

WOODEN BIOFUELS IN EUROPE - QUANTITIES AND CORROSION RELEVANT CHARACTERISTICS

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ABSTRACT: In a pre-normative research project on the corrosion load of flue gas from biomass combustion on metal chimney systems, the European wooden biofuel market was studied with respect to quantities and corrosion relevant properties. A methodology for estimating European wood fuel tree species by combining data from different statistical sources has been developed. Results indicate that France with an annual consumption of more than 40 Mm³ of wood for household energy production is leading, followed by Germany with approximately 25Mm³. Concerning wood fuel tree species the calculation identified oak as most important wood fuel in Europe with an annual consumption of around 38Mm³. Other important tree species are beech, spruce and pine with approximately 20 - 25Mm³ consumption per year for each. Together these four tree species cover more than 75% of wood fuel in Europe. The study of corrosive compounds in wooden biofuels revealed significant discrepancies between actual fuelwood analysis results and literature data as well as thresholds defined in the European fuel standard. In case of chlorine the average concentration in the samples (30mg/kg) was almost one order of magnitude lower than literature values and the threshold proposed for the highest wood pellet class in the European standard EN14961 (200mg/kg).

Keywords: wood, standardisation, market, corrosion, chemical composition, small scale application

1 INTRODUCTION

Efficiencies of biomass based small-scale combustion systems are continuously increasing. This obviously goes along with a reduction of flue gas temperatures. In certain circumstances, e.g. low flue gas volume flows in part load operation, inadequately dimensioned chimneys or a high water content of fuel, even at current flue gas temperatures of state-of-the-art combustion appliances condensation of water vapour in the flue gas can happen.

If condensation occurs in metal chimney systems acid corrosion is an important issue. Therefore a European standard (EN1856-1) for testing the corrosion resistance of metal flue gas systems has been worked out several years ago. Currently this standard foresees three different corrosion resistance classes: V1 – V3 corresponding to the fossil fuels natural gas, oil and coal. No specific test is available for flue gas systems used for biomass combustion, resulting in an attribution of biomass combustion to either V2 or V3 class.

In order to improve this unclear situation the European chimney manufacturing industry together with European stainless steel manufacturing industry launched a pre-normative research project at Bioenergy2020+ funded by the Austrian COMET (competence centres for excellent technology) programme. Within this project a corrosion test for metal flue gas systems conveying flue gas from biomass combustion appliances should be developed and a proposal for the implementation of this test into the existing European corrosion test standard should be worked out.

In the first step of this research project the European wooden biofuel market should be investigated with respect to fuel quantities and the share of different wood species used for household energy production.

In a second step typical fuels used in small scale combustion units in households should be analysed for corrosion relevant compounds. Increased levels of nitrogen, sulphur and in particular chlorine can shorten lifetimes of metal-made appliance parts and chimneys significantly.

Results of this study will therefore be used to work out a proposal for a standardised corrosion test for metal chimneys conveying flue gas from biomass combustion.

Further this information is important for the standardisation of biofuels for residential use on a European level ((EN14961) which is currently worked on in the CEN/TC335 group.

2 METHODS

2.1 Quantities of wooden biofuels

The information about the wooden biofuel market in Europe is limited. Particularly reliable data about the use of logwood and wood chips for energy production is rare and the information available is very inconsistent.

The main difficulty in the statistical capture of data about the European wooden biofuel market is generally the structure of the firewood supply chain in most European countries. Only a small part of logwood is sold by production- or trading-companies. The major part of firewood is acquired directly from private forest owners and therefore nearly impossible to be covered by official statistics. However, European countries have to report the production of fuel wood and the use of wood for energy production respectively. This information is either gathered from national micro-census data or from the forest statistics. The following international organisations compile the reported data from member countries and provide information about wooden biofuels in Europe:

- The Statistical Office of the European Union (EUROSTAT)
- Food and Agricultural Organization of the United Nations (FAO)
- European Biomass Association (Association Européenne pour la Biomasse, AEBIOM)
- Ministerial Conference on the Protection of Forests in Europe (MCPFE)

Additional information can be acquired from individual country reports and research publications.

Within this project different data sources for the estimation of the quantities of wooden biofuels for European countries have been analysed and evaluated. Based on this evaluation and the following selection of best available data for the quantities of wooden biofuels in Europe the tree species used for energy production in small-scale systems are estimated. Different to total

quantities of firewood there are no official statistics available which cover information about tree species used as biofuel. Therefore a method needed to be developed which combines different statistical data available and thereby estimates the tree species used for energy production.

2.2 Corrosion relevant characteristics

Following the main aim of the project corrosion relevant characteristics of European wooden biofuels have been investigated. In virgin wood-fuels nitrogen, sulphur and chlorine are the elements which are expected to cause the highest corrosion load on metal flue gas systems. To cover a highest possible number of fuels literature values from public fuel databases have been compiled. Additionally fuel samples were collected from different European countries and analysed for nitrogen, sulphur and chlorine as well as other ash forming elements in order to validate literature values.

3 TERMS AND DEFINITIONS

In literature dealing with renewable *energy for heating purpose* various definitions can be found for what generally is called “wooden biofuel”. Following definitions are used in different official European statistics:

AEBIOM:

The AEBIOM uses the term *Biomass for heat*, which covers various kinds of renewable energy sources: firewood, industrial by-products, black liquor, bark, pellets, biogas and wood chips.

EUROSTAT:

In its Energy statistics for the European Union the EUROSTAT gives data for *Wood and wood wastes*. This group covers purpose-grown energy crops (poplar, willow etc.), a multitude of woody materials generated by an industrial process (wood/paper industry in particular) or provided directly by forestry and agriculture (firewood, wood chips, bark, sawdust, shavings, chips, black liquor etc.).

FAO:

In its database FORESTAT the FAO compiles data from all member countries on production of *Wood fuel*. Herein included is wood in the rough (from trunks, and branches of trees) to be used as fuel for purposes such as cooking, heating or power production. Industrial by-products such as black liquor and wood waste are not included in the FAO statistics.

Units and conversion factors:

Units: J...Joule
Mm³...million solid cubic meters
Mtoe...Mega tons of oil equivalent
Wh...Watt hour

Conversion: $1\text{PJ} = 0,278\text{TWh} = 0,024\text{Mtoe} =$
Factors: $139000\text{m}^3 (0.139\text{Mm}^3) \text{ solid wood [1]}$

4 RESULTS

4.1 Wooden biofuel market

In its report *European Biomass Statistics 2007* [1] the European Biomass Association gives an overview about the biomass used for heat production in the EU25-countries in 2004 (see Fig. 1). Wooden biofuel contributes 19.2 Mtoe (40%) of 48.3 Mtoe total biomass for heat. The wooden biofuels sector which is relevant for small-scale combustion consists of 15.9 Mtoe firewood (83%), 2.0 Mtoe chips from forest (10%) and 1.3 Mtoe pellets (7%).

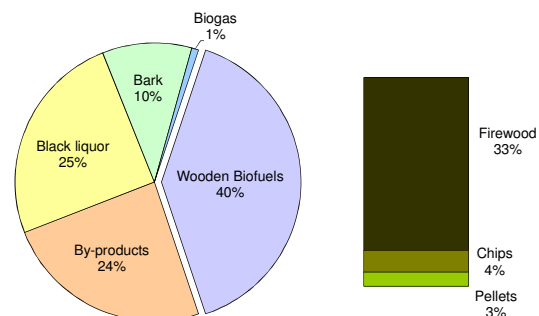


Figure 1: Biomass for heat in EU25-countries (2004). [1]

Similar results were found in the course of the EUBIONET 2 project. In the report “*Biomass fuel trade in Europe*” the total use of biomass is estimated at 2741 PJ (2004) with a *residential firewood* share of 34% (see Fig. 2) – AEBIOM estimates the firewood share at 33% (15.9 Mtoe of 48.3 Mtoe).

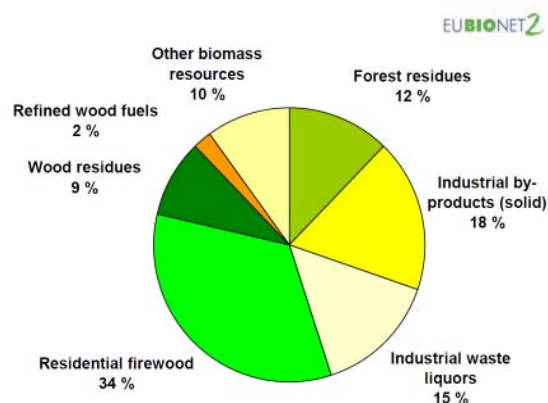


Figure 2: Total use of biomass in Europe (2004). [2]

The Food and Agricultural Organisation of the United Nations collects statistical data about production and trade of forestry products of the member countries. Information is gathered from individual country reports. Therefore the reliability of results highly depends on the effort that member countries make to obtain the national statistical data. All EU25 countries already reported official data for 2007 except Belgium, Greece, Luxembourg and Portugal. For these countries the FAO estimated the numbers for 2007 based on 2006 official data.

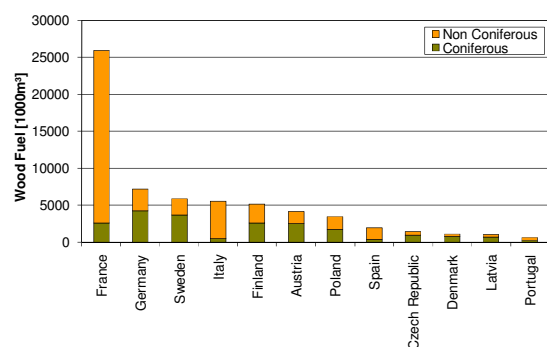


Figure 3: Wood fuel in European countries (2007). [3]

Figure 3 shows the wood-fuel production in 2007 as reported to the FAO. The leading countries are similar as in the estimation of *biomass for heat* by AEBIOM (Fig. 1). It is not useful to compare absolute amounts as the estimation by the FAO only includes fuel wood and does not cover by-products, black liquors and biogas which are included in the *biomass for heat* estimate of AEBIOM. What is noticeable, however, is the big difference between France and all other leading countries which is not the case in the AEBIOM estimate.

Different to all other official European statistics the FAO reports the fraction of coniferous and non coniferous wood fuel. This information is useful for estimating tree species used for household energy production in Europe as described later in this paper.

The statistical office of the European communities EUROSTAT offers a wide range of statistical data for member countries. In its energy statistics the EUROSTAT collects data about production and household consumption of different energy sources.

Figure 4 shows primary production and household consumption of wood and wood waste used for energy purpose for the ten leading countries in the European Union. Interestingly for some countries the gap between primary production and household consumption is remarkably higher than for other countries. This discrepancy is mainly caused by the definition of household consumption of wood for energy purpose – EUROSTAT does not account district heating to household consumption.

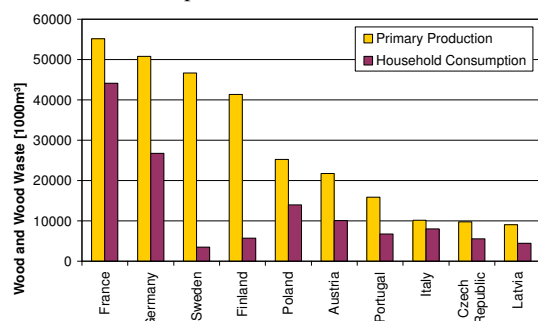


Figure 4: Primary production and household consumption of wood and wood waste from European energy statistics (av. 2004-2007). [4]

In Finland and Sweden, where the difference between production and consumption is very big, the share of district heating of *biomass for heat* [1] is higher than in all other European countries (see Fig. 5).

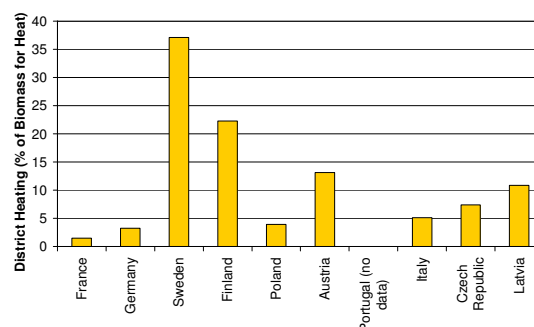


Figure 5: District heating share of biomass for heat consumption (2004). [1]

Table I: summarises wood and wood waste data from EU25 countries from the EUROSTAT energy statistics. All values are given in solid m³ as 4-year-averages (2004 – 2007). For Malta no data was available.

Table I: Primary production and household consumption of wood and wood waste [4]

	Primary Production	Energy Consumption Households
	Average 2004 - 2007	
	[1000m³]	
Austria	21707	10022
Belgium	3216	1146
Cyprus	46	32
Czech Republic	9735	5562
Denmark	7547	4357
Estonia	3947	1885
Finland	41321	5667
France	55142	44119
Germany	50747	26697
Greece	5525	4151
Hungary	5996	2883
Ireland	973	103
Italy	10137	7965
Latvia	9034	4438
Lithuania	4225	2462
Luxembourg	90	90
Malta	-	-
Poland	25181	13977
Portugal	15856	6734
Slovakia	2379	196
Slovenia	2625	1879
Spain	24251	11758
Sweden	46657	3479
The Netherlands	3013	1328
United Kingdom	4344	1428
EU 25	353694	162357

In order to validate the official statistical data for consumption of wooden biofuels in Europe results were compared with additional literature. For some countries individual fuel wood reports and research publications respectively dealing with fuel wood as source of household energy are available. If the data sources of these reports differ from the official statistics they offer the possibility to validate official statistical data. Additionally the results from the EUBIONET2 project are used for comparison of official data. In the course of

this project the partner institutions in all EU25 countries reported different statistical data mainly concerning renewable energy from biomass to the project team (see Fig 2.).

France

For France the EUROSTAT estimates the household consumption of *wood and wood waste* at 7.6 Mtoe / 44 Mm³ (average 2004 – 2007). The number given by the FAO for *wood fuel* production in France is significantly lower with 26 Mm³ (average 2004 – 2007). [3][4]

In its report *State of Europe's forests 2007* the Ministerial Conference on the Protection of Forests in Europe estimates the *total energy from wood* in France at 55 Mm³ (in 2005). The European Biomass Association estimates the *Biomass for heat* use in France at 57 Mm³. Both literature sources include black liquors, residues and waste wood in their numbers and therefore lead to an overestimation if used to assess household consumption of wooden biofuels. [1][5]

In its report *Fuelwood in France – Current Status, Statistics and Trends* the French Environment and Energy Management Agency (ADEME, Agence de l'Environnement et de la Maîtrise de l'Energie) estimates the household consumption of fuelwood in France to be 7.3Mtoe or 42 Mm³. [6]

The EUBIONET2 report for work package 2 includes residential firewood consumption data for EU25 countries for 2004. For France the project partners reported 43.5 Mm³ which is almost identical with the EUROSTAT estimate. This may indicate that both numbers originate from the same source. [2]

Nevertheless the EUROSTAT as well as the EUBIONET2 estimates appear to be feasible if compared with the ADEME numbers (see Fig.6).

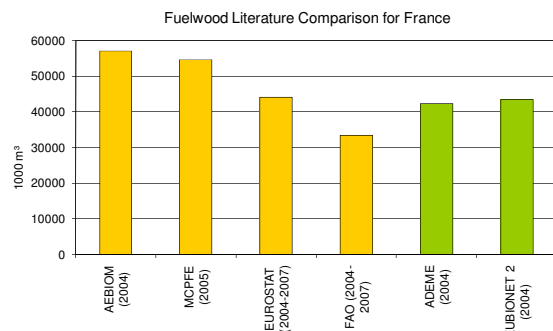


Figure 6: Fuelwood literature comparison for France

Germany

The household consumption of wood and wood waste for energy production in Germany is estimated by the EUROSTAT with 4.6 Mtoe / 27 Mm³ (av. 2004 – 2007). Wood fuel production in Germany estimated by the FAO is much lower at 7.2 Mm³ (av. 2004 – 2007). [3][4]

A research report from Mantau and Sörgel (2006) is dealing with fuelwood use in private households ("Energieholzverwendung in privaten Haushalten") in Germany. In this study the information was acquired in an extensive questionnaire survey among more than 11000 households in Germany. Therefore results from this study can be used to validate official statistical data: Fuelwood use in private households in 2005 is estimated to be 20.7 Mm³ and therefore in relatively good

agreement with the EUROSTAT estimate. The FAO data seems to be underestimated (see Fig. 7). In an older publication the TTS Institute in Finland estimated the fuelwood use in Germany in 2001 at 23 Mm³ without including information about the origin of this number. The residential firewood estimate from the EUBIONET2 project is at 16 Mm³ and therefore somewhat lower than the other literature values. [2][7][8]

It seems that the estimation of fuelwood use in Germany is very difficult. Nevertheless these results could be interpreted as range with the EUROSTAT value as upper limit and the EUBIONET2 report as lower limit. The FAO estimate seems to be too low.

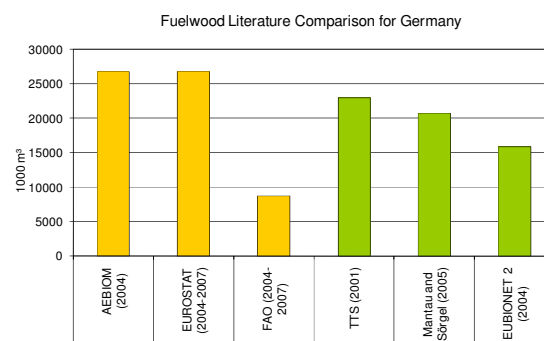


Figure 7: Fuelwood literature comparison for Germany

Austria

In Austria the *Statistics Austria* collected detailed information about fuelwood use households in its micro-census survey in 2004: 58.3TJ of logwood, 3.3TJ of wood pellets and 3.3TJ of wood chips were used for heating purpose in private households in 2004 - together 64.9TJ or 9 Mm³ of wooden biofuel. This number confirms the EUROSTAT estimate of 10 Mm³ and again shows the underestimation of the FAO (4.2 Mm³). [3][4][9]

The EUBIONET2 project report gives 10 Mm³ for the Austrian residential firewood use (2004) which also confirms the EUROSTAT estimate. [2]

Sweden

For Sweden the EUROSTAT estimates the household consumption of wood and wood waste with 3.5 Mm³. Interestingly the FAO estimate is higher with 5.9 Mm³ which is the other way round for most other European countries. [3][4]

In its report *Energy statistics for one- and two-dwelling buildings in 2007* the Swedish Energy Agency gives the wood fuel use as 8.1TWh or 4.1 Mm³. Both official estimates – EUROSTAT and FAO – are in general agreement with this data; nevertheless the EUROSTAT value is closer. The EUBIONET2 project gives an estimate of 4.6 Mm³ which is very close to the number given by the Swedish Energy Agency. [2][10]

Conclusions of wooden biofuel literature survey

Based on the results from the comparison of individual country reports with official statistical information it was decided to use the data from the European Energy Statistics (EUROSTAT) for *wood and wood waste consumption in private households* for further calculations. The numbers given in the EUROSTAT statistics are in better agreement with

supporting literature than FAO estimations for France, Germany, Austria and Sweden.

Additionally the results of the EUBIONET2 report were used for evaluation because the results are also in good agreement with additional literature data.

4.2 Estimation of fuel tree species

In official European statistics no information about specific wood species used for energy production is available. Even individual country reports do not include any wood species information. Therefore it was necessary to combine data from different sources to estimate quantities of European fuelwood species used for energy production in the household sector.

Figure 8 summarises the evolution pathway of a European fuelwood estimation based on different statistical data sources. Quantities of wooden biofuel on a country basis were taken from the EUROSTAT Energy statistics and the EUBIONET2 report respectively (see discussion under 3.1). In a second step the total amounts of fuelwood were divided into *coniferous* and *non coniferous* according to the fractions given in the FAO statistics for fuel wood production. The reason for not using the FAO data directly is the better agreement of the EUROSTAT data with individual country reports and research papers (see 3.1). A further subdivision of the two fractions *coniferous* and *non coniferous* was done by the means of forest inventory data – assuming that the wood species growing in the countries forests are also used as firewood in a similar proportion. The forest inventory information – which is the country-wise growing stock of different wood species – was obtained from the European Forest Institute (EFI). [11]

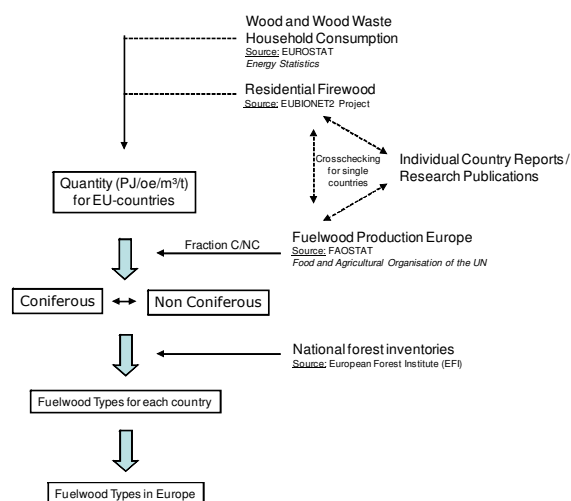


Figure 8: Method for the estimation of European wood-fuel species

The resulting quantities of European fuelwood species are summarised in Figure 9 (estimate based on EUROSTAT data) and Figure 10 (estimate based on EUBIONET2 data). The calculation based on EUROSTAT official data (Fig. 9) gives an average usage of 38 Mio m³ oak wood for energy production in households between 2004 and 2007. Beech, Pine and Spruce are the other important fuelwood species with

annual uses of 21 – 23 Mm³. Together these 4 wood species cover more than 75% of fuelwood in Europe.

The estimate based on the EUBIONET2 residential firewood data gives very similar results. Oak wood is again the most important fuelwood, pine on the second position - even the absolute numbers are practically the same as in the EUROSTAT calculation. Beech and spruce are the other most important fuelwood species, the absolute amounts in the EUBIONET2 estimate are approximately 15 – 20% lower than in the EUROSTAT based calculation.

Generally the main outcomes of both calculations are virtually the same: Oak is the most important fuelwood in Europe. Together with beech, pine and spruce it comprises three fourth of the total fuelwood use.

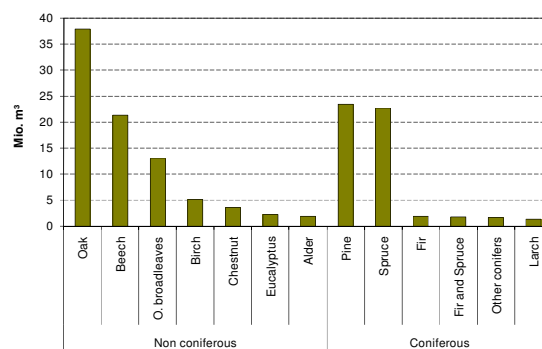


Figure 9: European fuelwood species estimate based on EUROSTAT data

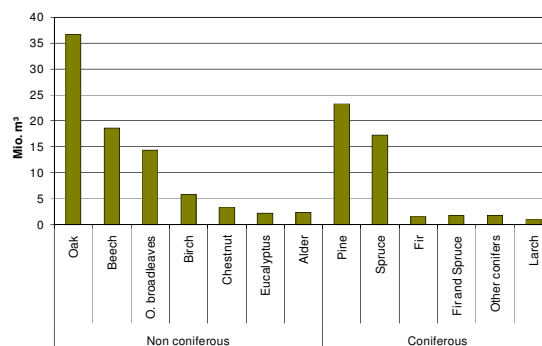


Figure 10: European fuelwood species estimate based on EUBIONET2 data

The described method (Fig. 8) additionally allows a country-wise estimation of tree species used for household energy production. Figure 11 summarises the country-wise fuelwood quantities and fuelwood tree species: The country-shading from yellow to green indicates the fuelwood quantity for EU25 countries according to the EUROSTAT energy statistics (see also Table I), the pie charts display the prevailing tree species for each of the ten most important European countries in terms of fuelwood use.

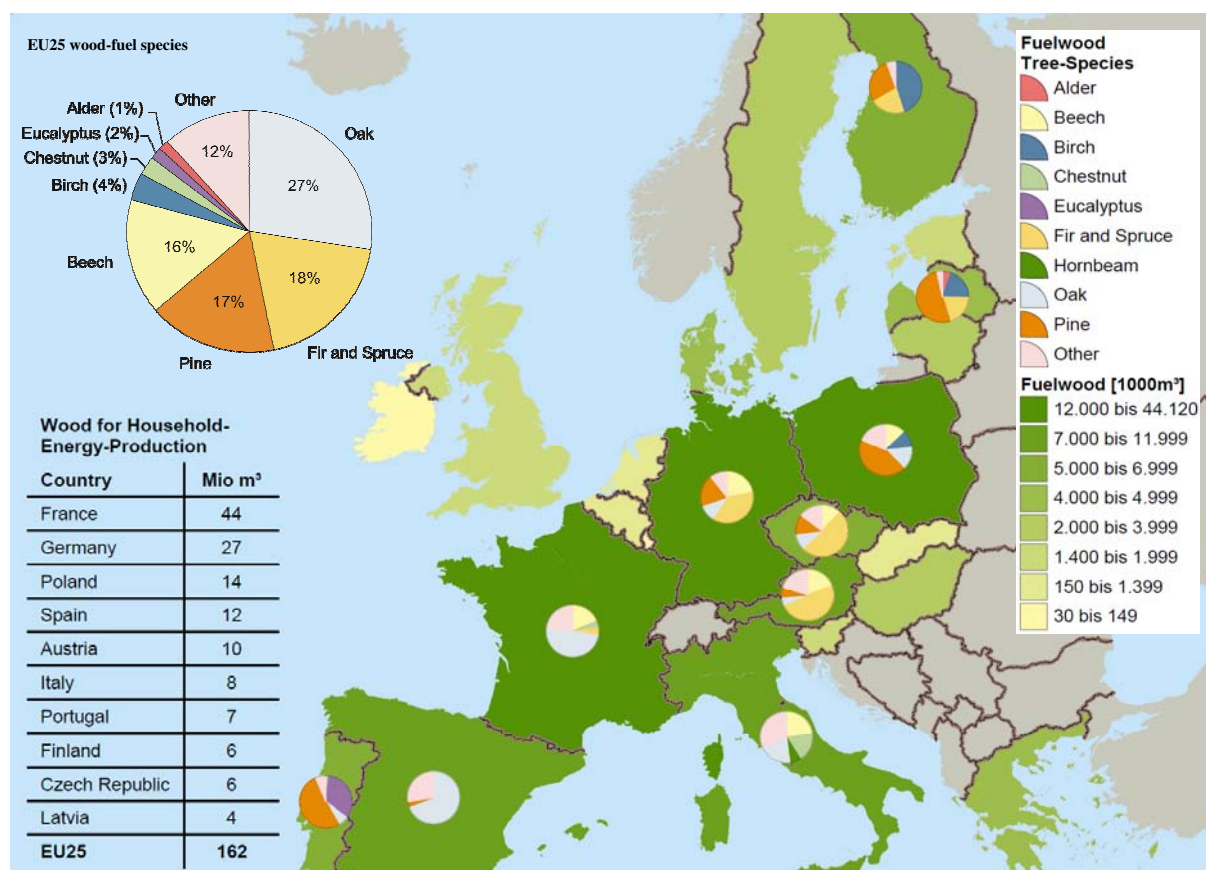


Figure 11: Fuelwood tree species for European countries.

4.3 Corrosion relevant characteristics

Corrosion relevant properties of European wood fuel have been assessed by a literature search and own fuel analysis.

For literature search only data records indicated as virgin (natural untreated) wood samples have been compiled. Following public databases include chemical analysis data for biomass fuels.

BioBank Database

Biobank is a set of three databases on the chemical composition of biomass fuels, ashes and condensates from flue gas condensers from real-life installations. The dataset was originally compiled by BIOS BIOENERGIESYSTEME GmbH, Graz, Austria, but is continuously expanding using data from other member countries of IEA Bioenergy Task 32. It currently contains approximately 1000 biomass samples, 560 ash samples and 30 condensate samples. Table II summarises the literature data extracted from the BioBank database.

Phyllis Database

Phyllis is a database, containing information on the composition of biomass and waste. Phyllis is designed and maintained by ECN Biomass, Coal and Environmental Research. At present the database contains about 2360 data records.

In Table II literature values from the BioBank database and the Phyllis database are compared. Chlorine, sulphur and nitrogen contents were found to be highly variable, even for one fuel-type the standard deviations were almost as high as the average values. [12][13]

Table II: Comparison of literature and analysis values for nitrogen, sulphur and chlorine contents with normative threshold values proposed in prEN14961 standard.

[mg/kg dry]	Nitrogen	Sulphur	Chlorine
<i>BioBank database</i>			
Wood Chips (83)	5.635	634	333
Wood (9)	14.362	742	533
Bark (21)	1.109	1.235	223
<i>Phyllis database</i>			
Log Wood (152)	2.445	660	381
<i>Fuel analysis</i>			
Log Wood (46)	1.549	130	25
Wood Pellets (20)	1.400	64	32
<i>Wood Pellets (prEN 14961-2)</i>			
Quality class A1	3.000	300	200
Quality class A2	5.000	500	300
Quality class B	10.000	500	300

Generally one has to mention that literature dealing with the chemical composition of wooden biofuels is difficult to handle. In most cases no origin of the data is provided. The chemical composition of wood chips fired in industrial plants for instance is not distinguished from wood chips used in private boilers. This causes a high variability of results and generally the tendency of too high values (originating from industrial biofuels) if the household fuel composition should be estimated.

An additional problem with nitrogen, chlorine and sulphur contents from literature in particular is the low concentration of these compounds in natural wood. In many literature sources numbers are given which in fact represent the limits of detection. For the chlorine content for instance a high number of literature values was given as 0.01% or 100mg/kg which therefore rather seems to be the limit of detection of the analytical method than a real measurement value.

If these numbers (limits of detection) are used for calculation of averages this automatically leads to wrong, necessarily too high, results.

Fuel analysis

For further investigation of corrosive agents present in wooden biofuels and evaluation of literature values a number of fuel samples was acquired from different European countries and analysed in the BE2020 laboratory. Totally 46 logwood and 20 wood pellet samples were analysed. Results from wood log and pellet analysis are presented in Table II.

For all three potentially corrosive compounds the analysed samples exhibited much lower concentrations than the data reported in the fuel databases. In case of chlorine this difference was remarkably high, namely around one order of magnitude.

The comparison of analysis results with proposed threshold levels for the European biofuel standard (EN14961) shows a similar discrepancy. For chlorine the average analysed concentration of around 30 mg/kg was a factor of 6 lower than the proposed threshold in parts 2 and 3 (pellets + briquettes) of prEN14961 of 200 mg/kg for the highest quality class. As displayed in Figure 12, from 65 analysed fuel samples 63 exhibited chlorine contents lower than 0.01%. One logwood (walnut tree, Austria) and one pellet (Great Britain) sample had higher chlorine contents between 0.01 and 0.02%. No sample exceeded 0.02% of chlorine per kg dry fuel.

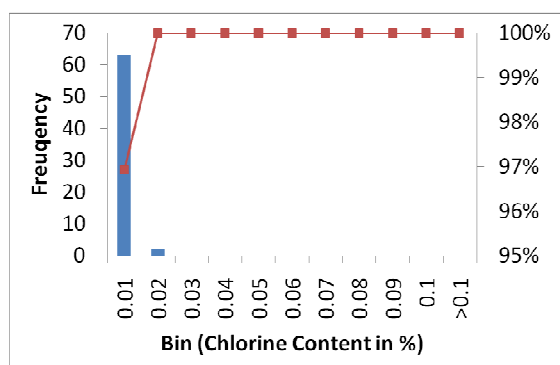


Figure 12: Histogram of analysed chlorine concentrations in wood log and pellet samples (n=65)

5 SUMMARY AND CONCLUSIONS

- Logwood is dominating the European wood fuel market with an approximate market share of 80%
- France with more than 40 Mm³ and Germany with more than 25 Mm³ are the leading countries concerning wood fuel use in Europe.
- Oak is the most important wood fuel tree species in Europe; approximately 35 – 40 Mm³

per year are used for household energy production (not including district heating). Other important tree species are beech, fir/spruce and pine with an annual consumption of around 20-25 Mm³. Together these four tree species cover more than 75% of wood fuel used in Europe.

On a single country bases, however, also other tree species are important, e.g. birch wood in northern countries.

- Corrosion relevant characteristics, i.e. fuel contents of nitrogen, sulphur and chlorine, reported in literature do not represent the real market situation mainly because many reported values in literature are in fact limits of detection which – depending on the analysis method used – often are much higher than real concentrations.
- Chemical analyses of 46 wood log and 20 wood pellet samples from 14 European countries have been done. Results confirmed that concentrations of corrosive compounds in virgin wood are very low. For instance only 2 samples exceeded chlorine content of 100mg/kg dry, the average was at 30mg/kg dry fuel.
- Threshold limits proposed in the European biomass fuel standard prEN14961 are much higher than concentrations found in virgin wood samples. For the highest wood pellet quality class (prEN14961-2) a threshold of 200 mg/kg chlorine is proposed which is approximately a factor of 6 higher than the average concentration analysed in the fuel samples. These high thresholds in the European fuel standard compromise the use of metal-made parts like heat exchangers or chimneys for flue gas from biomass combustion.

6 OUTLOOK

In the next step of the project the corrosion load of flue gas from biomass combustion is evaluated in a series of condensation tests (Fig. 13). Condensate samples from different wooden biofuels as well as different appliances are collected and analysed for corrosive compounds. A model to describe the correlation between the fuel composition and the contents of corrosive agents in the condensate should be developed.

Finally the current corrosion tests will be adapted to simulate flue gas and condensate composition determined in the condensate tests. Three different stainless steel types will be tested according to the modified corrosion test method at TÜV-SÜD in Munich.

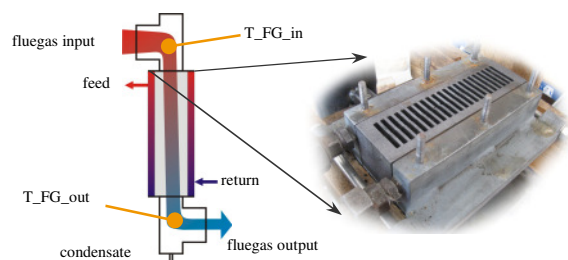


Figure 13: Experimental setup of condensate test.

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- BDH (Bund Deutscher Heiz- und Kühlgerätehersteller, Germany)
- CETIM (Centre technique des industries mécaniques, France)
- ECA (European chimneys association)
- EuroInox (European stainless steel development association)
- Schiedel (Austrian chimney manufacturer)

Scientific partners in the project are:

- BLT (Biomass Logistics Technology, Wieselburg, Austria)
- CERIC (Research and Testing Centre for the Chimney and Flue Industry)