http://www.umweltbundesamt.at/fileadmin/site/umweltkontrolle/2010/ukb2010_06_landwirtschaft.pdf
29 http://www.aua.gr/tsili/geostat_publ/FssEpegeConf02_web.pdf
30 http://etheses.whiterose.ac.uk/2941/1/Demetriou_D_Geography_PhDThesis_2012.pdf

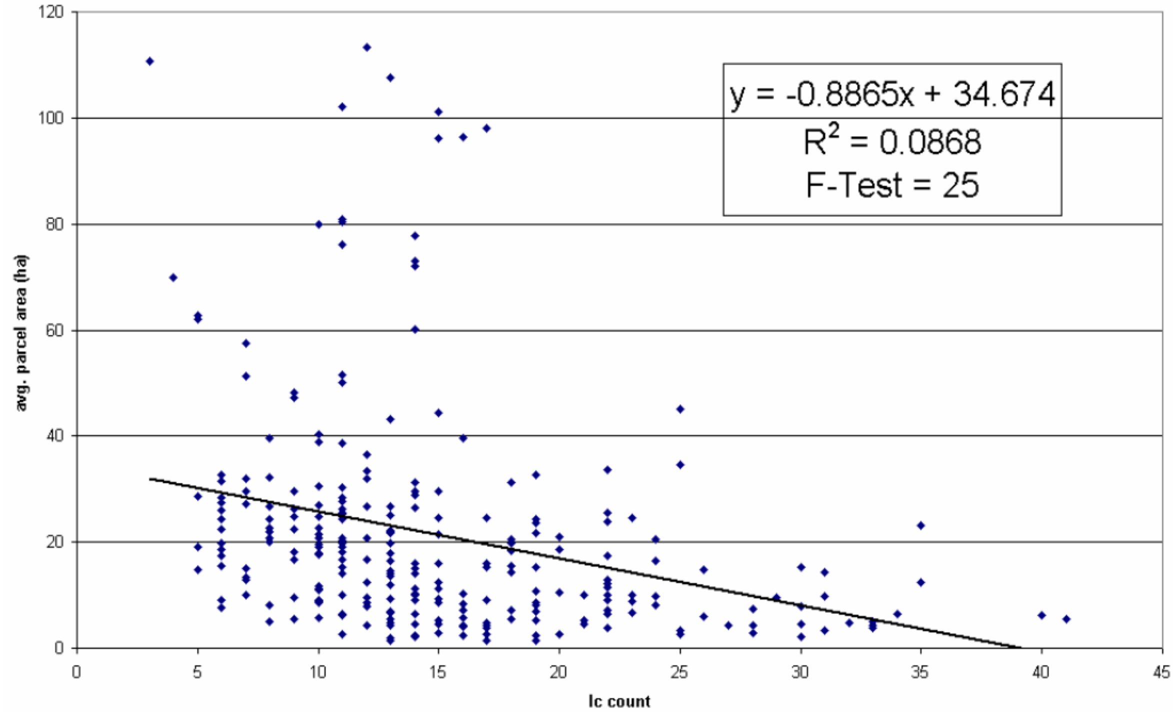

Figure 7: Variability of parcel size [ha, y-axis] in Portugal. Copyright: Campling, Willems, De Roeck and Buffaria, DG Agri & JRC[31].

The two figures above show the problem of using averages: The Polish average field size is 1.4 ha, which relates to about 20% higher costs for straw free field side compared to the reference size of 10 ha. However, there are 10 districts, which have averages of 5 to 9.3 ha field size. This is similar for Portugal where the parcel size ranges from below 1 ha to nearly 120 ha.

An alternative approach to more specifically approach the size of cereal fields from a single source of data is via EUROSTAT data on farm structure[32]. In the figure below the wheat production area of farms in the EU member states is sorted in 8 size classes. As reading guide e.g. 85 % of the Czech wheat production area is managed by holdings, which have > 80 ha cropped with wheat. So the size classes do not refer to the total agricultural area, or the arable area, or the area cropped with cereals but to the area cropped with wheat. This gives an impression on the production conditions between the EU countries. The average size of a cereal field is known only for Belgium where it is 2 ha. If sorted by a decreasing share of production area in the highest class, Belgium is on place 21 of 30. The average wheat production area per holding ranges from 76 ha in Czechia over 12.7 ha in Belgium to 0.5 ha in Montenegro and Cyprus. In some countries the distribution of the size classes seems to be a bit uneven: In Romania, Portugal, Poland, Croatia and Slovenia there is a significant production in farms, which have less than 1 ha wheat in total.

31 Paul Campling, Eric Willems, Bruno Buffaria (DG Agri) and Els De Roeck (JRC), Land cover indicators from IACS and LUCAS datasets – case study: Belgium and Portugal; http://agrienv.jrc.it/publications/pdfs/agri-ind/CH5IACS_LUCAS.pdf

32 http://epp.eurostat.ec.europa.eu/portal/page/portal/farm_structure_survey/data/Database

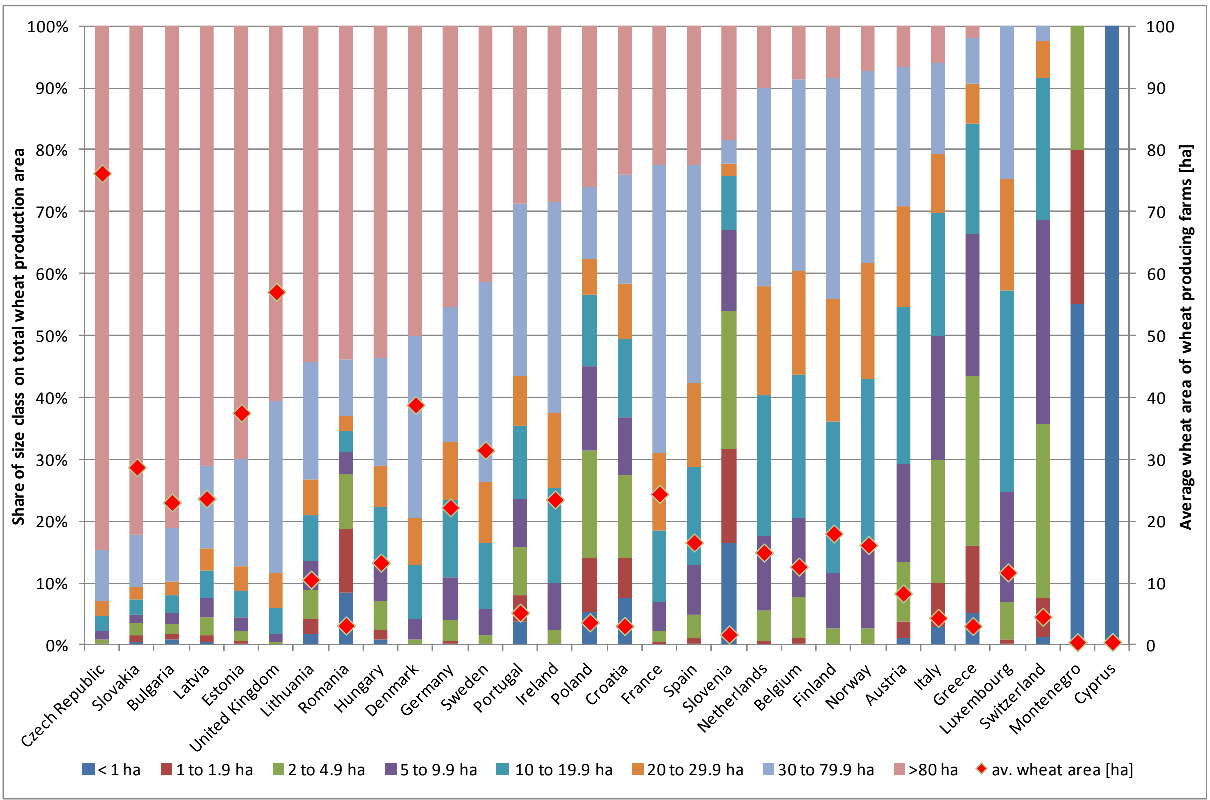

Figure 8: Wheat production area of the individual farm holdings in 2010, plotted by country and size classes and average wheat area per wheat producing farm; e.g. '85 % of the Czech wheat production area is managed by holdings, which have > 80 ha cropped with wheat, average area is 76 ha'. Based on EUROSTAT, farm structure survey.

The wheat and barley production areas in the individual farms over the whole of Europe are shown in the figure below. 41 % of the European wheat production area is managed by holdings which have >80 ha cropped with wheat; 25% of the barley is produced in this size class. The average wheat or barley production area in this highest class is 195 ha for wheat and 155 ha for barley. Wheat has a share of 40 % (barley 22%) of the European cereal production area; together they represent nearly 2/3 of the cereal production area.

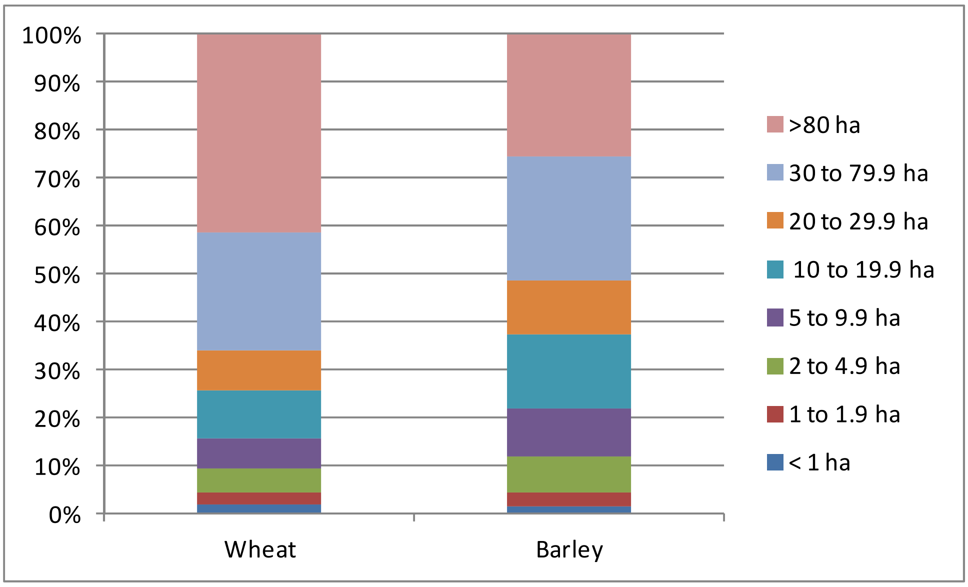

Figure 9: Wheat and barley production area in individual farm holdings in Europe; e.g. 41 % of the European wheat production area is managed by holdings which have >80 ha cropped with wheat. Based on EUROSTAT FSS.

The only information available with a geographic resolution of NUTS 2 on which the straw potentials were assessed is on the total agricultural area of cereal farms. This was retrieved from EUROSTAT and used for the assessment.

Cost calculation:
A purchase price of € 170,000 for a high density baler and depreciation over 100,000 bales in 8 years at 6% interest gives fix costs of €2.11 per bale. Variable costs of € 2.48 per bale include twine, repair and maintenance and result in full costs of €10.2 per tonne straw. The machine hours per bale depend on the time to reach the field, field size and geometry, the operating speed and the swath density. The costs for a 200 kW tractor, fuel (1.6 l per tonne straw) add another €70 per hour plus wages of €15/h making a total of €14.52 per tonne straw baled at a rate of 50 bales per hour. This relates to a straw density of 5 t/ha and a field size of larger than 10 ha or several smaller fields in close distance. The additional €2.3 compared to the €11 per tonne straw shown in the diagrams above covers the extra fuel and the stronger tractor. The more bales per year are made, the lower are the fixed costs per tonne due to reduced dept costs. The number of bales achievable per year is however limited as the fields should be cleared soon after the harvest. The typical time window for wheat harvest with less than 18% moisture is around 70 h at the German Baltic coast and 120 h in the more central German Börde, two important cereal production regions. With the other cereals and rape seed this adds up to 300 to 350 h per year. In the UK a typical value for cereal harvest is 300 hours. In areas with dryer climate balers will make more bales per year. Baling of energy crops out of the cereal season also increases the yearly operation and reduces the fix costs per bale.

An Australian field test with a 1290 HDP resulted in a throughput of 53 bales per hour or 23 t/h, a density of 177 kg/m³ and a fuel use of 1.6 l/t straw. Operating costs for baling were given with AUD 11.73/t[33].
A Spanish study determined baling costs to be €16.30 per tonne straw dry mass at 5 t/ha straw. This relates to €14.68 per tonne assuming a moisture of 10 % of the baled straw[34].

[33] SYNGAS, Yorke Peninsula Alkaline Soils Farmers' Group (2012): Logistics Management Field Trials. http://www.renewablessa.sa.gov.au/files/120224-final-report-logistics-mngt-field-trials.pdf
[34] Esteban et al 2010 CHRISGAS Del 36 Biomass resource and costs in Spain and southern EU countries.

A German study determined baling costs to be € 19.80 per tonne straw using a 120x90 baler with a 140 kW tractor at a bale density of 140 kg/m³, a productivity of 0.4 h/ha, a straw density of 3 t/ha, (9 bales per ha, 23 bales per hour) and a field size of 20 ha[35].

The average rates quoted from the UK contractors associations are GBP 6.55 for a 120x130 (and GBP 4.45 for a 70x120) large square bale in 2012/13[36]. Assuming a weight of about 525 kg and an exchange rate of GBP 0.82 per EUR gives € 15.2 per tonne straw, which would be a profit of 5 % compared to the € 14.5 calculated costs in BioBoost.

The rates of contractors in Northrhine-Westphalia for 80x120 large square baling is € 2.80 to 3.20 per meter, making in average a total of €7.2 per bale for 2012[37]. Assuming a weight of 400 kg per bale makes €18 per tonne straw. This is a bit higher than the UK-rate but may be due to the smaller fields (average England 7.5 ha, NRW 2.5 ha) and possibly lower competition on the straw/contractor market.

[35] C. Weiser, Technisch-ökonomische Analyse der Strohbergung in DBFZ-Report Nr. 13, Basisinformationen für eine nachhaltige Nutzung von landwirtschaftlichen Reststoffen zur Bioenergiebereitstellung.
[36] http://www.fwi.co.uk/gr/naac.pdf
[37] http://www.landwirtschaftskammer.de/landwirtschaft/beratung/pdf/erfahrungssaetze-rh.pdf

Bale collection and field stacking
There are two major possibilities for the collection of bales from the field and stacking at the headland. The universal method is based on a standard tractor with front loader and bale tines and two standard trailers (8 t), equipment available on most farms. The trailers are e.g. 5 m long and 2.5 m wide and can each hold 8 to 12 bales of 90 cmx120 cmx240 cm or 8 bales of 130x120x240 cm³, depending on the terrain. If this is operated stand-alone, it takes a lot of time for uncoupling of the trailers in a central position of the field, collection of the 7 bales of 550 kg or 12 bales 330 kg per hectare if 4 t/ha straw are baled, coupling of the trailers, transit to the stack, uncoupling and off-loading.

An alternative approach is using two tractor/trailer teams, a front loader tractor for loading and optimally a telescope stacker for unloading. Here, the loader and the transporter both drive over the field. If the transporter is full, it drives to the stack and is replaced by the second transporter. This is an efficient process if well organised and fitting to the field size/transport distance. However, it requires 4 persons, 4 trailers and 3 tractors for clearing the field of harvesting residues in a peak workload time, where drivers are needed for the combine and grain transport. And it has to be done in the same time as the harvest because the straw is dry then, and farmers are usually keen on having the field cleared for early soil preparation for the following crop. As the square bales tend to take up moisture from the ground, collection and stacking should be done as soon as possible after baling.

An alternative of reduced work force demand are so called bale chaser, pulled wagons with automatic bale collection and stacking, operated by a single person with a standard tractor of 80 to 100 kW. Three different types of varying capacities and brands are available on the European market. All pick up the bales without stopping and stack by tipping of the platform. Chasers are best on short transport distance as loading and stacking of a full load of 8 tonnes may be performed in 7 to 10 minutes but the total transport capacity is nearly halved compared to conventional systems. In the following, three common systems are presented:

Arcusin Autostack E2200
The big bales are collected with a lateral conveyor band without stopping. The chaser is available in two sizes with capacities of 12 or 14 bales of 130 x120x240 cm³ and 14/16 bales of 90x120x240 cm³, respectively. On a field test the smaller version had a gathering time of about 17 seconds per bale at a speed of 12.2 km/h, making for 14 bales a 243 s/wagon. The average 800 m field transit (relates to a field size of around 130 ha) took 7 minutes at a speed of 12 km/h, the stacking in average 4 minutes. This made 15 minutes per cycle and an average throughput of 18.8 t/h with 90x120x240 cm³ bales of 330 kg weight. The 52 bales collected are stacked in 7 layers of 6.3 m height on the headland. Accordingly, the larger 16-bale version of the wagon would take 16 minutes per cycle relating to 60 bales or 20 t per hour. The tractor should have at least 60 kW, 15 kW each for PTO and wagon traction and 30 for the tractor itself[38]. Costs were in the order of €75000 (in 2009).

[38] DLG 2003 http://www.dlg-test.de/pbdocs/5195F.pdf

Figure 10: Arcusin Autostack 2200. Copyright: Arcusin[39]

Walton Eclipse / Transtacker / Bale Shuttle / Ballenshuttle
The bales are collected with a lateral tine pick-up without stopping. The bales are put on a turn-table offering increased stack stability due to interlocked layers. The chaser is available in three sizes with capacities of up to 12 bales of 130 and 16 bales of 90x120x240cm³, respectively. In a field test the Eclipse 5668 version with a capacity of 14 90x120x240 cm³ bales was assessed. A gathering time of about 30 seconds per bale was achieved, making at 14 bales 7 minutes per load. Depending on the size of field and bales 70 bales per hour are achieved for field side stacking[40]. After redesign of the electro-hydraulic system the wagons are sold also under the name Transtacker in UK and Ireland, in other countries under Bale Shuttle or Ballenshuttle. These versions are reported to have a clearing capacity of up to 40 t/h straw. The bale chaser can also be used to load the stacked bales again. This feature might be used to merge smaller piles after the peak season or to cart bales to smaller customers.

Figure 11: Big Bale Transtacker. Copyright: Big Bale Transtacker[41]

39 www.arcusin.com
40 Profi 12-2005 p. 66f http://www.profi.de/dl/8/1/5/6/P_066_067_12_05.pdf
41 http://www.transtacker.co.uk/

<u>Heath Superchaser</u>
This wagon is a front loader. With a hydraulic drawbar the wagon's track is offset. A device carried in the front hydraulic of the tractor bumps the bales around so that the long side faces the wagon. The bale hits the tines of the pick-up fork, which lifts it on the wagon. While tipping over, the stack is held with tines at the back/bottom. The stack stability is improved by pushing-up the last bales a bit, once vertical, this interdents the top layer.

Figure 12: The Heath SuperChaser. Copyright: Big Bale Co (North) Ltd[42]

Cost calculation:
As there are only two test reports on bale chasers available and reliable data on e.g. throughput, yearly use and repairs are missing, a use of 8 years and 100,000 bales, price of €85,000, variable costs of 0.1 per bale for repairs were assumed. This gives costs of €1.08 per bale. Adding the costs of a tractor of 100 kW and €15 wages for the driver gives costs of €3.29 per tonne of straw stacked on the headland at a rate of 80 bales per hour.

A Spanish study calculated costs for forwarding over 500 m and piling at €3 per tdm[43], which is the same as above at 10% moisture. In contrast a German study calculated costs for collection and headland stacking to be €14.60/t with the conventional system and € 7.90/t with bale chasers (DBFZ/TLL).
The chamber for agriculture of Lower Saxony, Germany published costs for farmer - baling to be €12.40/t; conventional collection&stacking €11.70/t. A subcontractor typically charges €15.60/t for baling and €15.30/t for collecting and stacking.

[42] www.bigbalenorth.com
[43] Esteban et al 2010. Biomass resources and costs in Spain and southern EU countries. CHRISGAS Del 36. http://lnu.se/polopoly_fs/1.37501!CHRISGAS_D36_%20Biomass%20Resources%20and%20Costs_SpainS%20Europe.pdf

Wages

The following hourly rates were retrieved from the ITAG project which surveyed the agricultural wages in European countries[44] as of 2007. However, the influence of wages is relatively low when using the above described highly effective and very expensive machinery. With a total time demand of less than 4 minutes per tonne in the reference case, it would vary by about €1 per tonne straw free field side in the comparison of the €0.93/h of Bulgaria with the €14.19/h of Luxembourg. However, it is expected that personnel, which is qualified to reliably operate equipment worth €0.5 million is more qualified than the average and thus receives a higher wage. But the difference of qualification (and wage) to the average is less pronounced in countries with a general high level of mechanization in agriculture. In BioBoost, the production costs were calculated with a wage of €15/h and have a share of about 5.5% of the total production costs. An hourly wage of €10 leads to difference of €0.32 per tonne straw production costs. A respective reduction was made in countries with an average wage of less than €5/h.

Table 4: Employers gross average wages for agricultural workers with at least 2 years professional experience in 2007.

Country	Loan [€/h]	Country	Loan [€/h]	Country	Loan [€/h]
Austria	8,08	France	10,83	Malta	3,82
Belgium	11,45	Great Britain	9,59	The Netherlands	11,8
Bulgaria	0,93	Greece	4,43	Norway	13
Switzerland	10	Croatia	3,37	Poland	1,71
Cyprus	4,71	Hungary	2,54	Portugal	2,89
Czech Republic	3,93	Ireland	9,52	Romania	2,76
Germany	10,8	Iceland	7,35	Sweden	10,53
Denmark	15,3	Italy	7,46	Slovenia	5,9
Estonia	2,65	Lithuania	3,68	Slowakia	2,81
Spain	4,44	Luxemburg	14,19	Turkey	3,84
Finland	9,33	Latvia	1,09		

Total costs & other issues not included in the calculation:

The amount of fertilizer removed with the straw has to be replaced. The operational costs of fertilizer spreading are in the order of € 10/ha. However, chopping of straw in the combine is very power intensive and not-chopping may lead to a 20 to 25 % increase in combine capacity and reduces wear and tear-costs of the combine's chopping system. Contractors add around € 8.40 (UK) to € 20 (NRW) per hectare for straw chopping. Less harvesting residues facilitates the soil cultivation, may save additional fungicide applications in cereal-dominated rotations (€ 30/ha) and avoids problems with slugs.

Table 5: Comparison of straw costs [€/t] as determined in different projects.

	BioBoost	CHRISGAS-CIEMAT	DBFZ/TLL
Fertilizer replacement [€/t]	14.05	- (?)	17.00
Baling [€/t]	14.52	11.85 – 22.27	19.80
Collecting, stacking [€/t]	3.29	3	7.90
Total [€/t]	31.86	14.85 – 25.27	44.70

[44] http://www.agri-info.eu/english/tt_wages.php

Cost/Price issue
Basically, it is about the difference between how much it costs and how much you have to pay for. This depends on various influences as e.g. the quality (yellow – grey (rained/leached out straw), moisture content, siccation (drying) herbicide +/-, …), the ratio of supply and demand and how much is in stock. Empty stocks after a bad year result also in a good next year in a high straw price due to the psychological feeling of a 'deficite' although the demand matches the supply. Straw, which had been golden at harvest but was exposed to rain afterwards, gets grey and starts to mould depending on the time until it dries again. This is considered 2nd choice for animal rearing but preferred for bioenergy as the rain leached out a part of the problematic potassium and chloride content. The figure below shows the difference and variability of the straw price in several member states according to Eurostat except for Denmark, which was taken from Evald 2012[45].

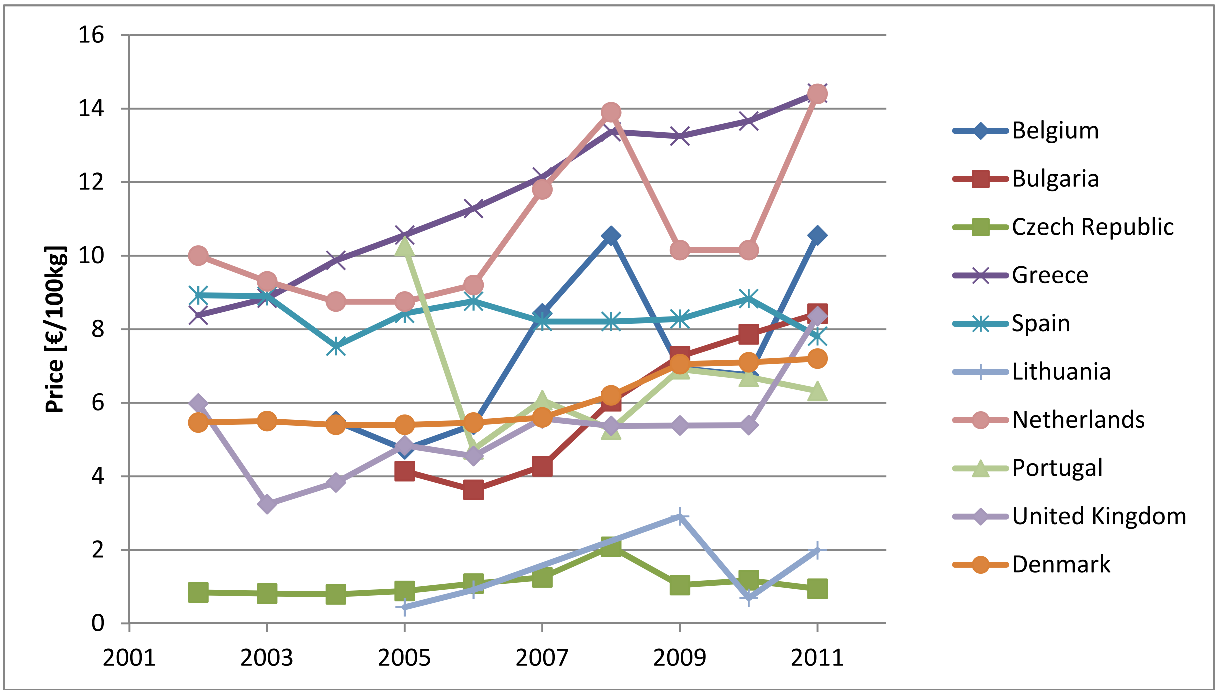

Figure 13: Straw price in €/100 kg. Source Eurostat, Denmark: Evald 2012

Denmark has a long tradition of using straw for energy generation, starting with small burners for heating of farm facilities, followed by ever-larger facilities for district heating, combined heat and power plants (CHP) and as power plant feedstock using a total of 1.6 million tons in 2010 (Evald 2012). For comparison, 1.8 million tons straw are used for other purposes and the average straw production is about 6 million tons. Agronomists estimate, that the share for energetic use may rise to a maximum of 2.3 million tons without much disturbance. Together with 'other uses', this would be a share of 2/3 of the average production.

[45] A. Evald, Country Report: Straw for energy in Denmark. 2nd int'l conference on straw energy, Berlin 2012.

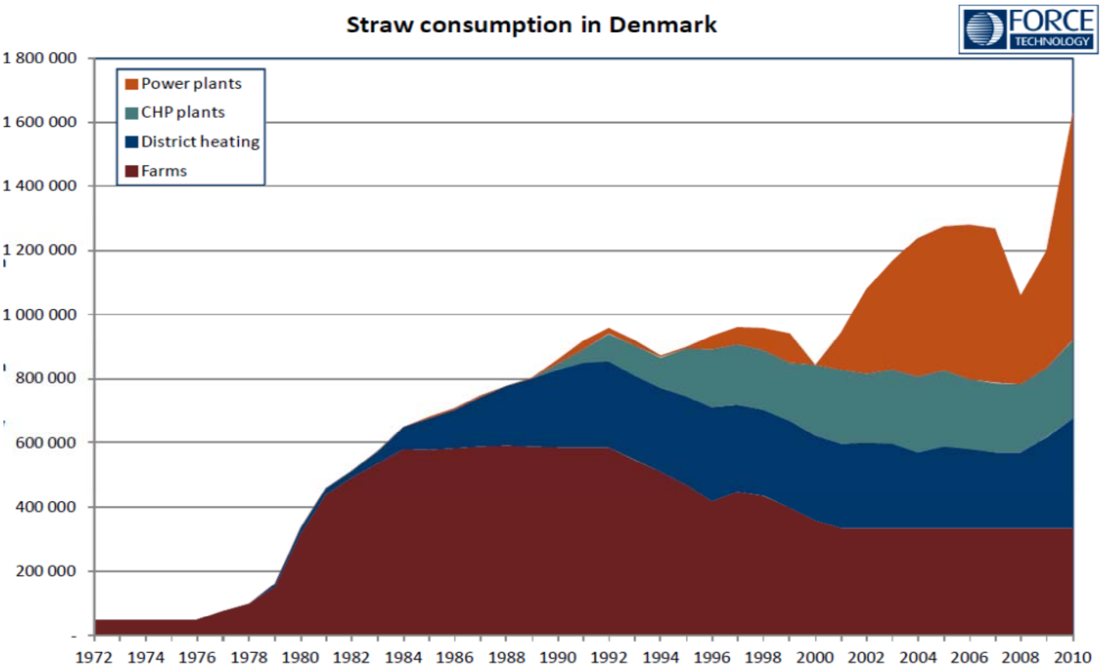

Figure 14: Development of straw consumption [t] for ENERGETIC purposes in Denmark between 1972 and 2010. Bordeaux – farm heating; blue – district heating; olive – CHP plants; orange – power plants. Copyright: Anders Evald, FORCE Technology[46]

The straw is often long-term contracted at local farmers. Farmers are allowed to return the minerals to the fields in applying ash proportional to the harvested straw. This kept the straw price quite constant at DKK 100 (~€ 13) per MWh (or €52/t) over many years. Since 2007/08 (or an energetic straw use of 1.3 million tons) the straw price slowly rose due to the large increase in power plant capacity. However, 2011 was a year with bad weather in the harvesting season in Denmark and large areas of central Europe and the straw price jumped over € 100 per tonne due to short supply and exports to countries, where the price was even higher. Among these regions is Lower Saxony, Germany. There, the price was relatively stable at € 45 to € 60 between 2001 and 2007, when it increased to € 85 until it nearly doubled to €160 in 2011/12.

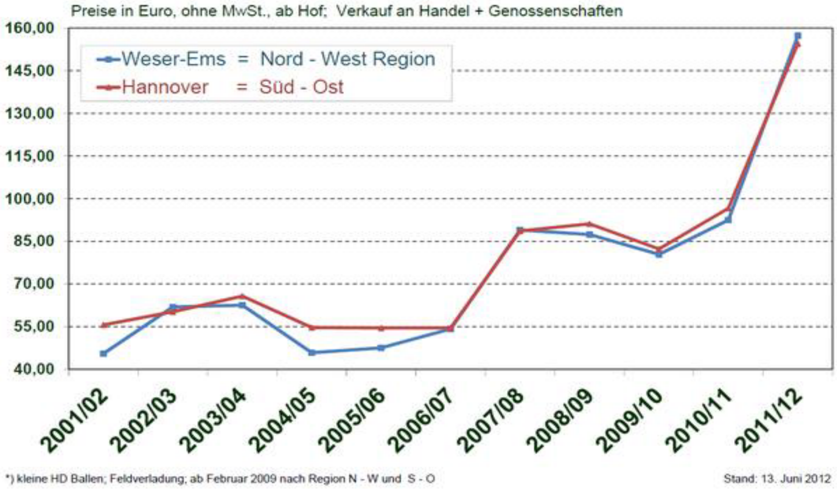

Figure 15: Development of straw prices [€/t] free farm in Lower Saxony, Germany. Blue - North-West; red - South-East. Copyright: Renke Harms, LWK Niedersachsen[47]

[46] Anders Evald, Straw for energy in Denmark. 2nd int'l conference on straw energy, Berlin 2012, www.forcetechnology.com
[47] http://www.lwk-niedersachsen.de/index.cfm/portal/6/nav/360/article/19578.html

The EU cereal farms report[48] is based on the farm accountancy data network (FADN) and gives detailed information on the production of common wheat, durum wheat, barley and grain maize in specialized farms. These are holdings, which generate at least 40% of their income from one of these cereals. Not every country or crop has a significant share of such holdings but they may represent a high share of the total crop production in some countries (e.g. 72% of the Spanish barley production). The table below gives an overview on the receipts from marketing of straw and grain and on the production area of the respective crop and the total area of the holding. Barley straw is favoured to the straw of wheat, durum or maize in animal rearing and gives usually a higher receipt. Wheat straw generates only in 3 out of 18 countries reliable double digit incomes per hectare. These are Denmark, Italy and the United Kingdom. Straw marketing may also lead to a loss of up to €23 as reported for Slovakia.

Table 6: Receipts from the marketing of straw and complementary information for holdings specialized on cereal production. Empty fields: No holdings with >40% income from that crop in that year. Source: FADN

		Receipts from straw [€/ha]								Receipts from grain [€/ha]			Wheat/durum/barley/ grain maize area [ha]			Total UAA [ha]
Country	**Crop**	2002	2003	2004	2005	2006	2007	2008	2009	2007	2008	2009	2007	2008	2009	2009
Bulgaria	wheat						2	1	0	392	510	341	127	108	79	152
Bulgaria	maize						6			538	756	601	10	10	10	
Cyprus	barley			24	34	59	45	0	58	292	0	356	20	0	23	26
Czech	wheat			2	2	1	3	1	2	902	783	531	57	77	93	174
Czech	barley			3	0	-10	2	2	2	881	488	422	52	52	52	
Denmark	wheat	40	32	25	40	26	27	42	52	1347	1208	841	33	29	35	53
Denmark	barley	13	11	5	12	12	16	24	32	942	850	540	23	27	20	32
Estonia	wheat									641	440	298	75	98	132	259
Estonia	barley			1					1	464	333	282	69	80	60	119
Finland	wheat	0	0	0	0	0	0	0	0	896	628	447	30	33	29	63
Finland	barley			0	0	1	0			838	502	381	30	31	33	56
France	wheat	8	9	10	4	5	11	12	9	1327	1165	939	51	52	51	107
France	durum	4	7	7	5	4	6	9	5	1251	1237	805	45	42	40	86
France	maize	4	4	5	3	6	7	4	6	1878	1384	1243	41	40	40	68
Germany	wheat	3	3	3	3	4	5	9	7	1548	1338	984	83	93	86	164
Germany	barley					2		18	15	0	927	717	0	37	44	87
Germany	maize						3	0	3	1734	0	1123	54	0	47	80
Greece	wheat									697	648	404	13	12	14	21
Greece	durum	1	4	1	0	0	0	0	2	552	654	517	14	12	12	17
Greece	barley						46	14	31	518	516	413	13	11	8	14
Greece	maize	4	2	2	1	3	0	0	1	2801	1726	1699	6	6	5	10
Hungary	wheat			6	2	1	4	2	0	699	751	439	30	27	38	71
Hungary	maize			3	2	2	2	2	1	992	950	724	28	34	34	68
Ireland	barley			65		137	146	105	133	1240	855	666	24	25	29	41
Italy	wheat	38	27	84	43	47	44	41	48	1248	1007	865	11	10	11	17
Italy	durum	26	24	22	17	22	29	23	22	1138	919	667	16	18	18	28
Italy	barley	1	38	0	32	17	39	12	50	910	803	663	14	12	8	14
Italy	maize	11	8	11	11	15	17	17	17	2116	1512	1497	11	12	11	18
Latvia	wheat			0	2	2	1	0	1	757	741	496	120	138	120	226
Lithuania	wheat			1	0	0	0	0	1	865	888	565	49	79	74	143
Lithuania	barley			0	0	0	1	1		573	461	308	35	43	32	64
Poland	wheat			2	1	1	3	3	1	1040	896	606	21	25	20	35
Poland	barley			0	2	2	5	5	1	647	588	386	12	13	14	22
Poland	maize			1	2	0	1	1	1	1457	880	813	34	43	29	55
Portugal	maize	3	37	4	0	3	0	0	3	2092	1883	1474	9	9	8	16
Romania	wheat						0	1	5	387	452	364	27	24	22	38
Romania	maize							1	5	694	782	590	8	9	9	19
Slovakia	wheat						2	-23	-23	625	674	333	131	46	46	
Slowakia	maize			6	0	0	0	0	5	1428	0	933	98	0	85	226
Spain	wheat	7	15	19	6	8	7	2	4	711	728	576	25	32	30	57
Spain	durum	0	0	10	2	1	0	3	0	668	725	535	38	40	41	86
Spain	barley	2	4	10	7	3	4	4	4	634	604	295	48	52	56	101
Spain	maize	3	6	4	2	3	1	2	1	2632	1616	1508	14	19	20	42
Sweden	wheat	2	3	1	3	0	7	14	8	1364	1145	608	52	36	56	129
UK	wheat	28	17	25	23	38	36	31	34	1617	1267	1046	89	101	89	178
UK	barley	69	55	47	79	120	115	62	83	1273	1076	805	50	62	66	113

[48] http://ec.europa.eu/agriculture/rica/pdf/cereal_report_2012.pdf

The forestry residue wood chips

Wood has always been used for energy generation and is still broadly applied in Europe. The figure below gives an overview on the standing stock, (the volume of wood which is present in the forests), the annual increment of this stock (the difference between growth and harvest) and the various uses of the harvested wood, of which energy applications are printed in red. About one third of the ~1 billion scm (solid cubic meter) annual increment is not harvested and increases the growing stock. In total, a quarter is used energetically along the production chain, 1/10 of which in large-scale CHP. Forestry residues which were not extracted are not accounted.

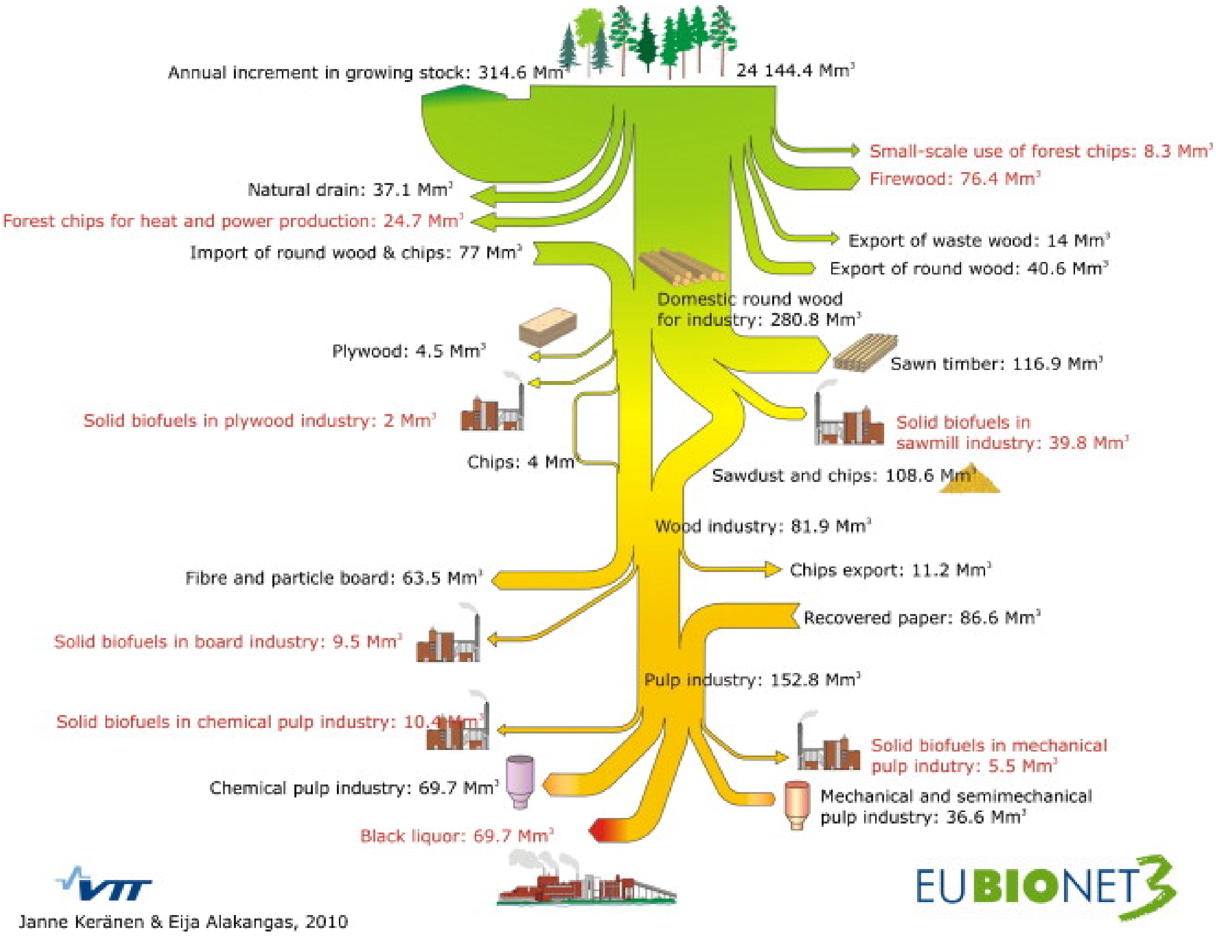

Figure 16: Wood flows in Europe in 2008. Red - energetic use; black - material use. Unextracted forestry residues are not accounted. Source Alakangas, EUBIONET3

Concerning the price and product specification of wood for energetic applications, there are large differences across Europe. This is due to differences in forest conditions, management, harvesting technology, market implementation, variety, quality and reference unit, e.g. hard-wood/softwood, broadleaves/coniferous, stems/whole trees/felling residues, water content, chip size, … Thus, wood chips are not a uniform commodity, quality and price have a wide range. Crushing gives a broader particle size distribution than chipping. In logging residues, the share of bark, needles or leaves is high compared to stem wood, which is paralleled by the ash content and chips are usually not dried to below 20% water content as it is practised with high quality stem-wood chips of end-consumer grade. Larger installations in the heat and power sector are more flexible concerning the feedstock properties particle size, ash and water content. Sufficient low grade heat may be available for feed drying, the feeding system is robust and has a larger dimension than in small facilities and the firing technology/flue gas cleaning system can cope with the higher ash content of low quality biomass. In small installations it is more economic to use high quality, dry, stem wood chips, which are disregarded in this assessment due to higher costs. BioBoost studies larger installations with a 10 to 100 MW fuel demand, where low feedstock costs are crucial for the economic outcome.

The share of forests on the total area range from 66% in Finland to 0 in Malta (dark green bars in the figure below) and all of the forest is available for wood supply (blue bars). The extent to which the increment (the tree growth, red bar) is harvested ranges from 99% in Switzerland to 25% in Cyprus. A permanent high share might not be sustainable, a low share over a long time (decades) means that forestry is on the decline. On the other hand an increase in forest area (light green 2010 compared to 1990)) usually means, that land formerly used for agriculture returns to its natural vegetation or was actively stocked with trees.

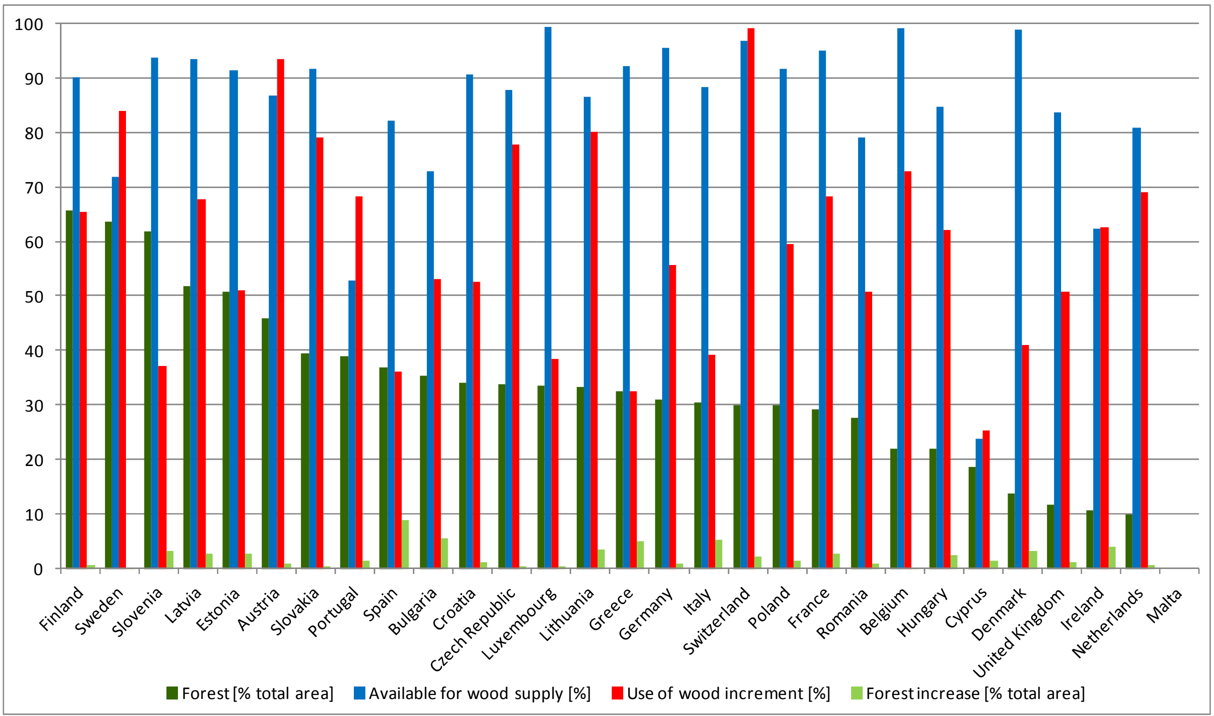

Figure 17: Forest coverage, availability of forests for wood supply, use of the wood increment and the increase in forest area (2010 compared to 1990) of European countries in 2010. Source: Eurostat.

Sweden and Finland have a long tradition of industrial forestry supplying a strong saw mill and pulp&paper industry. The use of forestry residues for energy generation and the development of respective technologies started in the energy crisis of the 1970ies, which makes them reference countries. Here, forestry is comparable to agriculture: In a rotation (the time between planting and harvest), which takes 80 to 120 years, the stands are thinned one to three times until clear cut harvest. The cutting is nearly 100% mechanized; A harvester grabs a tree, cuts it off, de-limbs (cut off branches and twigs) the stem and cuts it into the selected/optimum size and quality assortment; A forwarder collects the stems and piles them at a forest road, just like a combine for cereals. Treetops and branches may be forwarded loose or bundled. After some time for drying or when they are needed, loose residues are chipped into trucks, bundles are chipped at the plant. The stumps may be uprooted (and may also be used energetically), wood firing ash containing the removed fertilizer minerals is spread, and a new stand is established. The costs free power plant decreased with increasing experience but recently rose due to increasing supply costs (more competition, less 'oversupply') and competition in some areas of Sweden. This learning curve and typical costs for respective fuel wood procurement chains in Finland are shown in the figure below.

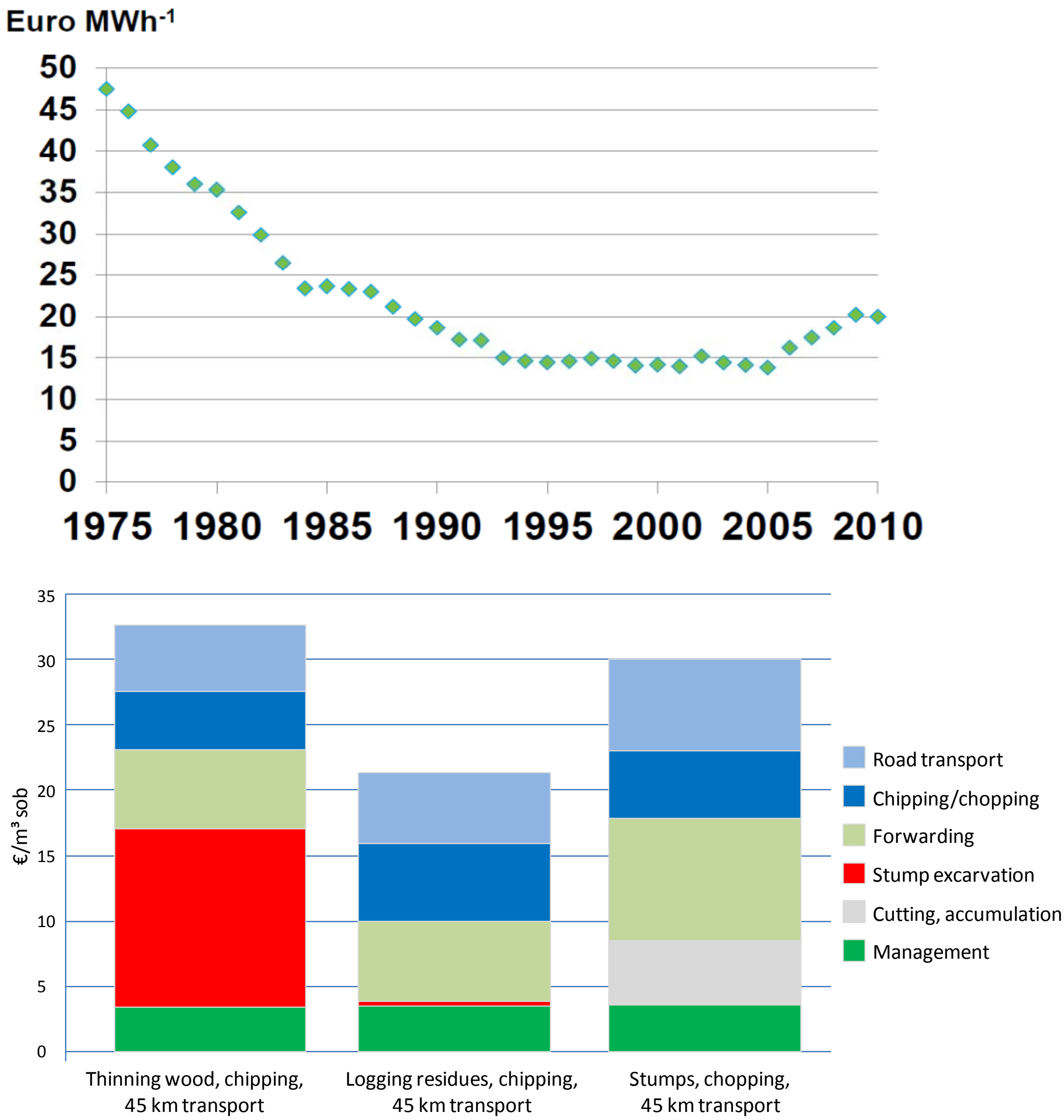

Figure 18: Top: 'Learning curve' of wood chip price free power plant in Sweden, recent increase due to increasing competition. Copyright: Rolf Björheden, Skogforsk[49] Bottom: Costs for fuel wood chips of the three commodities thinning wood, logging residues and stumps occurring in a Finnish forest rotation in 2012. Source: Metla

[49] http://enerwoods.ku.dk/documents/2_Bj_rheden_03092012.pdf/

There are different units for reporting of fuel wood and its price, the wood volume, weight or its heating value: The wood volume expressed as m³ solid over bark (sob) is the convenient and classical unit in forestry as it only requires a ruler. The heating value depends on the content of water and ash and on the wood species. Coniferous trees have -due to their terpenic resins- a higher energy content by weight than broad-leaved trees (about 19 vs. 18.5 MJ/kg), but a smaller energy content by volume due to their usually less dense wood (beech about 10 GJ/scm vs. spruce 6.7 GJ/scm). Chips from stem wood have less ash and a higher heating value than chips from branches and tree tops (forestry residues) as the ash contains the fertilizer elements which are concentrated in the living part of the plant, the bark and leaves. The water contained in the wood is subject of a phase transition from liquid (before combustion) to gaseous (after combustion) which relates to the lower heating value (LHV). The higher heating value applies if the water is in the liquid phase after the combustion.

There is a European statistic on the price of wood products or wood fuels under the topics ‘Removal, Production and Trade’ as well as ‘Economics and Employment’. Shown below is a table which combines the harvested volumes and economic return of the 3 roundwood commodities saw- and veneer-logs, pulp wood and fuel wood. Classically, saw-/veneer-logs have to be of the highest quality concerning straightness, diameter, knots, shakes and wood damages as e.g. rot or insect holes. Pulp wood also includes ‘grade B’ as it is grinded or cooked to fibres. Fuel wood is somewhat outside this quality scheme. Broadleaves are typically preferred to coniferous trees, access might be an issue for small private customers, which might also take logging residues. Saw logs and pulpwood are typically traded in solid cubic meters under bark free forest road but might also be sold as standing stock. Fuel wood might include further processing (cutting, splitting, chipping, drying) and delivery to the customer making it in some countries more expensive than pulpwood or even saw logs. So there are several reasons to interpret the data with care.

Table 7: Forest holdings return and traded volume of the three main commodities in 2010 (except other date stated), per country highlighted in orange-highest return per m³; yellow-average; green-lowest return per m³ sob. Source EUROSTAT

	Saw-&Veneer-logs			Pulpwood			Fuelwood		
	mio €	1000 m3	€/m3	mio €	1000 m3	€/m3	mio €	1000 m3	€/m3
Austria	848	11.387	74	107	3.488	31	255	4550	56
Belgium		2.930			1.502				
Bulgaria	57	1.491	38	48	1.866	26	73	2841	26
Cyprus	0	7	32				0	4	17
Czech Republic	560	10.277	54	178	6.091	29	71	1914	37
Denmark		950			737				
Estonia		3.680			2.080			1944	
Finland	1.211	22.477	54	494	30.107	16	65	4975	13
France	1.036	21.086	49	302	13.857	22	1021	26174	39
Germany	2.017	33.003	61	474	14.269	33	380	10783	35
Greece 2009	13	458	29				35	747	47
Hungary 2009	30	1.185	26	38	1.041	37	80	2879	28
Ireland		1.568			983				
Italy 2006							254	5606	45
Latvia	234	7.495	31	129	3.127	41	31	2312	13
Lithuania 2005							13	1130	12
Luxembourg		159			117				
Malta									
Netherlands 2006							1	290	3
Norway	253	4.813	53	123	4.320	28	80	2121	38
Poland 2008	786	15.708	50	468	16.232	29	62	3804	16
Portugal	94	3.427	27	206	7.762	27	31	600	52
Romania 2009	142	8.095	18	8	548	14	30	3969	8
Slovakia	271	6.217	44	98	3.868	25	10	510	20
Slovenia	92	1.601	57	11	345	31	35	1104	31
Spain 2007				181	10.549	17	16	1982	8
Sweden	1.998	42.120	47	1.060	36.840	29	93	5900	16
Switzerland	212	3.234	66	18	526	35	90	1499	60
United Kingdom	236	6.434	37	64	2.319	28	38	1381	28

Partners of the Intelligent Energy Europe project EUBIONET3 collected and harmonized average wood chip costs free industry customer from various European countries. The development of wood chip prices is shown in the figure below. These prices include logistic costs and there is any indication on the quality of the wood chips. The heating value as base for the price comparison has the drawback that 1 m³ sob may have 8 GJ if fresh harvested or 16 GJ if well dried to ~ 15% water content.

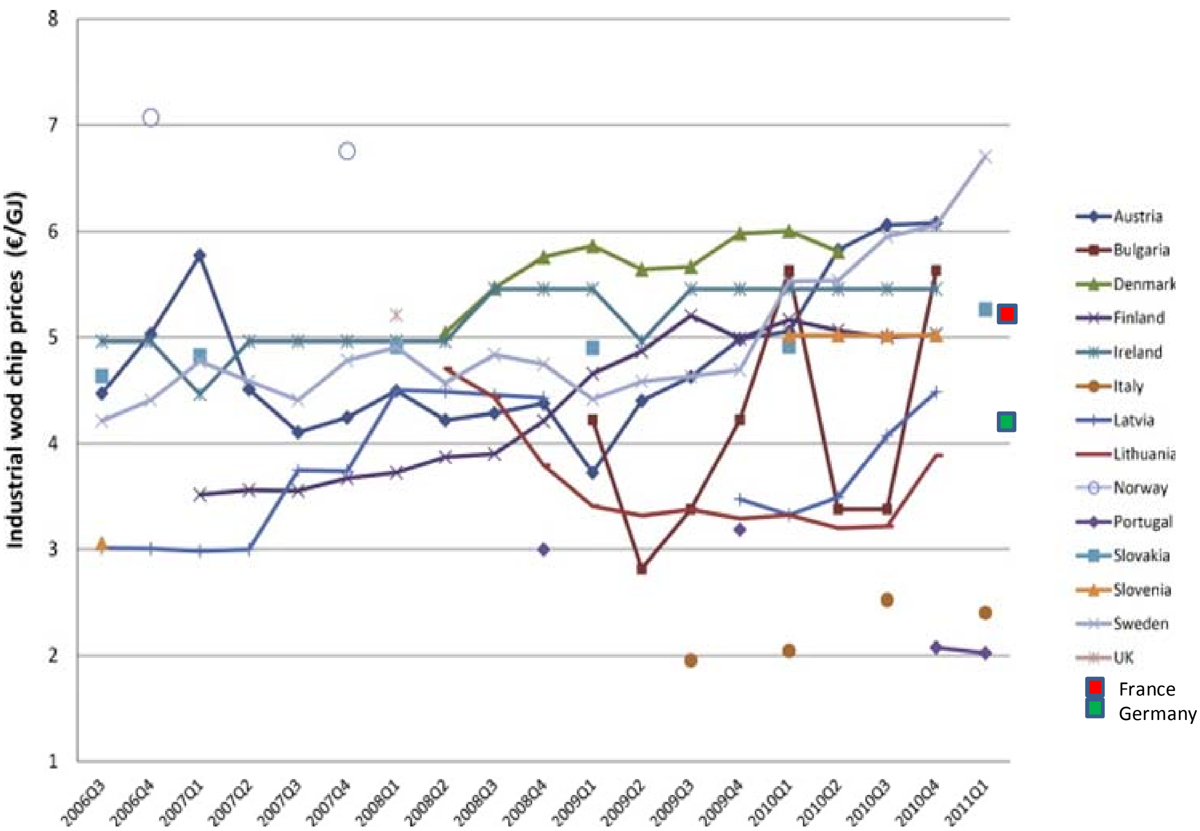

Figure 19: The development of wood chip prices of industrial consumers in some European countries in €/GJ. Source EUBIONET3 [50], ADEME[51]

Examples for spatial, temporal and commodity variation are explained in the figures below. Figure 20 shows the Swedish wood fuel market. Wood chips and wood processing residues for industry consumers and recycled wood for district heating are shown in a temporal resolution of quarters with differences of up to 38% between following quarters. The blue lines show regional differences between north, central and south Sweden, which might be up to 17%.

Figure 21 shows the wood chip prices free customer in 4 Austrian regions. The price is expressed as €/t dry mass (t atro). This does not mean that the commodity is delivered with a water content of zero but that the actual weight and water content of a load are used to calculate the theoretical dry mass as reference value for payment. The Austrian AMM means absolute dry, delivered with bark and calculated with bark. There are price differences of up to 17% between the regions.

[50] Alakangas et al, EUBIONET III—Solutions to biomass trade and market barriers (2012) Ren.Sus.Energ.Rev 16(6) 4277-4290 http://dx.doi.org/10.1016/j.rser.2012.03.051
[51] http://www.ofme.org/bois-energie/documents/Energie/20111101_ADEME_Evol_prix_bois_2010-2011.pdf

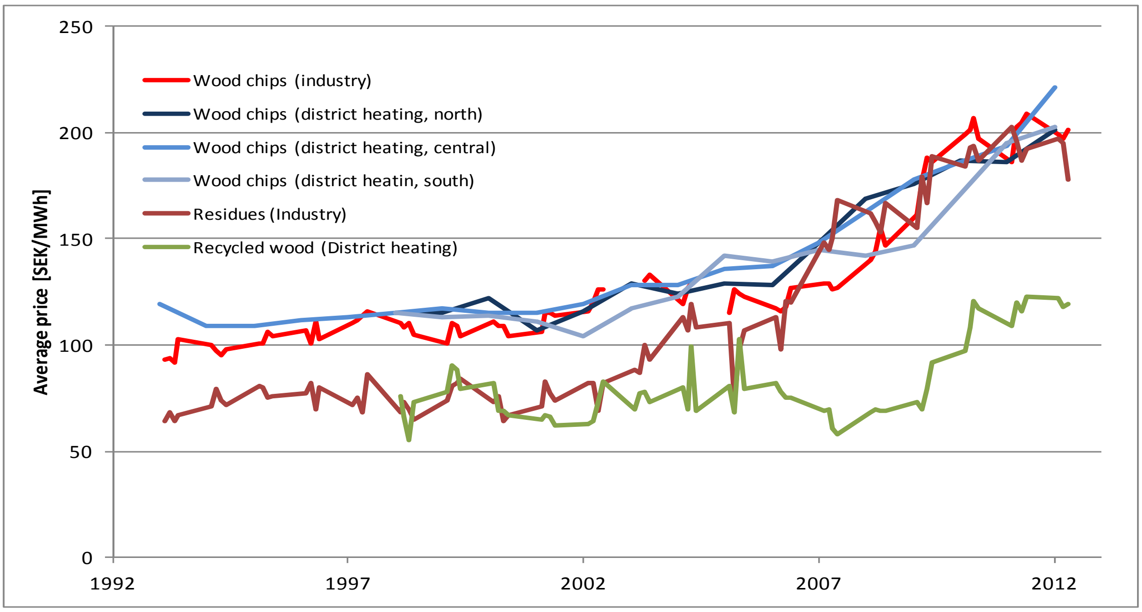

Figure 20: Development of prices for wood chips (large/small consumers), wood processing residues and recycled (waste) wood free plant in quartiles from 1993 to 2012. The average SEK 200 to be paid by industry wood chip consumers in Q4-2012 relate to about €120 per tonne dry mass (exchange rate of SEK 8.6 : € 1 in Q4 2012 = € 23.25/MWh; 5.1 MWh/t_{dm}). Source: Energimyndigheten[52]

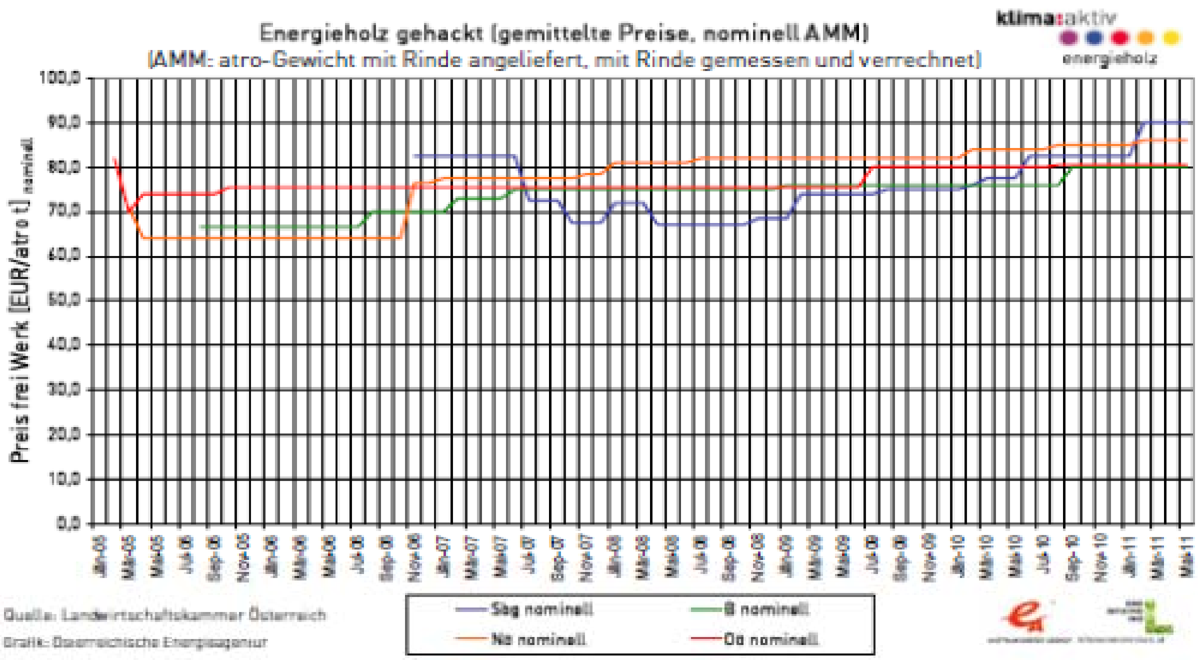

Figure 21: Development of wood chip price free customer in €/t dry mass including bark. Sbg – Salzburg; B – Burgenland; Nö – Lower Austria; Oö – Upper Austria[53]. 2011/12: €87/odt free plant Niederösterreich (Lower Austria); €105/odt Salzburg. Copyright: Herbert Tretter, Austrian Energy Agency[54]

The supply costs of different wood commodities and their volumes in Sweden were intensively studied by Lundmark in 2004[55] regarding competition of the sectors timber, pulp&paper and bioenergy. The decision to harvest a stand is based on the price for the two

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52 http://www.energimyndigheten.se/sv/Statistik/Energipriser/

53 http://www.klimaaktiv.at/dms/klimaaktiv/erneuerbare_energie/energieholz/marktanalyse/energieholzpreise/Marktanalyse_Preisentwicklungen.pdf

54 http://www.lk-ooe.at/?+Dezember++Holzmarktbericht+OEsterreich+&id=2500%2C1757413%2C%2C%2C

55 Lundmark (2004) The supply of forest based biomass for the energy sector: The case of Sweden. http://webarchive.iiasa.ac.at/Admin/PUB/Documents/IR-03-059.pdf

round wood segments, sawlogs and pulp wood. The price of round wood for sawmills was always higher than the price of pulpwood. The residues of final fellings are low quality trees, branches and treetops which have an economically minor role. Even today most are left on site for economic and ecological reasons. Forestry residues occur also at thinning operations. In commercial thinning operation a small stumpage fee of up to €3 may be necessary to compensate the loss of pulp logs. Residue costs were calculated to be (depending on the region and on final harvest or commercial thinning) between SEK 170 and 310 for pulp wood (210 – 350 including chipping) and between 155 and 310 for chipped residues. The average price for pulpwood was SEK 221 per m³ sub (solid under bark) free forest road, the average price of wood chips free consumer was SEK 273. The figure below shows the price/volume relation of wood chips from pulp wood and residues (pulp unusable). The intercept of the curves occurs at about 8.5 million m³ sub and a price level of €210 per m³. The maximum volumes extracted for energy generation never exceeded 3.6 million m³ per year (in the 1990ies), about 43% of the intercept. So in Sweden, a country with a highly developed forestry industry, the wood chip cost free forest road is in average a bit higher than the cost of (unchipped) pulpwood. Chipping of pulpwood is in average more expensive and seems to be limited to certain cases of relatively short transportation distances to the chip consumer.

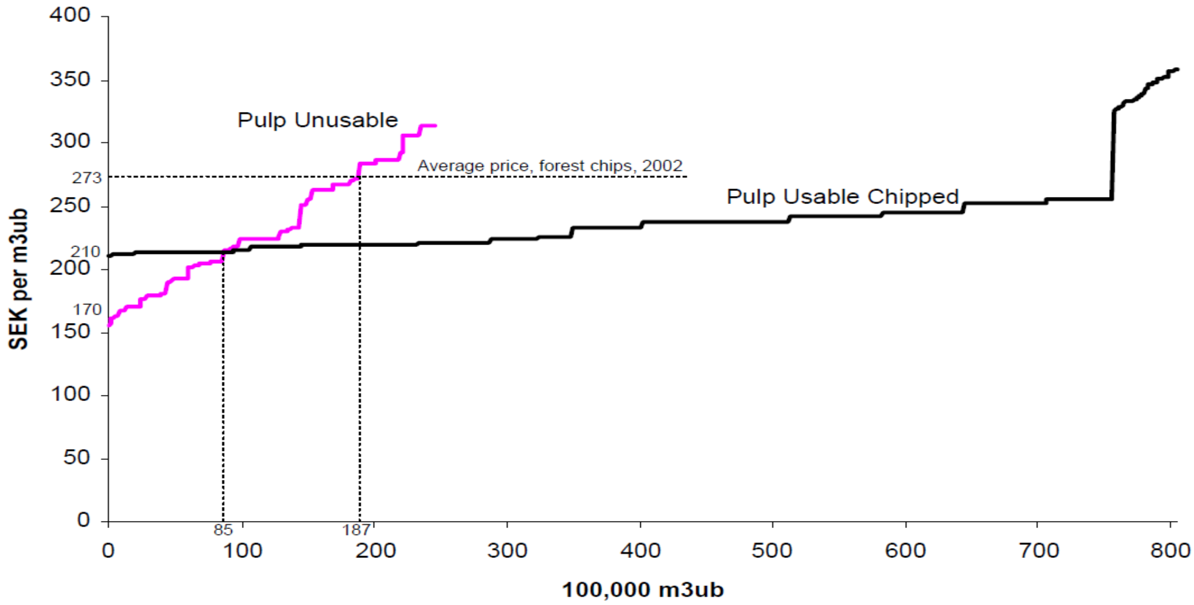

Figure 22: Supply curves for chipped forestry residues (pink, pulp unusable) and chipped pulp wood (black, SEK 40 chipping cost added for comparison). The average price of wood chips free consumer was SEK 273. Copyright: Robert Lundmark, IIASA/Luleå University of Technology[56]

Wood chip prices in Nordic countries

Sweden, Finland, Latvia, Estonia, and Lithuania are countries with a well developed and vivid forestry industry and intensive energetic wood use with highest contributions (13.4 to 27.1 %) to the total energy generation of the EC countries. Prices for energy wood are recorded and published underlining the fact that market transparency is a key factor for successful wood mobilisation. The prices for the least expensive industry wood are between 19 and 33 €/m³ (solid under bark) in these countries[57]. Forestry residue wood chips are at about 16-25 €/m³ sob (solid over bark; 65 – 100€/odt; €3.4 – 5.30/GJ), depending on the site and material[58]. Denmark is also a Nordic country but it is dominated by agriculture. Fuel wood has a high share of the harvest, wood chip prices free district heating plant were around DKK170/MWh

[56] Prepared in a fellowship at the International Institute for Applied Systems Analysis, Laxenburg, Austria
[57] Holzmarktinfo 2nd half 2012
[58] Metla

in 2011, which translates to €6.3/GJ, among the highest in Europe. As reference, a price for industrial wood pellets (0.9odt) of €122.75/t fob (free off board i.e. free harbour pier) Baltic was reported for November 2011. Fob Baltic covers the ports of Klaipeda (Lithuania), Liepaja, Ventspils (Latvia), Tallinn (Estonia), Vyborg and St. Petersburg (Russia). As pelleting costs in the Baltics about €40/t, a fictive wood chip price free port would be about €95-110 per tonne dry matter fob Baltic.

Wood chip prices in Mediterranean countries

Portugal, Spain, France, Italy, Slovenia and Greece (Cyprus and Malta have no or small forests) cooperate in the EU-project proforbiomed[59] to support the energetic wood use. Only Slovenia has a high share (50% of total removal) of quality logs (€57/m³ solid under bark) for saw wood and veneer. In France the price is a bit lower (€49/m³ sub) and the segment less important (32%) and negligible in price and volume in the remaining countries. In Portugal, Spain and southern France pulp mills are important wood consumers in some regions, in the former case often on base of Eucalyptus short rotation forestry (plantation wood). Fuelwood is the most important commodity in Italy (74%) and Greece (69%). However, pulp wood and firewood are segments of relative low margins leaving in the case of firewood only little residues. In regions with unfavourable conditions (steep, dry (low growth), low firewood demand, small parcels, scattered ownership) forest management was reduced to fire prevention or completely abandoned.

In Catolonia, Spain the price of €15 to 40 per tonne of delimbed wood (€30 – 80/odt) leads to abandonment of large forests as costs are in the area of €25 to 35 per tonne. This is reflected in the share of the use of the annual increment, which is between 25 and 40% with the exception of France (national average of 68%, but lower usage in the south[60]) and Portugal (also 68%) compared to the Nordic countries, where it is usually between 60 and 85%. These regionally unfavourable conditions go in hand with a low degree in harvesting mechanisation. In Greece for example there are no harvesters or forwarders, wood chips are not available. For Portugal chips from thinning for industrial users were reported to cost €7.4/MWh free municipal or industry consumer in 2004/05[61], which is about half the Swedish price in that time. Italy reports a wood chip price of €5/GJ (~€95/odt) free industry. In Slovenia coniferous fuel wood is €29/m³ and broadleaved fuel wood €40/m³. Fresh logging residues are available for €9.5/t (~€42/odt chipped), at 20 or 30% moisture the price is at €56-57/t (~€95/odt chipped). France reports a price of €19/MWh free industry consumer (>4 MW), which relates to €85-100/odt[62]. However, average costs of residues free forest road of a piling/forwarding/bundling chain (bundles slightly cheaper than chips free forest road) were CALCULATED to be between €29 and €87/odt as shown in the table below[63]. These calculated costs match the values given for Catalonia. The actual lower prices together with the wide abandonment of forest management implies, that the marketed residues are from stands with low harvesting costs or from forests with a higher value main product.

[59] http://www.proforbiomed.eu/sites/default/files/Situation%20report_all_7_8_2012_0-1.pdf
[60] Final project report "Prospects for the market supply of wood and other forest products from areas with fragmented forest-ownership structures" Schwarzbauer et al. 2010
[61] http://www.proforbiomed.eu/sites/default/files/Situation%20report_all_7_8_2012_0-1.pdf
[62] ADEME, Enquete sur le prix des combustibles bois en 2010 et 2011.
[63] Esteban et al 2010 Biomass resources and costs in Spain and Southern EU countries. CHRISGAS Del 36.

Table 8: Calculated costs of forest residues in €/odt free forest road. No stumpage included and bundles are slightly cheaper than chips. Source: Esteban et al. 2010.

	Spain	France	Italy	Greece	Portugal
Slope <20%					
Conifers	47	66	64	41	29
Broadleaves	53	61	62	47	36
Slope 20 – 60%					
Conifers	63	87	85	53	38
Broadleaves	70	83	87	63	46

Central Europe

Belgium, Netherlands, Luxembourg, Germany, Austria, Czechia, Slovakia, Hungary and Poland are a rather inhomogeneous group: Belgium and the Netherlands have a low share in forest area coverage but Belgium uses large amounts of wood for power generation. A benchmark of over-regional importance is the wood chip and industry pellet price 'cif ARA' (cost, insurance, freight to the harbours of Antwerp-Rotterdam-Amsterdam) which was around €6.1/GJ (€115/odt chips, industry pellets €7.8/GJ) end of 2011. Austria, Germany, Switzerland, Czechia, Slovakia and Poland are countries with a well developed forest sector, a considerable share of high value logs for saw mills (averages between €44 and €74/m³), pulp wood (between €25 and €35/m³) and some fuel wood. Slovakia reports €18/t energy wood, Poland has €37/m³ for beech, which costs €42 in Czechia, €45 in Austria and €55 (between €40 and €70) in Germany, each per m³ industry wood, relating to prices between €54 and 81€/odt, respectively. Chips from such wood are of superior quality. Commodities for low quality wood chips are at about €26/odt (€20-33) plus €26 (€23-30)[64] for chipping in Germany. Specifically, high quality chips come from tree tops with diameter >16 cm and cost €6-10/m³ loose (€40-67/odt). Medium quality chips are from residues with tops <16 cm and cost €4-6/m³ loose (€27-40/odt). Low quality chips do not contain much stem wood and cost €2-4/m³ loose (€13-27/odt)[65]. Hungary also belongs to central Europe but has a limited forest area. About a quarter is robinia (black locust), which has due to curvy growth a high wood chip potential. In 2009 wood chips free CHP were traded at about 67€/odt.

South-eastern Europe

Romania and Bulgaria have a forest coverage of 28 and 35% of the area. Considerable shares of saw logs and pulp wood are marketed. In Romania prices are with €18 (saw logs) and €14 (pulpwood) and €8/m³ (fuelwood) the lowest of all European countries. Reported prices are BGN40/MWh (2009; €108/odt)[66] for Bulgaria and €20-30/MWh free forest road in an example calculated for Berzasca, Romania (Kiemet project, 2013 [67]).

Ireland and the United Kingdom

Ireland and the United Kingdom both have a relatively low share of forest coverage (~12%) but nevertheless an efficient forestry: 80% of the timber is from clearcuts (final harvest an area) and the harvesting mechanisation is at 90 %. Use for saw logs and veneer is dominant but at a relatively low price of €37/m³ in the UK, with pulp- and fuel-wood at €28/m³. For Ireland wood chip prices between €27 and €30/MWh (2009-2011) free plant are reported[68].

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64 Alteheld 2013 http://www.landkreis-row.de/city_info/display/dokument/show.cfm?region_id=160&id=359138&design_id=1757&type_id=0&titletext=1
65 http://www.wbvmuehldorf.de/index.php/holzmarkt/hackschnitzel
66 IEE RADAR-Project http://eaci-projects.eu/iee/page/Page.jsp?op=project_detail&prid=1685&side=downloadablefiles
67 Hirvonen 2013 http://www.enreg-expo.com/fileadmin/Tagungsbaende_2013/Biomass/02.HirvonenEnreg2013presentation.pdf
68 http://www.raslres.eu/wp-content/uploads/2011/10/Review-of-Woodchip-in-the-WR.pdf

For the UK the price ranges from GBP6-8/t (~€12-20/odt) for low quality, fresh forestry residues (high in leaves or needles) to GBP35/t (~€70/odt) for high quality 'white-wood' chips. Stobart Biomass, a major provider, offers delivered prices of about GBP30/t for forest residues, GBP35/t for recycled wood and GBP40/t for saw mill wood chips[69].

Table 9: Overview on parameters for the energetic use of wood. Highlighted in green are the top five countries in each category.

	Forest coverage 2010 [% total area]	Wood energy 2010 [% total energy]	Timber from clear cut (2007) [%]	Mechanisation in harvesting (2007) [%]	Fuel wood 2011 [% total harvest]
Finland	66	20,8	71	97	10
Sweden	64	19,3	70	98	8
Slovenia	62	7,9	0	6	39
Latvia	52	27,1	76	35	9
Estonia	51	13,4	73	70	27
Austria	46	13	18	30	27
Slovakia	40	4	40	4	7
Portugal	39	10,6	70	30	7
Spain	37	3,6	70	40	30
Bulgaria	35	5	70	5	47
Czech Republic	34	4,4	83	40	12
Luxembourg	33	1	70	80	7
Lithuania	33	13,7	50	5	23
Greece	32	2,9	0	0	73
Germany	31	3,6	5	35	20
Italy	30	2,5	20	10	75
Switzerland	30	3,5			32
Poland	30	5,8	44	4	13
France	29	3,9	76	40	45
Romania	28	11,2	70	1	28
Belgium	22	2,4	70	80	18
Hungary	22	5,9	72	15	52
Cyprus	19	0,5	0	0	40
Denmark	14	13,2	70	50	43
United Kingdom	12	1	80	90	12
Ireland	11	1,4	82	95	7
Netherlands	10	1,6	80	25	26

Supply curve issues

A careful and thorough analysis of the wood fuel market was made by Olsson et al. in Deliverable 3.2 of the EUBIONET3[70]. It quotes, that the rapidly increasing demand for wood fuels in Sweden and Finland did not lead to an increase in price for a considerable time span. The forestry industry in these countries is well developed and was able to balance the increasing demand. In Finland prices even decreased in the 1990's due to increasing utilization of logging residues. The reason is that wood biomass was always available in sufficient quantities as residue all along the production chain, which just had to be collected and transported.

Also the international trade with wood fuels was studied. It was estimated that 50% of the world pellet production is traded internationally. In an integrated market, the price of a

[69] http://www.usewoodfuel.co.uk/media/333631/piers_presentation__1_.pdf
[70] Olsson et al. (2010) http://www.eubionet.net/GetItem.asp?item=digistorefile;178383;1087&params=open;gallery

commodity should differ only by the transport costs. The residential wood pellet markets of Sweden, Germany and Austria were analysed with the result that Germany and Austria have an integrated market but Sweden not due to a lack of trade as it turned out. Another analysis targeted the large-scale market of unrefined wood fuels. In the Baltic Sea area the wood fuel trade started in the 1990ies. Chips and pellets are exported from Latvia, Estonia, Lithuania and later Russia to Denmark, the Netherlands and Sweden. So trade is following a price gradient and not only from wood-rich to wood demanding countries. The comparison of wood fuel prices between Sweden, Finland and Estonia revealed that the mere addition of costs for transport over the Baltic Sea did not fill the price gap. However, it was observed that the coefficient of price variability of the average national prices decreased quite constantly from 0.6 in 1999 to around 0.3 in 2007 indicating a certain amount of long-term price convergence. The figure below gives an overview on trade flows of wood chips for bioenergy generation, not to be mixed with those for pulp&paper production.

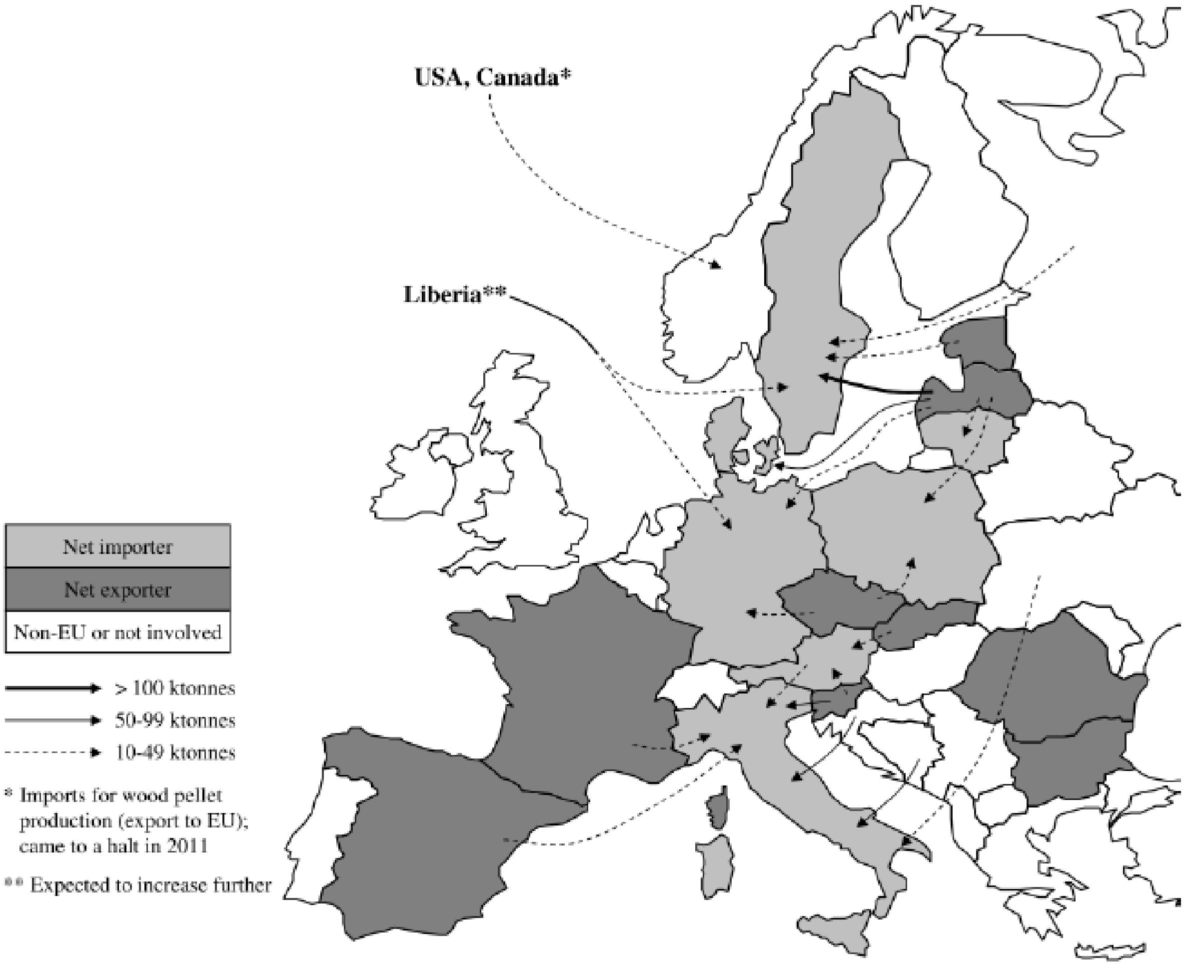

Figure 23: Trade flows of wood chips related to bioenergy generation. Copyright: Lamers, Junginger, Marchal, Schouwenberg, Cocchi; IEA Bioenergy Task 40[71].

[71] http://www.bioenergytrade.org/downloads/t40-global-wood-chips-study_final.pdf

Explanation on terms and parameters of wood fuel

In the following some expressions are explained and compared:

- Water content/moisture: The water content is the amount of water in the actual piece of wood, given in percent. In contrast the moisture is the amount of water divided by the dry mass of the wood. Moisture of 80% in a fresh cut beech relates to a water content of 45%.
- Volume: The solid cubic meter (scm) is the common forestry measure relating to the volume of the stem i.e. square of the average radius*pi*length. It may be differentiated by solid under bark (sub, default) or sob – solid over bark.

  A stacked cubic meter or stere relates to the volume of a wood stack and includes the volume of the wood plus the volume of air between the individual pieces of wood. Varying with the length of the wood pieces, their curvature, diameter and split (halves, quarters, …). For straight, unchopped pieces of 1 m length a proxy is 1.43 stere per 1 scm.

  A loose cubic meter (lcm) relates to the volume of e.g. bulk wood chips. It depends on the geometry of the pieces, a lcm of G30 wood chips is equal to 0.4 scm while G50 relate to 0.33 scm (FNR[72]).
- The density of wood varies depending on the wood species, growth conditions and the water content. Fresh cut German oak weights between 1180 and 1270 kg/scm, de-barked pine or spruce are between 750 to 880 kg/scm. Air dried (15% water content) oak has around 692, pine 527, spruce 425 kg/scm[73].
- In other countries the reference value is the energy content e.g. MWh the calculation procedure is similar.

[72] FNR Leitfaden Bioenergie Datensammlung http://fnr-server.de/cms35/fileadmin/biz/pdf/leitfaden/datensammlung/

[73] http://www.holzhandel.de/rohdichte.html

Prunings, landscape conservation matter, road side green & miscellaneous vegetation

There is a broad bandwidth of biomasses, which have to be cleared for some reason, as e.g. cutting back the road side vegetation; keeping the landscape in conservation areas open (free of trees or bush); clearing power line tracks; clearing hedgerows; remove orchard pruning cuttings; removing invasive species; fire protection; forest thinning; … The impetus in these cases is not to produce biomass of a certain grade but to have the job done with high cost efficiency. A suitable multi-purpose machine is the Anderson BioBaler WB55[74] shown below, which combines a heavy-duty forestry mulcher with an agricultural round baler.

Figure 24: The BioBaler around the clock in invasive species removing, baling of fruit tree prunings, landscape protection and removal of understory vegetation. Copyright: Anderson Group co.

The operation is straight forward: A tractor of at least 200 hp and stepless transmission with forestry protection and a front bumper is run over the vegetation to bend it down. The baler is attached with a swivel drawbar, which may be swung out hydraulically to position the bales out off the track or to operate in the track beside the tractor. The whole baler may be lifted by 60 cm to pass over obstacles. The mulcher has 50 fixed teeth over a working width of 2.25 m. Herbs or small dimension trees up to 10 cm diameter are chopped off and are transferred via the feed rotor into the baling chamber. It has a width of 1.2 m and a diameter of 1.25 m and is equipped with steel rollers and a bar conveyor chain, the baling pressure may be adjusted with

74 http://www.grpanderson.com/en/biomass/biobaler-wb55

hydraulics. The bales are tied with sisal twine (300 m/kg or synthetic 400 m/kg). This takes considerably longer than net binding (30 to 40 vs. ~10 to 15 seconds) but avoids 'non-biomass' complaints when using the bales. The bales have a volume of 1.5 m³ and a weight between 200 kg with Miscanthus to 600 kg with grass/herbs/shrub. This relatively low density is due to the broad variation in particle size (up to 1 m length) but the bales are stable (do not fall apart). An advantage is, that the bales can air-dry in storage without moulding: in Sweden willow SRC (short rotation coppice) was baled with 50 % water content in May and had 31 % water content in November. On flat, stone-free ground with reasonable biomass density, 30 to 40 bales per hour or up to 9odt/h were demonstrated[75].

The results of three trials are presented in the following:
In Georgia, USA, a 2009 version of the BioBaler powered with a 185 hp tractor was assessed in clearing the understory of a planted pine forest with ~17 odt/ha (Klepac, Rummer 2009[76]). This biomass with a water content of 40% was baled at a rate of 15 bales per hour. The bales weighed in average 455 kg (1004 lb) and had an ash content of 0.6%. Production costs were $30/odt for baling and –using a 6-wheel forwarder- $40/odt free forest road.

In 2011 the BioBaler was presented in Tennessee, USA (Langholtz et al.[77]), but only a very limited number of bales were made at a rate of 7-12 bales per hour due to small plots with a lot of turning. In Tennessee, drying of shrub bales from 37.5 % water content to 25% took 4 to 6 weeks. Costs were calculated to be between $32 and $57 per tonne dry matter including forwarding with a tractor pulled round bale chaser. Transport and chipping add $8 and $4.8, respectively, with total costs free plant of $52 -$71/odt. However, the Tennessee Valley Authority and land owners in the Oak Ridge area pay $250 to $750 per ha for mowing and land clearing and costs reported for forestry may go up to $3700/ha. Partial inclusion of these land management fees is expected to halve the costs free plant gate.

The operation of a BioBaler with a 300 hp tractor in a Swedish willow stand (22 odt/ha, 40-50 mm stem diameter, ~50% moisture content) was compared to the standard harvesting with a field chopper in 2010 (Lantmännen[78]). The BioBaler purchase price was reported to be €120,000. It made 100 to 150 bales per hectare of 0.188 odt in average. The throughput was about 40 bales per hour, fuel use was 0.43 liter per bale and baling cost SEK152/odt to which field transport with a forwarder added SEK96/odt. A strong advantage in comparison to the usual field harvester chain was the field side storability, which led to an air-drying of the biomass from ~50 % in May to 31 % in November. This resulted in a 50% increase of heating value from 7.85 GJ/odt of fresh salix to 11.7 GJ/odt. Wood chips produced by a field harvester are very fine and of even size but have to be used immediately or they mould with high biomass losses. A disadvantage of the BioBaler is the lower round bale transport density of 8.6 odt per load (46 bales with 0.188 odt; SEK313 at 40-50 km distance) on a truck with grapple compared to 16.3 odt for fresh wood chips (SEK156 at 40 km). Due to their high diameter the bales do not fit to standard chippers and have to be chopped in larger crushers (Doppstadt DZ-750, 23 odt/h, SEK133/odt). Total free plant costs of this chain were SEK694/odt or €77 to €83/odt, depending on the exchange rate.

This relates to a baling price of €16.9 to €18.2/odt, forwarding the bale to the field side adds about €10 per tonne dry matter. Chopping of dried (25-30% water content) bundles leads to a chip price of €42.3 to €45.6 per odt.

75 http://www.grpanderson.com/images/biobalerpres/tableauscenariobiobaler_thumb.jpg
76 http://www.srs.fs.usda.gov/pubs/36336
77 http://info.ornl.gov/sites/publications/files/Pub34055.pdf
78 http://www.salixenergi.se/uploads/Pilotstudie_av_buntskordaren_Biobaler.pdf

The BioBaler manufacturer Anderson published 'typical' yield and performance data observed in different applications. For SRC the productivity data match the Swedish observations except for the bale weight which was 6% lower. A rate of CAD 1.33/€ (average 2010-2013) the quoted CAD24/odt relate to €18/odt which is in the range of the Swedish report.

The job with the lowest costs of CAD22 per odt (€16.5/odt) was harvesting of the energy crop Cardoon (15t/ha) under perfect field conditions, allowing to achieve the maximum rate of 40 bales per hour with a dry matter content of 225 kg/bale. The highest costs of CAD79/odt (€59/odt) were quoted for low biomass densities (collection of fruit tree prunings, 3t/ha) and low driving speed due to difficult terrain (stumps, stones, slopes in slash forestry residues 7t/ha), where only 10 bales were made per hour. Clearing invasive shrub, or below power lines or between tree plantation rows at 15 to 45t/ha, 14 to 30 bales/h led to a bale price of CAD28 to CAD48 (€21 to €36) per tonne dry matter. This is the price range that will be used for the BioBoost assessment.

Table 10: Yields and productivities of the BioBaler baling different biomasses in harvesting or clearing operations. Copyright: Anderson Group co.[79]

Scenario	Type of biomass	Ground condition	Field Density (HM tons per ha)	Moisture content %	Average weight of fresh bale (kg)	Average baling capacity per hour	Wet Tons harvested per hour	Dry Ton harvested per hour	Hectare per hour	Harvesting cost per bale	Harvesting cost per wet ton	Harvesting cost per dry ton
Short rotation crop for bioenergy	Willow, Poplar, Acacia, Aronia	Excellent, flat as an agricultural field. Plant in double rows plantation 75cm between trees.	50	50%	400	40	16,00	8,00	0,32	$ 4,93	$ 12,33	$ 24,65
Power Lines cleaning	Mixt Shrub (brush, small vegetation, small tree)	Excellent, flat and no stone	20	50%	600	14	8,40	4,20	0,42	$ 14,09	$ 23,48	$ 46,95
Invasive shrub	Gorse / Ulex Europeaus	Excellent, flat and no stone (common on military land, or govt land or ex-agricultural field invaded by this plant)	45	60%	600	30	18,00	7,20	0,4	$ 6,57	$ 10,96	$ 27,39
Clearing vegetal biomass between plantation rows of Pine, Poplar, Eucalyptus, etc...	Mixt Shrub (brush, small vegetation, small tree)	Excellent, flat and no major obstacle, sufficient space between rows to operate	15	50%	550	15	8,25	4,13	0,55	$ 13,15	$ 23,90	$ 47,81
Fruit tree care operation	Apple,Vineyard branch,	Excellent, flat and enough distance between plantation rows	3	50%	500	10	5,00	2,50	1,66667	$ 19,72	$ 39,44	$ 78,88
Pellet production	Cynara Cardunculus	Excellent, flat as any agricultural field	15	50%	450	40	18,00	9,00	1,2	$ 4,93	$ 10,96	$ 21,91
Pellet production	Miscanthus	Excellent, flat as any agricultural field	15	20%	200	40	8,00	6,40	0,53333	$ 4,93	$ 24,65	$ 30,81
Fruit tree care operation	Olive	Excellent, flat as any agricultural field	20	50%	450	18	8,10	4,05	0,405	$ 10,96	$ 24,35	$ 48,69
Forest residues (post harvest)	Mixt	Unpredictable (stump, stone, hilly, etc...)	7	50%	500	10	5,00	2,50	0,71429	$ 19,72	$ 39,44	$ 78,88
Agricultural residues	Yellow dry corn post harvest	Excellent, flat as any agricultural field	7	20%	250	20	5,00	4,00	0,71429	$ 9,86	$ 39,44	$ 49,30
Forest residues (post harvest)	Eucalyptus branches and top tree	Flat ground, with stump at 3m distance.	6	20%	415	17	7,06	5,64	1,17583	$ 11,60	$ 27,95	$ 34,94

[79] http://www.grpanderson.com/de/biomasse-a-forstwirtschaft/biobaler-system/320-selection-of-harvesting-site

The relatively high costs of forwarding with forestry equipment in the Swedish test may be reduced with an automatic round bale chaser, which are also produces by Anderson. In the standard version a TRB2000 chaser with a capacity of 20 round bales (of max. 670 kg) pick-up while driving and off-loading by tipping the trailer cost €35,000 in 2013[80]. However, no data for cost calculation are available, and the bales are tipped off with the flat side by side, which is expected to impact the drying. For the assessment 50% are added to the Swedish €10/odt (36 bales per hour cleared from a field with a biomass density of 50t/ha) to compensate for lower biomass densities, longer forwarding distances and less even terrain.

For the chopping of the dried bales free roadside a mobile system with the power of the Doppstadt DZ750 crusher used in Sweden for chopping at plant has to be used. Chopping at the power plant cost €15/odt. Typically, stationary chipping/chopping is 50% to 70% less expensive than processing at the forest road, which would accordingly be at €22/odt. To be on the safe side, the BioBoost cost assessment operates with €30/odt for chopping of round bales. This results in total costs of €66 to €81/odt dried chips free forest road.

80 http://www.farmersguardian.com/home/machinery/machinery-news/arcusin-uk-to-import-anderson-range-of-round-bale-equipment/52460.article

Organic municipal waste

"Bio-waste" is defined in the Waste Framework Directive (WFD) as "*biodegradable garden and park waste, food and kitchen waste from households, restaurants, caterers and retail premises, and comparable waste from food processing plants*". It does not include forestry or agricultural residues, manure, sewage sludge, or other biodegradable waste (natural textiles, paper or processed wood). This distinguishes it from "Biodegradable waste" which is a broader concept defined in the Landfill Directive as any waste that is capable of undergoing anaerobic or aerobic decomposition, such as food and garden waste, and paper and paperboard.

The total yearly production of bio-waste in the EU amounts to 118 to 138 Mt of which around 88 Mt originate from municipal waste and between 30 to 50 Mt from industrial sources such as food processing. In the EU, bio-waste usually has a share of 30% to 40% – but can range from 18% up to 60% – in municipal solid waste (MSW). The bio-waste part of MSW comprises two major streams: ‘green waste’ from parks, gardens etc. and ‘kitchen waste’, i.e. food residues or food processing waste. The former usually includes 50-60% water and more wood (lignocellulose), the latter contains no wood and up to 80% water. Bio-waste has to be disposed of and its treatment raises costs, which are covered by a gate fee. Accordingly, the ‘price’ of bio-waste is that of the applied treatment technology and the value of its products.

BioBoost studies conversion technologies, which may use bio-waste as input. Although it might be feasible to apply hydrothermal carbonisation as sorting technology to separate lignocellulosic, HTC susceptible waste from inert materials (metals, minerals, plastics) of larger particle size, this is out of scope of BioBoost. Thus, it is about sorted or source-separated bio-waste, the amount of which differs considerably between European countries depending on its share in municipal solid waste and recycling rate. The share of recycled bio-waste is shown in the following figure [81].

[81] http://www.eea.europa.eu/publications/managing-municipal-solid-waste

Figure 25: Share of recycled bio-waste from total municipal waste in 2001 and 2010. Copyright EEA

A European review on compost production costs carried out in 2002 came out with €35 to 60 per tonne of waste for larger, closed system plants. For open, windrow-systems production costs may be less than €20/t. The compost is 'marketed' for typically 0 to €3/t free field including spreading, which is below the costs for transport and spreading[82].

The pitfall of bio-waste management is the highly variable purity, which leads to highly variable cost. This is shown in an example from Catalonia, Spain, where treatment costs of bio-waste were around €35/t in 2007[83]. However, these costs highly depended on the purity of the bio-waste and ranged between €20/t and >€100/t as shown in the following figure.

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[82] End-of-waste criteria on Biodegradable waste subject to biological treatment http://susproc.jrc.ec.europa.eu/activities/waste/documents/IPTS_EoW_Biodegradable_waste_3rd_working_document_wo_line_nr.pdf

[83] Giro 2008 http://www.atiaiswa.it/files/wrapper/ISWA_beacon_conference_2008/Proceedings%20Iswa%20Beacon%20Conference%202008/2%20-%20Friday%2023rd%20May%20-%202008/Session%205/Francesc%20Gir%C3%B2.pdf

Table 11: Dependency between purity of bio-waste and treatment costs in Catalonia, 2007. Copyright: Francesc Giró, Agència de Residus de Catalunya

Treatment Fee in relation to % of impurities								
Composting Plant	< 5	5-10	10-15	15-20	20-25	25-30	30-50	> 50
Plant 1			50,00 €/T		75,00 €/T			
Plant 2	50,25 €/T		58,50 €/T		94,90 €/T			
Plant 3			50,00 €/T		75,00 €/T			
Plant 4	58,13 €/T		62,06 €/T	70,45 €/T	81,37 €/T	NOT ACCEPTED		
Plant 5	30,95 €/T		36,72 €/T	42,98 €/T	53,39 €/T	NOT ACCEPTED		
Plant 6	67,72 €/T	71,07 €/T	74,43 €/T	77,79 €/T	81,16 €/T	84,52 €/T	95,87 €/T	
Plant 7	26,18 €/T		31,18 €/T	36,18 €/T				
Plant 8	19,96 €/T	52,91 €/T	67,68 €/T					
Plant 9	55,40 €/T		57,76 €/T	60,90 €/T	64,20 €/T	70,90 €/T	78,00 €/T	
Plant 10	56,03 €/T		58,05 €/T	60,06 €/T	62,07 €/T	64,08 €/T	NOT ACCEPTED	
Plant 11	33,17 €/T				36,38 €/T		50,83 €/T	
Plant 12	33,17 €/T				36,38 €/T		52,97 €/T	
Plant 13	25,33 €/T	28,00 €/T	28,00 €/T	30,68 €/T	NOT ACCEPTED			
Plant 14	25,16 €/T		26,16 €/T		32,70 €/T			
Plant 15	45,00 €/T	49,50 €/T	54,00 €/T	58,50 €/T	70,50 €/T	82,50 €/T	94,50 €/T	99,00 €/T
Plant 16	36,93 €/T	42,18 €/T	47,41 €/T	52,67 €/T	57,91 €/T	66,30 €/T	100,91 €/T	136,57 €/T

The purity of the bio-waste depended to some extent on the collection system, where individual bins collected door to door in small communities had in average a higher purity than road-side containers as shown in the figure below.

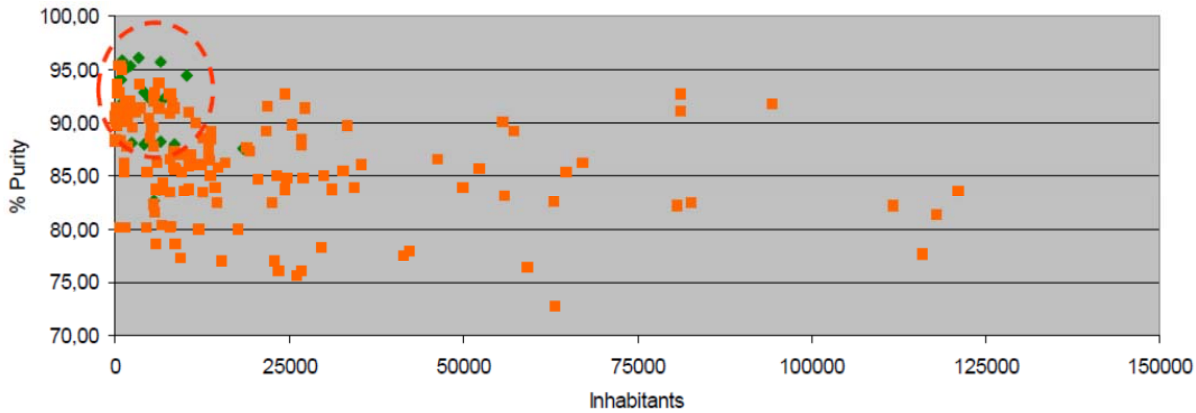

Figure 26: Influence of individual door-to-door (green) collection or road-side containers (orange) and size of municipality on biowaste purity. Copyright: Francesc Giró, Agència de Residus de Catalunya

The highest observed purity of bio-waste was about 96% the lowest purity was 73%; i.e. impurities are between 4 and 27%. This relates to a bandwidth of treatment costs starting at €20 to €68 per tonne for high grade bio-waste (below 5% impurities) and €33 to €95 per tonne low grade biowaste (25 – 30% impurities) or denial of treatment in 3 of 16 cases.

In an example for Germany, costs of different technologies are compared. Here between 8.3 and 8.5 million tons per year of organic waste (half is biowaste, half garden waste) are separately collected by about 45% of the population. Products from non-source separated organic waste (i.e. separated at the waste yard) have to be deposited, either as compost or as ash. Landfilling of untreated waste is prohibited. For separately collected waste several treatment technologies are established ranging from composting over anaerobic digestion, mono-incineration in biomass or waste power plants to co-firing in lignite power plants. Gate fees for biowaste composting are between €30 and €60 per tonne; €40 to €70/t for anaerobic digestion (AD) and €50 to €80 per tonne at incineration. The gate fee for garden waste is lower than that for kitchen-waste, typically between €15 and €25 per tonne. AD and mono-incineration profit of guaranteed feed-in tariffs for the produced power (EEG 2009: €77.9 to €116.7 per MWh). Compost is typically at €0 free customer[84].

For the sake of simplicity, a cost range of €30 to €60 is used for bio-waste. Cheaper windrow composting systems are expected to be phased out in some time due to emission regulations.

Supply curve issues

Waste disposal is a public concern and strictly regulated. The treatment of bio-waste is typically carried out by public entities or long term sub-contracted. Thus, volumes may be available, where treatment contracts end; (composting-) installations are out of depreciation, or have to be replaced due to emission regulations; or where new volumes become available due to increased separation capacities in order to reduce landfilling in line with e.g. the waste framework directive.

A recycling target of 50 % of the household waste by 2020 is set in the EU's Waste Framework Directive. As bio-waste has a significant share (see table below) and many countries have not reached this target, it is expected that large quantities of bio-waste will become available in the near future.

Table 12: Share of biowaste in municipal waste between 2008 to 2010. Source: EEA 2013[85]

Share of bio-waste in total municipal waste	Countries
Less than 20%	Lithuania, Norway, Slovenia
20 to 30%	Bulgaria, Denmark, Ireland, Hungary, Latvia, Switzerland
30 to 40%	Germany, France, Italy, Sweden, United Kingdom, EU-average
40 to 50%	Austria, Belgium, Czech Republic, Estonia, Finland, Luxemburg, the Netherlands, Poland, Romania, Spain
50 to 60%	Greece, Portugal, Slovakia
60 to 80%	Malta

[84] Dach 2010 http://www.iswa.org/uploads/tx_iswaknowledgebase/Dach.pdf
[85] http://www.eea.europa.eu/publications/managing-municipal-solid-waste/at_download/file

The agricultural residue livestock manure

Manure is a residue from animal rearing or livestock production. It consists of faeces and may contain varying amounts of straw and wood (dust or chips) as bedding material. It is high in nutrients and usually spread as fertilizer, reducing the demand for mineral fertilizers. The fertilizer content differs depending on the animal, amount and type of bedding material, age and water content. For water protection and eutrophication prevention the spreading of nitrogen (N) and phosphate (P or P_2O_5) containing manure is usually regulated to a maximum of 170 kg organic N per hectare and year. Additionally, the supply of N and P has to match the withdrawal via harvested crops and maximum values for soil concentration and losses are set. Accordingly, animal holding enterprises with little or no land have to market the manure. In regions of high cattle density the limit for manure-N and the phosphate balance make it impossible to spread the whole amount of manure. This requires either long distance transport of this low value commodity or energetic use and re-use (or disposal) of the ash (fertilizer) elsewhere. The figure below shows the livestock density per agricultural area in 2007[86]. It is expressed as livestock unit (LSU) per hectare, with 1 LSU equal to e.g. 1 dairy cow, 1.25 horses, 3.3 fattening pigs, 71 laying hens or 142 broilers[87]. In areas of the 2 highest classes (>2.8 LSU/ha) holdings usually have to pay for manure disposal although it’s value in terms of mineral fertilizer substitute. These regions are considered surplus regions.

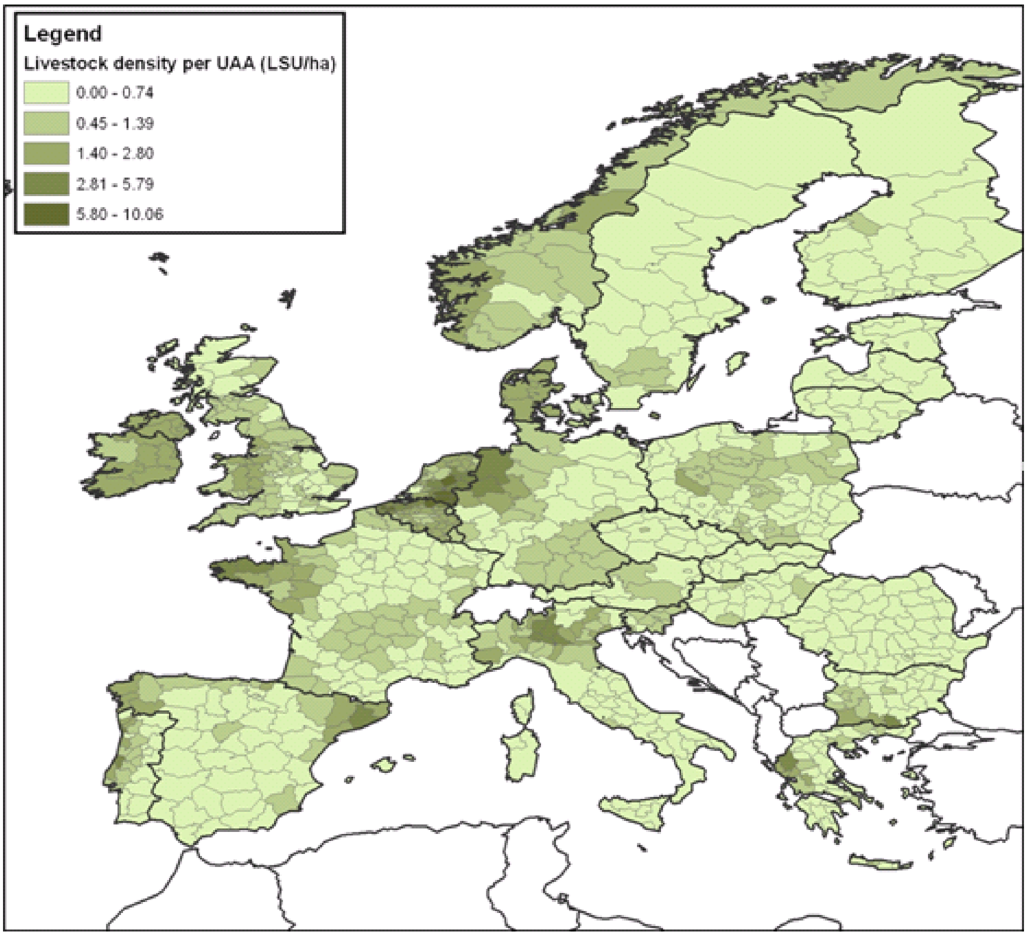

Figure 27: Livestock density per hectare utilized agricultural area in 2007. Regions with >2.8 are considered manure surplus regions. Copyright: EUROSTAT

[86] http://epp.eurostat.ec.europa.eu/statistics_explained/index.php?title=File:Livestock_density_at_regional_level,_2007.png&filetimestamp=20100921104706

[87] http://epp.eurostat.ec.europa.eu/statistics_explained/index.php/Glossary:LSU

According to the data from 2007, four regions seem to have a manure surplus: 1) the Netherlands, northern Belgium and north-western Germany; 2) north-western France (Bretagne); 3) north-eastern Spain (Catalonia); 4) northern Italy (Lombardy) and smaller areas in north-western Greece and southern Bulgaria.

The table below shows typical characteristics of manure from animal rearing, given as amount per animal place (e.g. 3 rotations of pig fattening per year) or per cubic meter or tonne of manure. For comparison, the costs for an equivalent amount of mineral fertilizer are indicated in the shaded cells.[88].

Table 13: Various characteristics of different manures. The physical state, dry matter content and amount per animal place is shown in the top, the fertilizer content in the bottom. When operating with conventional spreading equipment, 60% of the nitrogen in solid manure is plant effective; in liquid slurry, the efficiency ranges from 70% (pig) to 85% (cattle). Costs for respective amounts of mineral fertilizers are shown in grey. Source: Chamber of Agriculture Lower Saxony 2012

	(Mineral fertilizer)	Dairy / Cattle	Pigs	Poultry	Horses
State	-	liquid	liquid	solid	solid
Dry matter [%]	-	10	5	50	30
Amount	-	20 / 7 m³/a	1.5 m³/a	0.1-5 t/a*	5-10 t/a
Fertilizer	value	content			
	[€/kg]	[kg/m³]	[kg/m³]	[kg/t]	[kg/t]
Effective N	1.1	3.3 - 3.6	3.3	12.6 - 15	2.4
P_2O_5	1.25	1.8 - 2.2	2.6 - 3.2	18 - 21	3
K_2O	0.68	5.4 - 7.5	3 - 3.3	15 - 30	11
MgO	1.15	0.7 - 1	1.2 - 1.3	4 - 6	1
Total value	[€]	11.3 - 12.3	10.7 - 11	58 - 70	15

* Per 100 animals

The Netherlands have the highest livestock density in the EU with an average of 226 kg manure N per hectare agricultural area. In about a quarter of the country values of 300 kg N and 120 kg phosphate per hectare are exceeded. This amounts to an average annual nutrient surplus of 50,000 t phosphorus and 122,000 t nitrogen in the past 3 years[89]. In 2012 it exported 2.4 million tons manure, 16% more than in 2011. Germany received 1.7 million tons (after 1.5 in 2011), of which 641,000 t were horse manure, 343,000 t poultry manure, 341,000 t pig slurry, 362,000 mixed manure and 19,000 cattle manure. The phosphate content was 15,700 t (+1.3%), the nitrogen content was 21,300 t (+2.3%)[90].

In September 2008, the world's largest biomass power plant running exclusively on chicken manure was opened. It has a capacity of 440,000 t, which is about one third of the total Dutch production of chicken manure and has a 36.5 MWel[91]. This plant led to a drastic drop in costs for manure disposal from 2008 on, as shown in the figure below. In 2009 pig manure disposal costs related to 8 % of the total production costs. Today, disposal costs are between €15 and €25 per tonne. An example for a treatment plant is the Kumac Mineralen livestock manure treatment plant separating 70,000 t pig slurry into water and fertilizer-containing solids by

[88] Landwirtschaftskammer(chamber of agriculture) Niedersachsen, fertilizer content: 2010; Prices: 2011/12
[89] http://www.wageningenur.nl/upload_mm/4/6/7/8af886b7-2398-4d40-9540-8ddcf35b4895_Manure%20for%20value%203.pdf
[90] Land&Forst 11-2013 p 10
[91] http://news.mongabay.com/bioenergy/2008/09/worlds-largest-biomass-plant-running-on.html

separation, filtration, reverse osmosis and drying. About half of the input comes out as water, which is so clean that discharge to surface waters is allowed. About one third comes out as liquid fertilizer of 7 to 12 % N and 7 to 10% K. The remainder comes out as solid 12-17-5 NPK fertilizer. This saves about 816,000 km of truck transport. Manure disposal costs are about €8/m³[92].

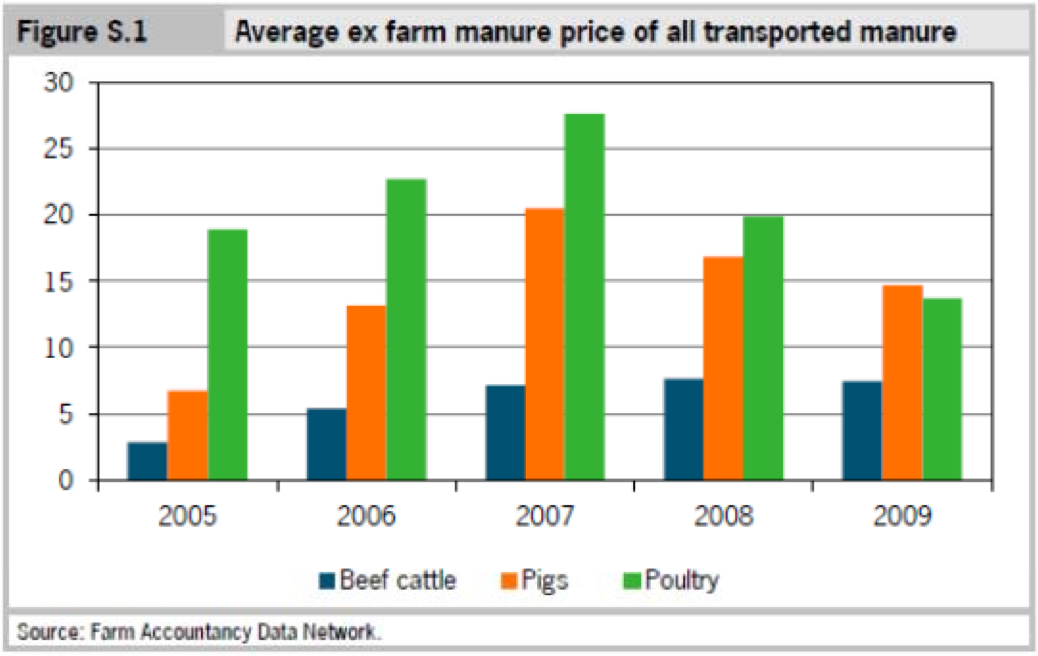

Figure 28: Development of the average disposal costs of manure from cattle, pigs and poultry. Copyright: De Koeijer et al., 2011[93].

In the north-western part of **Germany**, the **Weser-Ems** region, the cattle density is with up to 3.42 LSU per hectare considerably smaller than in the Netherlands. About 50% (57 million) of the German poultry, 30% of pigs (8 million) and 2.5 million cattle are stocked here[94], with even increasing tendency. The region had in 2012 a calculatory deficit of about 260,000 ha land for manure spreading with regard to the limit of 170 kg/ha manure-N. An area of 125,000 ha has to be added to cover the imports from the Netherlands. The nitrate concentration in the groundwater is increasing in the respective area and breach of the manure N-limit is suspected. Accordingly, a fertilizer tracking regulation was implemented in 2012, which covers all exports from the Netherlands, all accepting holdings and holdings giving more than 200t/a manure in Lower Saxony and Northrhine-Westfalia. Recently, the transportation distances increased from 40 to 50 km to now 85 to 100 km or even more, single distance. In neighboring parts of Northrhine-Westfalia (Borken) manure transfer costs of around €11/m³ were reported (see figure below), a level which is expected for parts of the Weser-Ems region (€9 to 10/m³) in the near future, too[95].

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92 http://agro-technology-atlas.eu/docs/21010_technical_report_IV_assessment_of_economic_feasibility_and_environmental_performance_of_manure_processing_technologies.pdf

93 De Koeijer T.J., Ham A.v.d., Luesink H.H. (2011) Quick scan economische aspecten van het mestbeleid. Evaluatie Meststoffenwet 2012: deelrapport ex post. , Evaluatie Meststoffenwet 2012, Den Haag, LEI Wageningen UR, LEI-rapport 2011-068. http://www.lei.dlo.nl/publicaties/PDF/2011/2011-068_summary.pdf

94 www.ml.niedersachsen.de/download/63184

95 http://www.susonline.de/archiv/Guelle-Kosten-explodieren-1124891.html

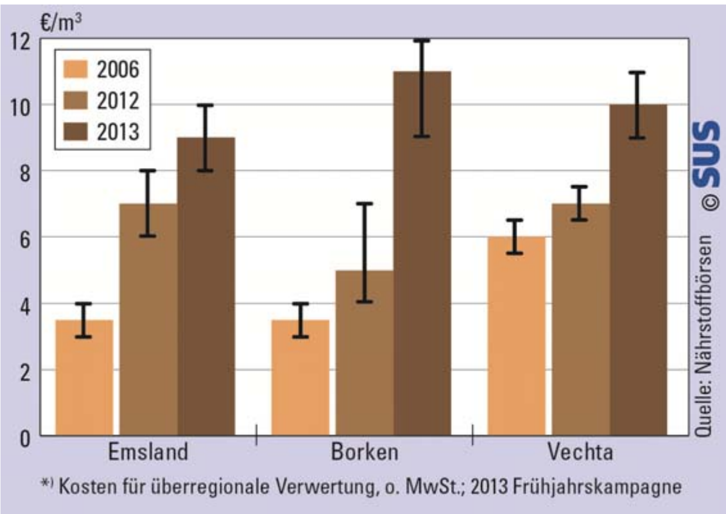

Figure 29: Costs for over-regional transfer of manure in north-western Germany in spring 2013. Copyright: Fred Schnippe, SUS online

The northern part of Flanders, Belgium is the southernmost part of this livestock producing area. Increasing nitrate concentrations led to the introduction of manure processing obligations of up to 60% of the surplus nitrogen amount (>170 kg/ha agricultural land). Certificates are granted for: The export of manure; disposal of manure on non-farming land; conversion to mineral fertilizer or removal as N_2. If an animal rearing enterprise has fewer certificates than required to cover its nitrogen surplus in a certain year, it is fined €2 per kg of surplus nitrogen. This fine is doubled to €4/kg N for shortfalls in subsequent years (up to 5 years)[96]. This translates to manure disposal costs of below €8.4/m³ (3.5 kg N/m³*€4/kgN*60%) if fines should have an effect.

Catalonia in **Spain** is home of 6 million pigs, 0.65 million cows and 38 million poultry, giving rise to 19 million tonnes manure per year which contains about 100,000 t N. Two examples for manure treatment and related costs are presented in the following: A farmer decided to treat his about 12,000 t manure from pigs and cows after solid separation in a nitrification/denitrification plant similar to sewage treatment plants. The liquid output has about 50% of the nitrogen and is used to irrigate field crops, the solid part is exported. This costs €2.86/m³ (€3.29/m³ unsubsidized). In the same area the Tracjusa plant is situated, which anaerobically digests about 110,000 m³ pig slurry, prior to evaporation of the water and pelletisation of all solids and salts (N loss 4-6% of total input). The dry pellets (5825 t/a) are sold and transported instead of a slurry to the receiving areas in 100 km distance saving 95% of transport efforts. The unsubsidized costs are €43.72/t, which is reduced to €1.9/t due to a high feed-in tariff for the biogas power plant[97]. For the BioBoost cost assessment a value of €10/m³ is assumed for this region as the transportation distance is similar to that in north-western Germany.

In 2007 **Denmark** had a production of 23 million pigs and a stock of 1.5 million cattle, which led to 32 million tons of manure (80% slurry), of which 90 % was spread directly and 10 % was treated in fibre-separation or in biogas plants[98]. Manure treatment in biogas plants is encouraged by a very strict water protection regulation. Spreading of degassed substrate is

[96] http://www.vcm-mestverwerking.be/information/index_en.phtml?informationtreeid=26

[97] Foged, Henning Lyngsø, Xavier Flotats, August Bonmati Blasi, Karl Martin Schelde, Jordi Palatsi, Albert Magri and Zivko Juznik. 2011. Assessment of economic feasibility and environmental performance of manure processing technologies. Technical Report No. IV to the European Commission, Directorate-General Environment. Unpublished draft. 130 pp.

[98] http://www20.gencat.cat/docs/DAR/OR_Organismes/OR02_GESFER/Documents/Jornades_2008/Fitxers_estatics/2008_jornada_expoaviga_livestock_denmark.pdf

allowed up to amounts which cover 100% of the nitrogen demand in contrast to direct spreading of manure which requires an additional 57 kg N of mineral fertilizer to achieve the maximum allowed application rate of 162 kg/ha in wheat. An example is the Morsø BioEnergy (MBE) biogas plant, which treats 120,000 tonnes or the solid (separateable) part of 375,000 tonnes pig manure per year. The net processing costs are in average €3.84/m³ (€4.9/m³ excluding subsidies) but there are different rates: Raw slurry collected at the farm and post-digestion separation liquids returned to the farm is at €2/t; Raw slurry collected at the farm, and nothing returns cost €6.4/t; and raw slurry separated at the farm by MBE, and MBE receives the separation solids cost €3.1/t. To that comes a yearly fee of €2400 per holding and €147 per 100 kg N in manure (~€6.6 per fattening place) (Foget et al 2011).

Energy crops

In the BioBoost project the focus is on residues and wastes avoiding the competition to food production and the high fertilizer and energy input to cereal and oil seed production, which are of public concern if used to produce a substitute for fossil fuel. Energy crops are considered as top-up option or to improve the feedstock supply by out-of-phase harvest. Most suitable seem to be ligno-cellulosic crops due to a lower demand for fertilizer input and perennial crops which are planted once and may be harvested over several years. Respective crops like Miscanthus, switch grass, cardoon and willow or poplar short rotation coppice are introduced here as examples. Miscanthus and switchgrass are harvested in late winter/early spring, about 7 month after wheat. At an approximated rate of €1.5 per tonne and month for storage in field side stacks, this would relate to a saving in storage costs of about €10/t for a year-round operating conversion plant.

Miscanthus

Miscanthus (*Miscanthus giganteus*) is a giant reed of up to 3.5 m height, which is planted as rhizome as the plant is a sterile hybrid. Like maize, it is a C4 plant which means that the CO_2 fixation is faster, the water use efficiency is higher (about doubled) than in the more wide spread C3 plants (e.g. wheat) and –correspondingly- the ash content is lower. Other site requirements are also similar to maize: The shoots emerge at increased soil temperatures and die off at frost; it is insensitive to high temperatures and drought (perennial plants have a well developed root system), but yield depends on water supply in the warm season. In the temperate regions (UK, France, southern Germany) the yield may exceed under optimal conditions 20 odt per hectare and year (on irrigated Mediterranean sites over 30 odt/ha*a). Maize may serve as orientation for the yield (after conversion to dry mass content) or twice the amount of the best adapted cereal grain harvest. It usually takes 3 years until full productivity is reached. The best time for harvest is in early spring before the new shoots emerge, as the mineral content in the stalks is then low due to leaves fallen off and some fertilizer leaching. The ash content of spring harvested Miscanthus is in the low 2% range[99], which is about a third to a half of the ash content in wheat or cereal straw. The harvest may be done with a field chopper or by swath mowing and baling. Large square bale density and abrasiveness is similar to straw. The average moisture content of bales made between February and April for IEC, a Miscanthus specialist, was 11% in the UK in 2010[100]. Contractors appreciate Miscanthus jobs due to the increased degree of utilization outside the typical harvesting season. However, planting and weed control in the first two years have to be done carefully. The rhizomes have to be fresh, best results are achieved with manual planting, application of a pre-emergent herbicide should be considered, drought impacts should be alleviated by watering (e.g. with a slurry spreader). Once well established Miscanthus is a reliable performing crop with low efforts for fertilizer spreading and harvest.

In the **United Kingdom** farmers are offered 5 to 10 year contracts at GBP70/t (€83.3/t) ex-farm for baled Miscanthus at a maximum of 15% moisture in 2013/14, with linkage to the retail price index for future harvests[101]. In 2011 the Miscanthus specialist *IEC* offered contracts of GBP64/t (€76/t) for transactions between August and November. A premium of GBP8/t (€9.5) is paid for stored bales collected between November and March and a respective reduction for April to June transactions[102]. Miscanthus is more expensive than straw, which was at GBP59/t barley straw and GBP40/t wheat straw in large square bales in August 2011 This relates to 92% and 63% of the rate offered for Miscanthus[103].

[99] http://biomassandbioenergy.nl/ParisConf/BakkerElbersen.pdf
[100] http://www.energycrops.com/?page_id=23
[101] http://www.farmersguardian.com/home/renewables/price-for-energy-crop-miscanthus-at-all-time-high/52643.article
[102] http://www.farmersguardian.com/home/business/miscanthus-contracts-offering-%C2%A364/tonne/41246.article
[103] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/182843/defra-stats-foodfarm-farmgate-commodity-haymth-130321.xls

For **Austria** the Miscanthus specialist *Giganteus* quotes a price of €80/odt free power plant[104] in 2010.

For **south-western Germany**, *Eifelacker* gives a price range of €80/t (at 10% moisture, €88.3/odt) to €65/t (€81/odt at 20% moisture) for Miscanthus chips[105]. These prices are similar to straw, however loose chips have a very low density of 110 to 140 kg/m³. Solutions for chipping into large square bales or balers with a pre-chop pick-up are available.

Figure 30: Top - Harvesting of a Miscanthus field and below – field side stacking in the UK in early spring. Copyright: IEC - International Energy Crops, www.energycrops.com

[104] http://www.miscanthus-giganteus.at/GIGANTEUS%20Deckungsbeitrag.pdf
[105] http://www.eifelacker.de/wp-content/uploads/2010/08/MiscanthusBroschuere1.pdf

Switchgrass

Switchgrass (*Panicum virgatum*) is a tall grass (1.5 to 2 m) summer crop from the North American prairies. Like Miscanthus it uses the effective C4 photosynthesis pathway but is propagated via seeds like other fodder grasses. It usually reaches full productivity in the 2nd or 3rd year but, depending on site and establishment conditions, it might take up to 5 years on heavy soils. It has very deep reaching roots (>2m) and tolerates acid soils due to interaction with mycorrhizae. As Miscanthus, switchgrass is harvest best after senescence in winter or early spring with a moisture below 15% using standard mowing and bailing equipment. However, younger shoots are delicate forage for cattle (grazed or harvested as hay) and wildlife, birds seek the cover and nourish of the seeds. Depending on the yield level fertilization may be required to replace the withdrawal. The production costs are lower than those of Miscanthus due to grass seeding technology and were estimated to be between €24/odt in Greece and €62/odt in the Netherlands[106]. Price information is not available but it is expected to be similar to straw.

Figure 31: The C4 forage crop switchgrass may be used for bioenergy generation after senescence in winter. Copyright: Warren Gretz, US-DOE/NREL

[106] www.switchgrass.nl

Cardoon

Cardoon (*Cynara cardunculus*) is a Mediterranean thistle highly adapted to drought. It is sensitive to frost but established plants usually recover from the 5 m deep roots. It grows on most soils and tolerates acid and alkaline conditions. It uses the CAM pathway, which stores CO_2 over night to minimise evaporation losses. The water use efficiency is increased 3- to 6-fold compared to C4 or C3 plants, respectively. This leads to a yield of e.g. 20odt/ha with a rainfall of 450 mm as observed in Spain, 400 mm still give a good yield. The vegetation cycle starts in autumn at the beginning of the winter rain season with a growth to a height of 2 m and width of 1 m. Flowering is in summer before the part above the surface desiccates (harvest for bioenergy generation). The next cycle begins with sprouting from the rosette. Cardoon may be harvested using conventional equipment, either a field chopper and chip trailers or a mower and a baler. The transport mode and composition (rich in salts) of Cardoon biomass is similar to straw and thus the price is expected to be comparable to straw.

Figure 32: Cultivated species of the Mediterranean thistle cardoon are also known as artichoke. The withered plant may be used for bioenergy generation. Copyright: Pixeltoo

Willow and poplar short rotation coppicing

Poplar and willow are trees, which are able to sprout from the stool after coppicing. This is used also for propagation by planting of cuttings. Plantations are harvested in winter every 2 (short rotation) to 20 years (long rotation) depending on the available machinery and envisaged application. Field choppers with a wood head or tractor powered systems are able to harvest stems of up to 12 cm diameter, larger dimensions require forest machinery. Field harvesters are usually most economic but wood chips with a moisture content of 50 to 55% require immediate use or vented storage to prevent molding. Tractor powered systems produce billets or rods, which may air dry with lower or insignificant losses. Forestry equipment is more expensive than a field harvester but has no tree size limitation and enables on site drying in whole tree bundles or loose stacks.

Willow and poplar require a good water supply but are able to access groundwater in deeper layers than cereals. With groundwater connection, yields of 20 to 30odt/ha*a (northern Germany/northern Italy) are achieved in rotations of 3 to 5 years. The growth of poplar culminates at higher ages (the annual growth increment increases from year to year until an age of 12-20 years per rotation) than willow, but even in 3 year 'short rotations' the poplar yield is typically higher yield than that of willow except for regions colder than northern Germany (e.g. Denmark and Sweden). However, poplar planting material is more expensive than willow. Short rotation wood (2 to 5 years) contains fewer nutrients than annually harvested energy crops but more than stem wood from forests. The fuel properties are similar to forestry (felling) residues and its price is on the higher end of the respective range (€50 to €80/odt)[107].

Figure 33: Willow on a sandy (poor) soil 14 month after planting in Brandenburg, Germany. Copyright: Kühner

[107] www.optfuel.eu Deliverable 1.5, 1.7, 7.2 and therein

Waste wood

The recycling of waste wood is politically encouraged e.g. by acceptance as biomass for the generation of renewable energy. Material recycling in fiber boards is restricted to untreated waste wood, which includes waste wood pretreated with de-painting or de-coating technologies. To keep the recycling risks of such a diverse feedstock low, waste wood is categorized, e.g. in three types untreated/treated/contaminated or in 4 types as in the following example from Germany:

Category A1 - natural or only mechanically treated waste wood: Wood is not more than insignificantly contaminated with foreign substances (e.g. nails), as saw mill cut-off, pallets, wood from construction works (untreated wood).

Category A2 - glued, varnished, coated, painted or otherwise treated waste wood without organic halogen compound and without wood protection agents, e.g. fiberboards, plywood, doors... (treated wood).

Category A3 - waste wood coated with organic halogen compound, without wood protection agents, e.g. PVC coated boards (treated wood).

Category A4 - waste wood treated with wood protection agents such as railway sleepers, line poles, hop poles, vine stakes and other types of waste wood (contaminated wood).

The waste wood market is international with a vivid trade to where the demand is high and prices are good. Between some countries waste wood commodities are exchanged to comply with national renewable energy policies. Germany has e.g. favorable conditions for power generation from A1, which is thus imported, while treated or contaminated assortments are exported.

The difference between the selling price and the production costs (transport, crushing, separation of metals & other waste and management) is the gate fee, which has to be paid by those, who dispose the waste at the recycling yard. This gate fee varied in 2012 in the **United Kingdom** for well-sorted, good material (high grade) between a receipt of GBP11 and a fee of 40; for low grade material a fee between GBP5 and 65 had to be paid. In Southern England it is more expensive to recycle wood than in Northern England and Scotland. The average fee of GBP8 for high grade material relates to €9.4 to €10.25 per tonne (low grade average fee of GBP32 relates to €37.6 to €41) depending on the exchange rate. Prices free plant were around GBP35 (€41 – €45) per tonne in 2012 depending on e.g. specification, location and volume[108]. So between reception at the recycling yard and use at the end-consumer the waste wood price rose by about €80/t. The waste wood prices were between those for chips from forestry residues and chips from wood processing (saw mills). The latter may also be used for animal bedding, board production or domestic heating pellets. The UK was a net waste wood exporting country in 2011/12.

[108] http://www.usewoodfuel.co.uk/media/333631/piers_presentation__1_.pdf

Table 14: Prices/gate fee in GBP per tonne of mixed wood delivered to a wood recycling yard[109]

	Jan	Feb	Mar	Apr	May	Jun
High grade	11 - -20	11 - -20	10 - -20	8 - -20	9 - -21	8 - -20
Low grade	-9 - -43	-8 - -45	-8 - -45	-9 - -47	-6 - -50	-7 - -55
	Jul	Aug	Sep	Oct	Nov	Dec
High grade	5 - -25	5 - -25	6 - -30	8 - -40	5 - -30	8 - -25
Low grade	-5 - -63	-7 - -65	-8 - -65	-10 - -65	-10 - -60	-8 - -55

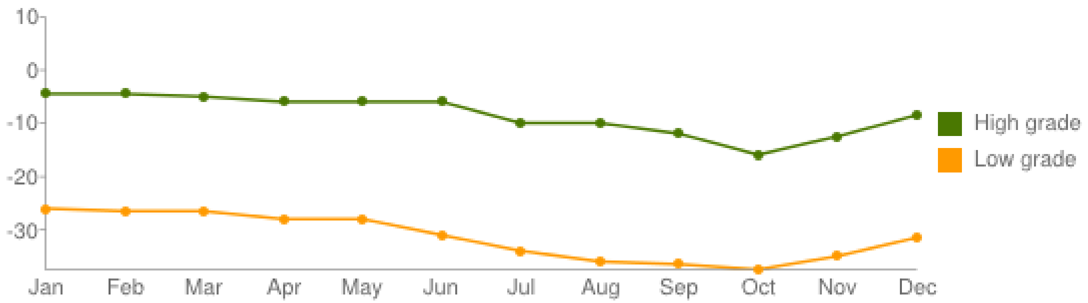

Figure 34: Waste wood prices in GBP per tonne free wood recycler in the UK in 2012. High grade material is untreated and clean; pallet wood or sawmill round wood may receive a small payment. Copyright: www.letsrecycle.com

In **the Netherlands** recycling centers paid a price of around €12 per tonne for quality waste wood. Consumers as CHP facilities paid €20 to 40 per tonne in 2009[110]. The Netherlands were a waste wood net exporting country in 2011/12.

German waste yards charge gate fees between €17[111] and over €79[112] per tonne waste wood, depending on the quality grade. Contaminated wood, e.g. A4 often has a higher fee than treated wood, untreated wood sometimes a lower fee. The price of treated waste wood chips free customer increased from €-5 per tonne in 2002 to €15 in 2010 as shown below[113]. An overview on the influence of waste wood type, particle size and regions in Germany in July 2011 is shown in the table below. Untreated, high quality chips are between €30 and €45/t, while treated and contaminated waste wood chips cost about the same, about €15 to €30/t free power plant. So the chain from the reception at the recycling center (gate fee) via processing and transport to the end user cost about €60/t for untreated to €80/t for treated or contaminated waste wood. This change is similar to the UK. Generally, the price of waste wood chips seems to be a bit lower than that of forest wood chips. Germany was a waste wood net importing country in 2011/12.

[109] http://www.letsrecycle.com/prices/wood/wood-prices-archive/prices?subCategory=2012
[110] http://www.iema.net/system/files/eu20waste20policy20context20brian20menzies_0.pdf
[111] http://www.landkreis-holzminden.de/staticsite/staticsite.php?menuid=214&topmenu=43
[112] http://entsorgungszentrum.de/Preise/Verwertung.php
[113] http://www.bv-agrar.de/bvagrar/termine/ergebnisse_handelstage/fht_2010/vortrag_burger.pdf

Figure 35: Price [€/t] development of treated waste wood chips free site in north-east Germany from 2002 to 2010. Source: EUWID

Table 15: Prices [€/t] of waste wood commodities in form of chips (0-150 mm) or crushed (0-300 mm) free customer in different parts of Germany in July 2011. Source: EUWID[114].

	untreated		treated		contaminated	
Germany	chips	crushed	chips	crushed	chips	crushed
NE	30-43	15-30	16-30	0-16	16-30	0-15
NW	30-42	18-30	15-27	-3-10	15-27	-12-5
S	30-45	15-30	15-26	-7-8	15-26	-15-6

Sweden has a long history in energetic use of waste wood. The figure below shows a comparison of the prices of forest wood chips, processing industry residues and waste wood free district heating plant. The regional prices for northern, central and southern Sweden were SEK139, 117 and 81 (average SEK117) per MWh in 2012 and SEK98, 110 and 79 (average SEK107) in 2011[115]. The averages relate to about €57/t in 2011 and €64.5/t in 2012 at 17 GJ/t. In the comparison of fuels for district heating plants, waste wood has the lowest price. Sweden was a waste wood net importing country in 2011/12.

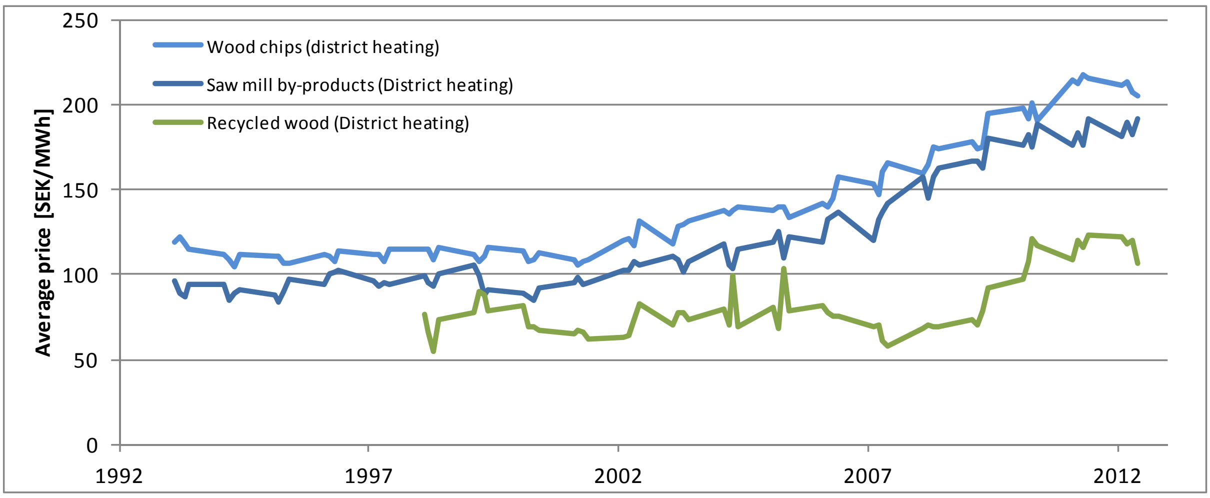

Figure 36: Development of different wood fuels for district heating plants in Sweden. Data from: Energimyndigheten 2013.

[114] EUWID 2011 The waste wood market in Germany www.euwid-recycling.com
[115] http://www.energimyndigheten.se/sv/Statistik/Energipriser/

The public available information on treated or contaminated waste wood prices in Europe is relatively limited. This might be due to restrictions concerning the emission of regulated substances, which limit its use to waste incineration facilities. However, information on 4 countries are available: Prices free consumer (e.g. district heating or CHP) were with about €57 and €65/t in the only importing Sweden (2011 and 2012) clearly higher, than in countries of import and export like Germany (€30 to €45 per tonne in 2011, depending on grade) the Netherlands (2009 €20 to €40/t) and the United Kingdom (€41 to €45/t, 2012). Generally, there seem to be costs of about €80/t between reception at the recycling yard and price free power plant. The price free consumer depends of the logistic costs, regulatory restrictions and the price of competing feedstocks. The latter relates to the feedstock demand (e.g. high share of district heating and long heating season in Sweden) and renewable energy incentives or feed-in tariffs. As the waste has to be disposed off and the political target of the EU nations is to reduce land-filling and to increase recycling, the difference of waste wood to competing feedstocks is covered with the gate fee.

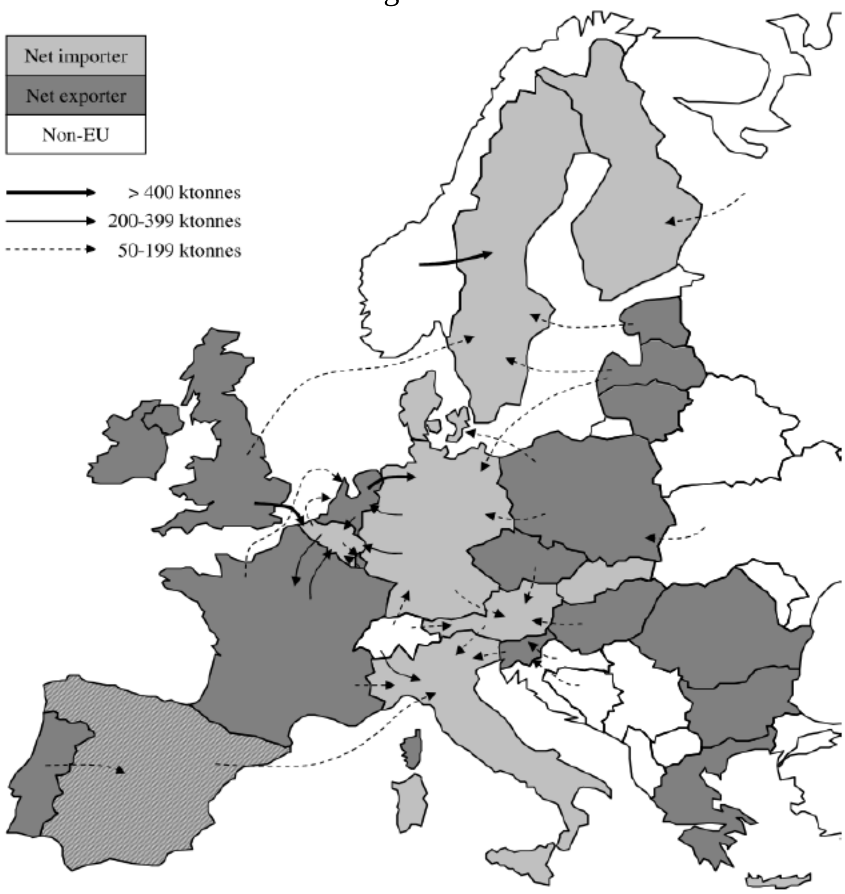

Figure 37: Typical waste wood trade flows in Europe. The waste wood trade of around 4 million tonnes between EU-nations in 2011 is considerably larger than the trade with forestry wood chips for energy generation (approx. 4 times). Copyright: Lamers, Junginger, Marchal, Schouwenberg, Cocchi; IEA Bioenergy Task 40 [116].

Concerning the assessment in the BioBoost project, costs of waste wood chips are estimated for 2 groups of countries: Countries with import only orient at the Swedish price free plant of about €57/t in 2011 and €64.5/t in 2012. In this group are Sweden and Italy. Countries without trade, import and export, or export-only have the somewhat lower cost, which orient at the UK and Germany with a per tonne gate fee of €-10 for high quality and €-40 for low quality wood waste and a price free customer of about €40 per tonne high quality and €20 per tonne low quality wood chips.

[116] http://www.bioenergytrade.org/downloads/t40-global-wood-chips-study_final.pdf

Residues of food processing industry

This is a particularly difficult sector for cost assessment as the location of a residue (or waste) producing facility plays a role together with the vicinity to and competition of up-taking enterprises (classically animal rearing holdings) the seasonality, the price of alternative feedstocks or the competing energetic use, regulations on food (feed) safety and waste disposal. Prices of feed components may vary by up to 10% from month to month.

In former times every organic residue and waste considered inedible for humans was fed to animals, which had to cope with it in one way or the other (high tolerance to e.g. alcohol if spirits were produced in the vicinity). With increasing expectations on product quality and animal well-being, the practice changed. Today, some well-characterised residues are used to substitute a part of the diet without loss of productivity but reduced feed costs.

Large volumes of residues and wastes are generated in

- Potato (starch, fries) and beet (sugar) processing residues
- Beer draff (spent grains)
- Alcohol distillation residues (distillers grains with solubles from liquor or biofuels production)
- Oil production residues (for vegetable oil or biodiesel)
- Juice and vine production residues (pomace, citrus fruit peels)
- Flour mills (cereal bran)

Potato and beet processing residues

The 'potato- and beet-campaigns' for starch and sugar production starts with the harvest (in Germany potatoes in August, beet September) and ends usually in December or January after the processing of several 100,000 to some million tonnes. Potatoes and beets are washed, chopped or mashed and extracted. The saccharose is extracted with hot water, the chips are desiccated to ~24% dry matter by pressing. Sometimes the molasses (crystallization residue) are added to the chips converting it to a carbohydrate-rich feed. After dewatering, the spent potato pulp still contains about 60% of the starch and has about 18% dry matter. Both products are high in carbohydrate energy (~12 MJ/kg dry matter), low in protein and used in feed. Dried beet molasse pellets are traded at about €270/odt; beet chips (24% dry matter) are at €150 to €200/odt free warehouse in Germany.

Beer draff

Beer is fermented around the year, the production is very stable, depending only on the beer consumption. For the production of beer cereals –usually barley and wheat- are malted, bruised, and mashed to convert the starch to sugars, which diffuse in the water. The grains are washed and pressed, the residues is called draff. It contains about 5% sugar, 11% fat and 25% protein in the dry substance (24%) and is used as feed. In Germany, it is usually sold at about €140 to €180/odt.

Alcohol distillation residues

As breweries, distilleries have no seasonality. The feedstock depends on the product but in principle all starch or sugar-containing crops or products are suitable, including wheat, rye, barley, rice, maize, potato, sugar beet, sugar cane, sugar beet molasse,… The production process starts similar to beer brewing but the solids are not separated before the fermentation and distillation. The residues are thermally dried (dried distillers grains and solubles, DDGS) or filtered and pressed to draff of about 35% dry matter. DDGS contains all the minerals and proteins (29 to 35%) the draff only the insoluble proteins and no minerals, 7 to 10% fat and all the fibers. DDGS is sold at about €300 to €370/odt; distillation draff (35% dry mass) at €140 to €180/odt in Germany.

Vegetable oil production residues

Depending on the product various oil crops are extracted for their oil. These may for example be olives, rape seed, sunflower, soy beans, oil palm … The feedstock is usually milled and pressed and/or extracted with solvents like hexane. The value of the residues is generally determined by the energy content, composition and content of digestible proteins and anti-nutritive substances (e.g. bitterns). Solvent extracted rape seed meal contains about 35% protein of which 20% is digestible, soy extraction meal has 48 to 51% total protein content of which about 30% is digestible, the energy content is 11.8 MJ/kg for rape and 13.7 MJ/kg for soy. Rape extraction meal (89% dry matter) is at about €390 free trader. For orientation, the rates are usually 5 to 10% higher than the unextracted meal. Soy bean peels are available for €240/t, palm expeller is at €225/odt[117].

Olive oil production residues occur on an order of 100,000 t/a in the Mediterranean countries. The IEE project 'Market of olive residues for energy'[118] made a survey on prices of residues and use options in 2010. In Liguria, Italy the residues are considered as waste and spread like manure in the plantations or are given away for free for shipping to refineries for kernel oil extraction. In the Chania region on Crete in Greece, olive oil mills sold virgin pomace (residue of physical extraction, 20 to 25% dry matter) for solvent extraction of kernel oil at €15/t. The dried extraction residues are often bough back for €50 to €60/t (87% dry matter) for burning in the oil mill. In Jaen, Spain, probably the largest olive oil producing region of the world, the pits and pomace is burned after oil extraction. In the Slovenian and Croatian parts of Istria, bioenergy generation was reported to be relatively new so the residues are spread like manure in the plantations to return fertilizer.

Juice and vine production residues

In Germany, apple juice production residues are given away for free or for a small fee of up to €50/t. There was no information on the use and price of citric fruit peels available.

Flour mill residues

Before milling the cereal grains have to be cleaned, leading to about 0.3% dust, grass seeds and various brittle. Several cycles of milling are used to separate the flour from the bran which occurs at about 15% of the grain mass[119][120]. The bran is high in carbohydrate energy and protein and is highly appreciated as feed and is traded at about €220/t (88% dry matter).

[117] Prices by May 2013, http://www.proplanta.de/Markt-und-Preis/Hamburger-Getreideboerse/Hamburg-Grosshandelspreise-14-05-2013_notierungen1368560752.html and Land&Forst 21/2013
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