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A Comparative Assessment of the Availability and Suitability of different Types of Biomass Feedstock in Skåne and Sweden for the Production of Biochar

List of Tables

Content

1. Introduction

Biomass as renewable energy resource is defined as any "material produced by the growth of microorganisms, plants or animals". (IUPAC, 1992) Ever since the utilization of wood-fuels for fire production, humans actively used biomass resources not only as food but also for energy purposes through thermo-chemical conversion. Nowadays, myriad different types of biomass resources play integral roles in a great share of modern processes in industry, agriculture, horticulture, energy production and many more branches of our economy. For each process, the used biomass must meet specific requirements which are mostly determined by the chemical composition as well as its physical characteristics. Chemically, biomass, like every organic matter, consists mostly of carbon, hydrogen and oxygen. Additionally to that, most naturally occurring biomass contains different levels of other elements like metals and halogens. The physical characteristics determine for example the moisture content, the density or the calorific value. In most processes the used biomass does not get used up entirely what leads to many biological residue or waste products. In a growing economy with more specialized products and processes, the amount of residue and waste products is increasing and with it the demand for a sustainable and long-lasting treatment of those. Among others, pyrolysis is a process which has gained more and more traction in the bioenergy field. Pyrolysis is a thermo-chemical conversion process that takes place at 300 to 650°C and in the absence of Oxygen and yields mainly syngas (mixture of hydrogen and carbon monoxide) and biochar. The syngas can be used for heat and power production or as platform chemical for the production of synthetic fuels. Biochar has a multitude of desirable chemical and physical characteristics. It functions as a carbon sink and has various promising applications such as filter material, food supplement or for soil remediation. For more information about pyrolysis and biochar please consult the following sources (Basu, 2013) (Komang Ralebitso & Orr, 2016)

This report presents the results of a study about a comparative assessment of the availability and suitability of different types of biomass feedstock in Skåne and Sweden for the production of biochar (through pyrolysis).

2. Objective & Scope

The objective of this study is to assess the availability of different types of biomass in Skåne and/or in Sweden and to make an objective statement about their suitability for conversion into biochar. The results shall give an overview of residual or waste biomass streams that have limited or no further industrial use cases. Furthermore, for each resource, an indication shall be given, based on qualitative and quantitative criteria, to what level it is expected to be applicable for production of biochar. The individual biomasses shall be ranked according to their expected performance. Finally, a preliminary statement shall be made about what kind of soil remediation the respective resulting biochar is most suitable for.

As NSR is located in Helsingborg, the study focusses first of all on biomass availability in the region of Skåne and after that also in the rest of Sweden. While Biochar has many different potential applications, here soil remediation is the one in the focus of attention. In and around urban areas, soil quality is more and more often found to be in need for stabilization of PAH or heavy metal contamination for example.

Additionally, an assessment will be made regarding beneficial prerequisites that should be looked out for when assessing the potential for adopting biochar production through pyrolysis specifically at existing waste management plants.

2.1 Boundary Conditions

At this point the general validity and limitations of the results presented in this report must be pointed out. This report is a preliminary assessment which's purpose is to provide an overview of the situation in Skåne and Sweden. The results shown here can be seen rather as an indication of expected availability, suitability and performance of the respective biomass for the production of biochar than as a definitive evaluation. The selected biomasses represent only a fraction of the organic material that is used in Skåne and Sweden. At the same time, while every type of biomass can exist in innumerable chemical compositions and physical conditions, these results are based on publicly available data of multiple sources indicating and evaluating a range of possible conditions. In the case of planning a biochar production facility, potential feedstocks must be identified and analyzed in detail in order to properly assess the expected performance of the process and the resulting quality of biochar.

The resulting ranking gives an impression of the particular situation in Skåne and Sweden and shall inspire for more in-depth feasibility and market studies in the future.

3. Methodology

3.1 Selection of Biomass

The biomass resource streams considered in this study have been chosen in order to represent different branches of industry, agriculture, etc and their corresponding residual and waste product streams. A focus has been laid on the region of Skåne with a broader scope taking into account whole of Sweden in a second approach. Between 2 and 9 individual biomass materials have been selected in the following classes:

- Waste products (9)
- Agriculture (6)
- Horticulture (2)
- Forest industry (6)
- Plants (3)
- Food (3)

The materials have been chosen based on their expected appearance in the region of Skåne and Sweden and backed up by the experience from both NSR AB and Pamoja Cleantech AB.

3.2 Evaluation criteria

Qualitative, quantitative (3 categories) → Scoring → Ranking

In order to ensure a high level of comparability of the evaluation criteria, a mix of qualitative and quantitative approach has been chosen. While the quantitative criteria are used to rank the feedstocks, the qualitative criteria give additional information which should be analyzed in more detail when considering the respective biomass for the production of biochar.

The quantitative criteria contain three categories (C1, C2, C3) with multiple factors as well as three individual criteria (C4, C5, C6). The considered criteria and their meaning can be seen in the following table:

Table 1 - List and descriptions of the considered quantitative criteria for the assessment

Criterium	Description	Possible Scores and Meaning
C1. Quantitative availability		
C1.1: Availability in Skåne	The amount of biomass available in Skåne in kt/y	0 – less than 8kt/y available*
		1 – no sufficient data available
		2 – more than 8kt/y available*
C1.2: Availability in Sweden	The amount of biomass available in Sweden in kt/y	0 – less than 8kt/y available*
		1 – no sufficient data available
		2 – more than 8kt/y available*
C2: Qualitative availability		
C2.1: Conflicting demands	The type and amount of industrial processes that use the respective biomass as input	0 – biomass has major industrial applications
		1 – biomass has minor industrial applications or no sufficient data available
		2 – Only application for energy generation or fertilization
		3 – No industrial applications
C2.2: Seasonality	The availability of the biomass supply throughout the seasons of the year	0 – major seasonal variation
		1 – minor seasonal variation or no sufficient data available
		2 – seasonal variation exists but is negligible (given no extreme climatic conditions)
		3 – no seasonal variatio
C3: Suitability		
C3.1: Density	The expected density of a representative biomass sample	0 – low (<200kg/m^3)
		1 – medium to low
		2 – medium (200-400kg/m^3)
		3 – medium to high
		4 – high (400-600kg/m^3)
		5 – high to very high
		6 – very high (>600kg/m^3)
C3.2: Ash content	The expected ash content of a representative biomass sample	0 – low (<2%)
		1 – medium to low
		2 – medium (2-6%)
		3 – medium to high
		4 – high (6-8%)
		5 – high to very high
		6 – very high (>8%)
C3.3: Moisture content	The expected moisture content of a representative biomass sample	0 – very high (>50%)
		1 – high to very high
		2 – high (<30-50%)
		3 – medium to high
		4 – medium (10-30%)
		5 – low to medium
		6 – low (<10%)
C3.4: Heat content		0 – low (<18MJ/kg)
		1 – medium to low

	The expected heat content of a representative biomass sample	2 – medium (18-20MJ/kg)
		3 – medium to high
		4 – high (20-22MJ/kg)
		5 – high to very high
		6 – very high (>22MJ/kg)
C4: Soil type	Whether biochar resulting from that biomass is expected to be suited for treating heavy metal or PAH contaminated soil	PAH – Polycyclic aromatic hydrocarbons (Ash content <6%) (Beesley, 2011)
		Heavy Metal (Ash content >6%) (Beesley, 2011)
C5: Data availability	For how many of the 8 quantitative scores of criteria C1, C2 and C3 data has been available	Between 0/8 and 8/8
C6: Further breakdown required	Whether the biomass feedstock is so heterogenous that a further breakdown into its typical fractions might be necessary	yes or no

*8kt/y is the threshold of biomass supply that has to be available in order to fulfill the criterium

The qualitative criteria consist of following components:

Table 2: List and description of the considered qualitative criteria for the assessment

Criterium	Description
C7: Description/ Comment	Place for additional information describing the biomass material, it's composition or characteristics
C8: Source	Possible sources where the biomass waste or residue material normally accrues
C9: Advantage	Advantages of the biomass material that have been apparent and confirmed throughout the literature research
C10: Disadvantage/ contamination	Advantages of the biomass material that have been apparent and confirmed throughout the literature research. Potential contaminations that need to be investigated regarding their impact on the pyrolysis process and/or the biochar quality.

3.3 Multi Criteria Assessment

In order to give the individual biomasses are ranking according to their likely availability and applicability for the production of biochar, the criteria C1, C2, C3, C5 and C6 have been evaluated uniformly based on their scores and put into context to each other. The priority of the criteria is decreasing from C1 to C6 and the criteria are getting evaluated one after another.

The Scores for the criteria are derived as can be seen in the following table:

Table 3: Evaluation logic of the quantitative criteria in the multi criteria assessment

Criterium	Priority	Evaluation logic
C1	1	This criterium is evaluated in 4 different scores.

		“Skåne”: Best score says that sufficient amounts of the biomass are available in Skåne (C1.1 = 2). “Sweden”: Second best score says that sufficient amounts of the biomass are available in Sweden (C1.1 < 2 & C1.2 = 2). “NA”: Third best score says that there is not enough data available to evaluate whether sufficient quantities of the biomass are available or not (C1.1 = 1 & C1.2 = 1 or C1.1 = 0 & C1.2 = 1 or C1.1 = 1 & C1.2 = 0). “<Threshold”: Worst score says that there is no sufficient amounts of the biomass available in Sweden
C2	2	Evaluated on a scale from 0 to 100 with 100 being the best. Score calculates as: $$\frac{(C2.1 + C2.2)}{6} * 100$$
C3	3	Evaluated on a scale from 0 to 100 with 100 being the best. Score calculates as: $$\frac{(C3.2 + C3.3 + C3.4)}{18} * 100$$ (Criteria C3.1 has been excluded from the assessment because the impact of a low or high density is more likely to vary strongly from case to case)
C4	-	Only informative
C5	4	The more data available the more preferable
C6	5	“No” score more preferable than “yes” score
C7	-	Only informative
C8	-	Only informative
C9	-	Only informative
C10	-	Only informative

4. Results

First a selection of biomass feedstocks was made. Within the mentioned biomass classes following feedstocks have been chosen to be assessed in this research report (table 4).

Table 4: List of biomass feedstocks covered in this assessment

Class	Biomass Feedstock
Waste	1. Garden Waste (Leaf and Grass) 2. Garden Waste (Branches) 3. Recycled Wood (Returträ) 4. Seaweed (Tång) 5. Sewage Sludge 6. Paper/Cardboard Waste 7. Pulp & Paper Waste 8. Textiles 9. Waste from Slaughterhouses

Agriculture	1. Straw 2. Rapeseed Straw 3. Corn (Fruit and Plant) 4. Manure 5. Grain 6. Grain Husk
Horticulture	1. Cucumber Farm Waste 2. Tomato Farm Waste
Forestry	1. Salix (Korgvide) 2. Sawdust 3. Hardwood 4. Softwood 5. Bark 6. Peat
Plants	1. Miscanthus 2. Reed Canary Grass (Rörflen) 3. Industrial Hemp
Food	1. Rejected Fruit and Vegetable 2. Coffee Roastery Residues 3. Cocoa Bean Shells

For each biomass feedstock, the required criteria have been researched and compared according to the methodology presented in chapter 3. The results can be seen in the following sections.

4.1 Waste

The class "Waste" contains nine waste biomass streams that have no or only little competitive demands. The biomasses listed here are very well known and make up very big quantities in Skåne and in all of Sweden. The result summary of the quantitative criteria and the ranking can be seen in table 5.

Table 5: Results summary and ranking of biomass class "Waste"

Class: Waste	Evaluation							
Biomass Feedstock	**Rank Category**	**Rank Total**	**C1**	**C2**	**C3**	**C4**	**C5**	**C6**
Sewage sludge	**1**	**1**	Skåne	100	50	Metals	8/8	Yes
Recycled Wood (Returträ)	**2**	**2**	Skåne	83	50	PAH	8/8	No
Garden Waste (Leaf and Grass)	**3**	**5**	Skåne	67	33	PAH	7/8	No
Gardenwaste (Branches)	**4**	**7**	Skåne	67	22	PAH	8/8	No
Waste from Slaughterhouses	**5**	**8**	Skåne	50	72	Metals	6/8	Yes
Paper/Cardboard	**6**	**9**	Skåne	50	67	Metals	7/8	No
Seaweed (Tång)	**7**	**13.2**	Skåne	50	28	PAH	5/8	No
Pulp & Paper Waste	**8**	**17**	Skåne	33	33	Metals	6/8	Yes
Textiles	**9**	**19**	Sweden	50	33	NA	4/8	No

Apart from Textile waste, all of these biomasses are available in very big amounts, well over the threshold of 8000t/y. Some of these waste biomasses are already available at recycling sites what gives them a big advantage against others. However, this criterium has not been included as factor in this assessment. It can be seen that even despite its high moisture content, sewage sludge is the best contestant in this class followed by recycled wood and the leaf and grass fraction of garden waste. The worst expected performance show Seaweed, pulp & paper waste and textile waste. Apart from Seaweed and textile waste, there is a good amount of information available publicly. Seaweed and textile waste are rather specific and have not shown many recycling applications so far. More research has to be made for these in order to gather more reliable information. All detailed biomass properties and additional information can be seen in the following tables 6 to 14.

Table 6: Sewage sludge fact sheet

4.1.1 Sewage Sludge				
C1.1 Avail. Skåne	133 kt/y (2019)			
C1.2 Avail. Sweden	1000 kt/y (2019)			
C2.1 Conflicting demands	Sewage sludge is mostly used for fertilizing purposes. However, in this way only around 25% of the available sludge can be treated due to high levels of contamination which often comes with a high purifying effort that is not justified by the purpose. In many cases, sewage sludge has a negative price as wastewater treatment companies are required to pay for handling of the highly contaminated waste fractions.			
C2.2 Seasonal dependency	The supply of sewage sludge has no apparent seasonal variations			
C3 Chemical and physical properties	C3.1	C3.2	C3.3	C3.4
	High	Very high	Very high	Medium to high
C4 Soil Type	Heavy metal contaminated soil			
C5 Data Availability	8/8			
C6 Further Breakdown required	Yes - Sewage sludge can consist of many different fractions depending. Every sewage sludge must be separated into its individual fractions and assessed individually			
C7 Description/ Comments	Sewage sludge is the byproduct of the treatment of wastewater from industries and municipalities. It can be rather solid or rather liquid depending on the site and the wastewater			
C8 Sources	Sources for sewage sludge are almost exclusively Wastewater treatment plants			
C9 Advantage	Very low (to negative price). Lack of competitive demands and no seasonal variation of supply			
C10 Disadvantage/ contamination	High moisture content can be an impediment for biochar production due to an increased drying effort. Contamination of sewage sludge is very likely and the impact on biochar or the feasibility of purification must be assessed in each individual case. Potential contaminations are: Sulfur, nitrogen, phosphorous, aluminum, iron, heavy metals, drugs, viruses, bacteria			
References	(Jernkontoret, 2012) (Strömberg & Herstad Svärd, 2012) (Rest till Bäst, 2020)			

Table 7: Recycled wood (returträ) fact sheet

4.1.2 Recycled Wood (Returträ)				
C1.1 Avail. Skåne	199 kt/y (2016)			
C1.2 Avail. Sweden	1488 kt/y (2016)			
C2.1 Conflicting demands	Recycled wood (mostly in the form of woodchips and bigger pieces) is predominantly incinerated and used for energy production. In some smaller shares, it is also used as bedding material for stables and forest roads for example			
C2.2 Seasonal dependency	There is no apparent seasonal dependency regarding the amount of recycled wood. However, the composition of the wood may vary throughout the seasons			
C3 Chemical and physical properties	C3.1	C3.2	C3.3	C3.4
	Medium	Medium to high	Medium	Medium
C4 Soil Type	PAH contaminated soil			
C5 Data Availability	8/8			
C6 Further Breakdown required	No			
C7 Description/ Comments	Waste wood in different sizes and shapes.			
C8 Sources	Forestry, sawmills, construction sites, industry, more			
C9 Advantage	High availability			
C10 Disadvantage/ contamination	Depending on the source and, recycled wood can come in very uneven particle sizes. It might contain halogenated organic compounds from impregnations, paints, coatings that must be analyzed in advance to an application in biochar production			
References	(Jernkontoret, 2012) (Strömberg & Herstad Svärd, 2012) (Naturvårdsverket, 2016) (Wilhelmsson, 2020) (Energimyndigheten, 2019)			

Table 8: Garden waste (leaf and grass) fact sheet

4.1.3 Garden Waste (Leaf and Grass)				
C1.1 Avail. Skåne	140 kt/y (2010)			
C1.2 Avail. Sweden	450 kt/y (2019)			
C2.1 Conflicting demands	The main use for this fraction of garden waste is for composting and soil improvement applications. Additionally, it gets incinerated and used for energy generation purposes			
C2.2 Seasonal dependency	Yes – The leaf and grass fraction of garden waste has its peak in summer and fall. During winter and spring, less of this fraction can be found in garden waste			
C3 Chemical and physical properties	C3.1	C3.2	C3.3	C3.4
	Low	Medium	High	Medium
C4 Soil Type	PAH contaminated soil			
C5 Data Availability	7/8			
C6 Further Breakdown required	No			

C7 Description/ Comments	Small components of garden waste mixture. Contains mostly grass, leafs twigs, flowers
C8 Sources	Household gardens, municipal green areas and parks, forests
C9 Advantage	High availability (already available at recycling plants)
C10 Disadvantage/ contamination	Gravel and sand impurities very likely. Metal and plastic parts can also often be found in garden waste. Potential heavy metal contamination. The feedstock can have very different compositions throughout the year which requires flexibility of the pyrolysis process setup
References	(Jernkontoret, 2012) (Strömberg & Herstad Svärd, 2012) (Boldrin & Chrsitensen, 2010) (Rest till Bäst, 2019)

Table 9: Garden waste (branches) fact sheet

4.1.4 Garden Waste (branches)				
C1.1 Avail. Skåne	47 kt/y (2010)			
C1.2 Avail. Sweden	450 kt/y (2019)			
C2.1 Conflicting demands	This fraction of garden waste is mostly used in energy applications like incineration for heat generation			
C2.2 Seasonal dependency	Complementary seasonal dependency to the leaf and grass fraction of garden waste. Peak in spring to summer with lowest supply during winter			
C3 Chemical and physical properties	C3.1	C3.2	C3.3	C3.4
	Medium	Low	High	Medium
C4 Soil Type	PAH contaminated soil			
C5 Data Availability	8/8			
C6 Further Breakdown required	No			
C7 Description/ Comments	Bigger components of garden waste mixture. Mostly branches, wood, bark, etc.			
C8 Sources	Household gardens, municipal green areas and parks, forests			
C9 Advantage	High availability (already available at recycling plants)			
C10 Disadvantage/ contamination	Soil and gravel impurities very likely. Can also contain plastics/metals and heavy metal contamination. Very uneven particle size must be expected			
References	(Strömberg & Herstad Svärd, 2012)(Boldrin & Chrsitensen, 2010) (Rest till Bäst, 2019)			

Table 10: Waste from slaughterhouses fact sheet

4.1.5 Waste from Slaughterhouses				
C1.1 Avail. Skåne	80 kt/y (2014)			
C1.2 Avail. Sweden	114 kt/y (2011)			
C2.1 Conflicting demands	Slaughterhouse waste is used for biogas production. Other uses are the production of Gelatine and composting			
C2.2 Seasonal dependency	NA			
C3 Chemical and physical properties	C3.1	C3.2	C3.3	C3.4
	NA	High to very high	Low	High to very high
C4 Soil Type	Heavy metal contaminated soil			

C5 Data Availability	6/8			
C6 Further Breakdown required	Yes, slaughterhouse waste contains several fractions which should be evaluated individually			
C7 Description/ Comments	Slaughterhouse waste is a very heterogenous mix of animal products like meat, fat, bones, skin, blood). C3 only considers meat and bone meal			
C8 Sources	Slaughterhouses, farms, stables			
C9 Advantage	Few competitive demands			
C10 Disadvantage/ contamination	Potentially very high levels of nitrogen and chlorine. Leakage must be avoided during transportation and storage to prevent unpleasant odor and soil contamination			
References	(Jernkontoret, 2012) (Strömberg & Herstad Svärd, 2012) (Konvex AB, 2014) (Thomten, 2011)			

Table 11: Paper/cardboard fact sheet

4.1.6 Paper/Cardboard

C1.1 Avail. Skåne	133 kt/y (2016)			
C1.2 Avail. Sweden	1000 kt/y (2016)			
C2.1 Conflicting demands	Paper and cardboard waste is one of the most recycled waste streams. Around 82% of it get recycled in Sweden on average			
C2.2 Seasonal dependency	No			
C3 Chemical and physical properties	C3.1	C3.2	C3.3	C3.4
	NA	Very high	Low to medium	Low to medium
C4 Soil Type	Heavy metal contaminated soil			
C5 Data Availability	7/8			
C6 Further Breakdown required	No			
C7 Description/ Comments	Paper and cardboard fraction of waste			
C8 Sources	Households, offices, public buildings			
C9 Advantage	Recycling supply chain already established			
C10 Disadvantage/ contamination	Very high level of recycling already done what might lead to low availability at times. Might be contaminated with ink and/or coatings (up to 2% of total weight)			
References	(Naturvårdsverket, 2016) (Wikipedia, 2020) (Hinde, 2019) (ECN.TNO, 2020)			

Table 12: Seaweed fact sheet

4.1.7 Seaweed (tång)

C1.1 Avail. Skåne	80 kt/y (2019)
C1.2 Avail. Sweden	NA
C2.1 Conflicting demands	Usage for erosion control at beaches in southern Sweden
C2.2 Seasonal dependency	NA

C3 Chemical and physical properties	C3.1	C3.2	C3.3	C3.4
	High	Low to high	Very high	NA
C4 Soil Type	PAH contaminated soil			
C5 Data Availability	5/8			
C6 Further Breakdown required	No			
C7 Description/ Comments	Seaweed and algae washed ashore from the see			
C8 Sources	Beaches, ports, harbors			
C9 Advantage	Very few conflicting demands. Using biochar from seaweed for soil remediation helps returning the phosphorous back to the soil that has been washed into the see after application in agriculture			
C10 Disadvantage/ contamination	Potential heavy metal contamination must be assessed on an individual basis. Moisture as well as potentially heavy sand impurities must be dealt with effectively			
References	(Rest till Bäst, 2019) (ECN.TNO, 2020) (lindkvist, 2020)			

Table 13: Pulp & paper waste fact sheet

4.1.8 Pulp & Paper Waste

C1.1 Avail. Skåne	73 kt/y (2016)			
C1.2 Avail. Sweden	930 kt/y (2016)			
C2.1 Conflicting demands	Pulp and paper waste products are used in agriculture (fertilization), construction sites and as fuel for energy generation			
C2.2 Seasonal dependency	NA			
C3 Chemical and physical properties	C3.1	C3.2	C3.3	C3.4
	NA	Very high	Very high	Low
C4 Soil Type	Heavy metal contaminated soil			
C5 Data Availability	6/8			
C6 Further Breakdown required	Yes – The pulp and paper industry produces a multitude of different solid and liquid waste products which must be assessed individually to obtain a clearer picture			
C7 Description/ Comments	Different types of solid and liquid waste products from paper mills (dregs, lime, mud, grid, sludge). C1 and C3 three only consider pulp sludge waste			
C8 Sources	Paper mills			
C9 Advantage				
C10 Disadvantage/ contamination	Very high moisture content. Potential very high contamination with Calcium			
References	(Simao, 2018) (Bajpaj, 2015) (Swedish pulp and paper technology group, pulp & paper in sweden) (ECN.TNO, 2020) (Budzyn, 2016)			

Table 14: Textile waste fact sheet

4.1.9 Textiles

C1.1 Avail. Skåne	7 kt/y (2018)

C1.2 Avail. Sweden	49 kt/y (2018)			
C2.1 Conflicting demands	Two uses for waste textiles are reusing or recycling (only 5% of waste textiles). Another use is for incineration			
C2.2 Seasonal dependency	NA			
C3 Chemical and physical properties	C3.1	C3.2	C3.3	C3.4
	NA	NA	NA	Low
C4 Soil Type	PAH contaminated soil			
C5 Data Availability	4/8			
C6 Further Breakdown required	No			
C7 Description/ Comments	Used, torn, old clothes and fabrics waste			
C8 Sources	Mixed in residual waste, donations, bulk textile waste at stations			
C9 Advantage	Low level of recycling at the moment due to difficult separation process			
C10 Disadvantage/ contamination	Potentially harmful contaminations from mix with other residual waste. Only very little information available online.			
References	(SYSAV, 2019) (Grip, 2018)			

4.2 Agriculture

Table 15 shows the results of the biomass feedstock class "Agriculture". This class contains 6 biomass residue feedstocks that accrue in agriculture processes in Skåne and Sweden. All biomasses show a significantly high availability well beyond the required threshold. The two best performing candidates are straw (from grain) and rapeseed straw. The two lowest performing candidates are grain husks and grain. These residue streams are all very well known and documented.

Table 15: Results summary and ranking og the biomass class "Agriculture"

Class: Agriculture	Evaluation							
Biomass Feedstock	**Rank Category**	**Rank Total**	**C1**	**C2**	**C3**	**C4**	**C5**	**C6**
Straw	**1**	**3**	Skåne	67	67	Metals	7/8	No
Rapeseed straw	**2**	**6**	Skåne	67	28	PAH	8/8	No
Manure	**3**	**10**	Skåne	50	50	Metals	6/8	Yes
Corn (fruit and plant)	**4**	**13.1**	Skåne	50	28	PAH	6/8	Yes
Grain husk	**5**	**14**	Skåne	33	61	PAH	6/8	No
Grain	**6**	**16.1**	Skåne	33	44	PAH	7/8	Yes

All detailed biomass properties and additional information can be seen in the following tables 16 to 21.

Table 16: Straw fact sheet

4.2.1 Straw				
C1.1 Avail. Skåne	250 kt/y (2012)			
C1.2 Avail. Sweden	1000 kt/y (2008)			
C2.1 Conflicting demands	Used as bedding materiel in agriculture, fertilization on straw and other fields, energy generation (incineration)			
C2.2 Seasonal dependency	Yes – peak supply in summer (however, fall/winter crops also available)			
C3 Chemical and physical properties	C3.1	C3.2	C3.3	C3.4
	Low	High	Low to medium	NA
C4 Soil Type	Heavy metal contaminated soil			
C5 Data Availability	7/8			
C6 Further Breakdown required	No			
C7 Description/ Comments	Left over plant from cereal production. The plants get partly left on the fields as beeding/fertilizers. Partly dried and recovered from fields for further uses			
C8 Sources	Cereal farms			
C9 Advantage	Abundancy in peak periods			

C10 Disadvantage/ contamination	Low density (depending on packing method). Potential contamination with potassium, chlorine. Can contain considerable sand/soil impurities
References	(Jernkontoret, 2012) (Strömberg & Herstad Svärd, 2012) (Simmons, 2008)

Table 17: Rapeseed straw fact sheet

4.2.2 Rapeseed Straw

C1.1 Avail. Skåne	285 kt/y (2019)			
C1.2 Avail. Sweden	700 kt/y (2019)			
C2.1 Conflicting demands	Uses as isolation and bedding material. Furthermore used as fertilizer. Also used for energy generation (incineration)			
C2.2 Seasonal dependency	Yes – peak supply during fall (however, winter and summer crops available as well)			
C3 Chemical and physical properties	C3.1	C3.2	C3.3	C3.4
	Low	Medium	High	Low to medium
C4 Soil Type	PAH contaminated soil			
C5 Data Availability	8/8			
C6 Further Breakdown required	No			
C7 Description/ Comments	Leftover plant from rapeseed harvesting. Partly left on fields as fertilizer. Partly removed and dried for further uses			
C8 Sources	Rapeseed farms			
C9 Advantage	Very big cultivation area in Skåne			
C10 Disadvantage/ contamination	Potential stones and soil impurities			
References	(Svenskraps, 2019) (AgMRC, 2018)			

Table 18: Manure fact sheet

4.2.3 Manure

C1.1 Avail. Skåne	2350 kt/y (2013)			
C1.2 Avail. Sweden	20000 kt/y (2013)			
C2.1 Conflicting demands	Manure is used for soil improvement in form of fertilization, composting and biogas production			
C2.2 Seasonal dependency	NA			
C3 Chemical and physical properties	C3.1	C3.2	C3.3	C3.4
	High	High to very high	High to very high	NA
C4 Soil Type	Heavy metal contaminated soil			
C5 Data Availability	6/8			
C6 Further Breakdown required	Yes – manure from different animals can have significant different properties. Can be predominantly solid or liquid			
C7 Description/ Comments	Animal dung (solid and liquid) – often mixed with bedding material			
C8 Sources	Cattle, horse, poultry, pig farms, horse stables			
C9 Advantage	Very high abundancy			

C10 Disadvantage/ contamination	Potential wood, stones, bedding material, plastic (gloves) impurities. Very high nitrogen levels can be expected
References	(Hemlin & Lalangas, 2018) (Strömberg & Herstad Svärd, 2012) (Jordbruksverket, 2013) (Skånefrö, 2020) (Björnsson, 2011)

Table 19: Corn (fruit and plant) fact sheet

4.2.4 Corn (fruit and plant)				
C1.1 Avail. Skåne	187 kt/y (2018)			
C1.2 Avail. Sweden	288 kt/y (2018)			
C2.1 Conflicting demands	Corn fruit is used primarily as animal feed and as food. The plants are used often as bedding material or for fertilization. Also it is used for energy generation (incineration)			
C2.2 Seasonal dependency	NA			
C3 Chemical and physical properties	C3.1	C3.2	C3.3	C3.4
	NA	Medium to high	High to very high	Low to medium
C4 Soil Type	PAH contaminated soil			
C5 Data Availability	6/8			
C6 Further Breakdown required	Yes – fruit and plant should be assessed individually			
C7 Description/ Comments	Left over plant from corn production, partly left on the field as fertilizer, partly dried and recovered from fields for further applications			
C8 Sources	Corn farms			
C9 Advantage				
C10 Disadvantage/ contamination	Higher moisture than other types of straw. Not often used for energy generation purposes			
References	(Wikipedia, 2020) (ECN.TNO, 2020) (Jordbruksverket, 2018)			

Table 20: Grain husk fact sheet

4.2.5 Grain Husk				
C1.1 Avail. Skåne	196 kt/y (2016)			
C1.2 Avail. Sweden	922 kt/y (2019)			
C2.1 Conflicting demands	NA			
C2.2 Seasonal dependency	NA			
C3 Chemical and physical properties	C3.1	C3.2	C3.3	C3.4
	High	Medium to high	Low to medium	Medium to high
C4 Soil Type	PAH contaminated soil			
C5 Data Availability	6/8			
C6 Further Breakdown required	No			
C7 Description/ Comments	Side product during cereal processing. Mainly grain husks and too small cereal grains			

C8 Sources	Cereal farms
C9 Advantage	Good handling properties due to small and very even particle size
C10 Disadvantage/ contamination	Potentially high sulfur and nitrogen contamination. Must be protected from moisture during transportation and storage to avoid congestion in tanks and conveyors
References	(Jernkontoret, 2012) (Strömberg & Herstad Svärd, 2012) (Jordbruksverket, 2016) (Jordbruksverket, 2019)

Table 21: Grain fact sheet

4.2.6 Grain				
C1.1 Avail. Skåne	1300 kt/y (2015)			
C1.2 Avail. Sweden	6400 kt/y (2019)			
C2.1 Conflicting demands	Used as animal feed, in food production and for energy generation (incineration)			
C2.2 Seasonal dependency	NA			
C3 Chemical and physical properties	C3.1	C3.2	C3.3	C3.4
	Medium	Low to medium	Low to medium	Medium
C4 Soil Type	PAH contaminated soil			
C5 Data Availability	7/8			
C6 Further Breakdown required	Yes – different kind of cereal can have quite different properties which should be assessed individually			
C7 Description/ Comments	Overproduced cereal grain, low quality harvests, waste			
C8 Sources	Cereal farms			
C9 Advantage	good handling properties due to quite small and even particle size			
C10 Disadvantage/ contamination	Potentially high nitrogen content. Must be protected from moisture during transportation and storage to avoid congestion in tanks and conveyors			
References	(Jernkontoret, 2012) (Strömberg & Herstad Svärd, 2012) (Jordbruksverket, 2016) (Jordbruksverket, 2019)			

4.3 Horticulture

Table 22 shows the results of the biomass feedstock class "Horticulture". This class contains only two different biomasses, tomato and cucumber farm waste. While tomato farm waste does show a better performance in the multi criteria assessment, there is very little information available regarding the availability of both feedstocks. In order to make a better state ment of the appropriateness for biochar production, the current production capacities of these biomasses have to be assessed in more detail.

Table 22: Results summary and ranking of the biomass class "Horticulture"

Class: Horticulture	Evaluation							
Biomass Feedstock	**Rank Category**	**Rank Total**	**C1**	**C2**	**C3**	**C4**	**C5**	**C6**
Tomato farm waste	**1**	**23.1**	NA	33	33	Metals	6/8	No
Cucumber farm waste	**2**	**25**	<Threshold	33	22	Metals	7/8	No

All detailed biomass properties and additional information can be seen in the following tables 23 and 24.

Table 23: Tomato farm waste fact sheet

4.3.1 Tomato Farm Waste				
C1.1 Avail. Skåne	NA			
C1.2 Avail. Sweden	1 kt/y (2015)			
C2.1 Conflicting demands	Tomato farm waste is reportedly used as the farms for composting			
C2.2 Seasonal dependency	Yes – Campaigns start in April until November			
C3 Chemical and physical properties	C3.1	C3.2	C3.3	C3.4
	NA	Medium to very high	Medium to very high	Low
C4 Soil Type	Heavy metal contaminated soil			
C5 Data Availability	6/8			
C6 Further Breakdown required	No			
C7 Description/ Comments	Plant and fruit waste from tomato farms			
C8 Sources	Tomato farms, greenhouses			
C9 Advantage				
C10 Disadvantage/ contamination	High moisture content especially in fruit waste fraction. Very low availability. Very little information available			
References	(ECN.TNO, 2020) (Frånsverige, 2020)			

Table 24: Cucumber farm waste fact sheet

4.3.2 Cucumber Farm Waste				
C1.1 Avail. Skåne	2 kt/y (2015)			
C1.2 Avail. Sweden	3 kt/y (2015)			
C2.1 Conflicting demands	Composting at the cucumber farm site, digestion for biogas production (also at farm site)			
C2.2 Seasonal dependency	Yes – 2 to 3 campaigns per year			
C3 Chemical and physical properties	C3.1	C3.2	C3.3	C3.4
	NA	Medium to very high	Very high	Low
C4 Soil Type	Heavy metal contaminated soil			
C5 Data Availability	7/8			
C6 Further Breakdown required	No			
C7 Description/ Comments	Plant and fruit waste from cucumber farms			
C8 Sources	Cucumber farms, greenhouses			
C9 Advantage				
C10 Disadvantage/ contamination	High moisture content especially in fruit waste fraction. Very low availability. Very little information available			
References	(Orkla, 2018) (Frånsverige, 2020) (ECN.TNO, 2020)			

4.4 Forestry

This biomass class contains six potential residue feedstocks which arise characteristically from the forest industry. The availability of all candidates is sufficiently higher than the defined threshold. Apart from softwood, there is also sufficiently information available publicly for this first assessment. The two best performing feedstocks are sawdust and bark while the two lowest performances show hardwood and peat.

Table 25: Results summary and ranking of the biomass class "Forestry"

Class: Forestry	Evaluation							
Biomass Feedstock	**Rank Category**	**Rank Total**	**C1**	**C2**	**C3**	**C4**	**C5**	**C6**
Sawdust	**1**	**4**	Skåne	67	44	PAH	8/8	No
Bark	**2.1**	**12.1**	Skåne	50	39	PAH	7/8	No
Salix (Korgvide)	**2.2**	**12.2**	Skåne	50	39	PAH	7/8	No
Softwood	**3**	**15**	Skåne	33	50	NA	1/8	Yes
Hardwood	**4**	**16.2**	Skåne	33	44	NA	6/8	Yes
Peat	**5**	**18**	Skåne	17	50	Metals	8/8	No

For Softwood, very little information was found publicly. All detailed biomass properties and additional information can be seen in the following tables 26 and 31.

Table 26: Sawdust fact sheet

4.4.1 Sawdust				
C1.1 Avail. Skåne	39 kt/y (2020)			
C1.2 Avail. Sweden	603 kt/y (2011)			
C2.1 Conflicting demands	Sawdust is a suitable starting product for the production of refined biofuels. Furthermore, applications exist as bedding material and for the production of fibre and particle boards. Furthermore sawdust gets incinerated for energy generation			
C2.2 Seasonal dependency	No			
C3 Chemical and physical properties	C3.1	C3.2	C3.3	C3.4
	Low	Low to medium	Medium to high	Medium
C4 Soil Type	PAH contaminated soil			
C5 Data Availability	8/8			
C6 Further Breakdown required	No			
C7 Description/ Comments	Very fine wood residue particles from sawing or other size reduction processes			
C8 Sources	Sawmills, wood processing industry, carpenters			
C9 Advantage	Good transportation and conveying properties (if moisture kept low)			

C10 Disadvantage/ contamination	Must be protected from moisture during storage and transportation to avoid congestion. Explosion risk fur to very fine particles and dust
References	(Strömberg & Herstad Svärd, 2012) (Lestander, 2011) (The Sawmill Database, u.d.) (Aqua-Calc.com, 2020) (Shyamalee, 2015) (ECN.TNO, 2020)

Table 27: Bark fact sheet

4.4.2 Bark				
C1.1 Avail. Skåne	47 kt/y (2020)			
C1.2 Avail. Sweden	6150 kt/y (2007			
C2.1 Conflicting demands	Used mostly for energy generation (often within the sawmill facilities for process heat)			
C2.2 Seasonal dependency	NA			
C3 Chemical and physical properties	C3.1	C3.2	C3.3	C3.4
	Medium to high	Low to high	High	Low to high
C4 Soil Type	PAH contaminated soil			
C5 Data Availability	7/8			
C6 Further Breakdown required	No			
C7 Description/ Comments	Inevitable waste product from wood industry. Different weight percentages at different type of trees			
C8 Sources	Sawmills, pulp & paper industry, forest industry			
C9 Advantage	Abundancy of feedstock			
C10 Disadvantage/ contamination	Potential contamination with potassium, calcium, nitrogen, natrium. Uneven particle size very likely			
References	(Jernkontoret, 2012) (Strömberg & Herstad Svärd, 2012) (Hillring) (Hagström, 2006) (Börjesson, 2020)			

Table 28: Salix (Korgvide) fact sheet

4.4.3 Salix (Korgvide)				
C1.1 Avail. Skåne	21 kt/y (2016)			
C1.2 Avail. Sweden	82 kt/y (2010)			
C2.1 Conflicting demands	Energy generation			
C2.2 Seasonal dependency	NA			
C3 Chemical and physical properties	C3.1	C3.2	C3.3	C3.4
	Low	Low to high	Low to high	Low to medium
C4 Soil Type	PAH contaminated soil			
C5 Data Availability	7/8			
C6 Further Breakdown required	No			
C7 Description/ Comments	Wood, bark, branches of Salix plant			

C8 Sources	Energy forests			
C9 Advantage				
C10 Disadvantage/ contamination	Size reduction process can be very demanding. Sustainable high plant yield is very hard to maintain and can lead to fluctuations in supply. Potential heavy metal contamination			
References	(Jernkontoret, 2012) (Strömberg & Herstad Svärd, 2012) (Jordbruksverket, 2010) (Christersson, 2018) (Crafoord, 2016)			

Table 29: Softwood fact sheet

4.4.4 Softwood				
C1.1 Avail. Skåne	120 kt/y (2020)			
C1.2 Avail. Sweden	NA			
C2.1 Conflicting demands	NA			
C2.2 Seasonal dependency	NA			
C3 Chemical and physical properties	C3.1	C3.2	C3.3	C3.4
	NA	NA	NA	NA
C4 Soil Type	NA			
C5 Data Availability	1/8			
C6 Further Breakdown required	Yes – there is many types of softwood available			
C7 Description/ Comments	Several softwood trees that are also available in Skåne (like Pine trees)			
C8 Sources	Forest residues			
C9 Advantage				
C10 Disadvantage/ contamination	Barely information available online. More in depth research to be conducted			
References	(Börjesson, 2020)			

Table 30: Hardwood fact sheet

4.4.5 Hardwood				
C1.1 Avail. Skåne	120 kt/y (2020)			
C1.2 Avail. Sweden	4100 kt/y (2007)			
C2.1 Conflicting demands	Sawmills, pulp & paper industry, energy generation			
C2.2 Seasonal dependency	NA			
C3 Chemical and physical properties	C3.1	C3.2	C3.3	C3.4
	High to very high	NA	Low to high	Low to medium
C4 Soil Type	NA			
C5 Data Availability	6/8			
C6 Further Breakdown required	Yes – there is many different types of hardwood available			

C7 Description/ Comments	Several hardwood (lovträd) species available in Skåne region.
C8 Sources	Forest industry
C9 Advantage	Common type of tree in Skåne
C10 Disadvantage/ contamination	More detailed research required to look into individual types of hard wood tree to determine availability and properties
References	(Jernkontoret, 2012) (Strömberg & Herstad Svärd, 2012) (Börjesson, 2020) (Sveriges Oficiella Statistik, 2019) (Hillring)

Table 31: Peat fact sheet

4.4.6 Peat

C1.1 Avail. Skåne	540 kt/y (2017)			
C1.2 Avail. Sweden	1350 kt/y (2012)			
C2.1 Conflicting demands	Horticulture, crop cultivation, energy production			
C2.2 Seasonal dependency	Yes			
C3 Chemical and physical properties	C3.1	C3.2	C3.3	C3.4
	Low to medium	High	High	Medium to high
C4 Soil Type	Heavy metal contaminated soil			
C5 Data Availability	8/8			
C6 Further Breakdown required	No			
C7 Description/ Comments	Peat is layer of partly decayed organic matter in or on the ground. The Swedish soil contains a lot of peat.			
C8 Sources	Peat producers, forest residues			
C9 Advantage	Good conditions for cultivation in Sweden			
C10 Disadvantage/ contamination	Supply varies a lot over the years. High dependency on the season. Potential contamination with Uranium, nitrogen and/or sulfur. Explosion risk due to dust at low moisture			
References	(Jernkontoret, 2012) (Hemlin & Lalangas, 2018) (Schoning, 2017) (Strömberg & Herstad Svärd, 2012)			

4.5 Plants

Table 32 shows the results of the biomass feedstock class "Plants". This class contains three of the most interesting plants which are cultivated for energy purposes. These feedstocks might not necessarily classify as waste or residue products. They might however have a great potential to be planted with low effort on available green areas to support the local flora and fauna and function as feedstock for biochar production at the same time. Reed canary grass shows the highest expected suitability for biochar production followed by Miscanthus and hemp. Cultivation of hemp is not as simple as of the other two candidates what makes it less interesting for available green areas at site. The quantitative availabilities of all three plants are neither reliably documented for Skåne nor for the rest of Sweden. Further research is integral for this class to evaluate their potential.

Table 32: Results summary and ranking of the biomass class "Plants"

Class: Plants	Evaluation							
Biomass Feedstock	**Rank Category**	**Rank Total**	**C1**	**C2**	**C3**	**C4**	**C5**	**C6**
Reed Canary Grass (Rörflen)	**1**	**21**	NA	33	50	PAH	7/8	No
Miscanthus	**2**	**23.2**	NA	33	33	PAH	5/8	No
Industrial Hemp	**3**	**24**	NA	17	44	PAH	6/8	No

All detailed biomass properties and additional information can be seen in the following tables 33 to 35.

Table 33: Reed canary grass (Rörflen) fact sheet

4.5.1 Reed Canary Grass (Rörflen)

C1.1 Avail. Skåne	NA			
C1.2 Avail. Sweden	4 kt/y (2010)			
C2.1 Conflicting demands	Energy production			
C2.2 Seasonal dependency	Yes – peak in late summer			
C3 Chemical and physical properties	C3.1	C3.2	C3.3	C3.4
	Low to medium	Medium to high	Low to medium	Low to medium
C4 Soil Type	PAH contaminated soil			
C5 Data Availability	7/8			
C6 Further Breakdown required	No			
C7 Description/ Comments	Also called energy grass. Up to ca. 6t(dry)/ha annual yield			
C8 Sources	Rörflen plantations			
C9 Advantage	Very easy and quick to grow plant			
C10 Disadvantage/ contamination	Low plantation density in Sweden. Potential nitrogen contamination. Ash content highly depending on plant growing site. Very fine particle fraction			

	can lead to congestion at higher moisture and dust/explosion risk at low moisture
References	(Jernkontoret, 2012) (Strömberg & Herstad Svärd, 2012) (Jordbruksverket, 2010) (Rörflenodlarna, u.d.) (ECN.TNO, 2020)

Table 34: Miscanthus fact sheet

4.5.2 Miscanthus				
C1.1 Avail. Skåne	NA			
C1.2 Avail. Sweden	NA			
C2.1 Conflicting demands	Fertilization, energy generation			
C2.2 Seasonal dependency	Yes, peak in spring time			
C3 Chemical and physical properties	C3.1	C3.2	C3.3	C3.4
	NA	Medium to high	High	Low to medium
C4 Soil Type	PAH contaminated soil			
C5 Data Availability	5/8			
C6 Further Breakdown required	No			
C7 Description/ Comments	Annual yield up to ca. 15t(dry)/ha			
C8 Sources	NA			
C9 Advantage	Source of bioavailable Silicium. Might be a possible intercrop on a landfill for example. Very low soil requriements			
C10 Disadvantage/ contamination	Cold winter months could damage the plant. Not much information available about current situation in Sweden			
References	(Jordbruksverket, 2010) (ECN.TNO, 2020)			

Table 35: Industrial hemp fact sheet

4.5.3 Industrial Hemp				
C1.1 Avail. Skåne	NA			
C1.2 Avail. Sweden	1 kt/y (2013)			
C2.1 Conflicting demands	Textile industry, cosmetics, oil			
C2.2 Seasonal dependency	NA			
C3 Chemical and physical properties	C3.1	C3.2	C3.3	C3.4
	Low	Low to medium	Low to medium	Medium
C4 Soil Type	PAH contaminated soil			
C5 Data Availability	6/8			
C6 Further Breakdown required	No			
C7 Description/ Comments	Canabis Sativa. Ca. 20-25t(dry)/ha annual yield achievable			

C8 Sources	Hemp plantations
C9 Advantage	Very high yield per hectare compared to other plants
C10 Disadvantage/ contamination	Successful plantation is relatively difficult and comes with high effort. Potential potassium contamination. Sintering could occur. Very little experience with Hemp for energy purposes
References	(Jernkontoret, 2012) (Strömberg & Herstad Svärd, 2012) (Aquilonius, 2013)

4.6 Food

Table 36 shows the results of the last biomass feedstock class “Food”. The best result show rejected fruit and vegetables. While this biomass can be expected to be very abundant, especially in Skåne which has a lot of import/export business through the ports, the feedstock must be analyzed in detail for each individual application due to big expected variations of composition of the feedstock. For the other two biomasses cocoa bean shells and coffee roastery residues, no reliable information could be found regarding the quantitative availability in the regions.

Table 36: Results summary and ranking for the biomass feedstock "Food"

Class: Food	Evaluation							
Biomass Feedstock	**Rank Category**	**Rank Total**	**C1**	**C2**	**C3**	**C4**	**C5**	**C6**
Rejected fruit and vegetables	**1**	**11**	Skåne	50	44	Metals	6/8	Yes
Cocoa Bean shells	**2**	**20**	NA	50	67	PAH	5/8	No
Coffee roastery residues	**3**	**22**	NA	33	39	PAH	3/8	No

All detailed biomass properties and additional information can be seen in the following tables 37 to 39.

Table 37: Rejected fruit and vegetable fact sheet

4.6.1 Rejected Fruit and Vegetable				
C1.1 Avail. Skåne	162 kt/y (2011)			
C1.2 Avail. Sweden	1200 kt/y (2012)			
C2.1 Conflicting demands	Fertilizing, energy production			
C2.2 Seasonal dependency	NA			
C3 Chemical and physical properties	C3.1	C3.2	C3.3	C3.4
	NA	Very high	High to very high	Low to medium
C4 Soil Type	Heavy metal contaminated soil			
C5 Data Availability	6/8			
C6 Further Breakdown required	Yes – composition can vary significantly (individual analysis will be required for every specific biomass composition)			
C7 Description/ Comments	Skåne has a lot of import business through the ports			
C8 Sources	Households, industry, supermarkets, catering services			
C9 Advantage				
C10 Disadvantage/ contamination	Potentially cross-contaminated from other residual waste			
References	(Hinde, 2019) (Börjesson, 2020) (Naturvardsverket, 2012) (ECN.TNO, 2020)			

Table 38: Cocoa bean shells fact sheet

4.6.2 Cocoa Bean Shells				
C1.1 Avail. Skåne	NA			
C1.2 Avail. Sweden	NA			
C2.1 Conflicting demands	Incineration			
C2.2 Seasonal dependency	NA			
C3 Chemical and physical properties	C3.1	C3.2	C3.3	C3.4
	Medium to high	Medium to high	Low	Medium to high
C4 Soil Type	PAH contaminated soil			
C5 Data Availability	5/8			
C6 Further Breakdown required	No			
C7 Description/ Comments	Residue product from chocolate production process. Mostly cocoa bean shells			
C8 Sources	Chocolate factories			
C9 Advantage	Good transportation and conveying properties due to small and uniform particle size			
C10 Disadvantage/ contamination	Potentially high nitrogen content. Must be protected from moisture in order to avoid congestion. Very little information available publicly.			
References	(Jernkontoret, 2012) (Strömberg & Herstad Svärd, 2012)			

Table 39: Coffee roastery residues fact sheet

4.6.3 Coffee Roastery Residues				
C1.1 Avail. Skåne	NA			
C1.2 Avail. Sweden	NA			
C2.1 Conflicting demands	NA			
C2.2 Seasonal dependency	NA			
C3 Chemical and physical properties	C3.1	C3.2	C3.3	C3.4
	NA	Low to medium	Low to medium	Low to medium
C4 Soil Type	PAH contaminated soil			
C5 Data Availability	3/8			
C6 Further Breakdown required	No			
C7 Description/ Comments	Many coffee roasteries in Skåne (Zoegas, Love, etc.)			
C8 Sources	Coffee roasteries			
C9 Advantage				
C10 Disadvantage/ contamination	Very little information available publicly. Detailed analysis to be made if necessary			
References	(ECN.TNO, 2020)			

4.7 All Biomass Classes

Table 40: Results summary of all biomass classes

All Classes		Evaluation								
Class	Biomass Feedstock	Category Rank	Total Rank	C1	C2	C3	C4	C5	C6
Waste	Sewage Sludge	1 (9)	1	Skåne	100	50	Metals	8/8	Yes
Waste	Recycled Wood (Returträ)	2 (9)	2	Skåne	83	50	PAH	8/8	No
Agriculture	Straw	1 (6)	3	Skåne	67	67	Metals	7/8	No
Forestry	Sawdust	1 (6)	4	Skåne	67	44	PAH	8/8	No
Waste	Garden Waste (Leaf and Grass)	3 (9)	5	Skåne	67	33	PAH	7/8	No
Agriculture	Rapeseed Straw	2 (6)	6	Skåne	67	28	PAH	8/8	No
Waste	Garden Waste (Branches)	4 (9)	7	Skåne	67	22	PAH	8/8	No
Waste	Waste from Slaughterhouse	5 (9)	8	Skåne	50	72	Metals	6/8	Yes
Waste	Paper/Cardboard	6 (9)	9	Skåne	50	67	Metals	7/8	Yes
Agriculture	Manure	3 (6)	10	Skåne	50	50	Metals	6/8	Yes
Food	Rejected Fruit and Vegetables	1 (3)	11	Skåne	50	44	Metals	6/8	Yes
Forestry	Bark	2.1 (6)	12.1	Skåne	50	39	PAH	7/8	No
Forestry	Salix	2.2 (6)	12.2	Skåne	50	39	PAH	7/8	No
Agriculture	Corn (Fruit and Plant)	4 (6)	13.1	Skåne	50	28	PAH	6/8	Yes
Waste	Seaweed (Tång)	7 (9)	13.2	Skåne	50	28	PAH	5/8	No
Agriculture	Grain Husk	5 (6)	14	Skåne	33	61	PAH	6/8	No
Forestry	Softwood	3 (6)	15	Skåne	33	50	NA	1/8	Yes
Agriculture	Grain	6 (6)	16.1	Skåne	33	44	PAH	7/8	Yes
Forestry	Hardwood	4 (6)	16.2	Skåne	33	44	NA	6/8	Yes
Waste	Pulp & Paper Waste	8 (9)	17	Skåne	33	33	Metals	6/8	Yes
Forestry	Peat	5 (6)	18	Skåne	17	50	Metals	8/8	No
Waste	Textiles	9 (9)	19	Sweden	50	33	PAH	4/8	No
Food	Cocoa Bean Shells	2 (3)	20	NA	50	67	PAH	5/8	No
Plants	Reed Canary Grass (Rörflen)	1 (3)	21	NA	33	50	PAH	7/8	No
Food	Coffee Roastery Residues	3 (3)	22	NA	33	39	PAH	3/8	No
Horticulture	Tomato Farm Waste	1 (2)	23.1	NA	33	33	Metals	6/8	No
Plants	Miscanthus	2 (3)	23.2	NA	33	33	PAH	5/8	No
Plants	Industrial Hemp	3 (3)	24	NA	17	44	PAH	6/8	No
Horticulture	Cucumber Farm Waste	2 (2)	25	<Threshold	33	22	Metals	7/8	No

Table 40 shows the combined results of all biomass classes and how they perform in contrast to each other. Under the ten best performing feedstocks are six from the class "Waste", three from the class "Agriculture" and one from the class "Forestry". The places eleven to 20 contain apart from two biomasses from the class "Food" (place 11 and 20) the remaining feedstocks of the "Waste, "Agriculture" and "Forestry" class. The classes "Horticulture" and "Plants" make up the places 21 to 25. The top five biomass feedstocks are sewage sludge, recycled wood, straw, sawdust and the leaf and grass fraction of garden waste. The 5 worst performing biomass feedstocks are cucumber farm waste, industrial hemp, Miscanthus, tomato farm waste and coffee roastery residues.

4.8 Impact of not available Data

At this point it is important to point out the impact of the criterium C1 (quantitative availability). Since this criterium has the highest priority, biomass feedstocks where no data is available regarding their available quantities will perform automatically worse. This explains partly the concentration of the biomass classes "Plants" "Food" and "Horticulture" in the end of the ranking. While only for cucumber farm waste information was available stating that the available quantities are not sufficient, the next six better candidates had not enough information available. Here it also must be mentioned, that, while it is very beneficial to have very big available quantities of feedstock, in individual cases, only one supplier can be sufficient to successfully run a biochar production facility. Keeping this in mind, the lower performing biomass feedstocks cannot be generally disregarded when selecting a feedstock for biochar production.

Taking cocoa bean shells as an example, assuming that a sufficient quantity of feedstock would be supplied by a specific partner, based on the remaining criteria, the feedstock would rank in the top ten (tenth place) right after paper/cardboard waste instead of place 20.

5. Outlook: Beneficial prerequisites of municipal recycling firms for biochar production

As an outlook, this report shall consider the potential for implementing biochar production facilities for municipal recycling firms as NSR is one. In this chapter some beneficial prerequisites will be elucidated to show synergies and impediments that can arise. In general, the pyrolysis process in the reactor itself is only one of many parts of a puzzle. The following picture shows schematically the process requirements for biochar production.

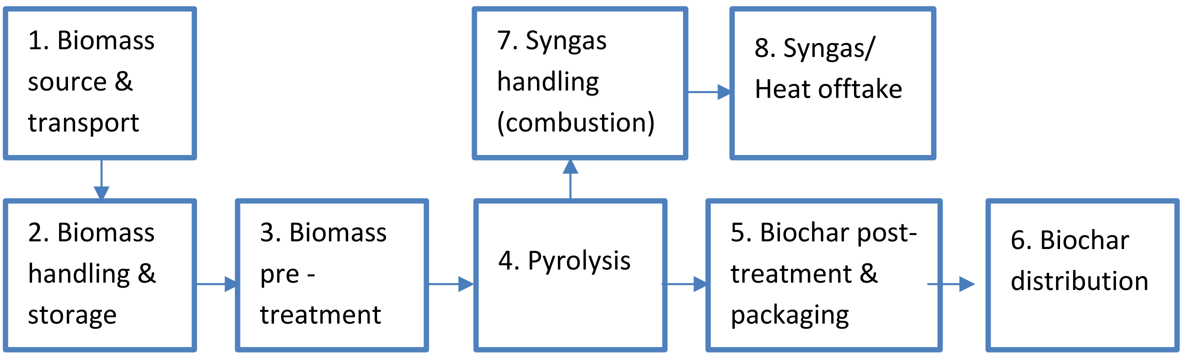

Figure 1: Pyrolysis process steps

Among these eight process steps many synergies and compatibilities with municipal recycling firms can be found as described in the following.

1. Biomass source & transport

Obviously, municipal recycling firms already have some kind of regular waste supply. The necessary transportation infrastructure (like own trucks or contracted transportation companies) is very likely to be already available. At the same time there is already a lot of biomass delivered and handled at the site. Depending on the types and amount of available biomass, no additional biomass needs to be identified but the available biomass can be used as feedstock for the pyrolysis process. Otherwise, in case a specific biomass waste stream would be identified in the vicinity of the recycling plant, transportation efforts would be easier to be implemented due to the already existing network of suppliers and means of transportation. The types and amounts of biomass that are handled at municipal recycling firms varies from site to site, however some type of waste will always be available. The appropriateness of it as feedstock for the production of biochar must be assessed in any case separately.

2. Biomass handling and storage

As municipal recycling firms take in waste from different sources and merge, separate and treat them, a minimum amount of biomass handling facilities must be available at everyone of them. In each specific case, the appropriateness of these must be evaluated regarding the type and amount of biomass that has been chosen as feedstock for the pyrolysis plant. At the same time, particular storage conditions must be maintained for example to keep the moisture level in an acceptable range or to avoid leaking of potentially contaminated liquids. In any case, available sites and infrastructures should be used to a maximum possible extent in order to minimize the cost for new constructions and equipment. For the transportation within the recycling site, already existing wheel loaders or moving floor containers can be used.

3. Biomass pre-treatment

When it comes to biomass pretreatment, first the intended feedstock must be analyzed in detail regarding its chemical and physical properties and the required targeted properties must be defined. Among others, possible necessary treatment processes can be size reduction (milling, cutting, shredding, etc.), separation (sieving, magnetic separation, etc.), drying, pelleting. Depending on the recycling firm, suitable machinery for these processes might be available. If this is the case, significant equipment cost can be saved. While the chance that an existing machine precisely fits the new requirements and also is available at a sufficient capacity is relatively low, the biomass can probably be prepared up to a certain extend which might reduce the size of the new equipment to be purchased.

4. Pyrolysis

The pyrolysis reactor will most likely have to be purchased as it is the key component of the new process that this section of the report focusses on. However, there is of course a wide range of different reactor designs and manufacturers with differences in application and quality. Regarding to the prevailing conditions and the available biomass as well as the intended use of the generated biochar and syngas the pyrolysis technology must be selected carefully. A comparative assessment of pyrolysis reactors has been made previously by Pamoja and NSR and can be downloaded at XXX.

5. Biochar post-treatment and packaging

Just like the pyrolysis reactor, the biomass post-treatment and packaging equipment is very likely to have to be procured specifically. Again, the intended use of the biochar must be taken into account to select the most appropriate technology.

6. Biochar distribution

As there are various applications of biochar in different sectors of industry and agriculture it is very important to identify effective distribution channels for the biochar. For most municipal recycling firms, it is not very attractive to establish an active sales network. However agricultural and garden supplies stores or similar retail firms can be used as intermediaries. In some cases, also direct distribution of biochar to some bigger clients like farmers, or municipalities could be suitable. For biochar applications in highly specified fields like filtration systems or for cosmetic products, an intermediary retailer will most probably be inevitable.

7. Syngas handling and combustion

Apart from biochar, syngas is the second main product of the pyrolysis process. Syngas can be used either directly for heat generation or as base for production of synthetic fuels. The simpler case of combustion for heat production has the advantage that it can be used to supply the energy for the possible drying process in the biomass pre-treatment process. The use of the syngas for the production of synthetic fuels makes in general only sense if there is a specific offtaker in the close vicinity as storage and transportation can become very complicated. At the same time an alternative source of heat must be available in case drying is needed for pre-treatment of the biomass.

8. Heat offtake

In case of combustion of the syngas at the site, the generated excess heat (the share that cannot be used internally in the process) must be supplied for example to the district heating network or any other suitable process that requires heat.

9. Synergies

Additionally, to the potentially existing infrastructure, space and equipment that could be beneficial for municipal recycling firms to install pyrolysis plants, there are even more synergies that can be beneficial. First of all the, the fact that a recycling plants main business is to handle waste streams in the most profitable and sustainable way gives an incentive to also invest into new technologies and profit from the development of biochar in its early phases of application. Even though, the process of pyrolysis has been known for hundreds of years, it just recently got some more traction mostly against the background of climate change and soil degradation due to extreme weather conditions. Through the production of biochar, a sustainable and carbon negative soil amendment can be produced while generating syngas for heat, power, or fuel/chemical production. At the same time, many waste management plants have some kind of involvement in research and development projects which means that they have the knowledge and experience to adapt such new technology. There is also skilled personnel available to operate the pyrolysis reactor and its additional equipment. And last but not least, many waste management plants have open green areas which can be used for field studies on biochar as soil amendment if this is in the interest and the capabilities of the firm.

All in all, municipal recycling firms can be expected to be very suitable sites to implement biochar production facilities. Due to many synergies and previously available knowledge and experience the effort, required to plan, build and operate a pyrolysis unit and its supplementary equipment can expected to be simplified even if no already available equipment can be used in the treatment or handling/storage processes.

6. Conclusion and Way Ahead

In this report a very general overview has been given about the availability of different biomass streams in Skåne and Sweden. Furthermore, a preliminary evaluation has been performed about the suitability of the individual feedstocks for the production of biochar through pyrolysis. 29 biomass resources divided in different 6 classes (waste, agriculture, horticulture, forestry, plants and food) have been investigated regarding their expected available annual quantities, their suitability for biochar production purposes and some of their chemical and physical properties. Additionally, qualitative information has been gathered regarding specific advantages/disadvantages that can arise. The collected information has been used to perform a multi criteria assessment resulting in an objectively comparable ranking of all biomass classes. The top five performers in the assessment are sewage sludge, recycled wood, straw, sawdust and the leaf and grass fraction of garden waste. The worst three performing feedstocks have been found to be Miscanthus, industrial hemp and cucumber farm waste. In general feedstocks from the classes “waste”, “agriculture” and forestry” have been generally speaking performing better than the feedstocks from the classes “horticulture”, “plants” and “food”. While this result is a representation of the publicly available data and based on an objective representation of the feedstocks, a distinction between theory and practice has to be pointed out at this point. As mentioned before in this report, the comparability of feedstocks not only among them but also within different fractions and different samples of them adds a layer of uncertainty to the applicability of the findings for practical scenarios. As for example with the leaf and grass fraction of garden waste, while according to most data online, it is the 5th most suitable feedstock for biochar production, from experience of NSR, plastic, soil, sand, metal and many more kind of impurities have shown to make a further processing to an even fuel composition very difficult. This being said, when it comes to comparison of biomass resources, no generally valid statement can be made but individual and in-depth analyses are imperative in order to be able to properly assess the feasibility and design a suitable process setup. Furthermore, it can be said that while a minimum availability of biomass is important to ensure a stable supply of feedstock for a pyrolysis plant setup, this does not have to be provided from a multitude of sources. Even with very little data available, just one reliable supplier of waste can make the difference between very inappropriate to very appropriate feedstock as the example with cocoa bean shells elucidated in section 4.8.

Nevertheless, while there is a lot of restrictions to the applicability of the found results, a general abundancy of feedstock within Skåne and Sweden could be confirmed and shall inspire for further detailed research into the individual feedstock classes. Especially sewage sludge should be further assessed as there is a very high abundancy of material with often negative prices due to the high contamination that makes it inappropriate for most other recycling processes. With the first pyrolysis plants taking up operation, the technology can also be expected to get more and more traction, making it easier to perform tests and creating experience and industrial standards.

Additionally, in the outlook (section 5) it has been shown that municipal recycling firms show many beneficial prerequisites that put them in favor of implementation of biochar production processes. Not only potentially already available equipment can decrease the required investment cost, but also the availability of skilled man force, and synergies for research tasks can play an integral role when assessing the feasibility of a such an investment.

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