Pyrolysis in the Countries of the North Sea Region

Potentially available quantities of biomass waste for biochar production

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Foreword

One of the objectives of the Interreg IVB project Biochar: Climate Saving Soils is to assess the amount of available biomass that could be used for the production of biochar. In this publication the authors give an impression of the amounts of biomass available for pyrolysis.

This publication can also be downloaded from our project website www.biochar-interreg4b.eu.

Frans Debets
Project leader for the Interreg IVB project Biochar: climate saving soils

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1. Introduction

During the last decade, biochar has received a lot of attention, both from scientists and policy makers. Biochar is charcoal when it is used for particular purposes, especially as a soil amendment. Biochar is produced after pyrolysis of biomass, i.e. the process of heating above 350-400 ^oC under very low or zero oxygen concentrations. Biochar is a stable solid, rich in carbon and can endure in soil for thousands of years. The interest from scientists and policy makers is triggered by the possibility to apply biochar to soils for carbon sequestration and simultaneously increase the plant production capacity. Biochar thus has the potential to help mitigate climate change, via carbon sequestration, resulting in negative CO2 emissions.

Production of large quantities biochar is very much related to the available amounts of biomass that can be pyrolised. Both biomass, which is currently considered waste, and biomass which may currently be used for other purposes, e.g. compost production. In this report a summary is given of the amounts of biomass waste produced in the countries in the North Sea Region (NSR): Belgium, Denmark, Germany, Netherlands, Norway, Sweden and the United Kingdom (UK).

Mostly waste products are taken into account, but as we want to give an impression of the potentially of the amounts biomass available for pyrolysis, also other some organic products are included in the survey.

2. Data collection

Data presented in this report are obtained from different sources, many are from the Eurostat database but also other sources have been used. Eurostat is the statistical office of the European Union. It is regarded as a reliable and trustworthy source of statistical data. However, also Eurostat data on feedstock potential for biochar remain partly fragmentary and uncertain. Not for all NSR countries data were available for all years for every waste materials. There also appears to be a discrepancy between the Eurostat database and data from national sources. (Arcardis, 2009).

Moreover, data sources are not always very accurate; e.g. data for Norway are often not found in EU statistics and some of the collected data are already from a few years ago. So, the amounts may have changed over the years. For those reasons the quantities mentioned in this report should not be considered as exact amounts, they are rather a certain indication of the potentially available amounts of biomass residues as a feedstock for pyrolysis.

3. Potential organic waste biomass

Organic materials (biomass) are needed to produce biochar. Biomass is biological material derived from living or dead organisms. In the context of pyrolysis, of course only dead, can be used, including plant based and animal biomass.

In principle, almost any source containing plant or animal biomass can be used as feedstock for pyrolysis. Sources with a high dry matter content may be pyrolised directly, whereas relatively wet sources may need to undergo a drying process first. Alternatively, wet feed stocks may be treated by hydrothermal carbonization (HTC) a special form of pyrolysis.

Probably the most suitable biochar sources are woody materials other sources rich in ligno-cellulose. However, also plant biomass with a low lignin content can be used.

It is foreseen that certain criteria , e.g. (stable) carbon content and limited concentrations in organic and inorganic contaminants, will be used to assess if the produced biochar may be applied to soils in the EU. Therefore, several initiatives are being developed. Once such criteria have been developed and accepted in EU legislation, sources from which no suitable biochar can be produced are likely to be excluded as a feedstock.

Moreover, potential feed stock also may undergo treatment processes other than pyrolysis. Many organic (waste) materials already are used for different purposes like animal feed, compost and energy production by anaerobic digestion or combustion . Pyrolysis will need to compete for feedstock with such alternative processes. The demand for products like biochar, animal feed, compost and energy, in combination with their market price and production costs will determine the winners in the end.

Here, we attempt to list all available organic sources which potentially may be used for pyrolysis, with the exclusion of materials which are used for food and animal feed production or as a construction material. This means that we will mostly concentrate on waste materials, realizing that a clear line between waste and useful materials cannot always be drawn.

Since the Biochar Climate Saving Soils project is being performed in countries of the North Sea Region, we also will focus on available biomass in these countries. However, for a number of potential sources, no specific information of specific NSR countries is available. For that reason, also information from other EU members states has been collected. In this study we will focus on the following waste materials:

1. Wood waste and wood residues
2. Sewage sludge
3. Paper waste
4. Textile
5. Animal residues
    a. Slaughter waste
    b. Animal manure
6. Agricultural crop residues
7. Residues currently used for composting
8. Digestate from anaerobic fermentation
9. Organic fraction of municipal solid waste (MSW)
10. Biowaste from households

3.1 Wood waste and wood residues

The forest industry in Europe is segmented into the pulp- and paper industry and the wood industry (sawn wood, panel and other). Besides the wood which is used in the industry, there is a substantial part of virgin wood which remains in the forest and wood which is used for production of energy use.

Virgin wood, i.e. wood and products such as bark and sawdust has had no chemical treatments or finishes applied. It's physical and chemical characteristics may be influenced by its source of origin. Virgin wood includes bark, logs ,sawdust, wood chips, pellets and briquettes and wood from forestry. It may originate from different places: municipal and private parks and gardens, pruning (Fig.1) and road verges.

Figure 1 *Wood pruning*

Also, wood from processing industries, such as sawmills and timber merchants, containing offcuts, bark and sawdust are a source of virgin wood.

Currently virgin wood is often used for energy production, but it is equally suitable for pyrolysis. Basically, all wood which can be used for energy production can also be used for pyrolysis, except material treated with heavy metals, which accumulate in the biochar and halogens and halides which may result in the production of toxic organic contaminants (e.g. dioxins).

Mantau (2012) gives an overview of the wood flows in Europe from resource to end-use as presented in the condensed wood flow chart (Fig.2). Mantau states that woody biomass is a perfectly recyclable product. The recycled amount of the overall recyclable potential depends very much on the effectiveness of the collecting system. The recovery rate for paper in the total of the EU27 is about 74% and has almost reached its technical maximum. The recovery rate for post-consumer wood in Europe is very divers. However, from the overall potential in the EU, 62% is already recovered.

As one may see from Fig. 2, large fraction of wood is used for energy production (Fig.3). In 2010, over 50% of biomass for electric power originated from wood.

Wood products containing non-wood components (e.g. resins, adhesives and fillers) i.e. particle board such as chipboard , MDF and hardboard and plywood sometimes may be used for energy production, provided it contains no harmful halogenated organic compounds or heavy metals. In that case they probably can also be used for pyrolysis.

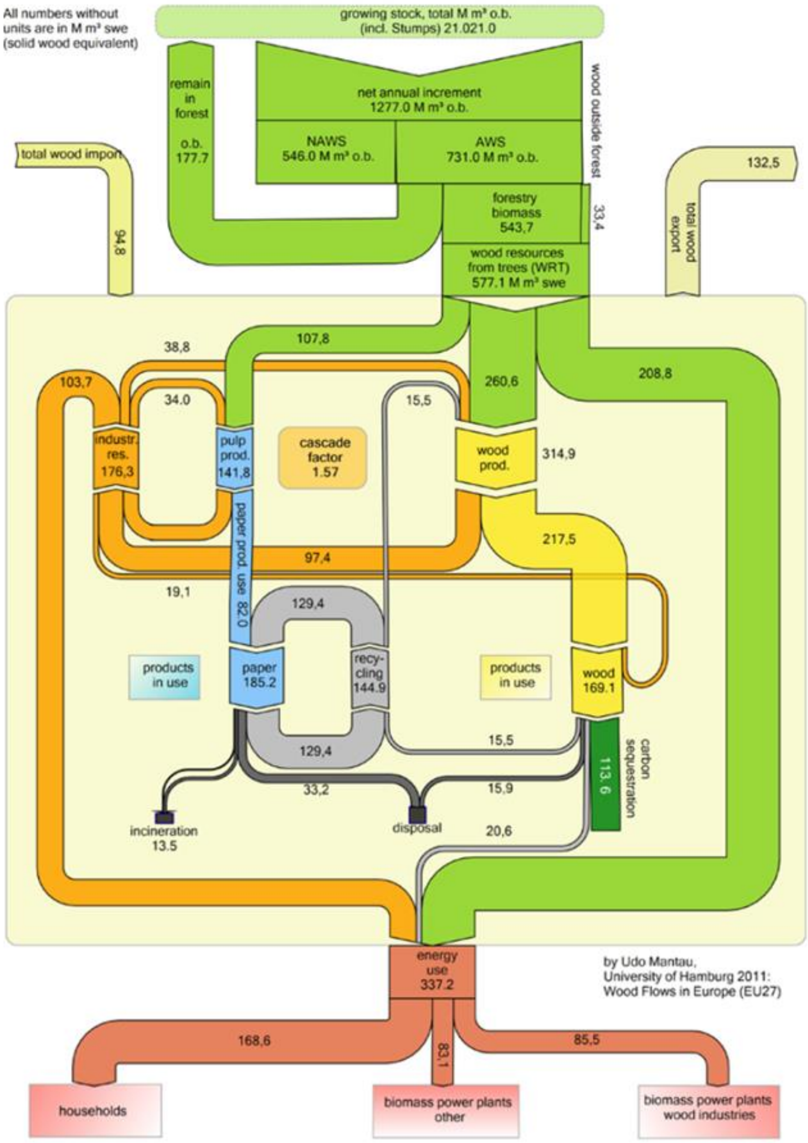

Figure 2. Condensed wood flow chart from resource to end-use in the EU 27 in 2010 (Mantau, 2012)

The production of raw wood is according to Eurostat, the highest in Germany and Sweden and the lowest in Belgium, Denmark and the Netherlands. Yet although Sweden has a high production of wood, their wood waste production is amongst the lowest (Fig. 4). The total production in the NSR countries is approximately 40 million tons per year.

Table 1 shows the amounts of wood used for fuel, compost and yet unused wood in the EU 27. The total amount used for fuel and compost in the NSR countries is 1.4 and 0.6 million tons, respectively, assuming a wood bulk density of 0.15 ton/ton. Thus the unused amount totals 0.8 million tons. The total amount of virgin wood is estimated at 2.9 million tons.

Figure 3. *Wood chips can be used for energy production*

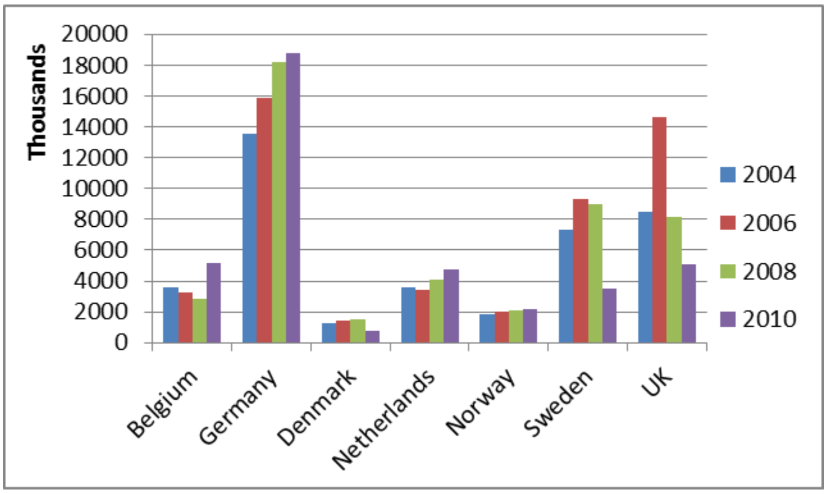

Figure 4. *Production of wood waste in2004, 2006, 2008 and 2010 in households and manufacturing in 1000 tons (Eurostat database)*

NSR Country	Amount of landscape care wood (1000 m3)		
	Used as fuel	**Used for compost**	**Not used**
Belgium	404	179	314
Denmark	488	217	380
Germany	3270	1453	2544
Netherlands	434	193	337
Norway	No data	No data	No data
Sweden	2394	1054	1862
United Kingdom	2390	1062	1859
Total (1000 m^3)	**9380**	**4158**	**5437**
Total (1000 tons)	**1407**	**624**	**816**

Table 1. *The production of wood from landscape use, currently not used or used as a fuel and for composting Source: http://ec.europa.eu/energy/renewables/studies/doc/bioenergy/euwood_final_report.pdf*

Next to the above mentioned primary wood products, also the industry also generates co-products and residues, which are not primarily woody in nature, but are still biomass derived and are also potentially suitable for pyrolysis. Examples of these are paper pulp and paper wastes, textiles and sewage sludge. These will be discussed below.

3.2 Sewage sludge

Sewage sludge originates from the process of aerobic treatment of waste water. Sewage sludge is rich in nutrients such as nitrogen and phosphorous and organic matter. Due to its high water content, however, dewatering and drying into sludge cake before pyrolysis may be necessary, and is energetically and financially costly.

Anaerobic digestion, a process converting biomass into biogas, does not require drying of the sludge and could be a more attractive option than pyrolysis. Nevertheless, sewage sludge is already converted into char by HTC in Germany and for that reason the amounts of sewage sludge produced in the NSR region is shown in Table 2.

The accumulation of heavy metals in the sludge, which hampers sometimes the use of sludge as a fertilizer or soil improver, may become even a larger problem in case of application of biochar. On the positive side, any poorly bio-decomposable trace organic compounds and potentially pathogenic organisms (viruses, bacteria etc.) still present in the sludge after waste water treatment, will completely be destroyed during pyrolysis.

Currently approximately 40% of the sewage sludge production is used in agriculture in the NSR countries, but the relative amounts vary from 0% in the Netherlands to 70% in Norway. The annual production of sewage sludge in the NSR countries is approximately 4.8 tons of dry solids (Table 2).

NSR Country	Sewage sludge Annual production (1000 tons dry solids)
Belgium	103
Denmark	140
Germany	2059
Netherlands	555
Norway[1]	148
Sweden	210
UK	1545
Total	**4760**

Table 2. *Annual sewage sludge production (1000 tons of dry solids in NSR countries*

3.3 Textile

Although textile waste can be burned, gasified or pyrolised for energy production purposes, only natural fibers are considered biomass. Moreover, as recycling of textile into new fabric is the most sustainable way of re-use, pyrolysis probably only will comprise relatively small volumes. For that reason it will not be discussed further.

[1] http://www.vkm.no/dav/2ae7f1b4e3.pdf

3.4 Slaughterhouse waste

Slaughterhouse waste is defined as animal body parts cut off in the preparation of carcasses for use as meat. Slaughterhouse waste is used at the moment for various purposes such as conversion into animal feed and production of bone-glue.

Table 3 summarizes the volume of poultry and pigs processed in slaughter houses in the NSR countries in 2010. In this overview cattle is not taken into account, due to the fact that waste products from cattle are not allowed be used due to the possible presence of diseases present (BSE). According to Sebek and Temme (2009) the percentage of animals processed into meat in slaughterhouses is 75-80 %. We therefore assumed a 23 % remaining as slaughterhouse waste.

Slaughterhouse waste (Table 3) consists of two large fractions: (i) soft tissue materials such as meat, blood and fat and (ii) hard tissue materials such as bones. The high content of proteins and fat in the soft tissues, makes conversion of such tissues by pyrolysis rather unlikely. Bones, however, can be pyrolised and in fact in the EU-FP7 project REFERTIL the production and application of such bone-chars is investigated. REFERTIL is an EU project in which Animal Bone Char is produced from food grade category 3 bones between at temperatures between 500°C– 650°C. [http://www.refertil.info/public/public_upload/files/REFERTIL_289785_BIOCHAR_POLICY_abstract_draft_v2_0.pdf]

For the reasons above, we have limited the inventory of slaughterhouse waste to bones from food grade category 3. Organic and mineral parts are approximately 40% of the total slaughterhouse waste (REFERTIL, personal communication), resulting in a total of 250 million tons of dry organic waste from animal production.

NSR country	Production of cattle (1000 t)	Production of pigs (1000 t)	Production of poultry (1000 t)	Total slaughterhouse waste (1000 ton)
Belgium		1124	404	351
Denmark	128	1666	160	420
Germany	1210	5443	1380	1569
Netherlands	378	1288	-	296
Norway				
Sweden	129	263	120	88
United Kingdom	862	772	1568	538
Total	991	1035	1688	626

Table 3. *The production of pigs and poultry and the total slaughter waste produced in slaughter houses in 2010, except cattle (2008). (Source: Eurostat, except cattle, REFERTIL)*

3.5 Animal manure

In the countries around the North Sea, mostly intensive farming systems with cattle, pigs and poultry produce large amounts of manure. In several local regions, the amount of manure is too large to be used as a fertiliser. Slurry transportation to areas with a nutrient demand is very costly due to the low dry matter content of slurries. Processing of slurry to improve its nutrient value and to reduce its water content is therefore highly needed. Pyrolysis is one of the possible options, but slurries are too low in organic matter to be pyrolised. Only relatively dry manure such as farm yard manure (FYM) and slurries from which the solid fraction has been separated from the liquids are suitable for pyrolysis without further pre-treatment. FYM production in the NSR regions is however very low as compared to slurry production.

In Table 4 the total amounts of organic material in animal manure produced in the countries around the North Sea are summarised for the years 2004-2008. Of these, only poultry manure is suitable for pyrolysis without pre-treatment. Poultry manure is, just like FYM, also only a small fraction of the total manure production.

The total annual production in the NSR countries is 17 million tonnes and manure production figures remain rather stable over the years. The national data in Table 4, do not indicate that also within countries large regional differences in production may exist.

	Organic matter in manure			
NSR country	**2004**	**2006**	**2008**	**Average**
Belgium	1158	1096	1072	1109
Denmark	1571	1573	1537	1560
Germany	8654	8473	8723	8617
Netherlands	2639	2665	2890	2731
Norway	*	*	*	*
Sweden	686	655	627	656
United Kingdom	2594	2576	2436	2535
Total	**17302**	**17038**	**17285**	**17208**

*no data for Norway in Miterra database nor in Eurostat

Table 4. *The total amount of organic matter in manure produced in 2004, 2006 en 2008 derived from Miterra data (Velthof et al, in press) in million tons*

3.6 Agricultural residues

Two types of agricultural crop residues can be distinguished: harvest residues and industrial process residues. Harvest residues are materials left in the agricultural field or orchard after harvesting the crop. Such residues include stalks and stems, leaves, roots and seed pods. Currently, most of the harvest residues remain at the field and are ploughed into the soil. These residues play a role in soil formation and soil process functions. Crop residues are for instance, the major source of nutrients and energy for soil microorganisms. Potentially, above ground crop residues can be harvested as well after which these can be used for e.g. pyrolysis.

The composition of harvest residues may vary largely among different crops, wheat straw is very different from for instance sugar beet tops; wheat straw having a higher dry matter content but lower nitrogen content.

Crop residues in North-western Europe are mostly produced at the end of the summer period, while production is low during the rest of the year. This means, most likely, that conservation and storage of is needed in order to guarantee a more or less evenly feedstock flow to pyrolysis installations throughout the year. The total annual production of crop residues is 36.5 million tons of carbon per year (Table 5).

A

B

Figure 5. *Crop residues straw (A) and sugar beet (B)*

Industrial process residues are materials left after harvested material is processed in order to obtain, for instance consumption products such as sugar. Industrial process residues include husks, seeds, bagasse, molasses and roots. They can be used as animal fodder and soil amendment, fertilizers and in manufacturing. They can also be pyrolised.

	Crop residues (in 1000 tonnes C)			
NSR Country	**2004**	**2006**	**2008**	**Average**
Belgium	2215	2125	1924	2088
Denmark	2901	2754	2899	2851
Germany	17579	15672	17166	16806
Netherlands	3256	2925	2972	3051
Norway				
Sweden	3821	3876	4065	3921
United Kingdom	6737	4023	6502	5754
Total	**38513**	**33381**	**37536**	**36477**

Table 5. *Production of crop residues (derived from Miterra database, Velthof et al, in press)*

In order to obtain some additional insight in the production of agricultural industrial waste, data from Eurostat of the production of animal and vegetal waste produced in food, tobacco and beverage industries are presented in Table 6. The total amount of animal and vegetable waste produced in food industry in 2008 in the NSR countries is approximately 17 million tons ,at a rather constant annual production.

	Animal and vegetal wastes(in 1000 tonnes)			
NSR Country	**2004**	**2006**	**2008**	**Average**
Belgium	4148	2323	2470	2980
Germany	1610	1850	1596	1685
Denmark	82	102	92	92
Netherlands	6419	6443	6336	6399
Norway	374	606	644	541
Sweden	466	614	614	565
United Kingdom	4660	5164	4594	4806
Total	**17759**	**17102**	**16346**	**17069**

Table 6. *Production of animal and vegetal wastes produced at manufacturing of food products, beverage and tobacco products next to the production in households in tonnes (according to Eurostat) in 1000 tons.*

3.7 Compost

Compost (Fig.6) is biomass that has been biologically decomposed in the presence of oxygen. It can be recycled to the soil as a fertilizer or an organic soil amendment. At it simplest level, the process of composting only requires the making of a heap of moist organic matter (leaves, "green" food waste) after which the materials start to decompose into humus during a period of weeks or months. Modern, methodical composting is a an economically viable, multi-step, closely monitored process with measured inputs of water, air, and carbon- and nitrogen-rich materials. Bacteria manage the chemical process by converting the inputs into heat, carbon dioxide and ammonium. The ammonium is further converted by bacteria into plant-nourishing nutrients. In that way, the compost is rich in nutrients. Compost is usually sold to farmers and to gardeners.

Figure 6. *Mature compost*

As compost still contains organic compounds, it may be used for pyrolysis. However the fraction of mineral compounds in many composts is high, due to the fact that a large part of the organic fraction has been decomposed during the composting process.

For that reason, one may argue that compost feedstock would be a better source for pyrolysis than compost itself. On the other hand, composting also results in the removal of water from the feedstock biomass which may be an advantage for pyrolysis.

Table 8 shows the reported and calculated potential compost from kitchen waste and green waste biomass in the EU. The total potential compost production in the NSR countries is 9224 thousand tons of kitchen compost and 18400 thousand tons of green compost. If one assumes an organic matter decomposition of 75% during composting, the total potential amounts of feedstock can be calculated ad 14648 and 36896 thousand tons of kitchen waste and green waste, respectively.

The amounts of biomass which can be used for compost are presented in section 3.11 (bio-waste from households and industrial agricultural residues).

NSR Country	Production (in 1000 tons)			
	Kitchen compost	**Green compost**	**Potential kitchen compost**	**Potential green compost**
Belgium	342	103	524	1048
Germany	350	15	295	542
Denmark	2089	849	4126	8251
Netherlands	719	935	816	1632
Norway				
Sweden	39	100	452	903
United Kingdom	316	1660	3011	6023
Total	3855	3662	9224	18399
Total original feedstock	**15420**	**14648**	**36896**	**73596**

Table 7. *Current and potential production of kitchen and green waste compost Source:* *http://ec.europa.eu/environment/soil/pdf/som/Chapters7-10.pdf*

3.8 Paper waste

Paper and cardboard are widely used products and the residues of their production processes can be divided in mainly three categories: mill broke, pre-consumer waste, and post-consumer waste. Mill broke consists of paper trimmings and other paper scrap from; it is recycled internally in the paper plant. Pre-consumer waste is material which has left the paper plant but has been discarded before it was ready for consumer use. Post-consumer waste is material discarded after consumer use, such as old magazines, newspapers, office paper, telephone directories, and residential mixed paper.

The total amounts of paper and cardboard waste in 2010 was about 51 million in the NSR countries. It remained constant during the recent years (Fig 7). Paper and cardboard waste can certainly be used for pyrolysis, but currently almost all such waste is recycled. Paper and card board waste are valuable and for economic reasons, it is not foreseen that in the near future paper waste will be available for pyrolysis. For that reason paper and cardboard waste are excluded in the overall evaluation of the NSR region (Chapter 4).

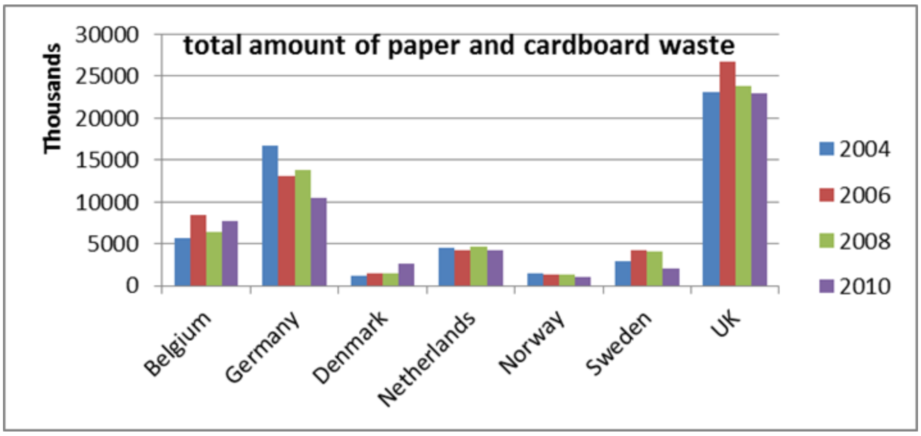

Figure 7. *Production of paper and cardboard waste from households and manufacturing, agriculture, forestry and fishery in tonnes in 2004-2010*

A number of countries are using black liquor to produce energy by combustion or gasification. Black liquor is lignin that is dissolved from the cellulose fibres as is required for high quality paper production. However, due to its high water content black liquor seems less suitable for pyrolysis. For that reason it will not be discussed further, even though processing by HTC could be an option.

3.9 Digestate

Digestate (Fig. 8) is biomass material which remains as a by-product after the anaerobic digestion of a biodegradable feedstock. Anaerobic digestion is used to produce biogas. The bio-degradable feedstock for anaerobic digestion mainly consists of manure, sludge and energy-rich co-products in meant to increase the biogas production. The composition of the digestate is very much dependent on the products which are used for the digestion process.

Figure 8. *Solid fraction of digestate from a biogas reactor*

Digestate still contains a large amount of organics and thus it can be used for pyrolysis, although pre-treatment may be required, for instance by separating the solid and liquid fractions.

There are no data available of digestate production in the NSR region, for that reason we will not consider it here further.

3.10 Organic fraction of municipal solid waste

Municipal Solid Waste (MSW) consists of everyday items we use and then throw away, such as product packaging, grass clippings, furniture, clothing, bottles, food scraps, newspapers, appliances, paint, and batteries. According to the Council Directive 1999/31/EC) on the landfill (Article 2(b) waste is defined as: waste from households, and all other waste which, because of its nature or composition, is similar to waste from households.

MSW contains hazardous and non-hazardous compounds, including organic compounds, mostly from gardens, kitchen and paper and board (Fig. 8). There are techniques to separate the organic components from MSW, but they are not used everywhere and no data of the amounts of organic matter that can be extracted exist. In a number of the NSR countries, the organic fraction is collected separately, but not everywhere at the same level. For that reason, we have excluded MSW from the survey. The separately collected organic waste is defined as bio-waste of which the amounts are discussed in section 3.11.

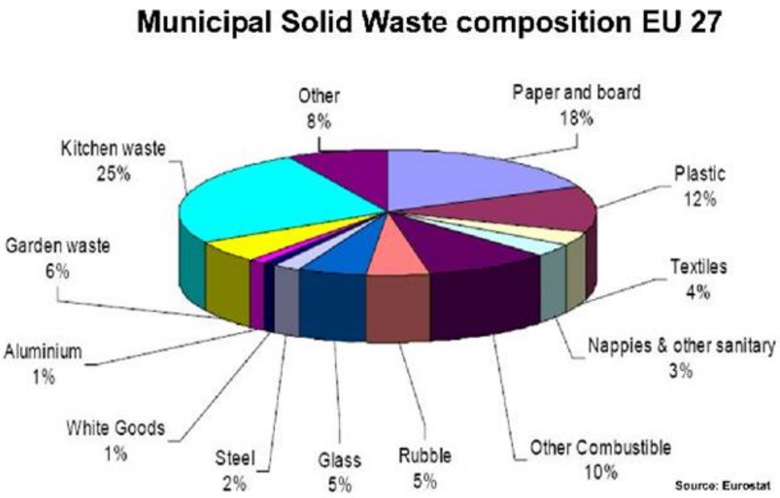

Fig. 8 *Municipal solid waste composition in the EU 27 Source: http://www.zerowasteeurope.eu/wp-content/uploads/2012/05/Waste-composition-EU-2007-eurostat.jpg*

3.11 Bio-waste from households

Bio-waste is defined by the Waste Framework Directive 2008/98/EC as "biodegradable garden and park waste, food and kitchen waste from households, restaurants, caterers and retail premises and is comparable to waste from food processing plants".

The total production of bio-waste determines its feedstock potential to produce biochar. Bio-waste may be produced in relatively small amounts and fragmented over the land area of a country, which may result in logistical problems regarding collection and storage.

Moreover the quality and quantity of biomass may vary widely between regions (urban waste, for instance, contains more food residues than rural wasts) and also during the year due to seasonal variation of garden waste production.

The total annual production of bio-waste from households in the NSR region is rather stable at 45 million tons (Table 8).

	Bio-waste (excluding green waste)				
NSR Country	**2004**	**2006**	**2008**	**2010**	**Average**
Belgium	6887	4390	4266	4588	4588
Germany	8179	12052	12231	12933	12933
Denmark	165	187	166	886	886
Netherlands	11825	12289	13255	13558	13558
Norway	811	1081	1173	945	945
Sweden	1551	1754	1788	1684	1684
United Kingdom	10121	12025	12842	10211	10211
Total	**39539**	**43778**	**45721**	**44805**	**44805**

Table 9. *Production of bio-waste (excluding Green waste) in households in 1000 tonnes (according to Eurostat)*

Next to animal and vegetable kitchen waste from households, there exists separately collected bio-waste from household gardens together with green waste from municipal origin.

Table 10 gives an overview of separately collected green waste in the NSR countries. Data are however scarce and will not be included in the overall NSR analysis of Chapter 4. Instead we will use the quantities as given in the table with food related biowaste (Table 11).

	Green waste
NSR Country	**2005**
Belgium	n.d.
Germany	4254
Denmark	737
Netherlands	1700
Norway	-
Sweden	250
United Kingdom	n.d.

Table 10. *Green waste from households separately collected and composted in 1000 tonnes (data provided by national experts according to Barth et al, 2008)*

	Food related bio-waste			
NSR Country	**2004**	**2006**	**2007**	**Average**
Belgium	19704	18346	19757	19269
Germany	14800	12750	13075	13542
Denmark	113228	94848	102844	103640
Netherlands	29269	28753	28585	28869
Norway				
Sweden	10587	9061	10331	9993
United Kingdom	55774	53848	53144	54255
Total	**243362**	**217606**	**227736**	**229568**

Table 11. *Quantity of food related bio-waste Source: http://ec.europa.eu/environment/waste/prevention/pdf/SR1008_FinalReport.pdf*

4. Potential biochar production in the NSR countries

The total annual production of biomass waste as a potential feedstock to convert into biochar in the NSR countries is shown in Table 12 in million tons of carbon (for calculation see Annex 1).

We have excluded the following potential sources for this evaluation: Paper waste, textile, slaughter house waste, digestate from anaerobic fermentation and the organic fraction of municipal solid waste (MSW). The reason for exclusion is that animal bone waste can be pyrolised very well, but the biochar produced from it (animal bone char) contains so little carbon (< 10%), that it should rather be considered a phosphate fertilizer. Animal bone char contains a large fraction of calcium-phosphate, a potential phosphate fertilizer. Of the excluded sources, either too little data were available (digestate) or it seems very unlikely that they will ever be used for biochar production (e.g. textile).

By assuming a conversion factor of 30% from feedstock carbon to biochar carbon during pyrolysis, the potential annual biochar production can be calculated and these values are also shown in Table 12.

As can be seen from the categories in Table 12, it is very likely that certain sources have been counted more than once. It seem e.g. very likely that kitchen waste is also included in food related Biowaste. For that reason it is almost impossible to present a reliable figure of the potential biochar for the NSR countries and the figures in Table 12 should be considered with a certain reluctance.

	Annual production (million tons)	
Potential biomass source	**Carbon**	**Biochar -carbon**
Wood waste and wood residues	1.21	0.36
Sewage sludge	3.57	1.07
Animal residues		
Slaughter house waste		
Animal manure	17.21	5.16
Agricultural crop residues	36.48	10.94
Compost		
Kitchen waste	2.34	0.70
Green waste	8.30	2.49
Biowaste households	7.17	2.15
Food related bio-waste	36.73	11.02

Table 12 *Potential biochar production from biomass waste in the NSR countries*

The total biochar production from the sources wood waste and wood residues, sewage sludge, animal manure, crop residues, green waste and food related bio-waste is approximately 30 million tons annually. At an application rate of 20 tons per ha, one may estimate that 1.5 million of ha could potentially be provided with biochar each year. The total area of arable land in the NSR region is 25.5 million ha (Eurostat 2010 data)

However, a figure of 30 million tons of biochar is most probably far beyond any realism. First of all, not all biomass mentioned above will become available for pyrolysis. A large fraction will not meet the correct characteristics, or it will remain to be used as it is now. Examples are animal manure slurry or feed stock for composting with high moisture contents. Another example is formed by crop residues which cannot, or only after overcoming serious problems, be harvested. Moreover, the biomass waste may be more valuable for purposes other than biochar production. Especially if it contains valuable resources such as proteins (agricultural and food residues) or natural fibers (straw, grass), a relatively simple form of bio-refinery may already be sufficient to extract such resources from the raw materials.

So to conclude with, there is a large amount of biomass waste produced in the NSR countries, which can potentially be converted into biochar. However, only a considerable (yet unknown) fraction of this amount will be used for biochar production if biochar:

1. successfully proofs its value for North-western European agriculture,
2. or can be successfully applied or for other than agriculture purposes, and
3. can economically compete successfully with other existing and developing techniques to convert biomass waste into useful products.

Even then, it will take many years to supply all arable land in the NSR with 20 tons biochar per ha.

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Annex A

Potential biomass source	Quantity (million tons)		d.m.	o.m.	Quantity Carbon (million tons)
Wood waste and wood residues	2.846	*(f.m.)*	50%	85%	1.21
Sewage sludge	4.760	*(d.m.)*	100%	75%	3.57
Animal residues					
Slaughter house waste					
Animal manure	17.208	*(o.m.)*	100%	100%	17.21
Agricultural crop residues	36.477	*(C)*	100%	100%	36.48
Compost					
Kitchen waste	14.648	*(f.m.)*	20%	80%	2.34
Green waste	36.896	*(f.m.)*	30%	75%	8.30
Biowaste households	44.805	*(f.m.)*	20%	80%	7.17
Food related biowaste	229.568	*(f.m.)*	20%	80%	36.73

Table A1*. Conversion of quantity of feedstock (Figures from Chapter 3) into quantity of carbon. f.m, fresh matter; d.m, dry matter; C, carbon; o*

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