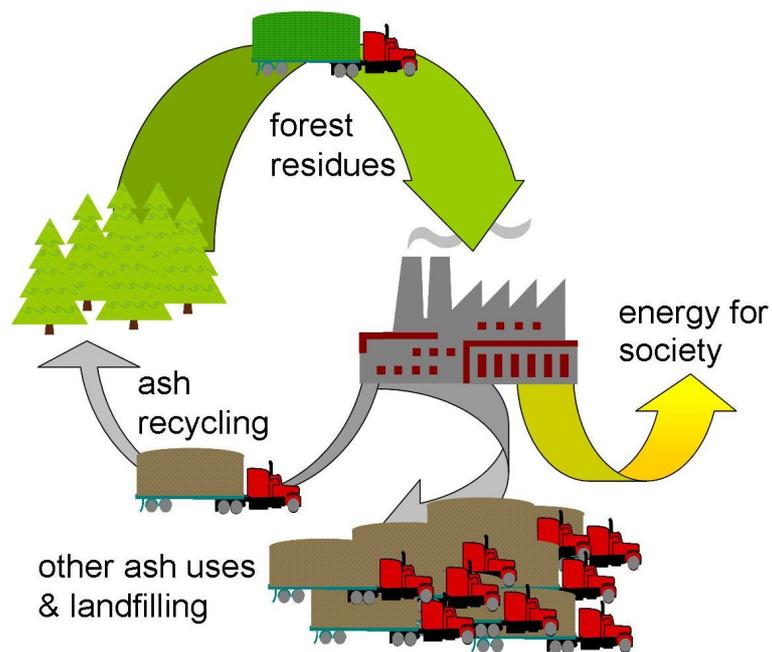


# The contribution of ash recycling to the sustainability of bioenergy from forest biomass: An analysis of Götaland, Sweden.



Thesis submitted in partial fulfillment of the requirements of the  
Degree of Master of International Environmental Science  
Lund University, Sweden.

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Lund, 24.05.2010  
Word count: 14466

**Abstract.** In Sweden, bioenergy use is promoted under the light of climate change mitigation and energy security. In 2009 31% of Sweden's total energy supply was provided by bioenergy. Almost half of this energy is generated from forest biomass. Forestry has a long tradition in Sweden and sustainable resource management is advanced. However, the increased extraction of forest biomass results in export of nutrients and alkalinity which are important for forest growth and vitality. Recycling the ash, which is produced during bioenergy generation, is a well-known compensation method. In Sweden it is only applied to 5% of suitable ash in 2006. The Swedish Forest Agency's goal to spread ash on all areas where forest residues are extracted in 2010 is far from reached. This study assesses the barriers to ash recycling and opportunities to increase this process. A systems perspective using causal loop diagramming and the Driver Pressure State Impact Response (DPSIR) scheme is employed. A quantitative approach, namely material flow analysis, and a qualitative approach, stakeholder analysis are carried out. The research is embedded in theoretical considerations evolving around concepts of industrial ecology, precisely the precautionary approach and ecological modernisation. The study shows that incentives for bioenergy plants, other than environmental consciousness, to ash recycling are missing. However, bioenergy plants own the ash and should recycle suitable ash to ensure long term sustainability of forestry and thus bioenergy. Recommendations how to establish incentives are discussed, including the potential connection of ash recycling to the electricity certificate. Other results like technological, organisational and social barriers were identified and incorporated in these considerations.

**Key words:** Sweden, bioenergy, forest biomass, ash recycling, industrial ecology, stakeholder analysis.

## **Acknowledgments**

I am thankful for all the support I experienced during the time of intensive thesis-work. I appreciate the help I got related to every-day-tasks-and-dilemmas, which proved to be demanding when thesis-work is taking over. Thanks to all my friends, my supervisor and interviewees!

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## **Abbreviations**

EC European Council

EEA European Environment Agency

EEB European Environmental Bureau

EU European Union

FSC Forest Stewardship Council

SEA Swedish Energy Agency

SFA Swedish Forest Agency

UNEP United Nations Environment Programme

# 1 Introduction

Climate change is one of the six environmental challenges of the 21<sup>st</sup> century and is often cited as the 'single greatest challenge facing decision makers on many levels' (K.M. Ban in UNEP, 2009). The transition to a low carbon society is one strategy to mitigate climate change (UNEP, 2009). This includes energy generated from renewable energy sources, from, for example, biomass. Bioenergy replaces fossil fuelled energy and has the potential to decrease green house gas emissions and to contribute to climate change mitigation (Stupak et al., 2007). With its goal of 20% renewable energy by 2020 the EU pushes each member state for increased use of renewable energy (EC, 2009). Sweden, as one EU member country, sets its policy goal to generate half of its total energy use through renewable energy sources by 2020 (Naturvårdsverket, 2009). In the past 30 years Sweden has increased its use of renewable energies considerably, with bioenergy increasing the most (Swedish Government, 2009). Currently bioenergy contributes 31% to the total energy supply of Sweden (Svebio, 2010) and the trend is expected to continue (Swedish Government, 2009).

Bioenergy systems are inevitably linked to biomass production systems and thus natural resources. To ensure sustainable development, environmental limits and thresholds of natural resources need to be understood and kept (Haines-Young et al., 2006). This is because once environmental limits are crossed the impact on a natural resource leads to a state which is not bearable for the environment, including society (ibid). Thus while bioenergy generation should be promoted in order to decrease green house gas emissions, negative impacts on fuel-providing natural resources need to be avoided. One negative is the increased export of nutrients and base cations<sup>1</sup> from the forests (Röser et al., 2008). This, depending on soil and forest type, results decreased long term forest health and growth, and acidification of soil and bordering water bodies (SFA I, 2008).

A well-known measure to both balance nutrient status and mitigate acidification is the recycling of ash, a by-product of bioenergy generation, back to the forest<sup>2</sup>. Ash contains both macro-nutrients, for instance phosphorous which can stimulate forest growth, and micro-nutrients such as copper and zinc which are important for forest vitality (Thelin, 2010). The contained potassium, magnesium and calcium are exchangeable base cations which contribute to the base saturation of soils. The addition of ash improves the nutrient balance of the forest and adds to the natural available base saturation and thus decreases or averts acidification (Röser et al., 2008).

However, ash is categorised as waste and a tax of 500 SEK ton<sup>-1</sup> is charged if ash is dumped on a landfill (Thelin, 2010). The tax can be avoided if ash is used and a high share is used for covering landfills, or as undergrounds for road construction (Engfeldt, 2007). The author takes the stance that ash should always be used for some purpose, to reduce the amount of waste, but that recycling of suitable ash should be prioritized because this closes the loop between forestry and energy production and ensures the long term sustainability of

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<sup>1</sup> Base cations (Ca, Mg, K and Na) are free cations which neutralise soil acidity.

<sup>2</sup> From here on the expression „ash recycling“ refers to the recycling of suitable ash to the forest according to SFA's recommendations (see SFA, 2008). Suitable ash meets the quality criteria of the SFA and in 2006 it was estimated that 300 000 ton ash out of 800 000 ton generated ash is potential suitable (Emilsson, 2006).

the forest (Röser et al., 2008). In 2006 only 5% of suitable ash was recycled in Sweden (Emilsson, 2006). This provides an opportunity to improve the sustainability of bioenergy from forest biomass in the future.

*But why is such an obvious and simple measure bearing numerous advantages not used more in a developed and environmentally conscious country like Sweden? What are the barriers inhibiting increased ash recycling?*

The aim of this thesis is to analyze the barriers to ash recycling from bioenergy generation from forest biomass back to the forest. The author endeavours to make suggestions on how ash recycling could be enhanced and thus contribute to the sustainability of bioenergy from forest biomass.

The aims will be pursued by examination of the following research questions:

- 1) How do Sweden's geophysical, demographical and industrial preconditions affect the development of ash recycling from a systems perspective?
- 2) Which incentives and barriers influence the implementation of ash recycling?
- 3) How effective is ash recycling as a response to mitigate the potential unsustainability of increased forest biomass extraction for energy purposes?
- 4) Which incentives and legislative measurements could be established to increase ash recycling?

Götaland, the most southern part of Sweden, is the most densely populated area in Sweden with a high energy demand (Appendix I). The current and potential extraction rates of forest biomass for energy production are high in Götaland (Kunskap Dirket III, 2009; Kunskap Direkt I, 2009). For these reasons, this thesis focuses on Götaland. In some cases, this spatial boundary is ignored for causes discussed as they occur.

The study will focus on ash from district heating plants and cogeneration plants<sup>3</sup>, even though they produce only one third of all ash suitable for recycling. The other two thirds are produced by pulp and paper industry and saw-mill industry (Emilsson, 2006). However, bioenergy plants use the most forest biomass, which is specifically extracted for energy purposes (Kunskap Direkt II, 2009). They contribute most to the export of nutrients and base cations from the forest. Also, the author is aware that there are uncertainties about long term effects of ash recycling and that this is a research field in itself but assumes that the identified positive effects of ash recycling outweigh possible negative effects.

This thesis is structured as follows. The subsequent section describes the theoretical base, followed by the methodology section. The background to bioenergy, forestry and ash recycling prepare the reader for the ensuing analysis and results chapter. The discussion including the conclusions completes the thesis.

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<sup>3</sup> Interchangeably used with the simplified term bioenergy plants and only differentiated when needed.

## 2 Theoretical basis: sustainable development and industrial ecology

In this thesis, it is argued that ash recycling can be seen as a process which connects the energy industry and the forest industry. The other more obvious link between the energy system and natural resource system is the wood fuel supply (Fig. 1). There are several studies assessing potential feasibility and sustainability of the wood fuel supply, but few focusing on the implementation of ash recycling. However, ash recycling is the link which connects the energy system back to forestry, closing the loop between the two systems and uniting them into a sustainable bioenergy system. Ash recycling and the barriers which inhibit its implementation on a larger scale are studied and is the research problem. Ash recycling is influenced by the development of the energy industry and the forest industry, and these two sectors also require examination. Together they delineate the research area, in which the research problem is embedded, see Fig. 1.

The research area is regarded from a sustainable development point of view and the research problem, ash recycling, is analysed from an industrial ecology perspective, see Fig. 1.

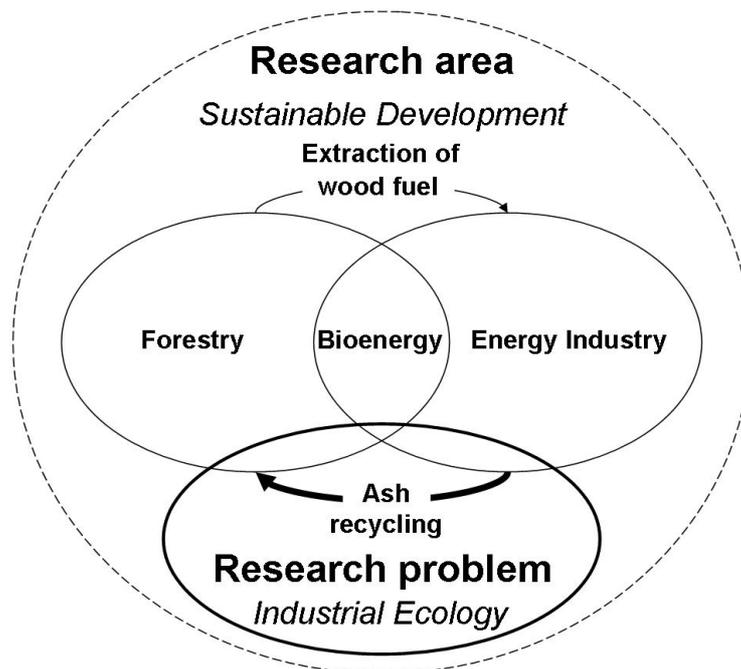


Fig. 1: Theoretical basis for studying the process of ash recycling (research problem, oval with thick line), which is embedded in the research area (circle with dashed line). The research area consists of the forestry and energy industries, and through the linkages of wood fuel extraction and ash recycling they become the bioenergy system.

Industrial ecology's objective is to study, in a multidisciplinary manner, the linkages between economic systems and environmental systems (Allenby, 2000). It applies a systems approach providing a holistic view on environmental problems. The holistic perspective makes it easier to identify and to solve environmental problems (Garner and Keolian, 1995) and suits the format of this study well. The main goal of industrial ecology is to change the linear nature of industrial systems through closing the production loop (ibid). It highlights the need to use opportunities and processes which are economically beneficial while emphasising a long-term and holistic view on technology development, sustainable resource use and environmental protection (Thomas et al., 2003).

Ash recycling is an opportunity to reconnect flows within the bioenergy systems and can be related to a number of concepts applied within industrial ecology. Ecological modernisation and the precautionary principle were chosen as they are very appropriate for ash recycling,

Ecological modernisation implies that newly implemented products or processes improve the environmental and economical benefits of a system (Milanez and Bührs, 2007). It is not only about economic efficiency, for which the concept is often criticised, but about ecological consistency between material flows, resource use and consumption (Andersen and Massa, 2000). Even though ecological modernisation can be seen from other stances as discussed by Milanez and Bührs (2007), in this thesis the above outlined understanding is applied. However, it is important to stress that ecological modernisation alone is not sufficient to reach the goals of sustainable development, but is a necessary strategy (Langhelle, 2000) and is seen as embedded within sustainable development (Fig. 1).

The process of ash recycling gives nutrients and alkalinity back to the forest and removes waste from the bioenergy system. Thus it improves the environmental benefit and should also imply economic benefits. At the same time ash recycling has a precautionary character, because it helps to prevent unsustainable use of the forest system.

The precautionary principle is an additional concept used in both sustainable development and industrial ecology. It implies that early action in the case of uncertainty and ignorance is justified to prevent potential harm and unacceptable impacts on the environment and society (EEB, 1999).

As harvesting of wood fuels for bioenergy generation in Sweden increased drastically only in the last 30 years, it is hard to predict what the impact will be on the forest ecosystem and other connected earth systems. Nevertheless, most scientists agree that the increased export of wood fuels, and thus nutrients and alkalinity, needs to be compensated (Röser et al., 2008), which is a precautionary approach.

### 3 Methodology

#### 3.1 Research structure

To answer the aforementioned research questions the research area was framed from a systems perspective. This assesses the complexities of the research area and allows a consistent definition of system boundaries for the subsequent investigation of the research problem. The barriers and potential of ash recycling were studied using a quantitative and a qualitative approach: material flow analysis and stakeholder analysis respectively. The systems perspective was then re-applied to assess the contribution of ash recycling to the sustainability of bioenergy (Fig. 2).

The systems perspective applied causal loop diagramming<sup>4</sup> and the Driver Pressure State Impact Response (DPSIR) scheme. The approaches were carried out with a set of methods. The research was carried out as reflexive research, using the understanding from CLDs to prepare for the more detailed approaches material flow analysis and stakeholder analysis, and the concluding DPSIR-scheme. The research was an iterative process, where the earlier results helped to refine and to improve the conduction of later research.

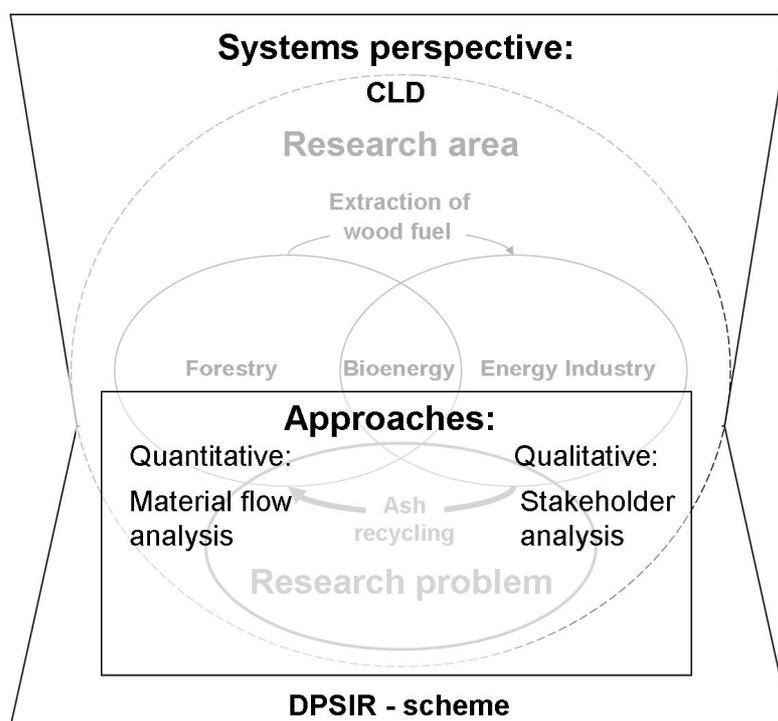


Fig. 2: Overview of the applied research structure. The systems perspective assesses the research area employing the CLD tool and the DPSIR-scheme. The approaches focus on the research problem. The material flow analysis covers the quantitative aspects to existing barriers while the stakeholder analysis analyzes the barriers in a qualitative manner.

<sup>4</sup> Causal loop diagramming results in causal loop diagrams, short CLDs.

## **3.2 Approaches**

### **3.2.1 Material flow analysis**

Material flow analysis is a systematic assessment of material flows and stocks within a time and space-wise well-defined system (Appendix II; Brunner and Rechberger, 2003). It connects the sources, the pathways and the intermediate and final sinks of a material and is an input-output study with the simple rule that material is never lost, but only transformed (ibid).

The material flow analysis aimed to assess quantitative barriers of ash recycling; meaning how much ash there is to recycle and if this is enough to implement the Swedish Forest Agency's (SFA) recommendations for ash recycling. To include all possible pathways that forest biomass can take before being used for energy generation (for example the refining of forest residues to pellets) and all possible pathways the ash can take after energy generation (for example use for construction) was limited to developing a qualitative material flow chart. A quantitative material flow analysis considering the use of primary forest residues and the recycling of ash back to the forest was conducted, as the recycling of ash should mainly be done in connection with extraction of primary forest residues (SFA I, 2008).

### **3.2.2 Stakeholder analysis**

The qualitative in-depth analysis assessed stakeholders' influence on processes related to ash recycling. In this study stakeholders are defined as 'those who have an interest in a particular decision, either as individuals or representatives of a group. This includes people who influence a decision, or can influence it, as well as those who are affected by it' (Hemmati, p.2, 2002).

The characteristics of stakeholders, for instance the involvement in ash recycling and the impact of ash recycling on the stakeholder, were assessed. The obtained information was used to populate an involvement-interest-power-position-impact – matrix (according to Varvasovszky and Brugha, 2000; Appendix III).

The stakeholder analysis was used to identify further barriers than already encountered and to analyse these existing barriers which impede a higher percentage of ash recycling. It contributed to outlining possible solutions to overcome these barriers. The stakeholder analysis captured the development of ash recycling in the last years but also tried to make a glimpse into the future.

## **3.3 Tools and methods**

### **3.3.1 Causal loop diagramming**

The CLDs were used to conceptualise the understanding of information assessed in literature. They contributed to assessing the affects Sweden's preconditions have on the development of ash recycling. To draw a CLD, key variables which characterise parts of the study system are connected with each other and causal relationships between them are noted (Appendix IV; Kim, 1992). The relationships of different variables of the bioenergy system and ash recycling were 'causal loop diagrammed' and will be presented in the background section.

### 3.3.2 Calculations for material flow analysis

Information and values of processes related to ash recycling were derived from literature. This was supplemented with one expert interview with a neutral insider, as recommended by Brunner and Rechberger (2003). The neutral insider should be familiar to ash recycling, but not biased regarding other stakeholders. G. Thelin, head of the company EkoBalans, was chosen. This company offers services around analysing nutrients-balances' of forests and developing fertilizing plans, including ash recycling. Both in-depth analyses were built upon this understanding. As there was no detailed data found for only Götaland, data for Sweden as a whole was used. The calculation was conducted using the starting point of 85 000 ha wood fuel extraction and from there on average values were used (Appendix II).

### 3.3.3 Interviews and survey for stakeholder analysis

#### *Sampling*

To conduct a stakeholder analysis the first step is to identify the stakeholders. This was done using the results of the CLDs for indirect stakeholders. Stakeholders, which conduct the processes assessed in the material flow analysis, were considered as direct stakeholders. Then companies or individuals carrying out the identified stakeholder role in Götaland (for example suppliers of wood fuels) were approached. Contact information was accessed through internet presences of the chose companies.

An exception to the spatial boundary of Götaland was made regarding the energy plants, because a geographical trend in distribution of power plants that recycle or not recycle might occur. All bioenergy plants in Sweden chosen according to the selection-scheme (Appendix V) were asked to fill in the survey. To obtain more qualitative data bioenergy plants in Mark, Tranås, Eksjö and Eskilstuna were chosen (Appendix V) and their employees were interviewed.

To fill the stakeholder role of forest owners, the author needed to rely on a sample with contact information provided by two stakeholders, SFA and Askungen Vital. Initially it was thought to interview both forest owners who did and who did not recycle so far, but it proved to be hard to get contact information about forest owners who did not recycle. A biased sampling method could not be avoided and is a limitation of the study.

#### *Survey*

A mainly quantitative survey was used to collect data from bioenergy plants in Sweden (Appendix VI). The survey was analysed according to combination of key variables like fuel use, plant size and recycling or not recycling and the results were graphically visualised. Incorporated in the stakeholder analysis was a survey sent out to 48 energy plants which had a response rate of 44%. Only complete and correct filled in surveys were included. Two responses could not be used.

#### *Interviews*

Data of the other stakeholders was collected through informal semi-structured interviews (Appendix VII). The interviews were carried out face-to-face or via phone and lasted between one and three hours. Only the interviews with forest owners were more structured and shorter; they took 10-20 minutes (Appendix VIII).

### **3.3.4 DPSIR-scheme**

DPSIR is appropriate to evaluate the efficiency of responses (EEA, 1999; Appendix IX) and was used to assess the efficiency of ash recycling to mitigate the potential long-term unsustainability of bioenergy from forest residues. Key variables related to ash recycling were selected, excluding many indirect related factors which were present in the CLDs. Inclusion of all factors which indirectly influence the development of ash recycling was outside the scope of this study. While the CLDs provided the overview about the complexity of bioenergy and ash recycling, the DPSIR was used to condense and to focus on the main factors. The key variables were structured and graphically displayed.

### **3.4 Materials**

The thesis was conducted using both peer reviewed literature and grey literature. Grey literature consisted, mainly, of reports published by the SFA, the SEA, and information of Kunskap Direkt, as service by the Forestry Research Institute of Sweden. In connection to the stakeholder analysis primary data was obtained through interviews and a survey. The information obtained through interviews might be biased, because interviewee is both representative of the company and an individual. Therefore additionally to interviews, published documents and statements on for instance web pages were used to characterise the stakeholder in the best manner. Indirect stakeholders have no direct involvement in the issue but can influence other stakeholders' behaviour regarding ash recycling. Information about them was assessed through published and unpublished literature.

As much of the research was conducted in Swedish, certain language barriers were encountered. This had a minor impact due to patience and the friendliness of Swedish people and the chance to repeat questions. However, to guarantee consistency in translating literature and interviews, translation for key words of this study are included in the Appendix X.

## 4 Background

### 4.1 Energy and bioenergy development in Sweden

In western societies, such as Sweden, economic growth triggers the increased consumption and demand of energy services<sup>5</sup> and thus drives energy generation, including bioenergy generation (Ericsson et al., 2004). Energy-intensive societies are reliant on energy that is cheap enough to allow excessive use. Traditionally the generation of non-renewable energies excludes external costs of degraded environmental services, for example the service of balancing greenhouse gas emissions in the atmosphere (Fig. 3). If degraded services are ignored, environmental problems occur with severe consequences for both ecosystems and human wellbeing (dashed arrow, Fig. 3). To avoid these, the unsustainable energy generation from fossil fuels needs to be mitigated. This drives bioenergy development, which is a climate-neutral alternative if certain criteria<sup>6</sup> are kept.

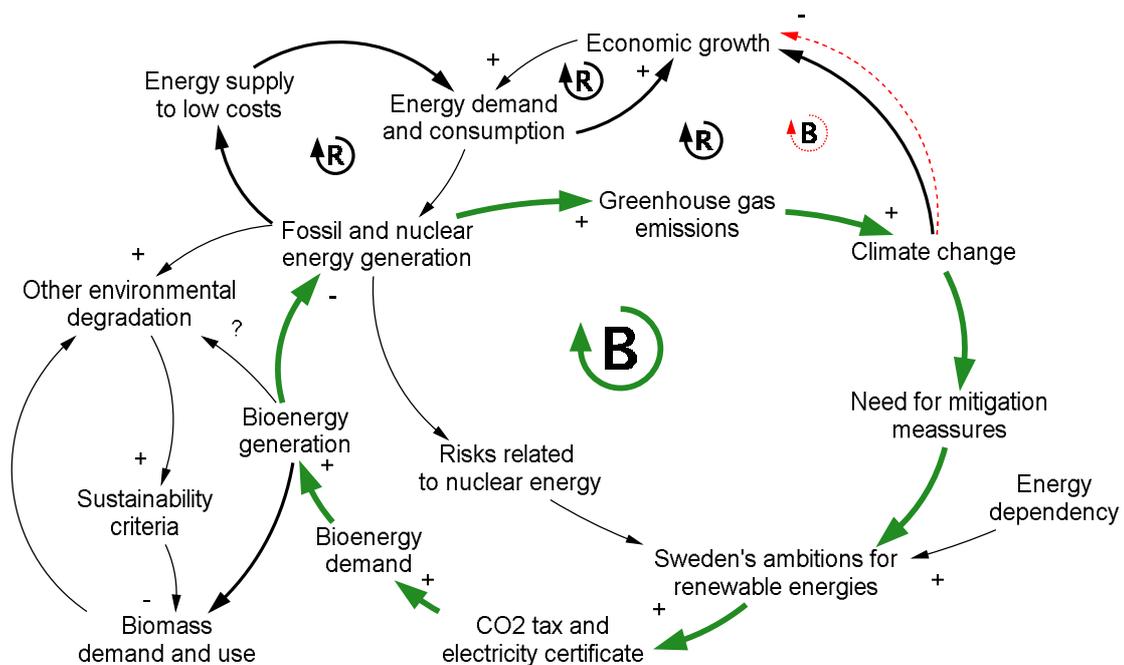


Fig. 3: Simplified CLD depicting relationships of economic growth, energy demand, climate change, bioenergy and the demand for biomass. If a biomass producing system has negative impacts is context dependent and therefore the uncertainty of the relationship is indicated using a question mark (?). See appendix XII for complex version.

<sup>5</sup> This includes power, heat, transport and energy for production, storage and transportation of goods.

<sup>6</sup> The EU criteria for biofuels require that maximal 35% of contained energy is used during the bioenergy producing process. If bioenergy is sustainable and a green alternative to fossil fuelled energy is dependent on the biomass providing system and its management. Sustainability criteria have to regulate the biomass systems to avoid reverse effects on ecosystems and climate system (Danielsen et al., 2008).

The increased use of renewable energies, including bioenergy, is an essential goal of both the European and also Swedish energy policies. Sweden is attempting to reach this goal by implementing a CO<sub>2</sub> tax and green electricity certificates.

In 1991, a CO<sub>2</sub> tax was established in Sweden, which excluded the industrial and electricity production sector. It mainly had an impact on the district heating sector (Johansson, 2000) (Fig. 4). The development of the district heating sector in the last 25 to 30 years is characterised by a fast and continuously increasing share of bioenergy in response to the CO<sub>2</sub> tax. Eighty percent of district heating in 2008 is provided through bioenergy (Fig. 4).

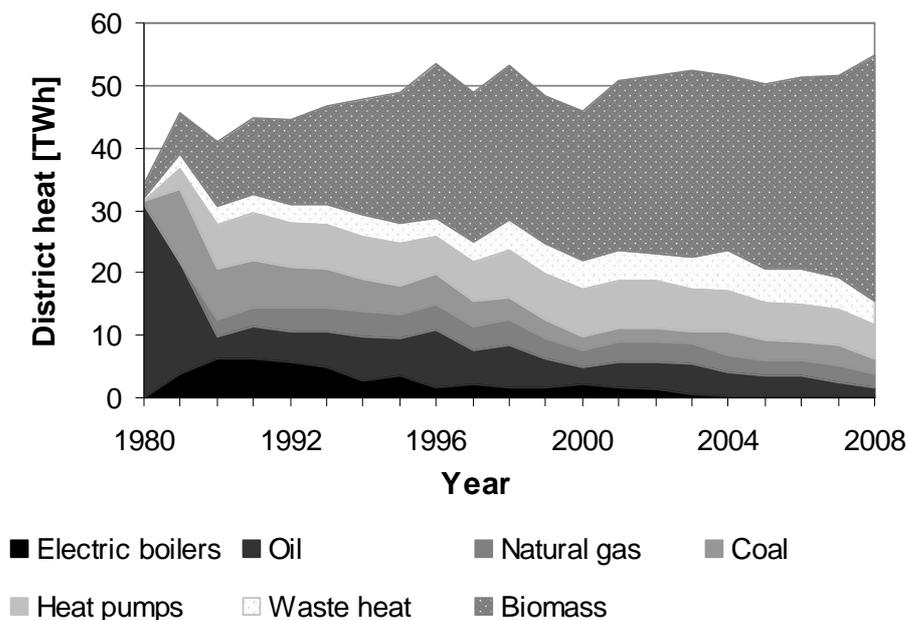


Fig. 4: Energy carriers for heat generation in Sweden, 1980 to 2008 (Data: SEA, 2009).

The electricity certificate was introduced in Sweden in 2003 to increase the share of renewable energies within other energy sectors than the district heating sector (Rättsnätet I, 2003). The scheme aims to lower the transition costs for energy plants to change to renewable energy sources and helps to establish these on the market. The scheme obligates electricity retailers to buy the certificates from bioenergy plants which in turn are certified if their energy generation complies with the law (Rättsnätet II, 2003). A trend of increasing bioenergy share in electricity generation after 2003 is observable (Fig. 5; Hansen et al., 2006). In 2008, 9% of total electricity in Sweden was generated from biomass (SEA, 2009).

The Swedish Government also emphasises bioenergy development as a replacement for nuclear energy, and in order for Sweden to become energy independent (Björheden, 2006). However, for the last 25 years, nuclear power has provided around half of Sweden's electricity (Fig. 5). An additional advantage of biomass for energy generation is that it can be stored and energy can be generated when needed. Therefore, it is a suitable replacement for fossil fuels, which have the same storage advantage (Hall and Scrase, 1998). In Fig. 5 (and even Fig. 4) it can be seen that bioenergy is mostly in competition with fossil fuels, partly for that reason.

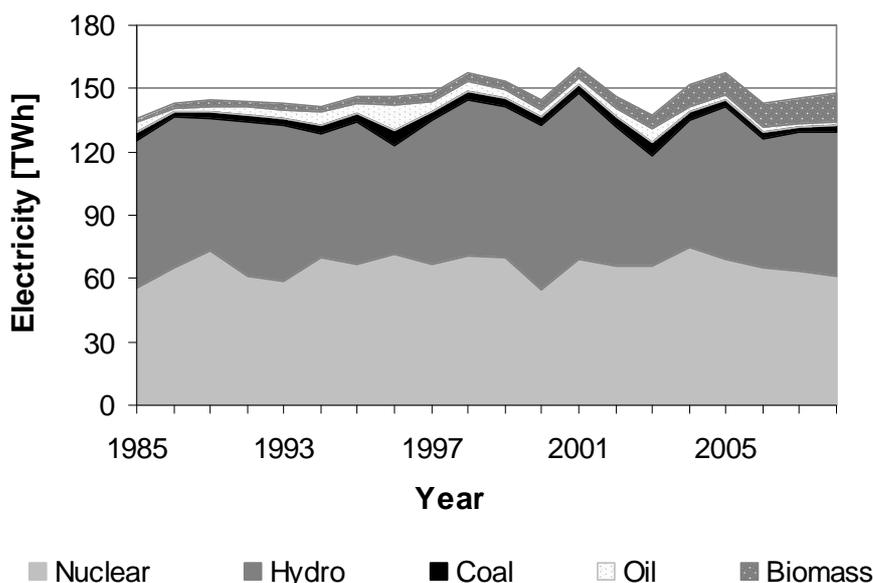


Fig. 5: Energy carriers for electricity generation in Sweden, 1985 to 2008 (Data: SEA, 2009).

The third important energy sector, industry, is traditionally strongly related to forestry and always produced a high percentage of its energy from forest related biomass. In the last 25 years, 40 to 55 TWh bioenergy were produced annually from biomass (SEA, 2009).

Access to biomass in Sweden is high, and the prices for wood fuel were, in recent years, relatively low and stable in comparison with fluctuating oil prices (Andersson, 2008). With increasing oil prices in the 1970s, the use of wood fuels for energy generation became more favourable (Ericsson et al., 2004), and due to CO<sub>2</sub> taxations and the electricity scheme the generation of bioenergy from wood fuels is now sufficiently competitive on the market (McCormick, 2005).

For all these reasons, bioenergy development is further emphasised by the Swedish government (Swedish Government, 2009). In 2009, bioenergy contributed 31% to Sweden's total energy consumption of 364 TWh (Svebio, 2010). Almost 90% of bioenergy is generated from forest biomass (Svebio, 2008; Bioenergiportalen, 2009). The current bioenergy generation in all sectors decreases the energy generation from non-renewable sources and closes the balanced loop and thus mitigates climate change (Fig. 3, thick grey loop). However, it increases the demand for biomass.

## 4.2 Forestry and forest biomass supply in Sweden

From Sweden's total land area of almost 45 Mio ha, around 27.5 Mio ha (67%) is forested (Röser et al., 2008), whereas 51% are productive forest (SFA I, 2010). Eighty-five percent of the Swedish forest is coniferous forest, which has a life cycle from 50 to 100 years (SFA I, 2010). The forests are mostly managed according to the principles of silviculture (Appendix XI). Forestry and related wood industries stand for 25-30% of Sweden's industry (Björheden, 2006). They are an important economic sector in Sweden, contributing 4% of GNP and 15% value of export (ibid).

The rising bioenergy market was initially seen as a competitive threat to the forest industry, especially for the pulp and paper industries (Björheden, 2006), but it proved to be vital for forest industries because utilisation of its by-products is an important income (Kåberger, 2004). The extraction of primary forest residues is not very economical, but is generally supported for environmental reasons and the advantages for following silvicultural measures (Stupak et al., 2007).

Both by-products from saw-mill industries, for example, and residues from felling, are wood fuels which are categorised in Sweden according to Fig. 6. Wood fuels contribute to more than 50% of the bioenergy production. Another 40% are generated from black liquor, a waste product from the pulp and paper industry. The remaining 10% are produced from other biofuels like waste, peat and agricultural fuels (Bioenergiportalen, 2009).

The development of the forest industry and the wood fuel market is driven by other factors like international demand and trade for Swedish wood products, but the detailed analysis of these factors goes beyond the scope of the study.

If the extraction of forest residues is economically viable is influenced by the use of secondary forest residues. These are cheaper because they do not need to be extracted with additional cost (Ericsson et al., 2004, Appendix XII). Primary residues for wood fuels consist mostly of logging residues from final cuttings but there is growing interest in the extraction of stumps (Röser et al., 2008).

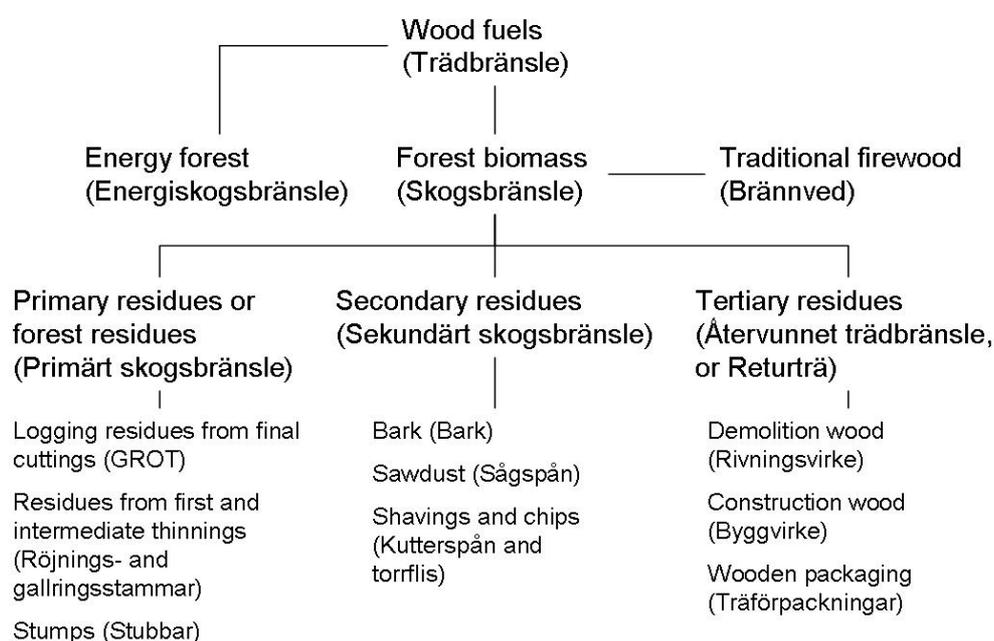


Fig. 6: Classification of wood fuels in Sweden, see brackets for according Swedish terms. For ash recycling all forest biomass except tertiary residues produces suitable ash. Ash from energy forest is mostly suitable, if the Cadmium content is not too high (Based on: SFA, 2009; Röser et al., 2008).

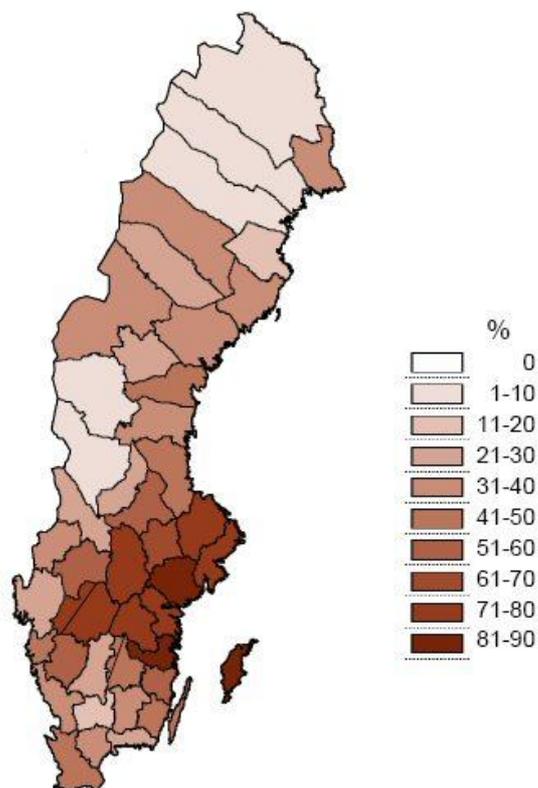


Fig. 7: Reported extraction of forest residues in 2008 (Kunskap Direkt III, 2009).

In Sweden, the harvesting of forest residues is regulated by the Swedish Forestry Act, which obliges forest owners to inform the SFA if extraction from final fellings or additional thinnings is planned (Stupak et al., 2008). In 2008, extraction of forest residues was registered on 85 000 ha, accounting for 41% of all final felling areas (Kunskap Direkt III, 2009; Fig. 7).

In Sweden, biodiversity is protected through the regulation that extraction of forest biomass for energy purposes should not occur in key biodiversity biotopes. In every extraction area 20% of forest residues are recommended to be left to preserve habitats and niches (SFA I, 2008). It is recommended to leave forest residues for one year to ensure that needles fall to the ground. The needles should be evenly spread afterwards. However, this proved to be impracticable (Röser et al., 2008).

In Sweden there is no sustainability criteria regulating the wood fuel extraction, instead wood fuel extraction is part of forest management and sustainability criteria from FSC, for example, can be applied on a voluntary basis (Stupak et al., 2007).

The forest residues of 85 000 ha equal 9.6-16 TWh, depending on the forest's yield power, if 80% of logging residues from final fellings is extracted<sup>7</sup>. This is, however, only a small percentage of wood fuels, in respect to both the current use (56 TWh, including other wood fuels) and their potential. It is estimated that forest biomass, particularly forest residues have the highest potential to contribute to bioenergy production in the future (Ericsson et al., 2004; Svebio, 2008). Studies, with different ecological, economical and technological criteria, estimate the annual wood fuel potential in Sweden between 91.1 and 190 TWh (Svebio, 2008; Hagström, 2006; Ericsson and Nilsson, 2006). Studies on a European level argue that bioenergy from forest biomass can make an essential contribution to reach the renewable energy target and due to its geography Sweden, along with Finland, holds the highest potential (Röser et al., 2008; EEA, 2006). The EEA (2006) limits Sweden's forest biomass potential due to the risk of nutrient imbalance and acidification. If fertilizing or ash recycling were to be carried out, much of Sweden's forest would be classified as highly suitable areas for wood fuel extraction (EEA, 2006). This stands in contrast to most Swedish studies, where the potential is calculated based on the underlying assumption that ash is recycled (Svebio, 2008).

<sup>7</sup>Excluding stumps, calculated using conversion factors see Appendix II.



This decreases the forest's potential to mitigate climate change firstly indirectly through less available biomass for bioenergy generation and thus less replacement of fossil fuels and secondly directly through less CO<sub>2</sub> uptake through the forest (Fig. 8).

Naturally the residues would decay and add to the forest's nutrients pool. The need to add the nutrients back to the forest in form of ash is especially high, if needles are not left at the extraction site. This is because needles contain seven times more nutrients than stem wood (Röser et al., 2008). Ash recycling closes the loop in the production of bioenergy because the nutrients and base cations extracted with wood fuels are brought back to the forest in the form of ash. This implies the nutrient status of the forest is balanced which ensures long term sustainable yields. Soil acidification is mitigated which is important for bordering water bodies, biodiversity and forest health (Fig. 8, black thick loop). Accumulation of ash on landfills is avoided and waste is reduced.

Recycling of ash from bioenergy generation back to the forest is not a new concept. In Finland in the 1930s, first trials to recycle ash were carried out, mainly to increase tree growth on nutrient poor peat soils (Vesterinen, 2003). In Sweden, the variations of soil types and forest types differ from Finland and ash recycling is regarded as an ecological compensatory fertilisation measure. In the end of the 90s the SFA recommended ash recycling at the first time but the implementation rate was low (SFA II, 2010). After a number of studies which identified missing know-how and regulations about ash recycling (Bohlin and Mårtensson, 2004), an EU financed research program 'RecAsh' was carried out and finished in 2006. It resulted in a comprehensive information wave and new recommendation guidelines about ash recycling (SFA II, 2010). In the same year the Swedish Forest Agency estimated that out of 300 000 ton wood ash 15 000 ton, equal to 5%, was being recycled (Emilsson, 2006). In 2010, the SFA aims to recycle ash in all areas where forest residues were or will be extracted (ibid).

## 5 Analysis and results

### 5.1 Results of the material flow analysis

The material flow analysis aimed to analyse how much ash there is, how much ash potentially could be used for ash recycling and how much ash would be needed if the SFA’s recommendations are followed.

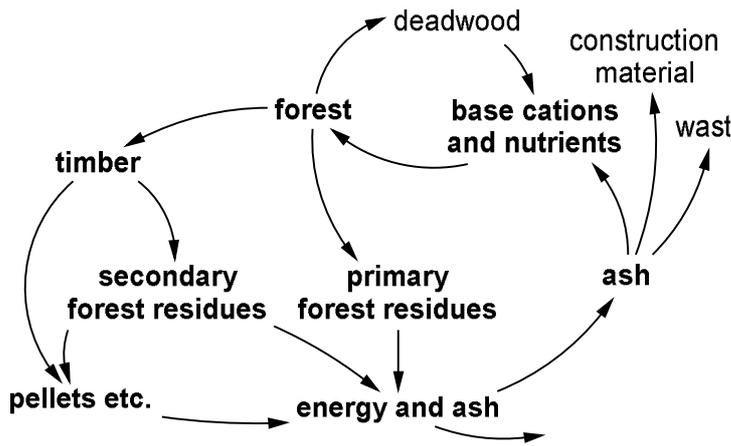


Fig. 9: Qualitative description of material flow, including the natural cycle of deadwood decomposition (output and inputs grey).

The material flow, here including secondary residues is depicted in a qualitative manner in Fig. 9.

Energy is marked as grey because it leaves the system, as are the pathways for ash when they become construction material or waste. Fig. 10 displays the scope and results of the quantitative analysis, where the system boundary (dashed line) was drawn around materials flow cycle for primary forest residues, excluding other uses of ash than recycling.

Fig. 10 is more detailed in terms of how each material is transformed through a process, for instance forest is transformed to primary forest residues by extraction.

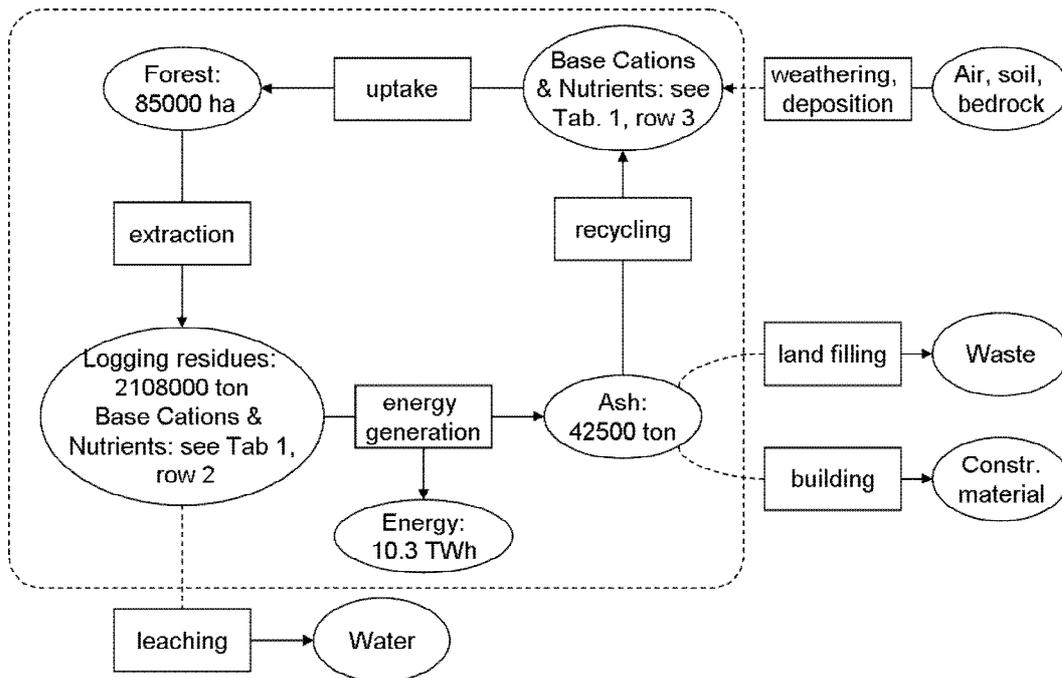


Fig. 10: Material flow analysis for extraction area in 2008, assuming mixed forest (pine and coniferous), average forest yield power and low ash content.

The material flow analysis shows that the generation of 10.32 TWh results in approximately 42500 ton DM (Dry Matter) ash, which distributed over 85 000 ha would be 0.5 ton DM ash per hectare. The corresponding nutrients and base cations values are listed in Tab. 1. SFA's recommendation for ash recycling for forest with the assumed forest yield power is on the borderline between 2 and 3 ton hardened DM ash per ha.

*Tab. 1: Nutrient content of extracted stemwood and logging residues, of recommended dose.*

Macro-nutrients:	Nutrients Stemwood and logging residues [kg ha <sup>-1</sup> ]*	Nutrient content ash dose 0.5 kg [kg 2 ton <sup>-1</sup> ]	Nutrient content ash dose 2 kg [kg 2 ton <sup>-1</sup> ]	Nutrient content ash dose 3 kg [kg 3 ton <sup>-1</sup> ]
Calcium	379	> 62.5	> 250	> 375
Magnesium	61	> 7.5	> 30	> 45
Potassium	241	> 15	> 60	> 90
Phosphorous	54	> 3.5	> 14	> 21
Nitrogen	469	-	-	-
Micro-nutrients:	g ton <sup>-1</sup>	g ton <sup>-1</sup>	g ton <sup>-1</sup>	g ton <sup>-1</sup>
Boron	no data	< 400	< 1600	< 2400
Copper	no data	< 200	< 800	< 1200

\* Calculated with Snurran (Jacobson and Mattson, 1998), using same values as for the other calculations (see Appendix II).

As Fig. 10 indicates the forest's nutrient pool is not steady, but characterised through flowing processes like leakage, deposition and weathering. These flows are essential when estimating if nutrients imbalance occurs, but the calculation of these processes is beyond the scope of this study. The Swedish study by Akselsson et al. (2007) shows that, especially if whole tree harvesting is applied, negative nutrient balance occurs. For example, in 74% of spruce forests a net loss of more than 4 kg ha<sup>-1</sup> y<sup>-1</sup> Calcium was estimated. It is estimated that whole-tree harvesting results in yearly losses of Calcium, Magnesium, Potassium of 5%, 8% and 3% of the whole nutrient pool, which leads to very low base saturation of the soil and long-term unsustainability of the forest (Akselsson et al., 2007).

Generally the latest report of the SFA states that a dose of 2 ton hardened DM ash is sufficient to compensate for nutrient loss. On the other hand, ash needs only be recycled if the export of logging residues results in more than 0.5 ton DM ash. Thus in the theoretical, simplified example above, ash recycling would not be necessary if following the recommendations, but nutrient imbalance would occur nevertheless. In reality there is much variety in forest yield power, depending on species assemblage, soil, climate, and forest management. However, the extraction of wood fuels mainly occurs on productive land with higher forest yield power (Emilsson, 2006), resulting in a clear need for compensation with ash recycling.

It can be concluded that the need for ash recycling is high in most Swedish forest if considerable amount of forest residues are extracted additionally to stemwood harvest. However, the primary residues of the forest may produce, for example, 0.9 ton DM ash ha<sup>-1</sup> while the compensation dose is 3 ton hardened DM ash ha<sup>-1</sup>. The material flow analysis shows that recycling of ashes cannot focus only on ash generated from primary residues. Published numbers of how much ash is recycled and could be recycled affirm that other wood fuels are considered for ash recycling as well. In 2006, the SFA estimated that 800 000 ton ash are produced yearly, of which 300 000 ash are suitable to recycle (Emilsson, 2006). According to the SFA's criteria all ash are suitable which pass the minimum and maximum thresholds of certain elements, without regard to the actual source of the ash. This supports that ash from other wood fuels should be recycled as well. In comparison to another study, which assessed ash quantities in Sweden in 2006, it shows that all biomass in Sweden is producing around 140 000 ton ash (Engfeldt, 2007). Biomass used in pulp and paper industry produces a further 141 000 ton (including green sludge), and wood fuel combusted with peat produces almost 80 000 ton. This results in 360 000 ton assumed suitable ash from forest biomass. Finally, the study results show that almost 28 000 ton of ash are recycled to the forest (Engfeldt, 2007). These numbers are slightly different in comparison to numbers of the SFA, which might be due to different methods of obtaining data, different conversion factors during calculation of dry matter and different classification of which ash are suitable. However, both sources point to a low percentage recycled in 2006 (5% vs. 7.7%).

It was reported by the SFA that in 2009 approximately 30 000 ton ash was recycled, which equals 10% (Andersson, 2010). The 10% are based on the total amount of 300 000 ton in 2006, and one could wonder if the ash amount should not increase with the increasing bioenergy generation from forest biomass.

## 5.2 Ash recycling: a balancing act between two industries

The organisational structures of the energy and forest industry in Sweden are preconditions that influence the development of ash recycling. Forestry and energy industry have different management frameworks, which include definitions, planning horizons, certification standards and sustainability criteria. The forestry's planning horizon lies in the range of hundred years, due to the long rotation cycles in cold climates. The bioenergy plants, by contrast, are dependent on, and must adapt to, the steady development of the fuel market. They have a planning horizon ranging from a few months up to several years (Pedersen and Pedersen, 2010). Forest owners, for instance, need to recycle ash in their forest once (maximum twice) per rotation time, while the bioenergy plants need to dispose of ash annually.

Both industries also have their own agencies with which they cooperate, but ash recycling is connected to both. Both the SFA and the SEA support research regarding ash recycling and are in information exchange, but hesitate to implement a binding measurement (see subsections 5.8 and 6.4). A further difference between forestry and energy industry is the almost even distribution of forest and forestry versus the uneven distribution of energy demand and energy plants in Sweden. These differences complicate the process of ash recycling.

### 5.3 Geographical trend of ash recycling: reasons and implications

Sweden' geography showed to be another influential precondition for the development of ash recycling. The interview with the SFA indicated that the main part of ash was recycled in southern Sweden (Andersson, 2010), which the stakeholder analysis with its survey to bioenergy plants affirms (Fig. 11). Around and north of Stockholm recycling of ash was not reported, despite the fact that these regions record the highest extraction rates for forest residues and the need for ash recycling as compensation is especially high (Fig. 7).

The geographical distribution shows a higher density of recycling bioenergy plants in south-western Götaland which has several reasons and implications. One possible reason is the increased need to mitigate acidification in south-western Götaland. This is due to higher precipitation rates, higher weathering rates and past larger depositions of sulphuric acid (Aksellson, 2006).

Another, not negligible reason is that the company Askungen Vital AB is situated in Götaland, which pushed the development of ash recycling with much effort in the last years (Pedersen and Pedersen, 2010). Askungen Vital takes the stance that if Sweden wants to reach its goals of 50% renewable energies, bioenergy will need to contribute significantly, which increases the pressure on the forest and thus makes ash recycling inevitable.



Fig. 11: Geographical distribution of wood fuel fired heat and power plants that responded the survey. Black arrows indicate no recycling of ash, grey arrows indicate partial recycling of ash and white arrows indicate recycling of ash.

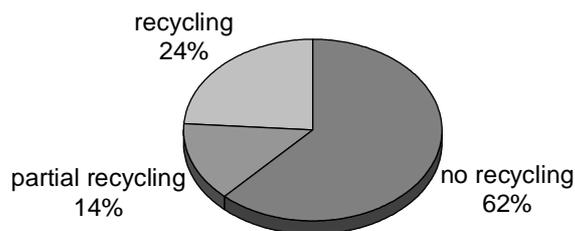
The SFA reported that forest owners in Götaland are less resistant to the idea of ash recycling due to information efforts of the SFA (Andersson, 2010). In Götaland, ash recycling has positive effects, partly even connected with additional growth, while in northern Sweden due to nitrogen inefficiency an initial decrease in growth can occur. This can explain why forest owners' attitudes northern Sweden are more negative than in Götaland.

Ash recycling is easier to carry out in Götaland because distances between forests and bioenergy plants are shorter. Ash is transported shorter distances than forest residues (50-70 respectively 100 km) because ash is more concentrated in comparison to forest residues (Möller Pedersen, 2010). The uneven geographical distribution of ash recycling results in different barriers and needs on how to increase ash recycling in different parts of Sweden. This aspect needs to be incorporated if solutions to increase the amount of ash recycling are proposed.

#### 5.4 Incentives for ash recycling

Before presenting barriers for ash recycling, the existing incentives are examined. The conceptualisation of ash recycling and the related energy and forestry sectors showed that direct driving forces for ash recycling are missing. Other than moral incentives related to environmental consciousness and 'closing-the-loop thinking' are not present. It could not be observed in literature or in interviews that forest owners claimed the ash as their property or took action to get the nutrients as ash back to the forest, although that would ensure the long-term sustainability of their forests. There is no economic incentive to recycle ash for forest owners. This was an incentive earlier, when ash recycling was conducted in connection to liming. Liming was done to mitigate acidification and subsidised. However, the subsidies were frozen in the 90s (Pedersen and Pedersen, 2010). The SFA recommends compensating all areas with ash recycling where forest residues were extracted, but no binding measures for ash recycling are present. Bioenergy plants derive no direct advantage from applying ash recycling. They have the responsibility to take care of the ash, but they gain no direct benefits of recycling the ash to the forest. By contrast, ash recycling often has higher costs in comparison to other uses. Currently moral or environmental conscious concerns are certainly incentives, but not influential on ash recycling because currently bioenergy plants own the ash and thus have the decision powers on what to do with the ash.

#### 5.5 Barriers to ash recycling for bioenergy plants



From the responding bioenergy plants, five plants recycle completely, three recycle partly and 13 do not recycle (Fig. 12). The bioenergy plants' size proved to be a variable which determined if ash recycling was carried out or not; see Fig. 13 for heat generation and Fig. 14 for power generation.

Fig. 12: Percentages of bioenergy plants, who recycle (light grey), partly recycle (grey) and not recycle (dark grey).

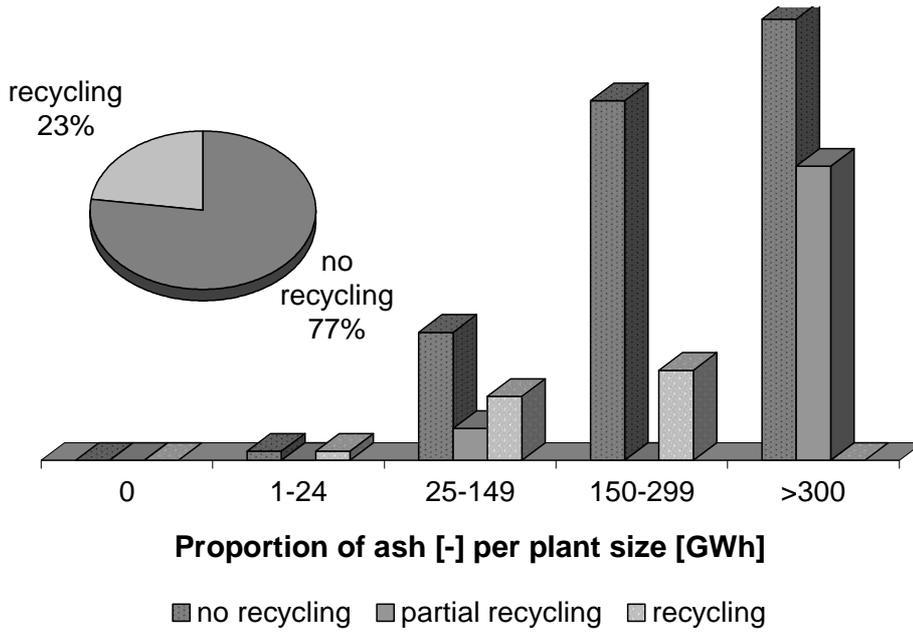


Fig. 13: Proportions of ash recycled from district heat production depending on plant size.

The pie-diagrams in Fig. 13 and Fig. 14 show that the percentages of ash recycled equals 23% for heat and 18% for power generation. It was assumed that partial recycling contributes equally to recycling and no recycling. This is above the estimated percentage for ash recycling in 2009 (10%), but one should not forget that bioenergy plants related to pulp and paper industry or saw-mill category were not included in the study, but were reported to recycle less (Thelin, 2010).

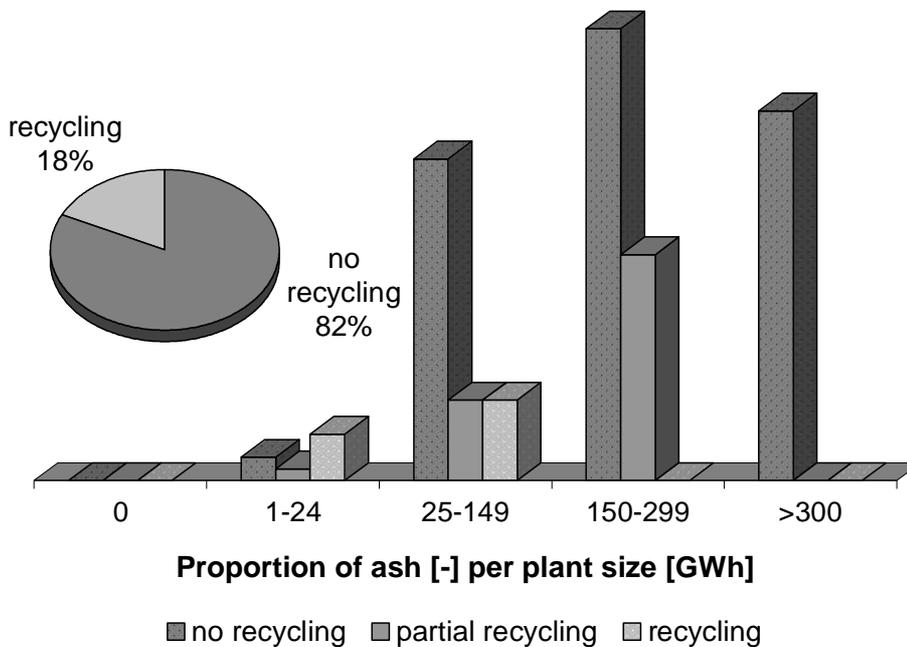


Fig. 14: Proportions of ash recycled from power generation depending on plant size.

The depicted proportions of recycled ash<sup>8</sup> show that most ash is recycled by medium size bioenergy plants. District heat plants recycled more if they were larger in medium production size in comparison to cogeneration plants. This can be explained by the fact that relatively more biomass is needed to generate electricity than heat that often is a by-product.

The kind of wood fuel or wood fuel combination used was considered as another determining factor of whether ash recycling was carried out or not, as the literature commonly reported a connection between logging residues and ash recycling. Logging residues showed to be the most frequently used source of forest biomass for all three options (recycling, partial recycling, and no recycling). Most ash which was recycled stemmed from logging residues, or other primary and secondary forest residues (Fig. 15).

Waste, peat and especially recycled wood, proved to be factors determining why ash was not recycled, as ash from these biomasses does not meet SFA’s recommended values regarding certain elements and heavy metals.

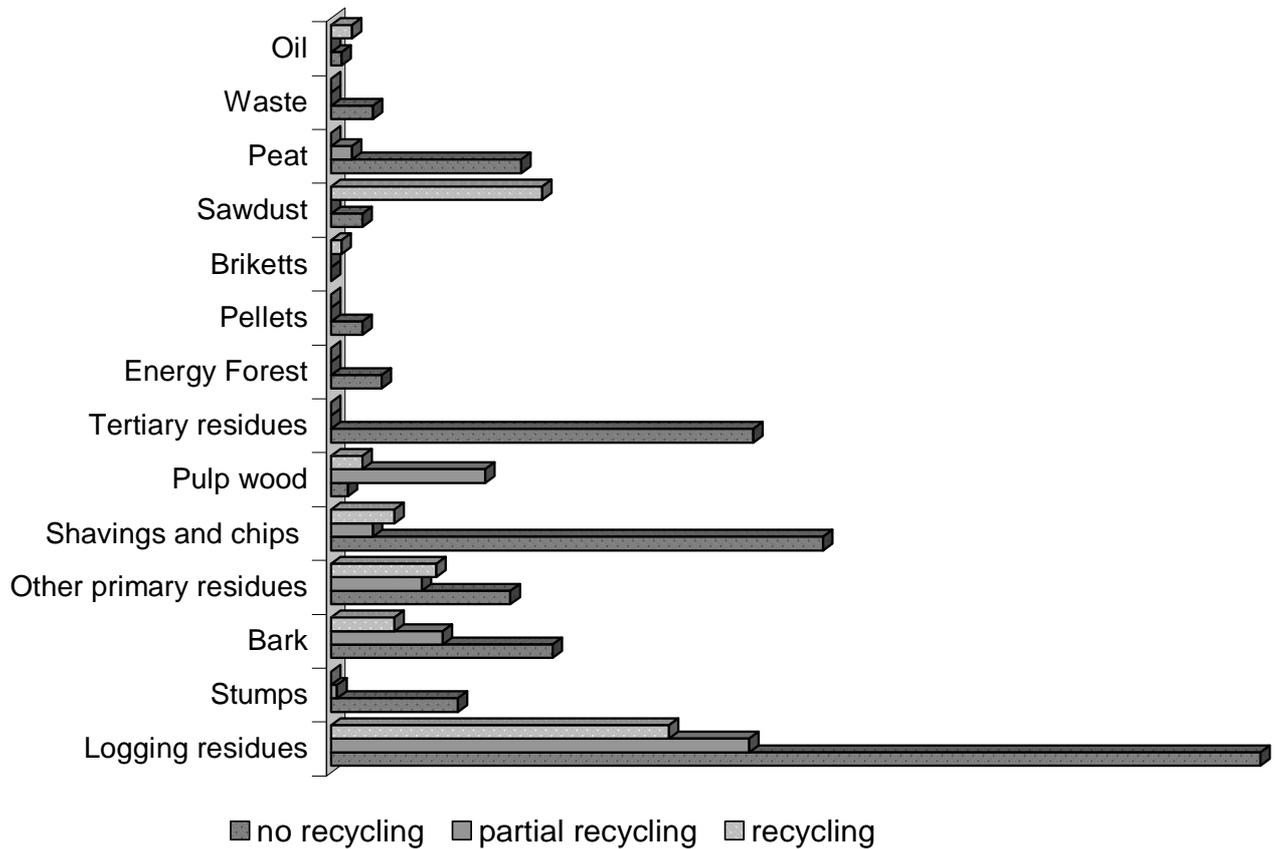


Fig. 15: Summarised proportions of used bio fuels without differentiating power and heat production nor plant size.

<sup>8</sup> The proportions of ash were estimated through assuming average plant size in each category and summarising the ash amounts in each category for all three options (recycling, partly recycling, and no recycling). Because bioenergy plants who partly recycle contribute to both ash which is recycled and ash which is not recycled, the pie diagrams in Fig. 13 and Fig. 14 represent the percentages of ash recycled and not recycled, assuming that the contribution is equal to both.

Suitable forest biomasses showed to be often combined with other non-suitable fuel sources. Up to 5% of oil in the fuel mix is common to enhance the burning process and does not influence the ash's quality adequately to be unsuitable for recycling (Pedersen and Pedersen, 2010). The combination of, for example, 80% logging residues with 20% waste makes a major proportion of ash unsuitable for recycling, which is a technical barrier to ash recycling. Of the bioenergy plants which do not recycle, six (out of 13) use a fuel combination, which includes a share (5% to 75%) of recycled wood fuel or waste. The ash from all other non-recycling bioenergy plants is not mixed with other ash and could be recycled without additional effort.

The survey showed that bioenergy plants recycle ash to support environmental development, as compensation for nutrient export and ecological loop thinking. In some cases it was reported that ash recycling is more expensive in comparison to other uses of ash but seen as a moral responsibility towards the environment. The bioenergy plants that were interviewed in more detail mentioned, in addition to the reasons stated above, that the County Administrative Board's recommendations to use the ash for a good purpose triggered their decision to recycle the ash (Bioenergy plant in Mark). It was found to have a high value to use the ash for some purpose instead of sending it to the landfill, without giving the use 'ash recycling' a high priority from the company's perspective (although some interviewees mentioned that they personally would prefer ash recycling).

It was reported that municipalities approached the bioenergy plants to get the ash for covering of landfills, which is an economically convenient solution. This was also the case for the larger bioenergy plant in Eskilstuna that is owned by the municipality, which also owns the local landfill and sewage plant. Despite having a high quality ash (100% use of logging residues) the ash is used to stabilise the sewage sludge and this mixture is used to cover the landfill. It is not seen that this will end in the near future because it was emphasised that it is a very big landfill. Furthermore the sewage sludge needs to be stored somehow and somewhere.

One reason for the normal (Gaussian) distribution of ash recycling by size of bioenergy plants (see Fig. 13 and Fig. 14) was reported by a rather small district heating plant (Eksjö and Neova): the amount of ash generated during combustion is not worth the effort of ash recycling, despite the plant owners being interested and even having contact with recycling companies. For larger power plants the fact that ash is not recycled can be explained due to the lack of binding measures and the economic disadvantage of ash recycling. Medium-sized plants are often owned by municipalities and they tried to use ash in the best way. This implies that, if more economically-preferable options to ash recycling are not present, ash recycling is increasingly supported.

Other stakeholders observed that bioenergy plants started to consider ash recycling as a more serious alternative to other uses for ash (Pedersen and Pedersen, 2010). It was confirmed that municipalities often have plans to recycle ash from district heating plants, while it is a more difficult challenge to convince large power plants and industry to recycle ash as there is no pressure and no interest in ash recycling (Andersson, 2010, Pedersen and Pedersen, 2010).

## 5.6 Barriers to ash recycling: Results for other stakeholders

Bioenergy plants have a high decision power on what is going to happen to the ash, but a rather small interest in the use of ash for compensating negative effects of wood fuel extraction in the forest. This power–interest constellation for other stakeholders is displayed in Tab. 2.

Tab. 2: Characteristics of different stakeholders in respect to ash recycling, arrows indicate to which characteristics the stakeholders would ideally develop (issue = ash recycling).

Stakeholder		Characteristics				
		Involvement in the issue	Interest	Power	Position	Impact*
Forest Owners	Private	Own forest where the ash is to be spread.	medium → high	low → high	passive → active	high
	Association: Södra**	Could support private forest owners to become active by informing and organising them in interest groups.	high	low	passive → active	low
	State: Sveaskog	Owns forest and spreads the ash in them.	high	high	active	high
Suppliers	Sveaskog	Harvests forest biomass and sells to bioenergy plants. Exports nutrients.	high	high	active	high
	Neova	Harvests forest biomass and sells to bioenergy plants and other users. Export nutrients.	medium → high	low → high	passive → active	low
Bioenergy plants	Eksjö	Produces and owns ash, gives it to municipality to cover a landfill.	high	medium → high	passive → active	low
	Tranås	Produces and owns ash, partly recycles it.	medium → high	high	half active → active	low
	Mark	Produces and owns ash, gives it to Askungen Vital.	high	high	active	low
	Eskilstuna	Produces and owns ash, mixes it with sewage sludge and covers own landfill.	medium → high	high	passive → active	low (in short-term), then high

Tab.2 continued: Characteristics of different stakeholders in respect to ash recycling.

<b>Recycling companies</b>	Sveaskog	Recycles the ash from bioenergy plants which they supplied with forest biomass.	high	high	active	high
	Askungen Vital AB	Recycles ash from bioenergy plants, organises hardening, spreading and all related tasks.	high	low	active	low
<b>State Agencies</b>	SFA	Controls that ash recycling is done in an appropriate manner, organises where ash should be spread.	high	low → high	half active → active	medium → high
	SEA**	Distributes green e-certificates; is responsible for sustainability of energy.	medium → high	low → high	passive → active	medium → high
<b>Researchers</b>	Skog Forsk**	Researches ash recycling, especially long term effects.	high	low	half active	low
	Värmeforsk**	Researches all different kinds of ash use, including ash recycling.	medium → high	low	half active	low
<b>NGOs</b>	Naturskydds-föreningen**	Distributes the certificate 'Bra miljöval' (Good Environmental Choice), includes ash recycling.	high	low	active	low

\* Impact of the issue on the stakeholder.

\*\* Indirect stakeholders.

As Tab. 2 shows, there is an imbalance between the distribution of power and interest. Stakeholders who have a high interest in ash recycling, like SFA and forest owners, have low power regarding the decision of what happens with the ash. Stakeholders with a high power to decide on the use of ash, for instance bioenergy plants, have a comparatively low interest in recycling. At the same time, the bioenergy plants do not feel any impact in the short-term if ash recycling is done or not.

It is revealed from Tab. 2 that many stakeholders are involved, and this list already represents a condensed stakeholder selection. The full range of stakeholders is presented in Fig. 16.

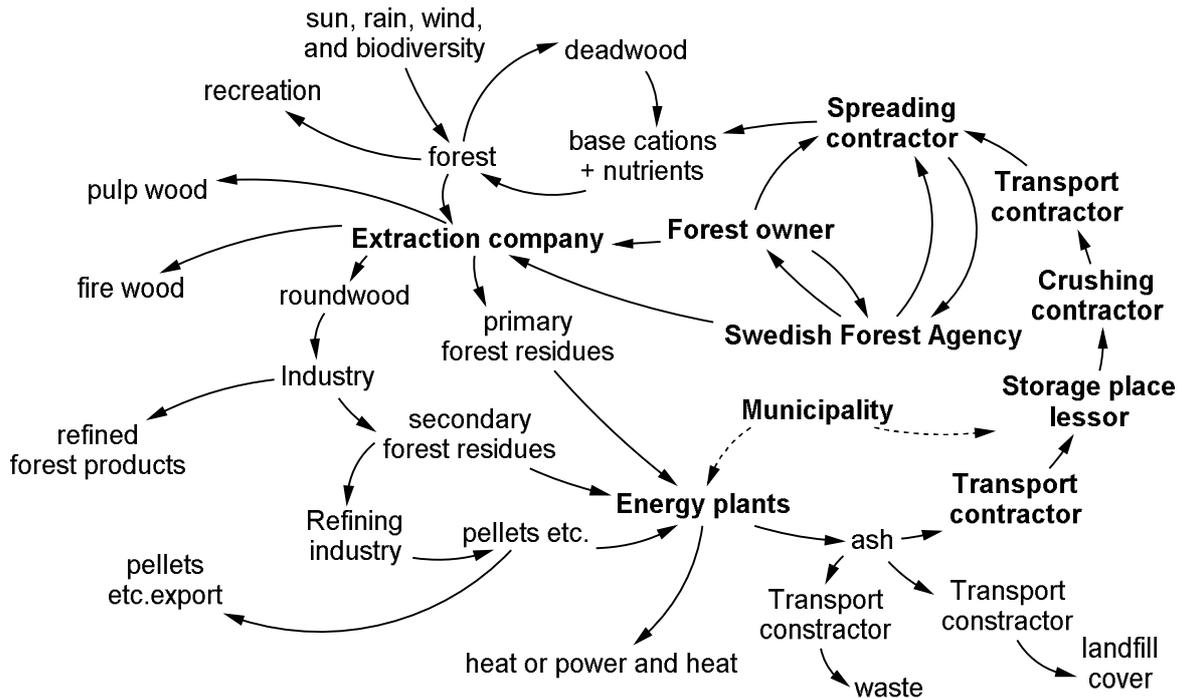


Fig. 16: Conceptualisation of stakeholders (Capital letter, black thick directly related to ash recycling, grey without the system) which are responsible for the material flow (black within the system, grey input or output of the system).

In this study, all processes related to ash recycling, for example transport, crushing and spreading, are carried out by one stakeholder. Askungen Vital AB and Sveaskog, which operate mainly in Götaland were selected (Fig. 17). Although these companies fulfil the same task; the main difference is that Sveaskog is state-owned, owns forest and carries out all tasks related to forest management, which has several implications (chapter 5.7).

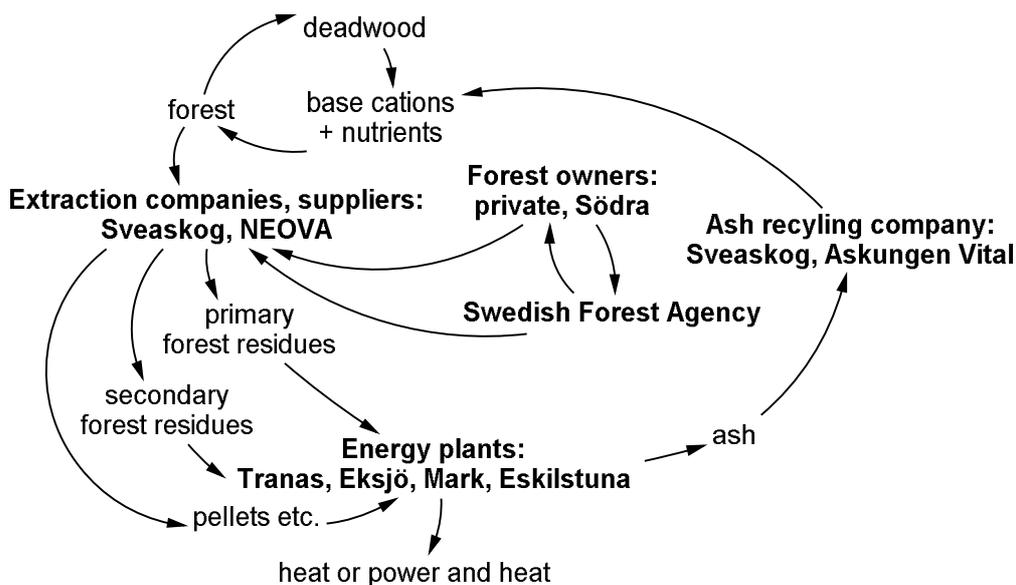


Fig. 17: Simplified conceptualisation of processes related to ash recycling including the identified direct and indirect (black thick, Capital letter) stakeholders in Götaland.

Because ash recycling consists of many processes and connects two industries it is related to a high degree of organisational and administrative work (Pedersen and Pedersen 2010; Runestad, 2010). Where a company providing this service is not present, this is a key barrier to ash recycling, as for example in the region around Stockholm (Andersson, 2010). Due to high population density and high energy demand in the Stockholm region, the most logging residues are extracted here (Fig. 7), but ash recycling is not common due to lack of entrepreneurship (Andersson, 2010). The lack of companies also decreases the competition for companies, which was seen as a reason why ash recycling is expensive and not necessarily competitive with other uses for ash (Runestad, 2010).

If no companies are available, or ash recycling is not economically viable, ash is used for other purposes. It was reported that the demand for ash is currently higher than the supply (Andersson, 2010), but the stakeholders had very different perspectives on competition's implications for ash recycling in the future. Some stakeholders acknowledged the current high competition for ash, but were very confident that covering from landfills will end latest in 2015 and that competition will decrease afterwards (SFA: Andersson, 2010; Södra: Gustafsson, 2010). Other stakeholders were less optimistic and reported that there are no regulations regarding thickness of final covers and that there are landfills with an operating-permission until 2028, concluding that the competition from final covering of landfills will not end soon (Pedersen and Pedersen, 2010). The competition with construction of roads is not time-restricted. Other competitive uses for ash include, for instance, use in agriculture or producing soil.

Another barrier reported from several stakeholders is the problem of finding forest owners that want to have ash recycled in their forest (Neova, Askungen Vital). On the other hand, SFA assumes that today every forest owner who extracts wood fuel would like to recycle ash. Initial scepticism in Götaland was overcome by a change in attitude towards ash recycling during the last years. In the SFA's view, the remaining scepticism is mostly related not only to ash recycling, but to the extraction of primary residues. In northern Sweden, by contrast, there is still more scepticism due to initial lower forest growth increments (Andersson, 2010).

These statements were affirmed by interviewing the forest owners. The interviewed forest owners were all in favour of ash recycling, but about one third reported initial scepticism. Reasons stated most commonly were fear for pollution of forest areas through heavy metals or PAHs<sup>9</sup> in ash, damage to trees and soils through machinery, spreading of big chunks of ash and unknown consequences for the forest. Several forest owners observed the development of ash recycling over a few years before they actually recycled in their forests. The motivation to recycle was in half of the cases related to economic thoughts. Some forest owners recycled when there were still subsidies for recycling in connection to mitigate acid rain and saw ash recycling as a cheap and good compensation method. Other forest owners reported hope for additional forest growth. The motivation reported by the other half were ecological reasons, for example they cared about forest vitality and wanted to compensate for increased export of nutrients from their forests. One forest owner mentioned that he would feel pressured to extract as much biomass as possible from his forest and that ash recycling is essential to compensate for nutrients export. Another forest owner reported explicitly acidification and the quality of bordering water bodies and related

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<sup>9</sup> Polycyclic Aromatic Hydrocarbons; environmental pollutant.

quality and quantity of fish in them. After experiencing ash recycling, all forest owners were very satisfied with the ash recycling procedure, partly even surprised about the efficiency and unproblematic performance. Ash recycling was most of the time carried out only on parts of the forest, due to accessibility or other reasons, but in most cases there were potential areas left where ash recycling could be done. All forest owners except one said they would spread ash on their land again, although none of them took initiative to do so. Furthermore, all forest owners except one were contacted by SFA or were approached during SFA's information days. Only one took initiative to get ash to the forest. In this case, the forest owner was interested in organic forestry and as ash recycling is allowed in organic forestry it was seen as a very good possibility to improve soil nutrient status.

It can be concluded that the interviewed forest owners are interested and positive towards ash recycling, but that most of them are not taking the initiative to implement ash recycling. In Götaland, it is not a barrier to convince forest owners, but rather, it is challenging to organise that on smaller, close patches of private forest ash is spread at the same time to increase efficiency and make ash recycling feasible (Pedersen and Pedersen, 2010).

Information and education to forest owners should be continued and it will be interesting to observe if the information campaign started by the SFA in summer 2009 will increase the demand for ash recycling from the forest owner's side. This would be very positive, because from a theoretical point of view the forest owners should have the highest interest in ash recycling and thus should become active by themselves. But because private forest owners own small patches of forest and their individual voices might not be heard, possible support from Södra was examined. Södra is an economic association and 51 000 Southern Swedish forest owners are members. Södra does not recycle itself, but has a positive attitude towards ash recycling because it believes in 'closing-the-loop thinking' and the contribution of ash recycling to the sustainability of forests (Gustafsson, 2010). Södra aims that up to 100% of the ash is recycled in future. To support ash recycling, Södra informs on their Forest Days about the concept of ash recycling and has information about ash recycling on the intranet for forest owners. So far they do not actively approach forest owners with information (Gustafsson, 2010).

## **5.7 State-owned Sveaskog vs private forest owners and companies**

As already touched upon there is a difference on how Sveaskog, the state owned company, includes ash recycling in their management and how private forest owners and companies approach the issue of ash recycling.

Sveaskog owns 3.3 Mio ha productive forest and extract logging residues on approximately 30 000 ha yearly (Möller Pedersen, 2010). Sveaskog sells the wood fuel directly to bioenergy plants and at the same time receives ash from the bioenergy plants. Sveaskog then distributes the ash in its own forest. Currently, Sveaskog recycles approximately on 1 500 ha, which equals 5% of the extracted area. Nevertheless Sveaskog is optimistic about fulfilling their aim to spread ash on all areas where forest residues are extracted in the future. In contrast to other recycling companies or SFA, Sveaskog has not experienced problems so far in obtaining ash or finding forest to spread the ash. This is due to the unique structure of Sveaskog, which results in a much clearer and more direct connection of forest owner and bioenergy plants. It was regarded as more efficient to do both fuel extraction and ash recycling because it decreases administration and logistics. For Sveaskog ash recycling is integrated into forest management and reported to work well (Möller

Pedersen, 2010). Companies, who already have an established connection between forest owners and bioenergy plants, could conduct the ash recycling (Emilsson, 2006). In connection to this, a further wood fuel supplier was interviewed. Neova is located in northern Sweden, but operates even in Götaland. Neova showed a very positive attitude towards ash recycling to the forest and recycled ash for a while but stopped due to economical and organisational reasons. Neova has no forest of their own and they had difficulties finding forest owners willing to recycle the ash. The logistics to avoid long transports was reported to be very challenging. Much administrative work related to ash recycling was reported. Neova could imagine finding an entrepreneur to provide their customers with ash recycling (Runestad, 2010).

The ash recycling company Askungen Vital mentioned that one potential problem is that Sveaskog due to its size and influence receives ash that is only partly originating from their forest biomass. The other part might be supplied from other forests, which then in turn could not benefit from ash recycling because Sveaskog only recycles in its own forests (Pedersen and Pedersen, 2010).

Sveaskog as a big forest owner can be compared with the private forest owners. In the forests owned by Sveaskog, ash recycling is emphasised. Private forest owners have interest in ash recycling, but do not get active in most cases. The rationality of a small scale forest owner is understandable, if he or she does not understand the scale (spatial and temporary) and implications of a small forest part being managed including ash recycling to ensure long-term biomass supply and thus does not actively support ash recycling. Sveaskog instead has more forest and power, and seeing the impact from extraction of forest fuels on another level.

## **5.8 The current role of indirect stakeholders: SFA and SEA**

As discussed before there are no strong direct incentives to recycle ash. The incentives to increase ash recycling could be established at two fronts, for bioenergy plants or for forest owners. These incentives would consequently be established by the SFA and SEA. Both are indirect stakeholders with potentially high influence on stakeholders' decisions regarding ash recycling.

The SFA's current role lies in quality control of ash recycling. The SFA approaches the forest owners and organises the spreading of ash, for instance providing maps which indicate which areas are to be spread etc. For forest owners, the SFA provides information on the internet and educates forest owners during the so called Forest Days. This is seen as sufficient to educate forest owners. The SFA relates the forest owner's change in attitude towards ash recycling to achieved system thinking and the forest owner's gained ability to now understand the importance of closing the loop between extraction and recycling.

The SEA ensures that bioenergy plants meet their standard. This includes examination of the plant and fuels used (Rättsnätet I, 2003). Concerning ash recycling, the SEA emphasised during the interview that they have high interest in making bioenergy generation truly sustainable. However, it was stressed that the effects of ash recycling are not sufficiently known in all parts of Sweden. The SEA supports research projects which for instance assess these effects (SEA, 2006). They work closely together with the SFA and see the SFA as target group for their research.

## 5.9 Ash recycling and its sustainability in terms of process sustainability

This section presents the results of the DPSIR assessment which aimed to evaluate the efficiency of ash recycling in respect to approach the potential unsustainability of bioenergy from forest biomass (Fig. 18). In this assessment efficiency does not mean the chemical and biological effects ash recycling has on the forest, but which effect ash recycling can have on the development of bioenergy.

As indicated by the numbers 1-4, the response of ash recycling has the potential to tackle the impact, state, pressure and/or drivers. State (2) and impact (1) are eased if ash recycling is done according to the scientific knowledge and the SFA's recommendations. However, so far the measurement of ash recycling does not affect the pressures (3) because the costs for ash recycling are excluded from wood fuel costs and the production of bioenergy in general. Thus the extraction of forest biomass is relatively cheap and not influenced by the environmental consequences they cause. The time lag in occurrence of serious impacts for forest owners and bioenergy plants like the decreasing forest growth and possibly increasing forest biomass prices explains why the connection has not been made so far. It is important to argue for a precautionary approach to avoid impacts on forest ecosystem and connected anthropogenic systems. If instead the costs for ash recycling are accepted as a compensation method to ensure the sustainability of forests, the extraction of wood fuels would only take place if it is economically viable, and now also ecologically, feasible. The wood fuel price would then include the price for ash recycling, which would need to be paid by forest owners. Forest owners have no high additional income through the extraction of forest residues. In order to cover costs from income, the wood fuel prices would need to increase. However, this could have negative impacts on the potential of forest biomass for bioenergy generation (EEA, 2006). The initial driver (4) can only be tackled if precautionary approaches as ash recycling are incorporated bioenergy generation (chapter 6.5).

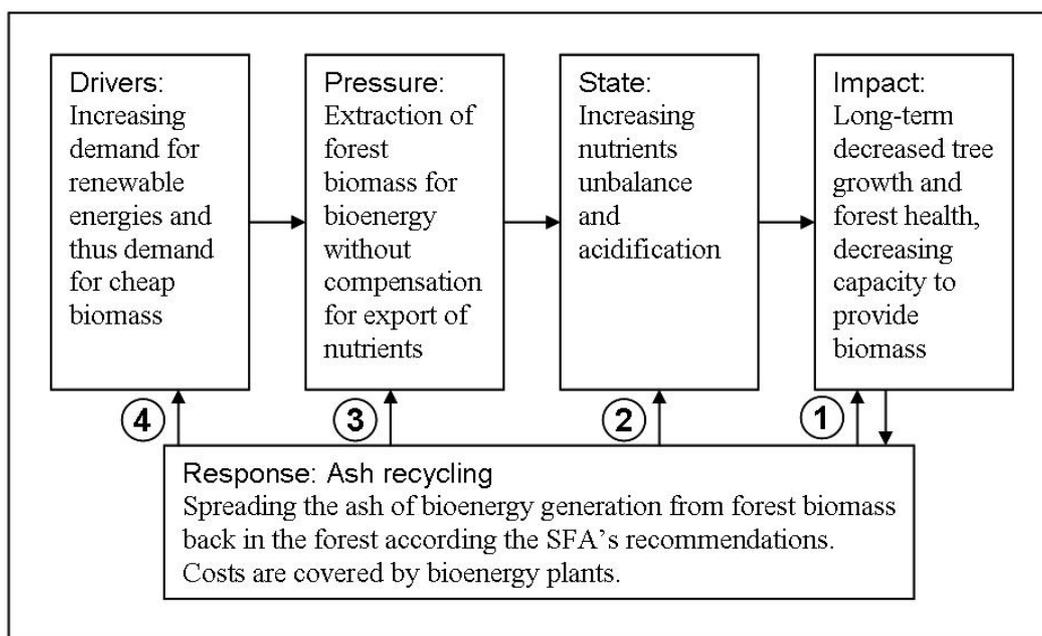


Fig. 18: DPSIR-scheme to assess the contribution of ash recycling to the sustainability of bioenergy from forest biomass.

## 6 Discussion

### 6.1 Discussion of main findings

The share of recycled ash increased slightly in the last years, but this increase is taking place at a much lower rate than the increase of the primary residue extraction (Thelin, 2009), due to presented barriers. It seems contradictory; on one hand ash recycling rate is only 10% and on the other hand there is not enough ash to spread. There are multiple reasons to this. Firstly, the geographical uneven distribution and long distances decrease the amount of ash that can be spread efficiently. Secondly, the burning of fuel-mixes makes ash from suitable wood fuels unsuitable and drastically decreases the potential amount to be recycled. Thirdly, ash recycling is in some cases not sufficiently competitive with other uses for ash and even ash suitable for recycling is used for other purposes. Further reasons are that ash quantities from small district heating plants are too small to be efficiently recycled and that the recommended doses overcompensate for the actual nutrients export (Andersson, 2010).

To make it possible to compensate in all areas where logging residues are extracted, lower doses might need to be discussed (Andersson, 2010; Gustafsson, 2010). However, using minor amounts of recycled ash would potentially decrease the efficiency of ash recycling.

Ash recycling requires extremely well planned logistics and organisation, where all stakeholders need to be incorporated. If no companies providing this service are located in an area this proves to be a major barrier to ash recycling. The lack of executing companies was identified as a main hindrance to ash recycling in a study conducted in 2003 (Bohlin and Mårtensson, 2004). This study reported further a knowledge gap as a barrier, but this finding could not be affirmed in this study. The SEA's research projects between 2003 and 2009, for instance RecAsh, resulted in very comprehensive information and reports about ash recycling. Open questions are already subject for further studies, for instance studies on long-term effects of ash recycling and the competitive use of ash (Skogsforsk, 2010; Värmeforsk, 2010). In line with the precautionary principle the SFA recommends not to exceed ash doses above 3 ton ha<sup>-1</sup> per spreading or above 6 ton ha<sup>-1</sup> per rotation, to avoid unknown effects on the ecosystem (SFA I, 2008). Even so, theoretically higher doses are possible to increase growth on sites with certain characteristics (Thelin, 2010).

It was found that information is easily accessible through the internet, but it is questionable if most of the interviewed forest owners would make the effort to actively find this information. Some reports are long, and rather technical and not necessarily written for forest owners, but for other researchers (Pedersen and Pedersen, 2010). The information days of both SFA and Södra are valuable and need to continue presenting ash recycling to forest owners. All forest owners interviewed were now in favour of ash recycling, which differs from Bohlin and Mårtensson's findings (2004), where more forest owners were sceptical of extraction of logging residues and ash recycling. This difference in findings is due to the focus on Götaland and a time gap of almost six years. This supports the SFA's claim that a change in attitude has taken place throughout recent years.

Another barrier to ash recycling is that, except for environmental consciousness and moral attitude, no incentives to use ash for ash recycling exist for bioenergy plants. Bioenergy plants have free choice to use the ash for any purpose and often ash recycling proves to be less economically viable, even though it is morally preferable. All bioenergy plants

interviewed expressed the need for binding regulations and despite the SEA's concern did not see a legislative binding measurement enforcing ash recycling as a barrier to bioenergy production. By contrast, without binding measures the attempts to increase ash recycling were expressed to be 'environmental comedy' (Interviewee bioenergy plant Eskilstuna). However, it needs to be considered that interviewed persons at bioenergy plants did not always necessarily agree with their company's policy and may not have a holistic perspective.

The much discussed issue that ash recycling is a link between energy industry and forestry makes the introduction of binding regulations challenging. Generally the stakeholders argued that whatever measurement should be implemented, it is outside their scope and that another stakeholder would be better suitable or would have more power.

In the development of bioenergy, the bioenergy association Svebio is evaluated as a strong driver (Kårberger, 2004). However, regarding the development of ash recycling Svebio has a rather passive role. Svebio seems to be rather more focussed on technological progress than to implement existing compensation measures like ash recycling. The bioenergy industry is finally an industry which works for profit as all other industries, and economical interests are more valued than environmental concern (Pedersen and Pedersen, 2010).

Before potential solutions can be recommended, two issues need to be discussed. The first issue is the connection between ash recycling and the extraction of logging residues and secondly the implications of ash handled as waste or a product needs to be examined.

## **6.2 Connection between extraction of logging residues and ash recycling**

All stakeholders interviewed mentioned that ash is mainly recycled to compensate nutrients loss, which occurs when forest residues are extracted. However, forest owners reported that if they recycled this was not in connection to extraction of forest residues, implying that they would extract in different places than recycled. It is very challenging to judge if ash recycling happens in connection to extraction of logging residues due to the long rotation time. The connection can be even established if a time gap of more than 50 years separates extraction and recycling. Therefore there might be the connection reported in literature, even so it could not be clearly identified in practice. But it is not always practical to spread ash where forest residues were extracted, which especially applies to forest residues extracted in northern Sweden because long transportation makes ash recycling inefficient and the effects of ash recycling in northern Sweden are less immediately positive than in Götaland (Möller Pedersen, 2010). Moreover, the focus of research projects show that there is an increased interest in ash recycling on drained peat soils to increase growth (Värmeforsk, 2010), while the extraction of forest residues from these forests is very unrealistic due to ecological limitations (Pedersen and Pederson, 2010).

Regarded from the other end, that is which ash should be recycled, the material flow analysis showed that recycling from only logging residues is not sufficient. This is not done in practice and one could question why the material flow analysis was focused on this aspect. The thought was that it would be easier and more direct to establish binding ash recycling for bioenergy plants which use logging residues. However, it was affirmed through the material flow analysis, the survey to bioenergy plants and by observations of Södra that is neither sufficient nor done with this focus. For example one bioenergy plant

recycles all their ash, but uses only wood powder. While another bioenergy plant, which only uses logging residues, does not recycle at all.

In conclusion, the connection between recycling of ash and the use of forest residues cannot be seen as strongly as reported by stakeholders and literature, but the establishment of a stronger connection needs to be emphasised.

### **6.3 Classification of ash: Waste or product?**

The second point to be discussed is whether ash should be classified as waste or product. Currently ash is classified as waste, which makes the handling relatively easy, but decreases its value. By contrast, as long as ash is not used for a purpose, bioenergy plants need to pay a waste taxation of 500 SEK ton<sup>-1</sup> (Thelin, 2010). The storage of ash is demanding, due to fact that ash is classified as waste (Pedersen and Pedersen, 2010). The classification of ash as a product on the other hand would include a lot of administrative work, which would complicate ash recycling even further (Pedersen and Pedersen, 2010). In some cases, ash is used to produce pellets, which then are a product, as for instance Ecofor produce a mixture from green sludge and wood ash (Askprogrammet, 2009). The advantage of Ecofor's product is that the nutrients are released at a slower rate which makes it possible to spread on bare soil without a time gap after harvesting the forest residue (ibid). Södra is positive that these pellets could be used in both small and large scale forest management and hopes to introduce the product to the market soon (Gustafsson, 2010). However, pelleted ash is more expensive, increasing the cost and decreases the competitiveness of ash recycling, as long as there are no considerable advantages in handling the pellets which would in turn decrease effort and costs of ash recycling. Currently this was estimated to be unrealistic (Pedersen and Pedersen, 2010).

The author takes the stance that at the present time waiting until products like Ecofor's are established on the market is not an option, but that ash need to be continued to be handled as waste. However, it would be desirable to loosen the restrictions regarding storage of clean wood ash. It is surprising that ash can be used for road construction and thus can be present in large quantities in a small area, while the storage of ash for ash recycling is very strict due to possible leakages (Thelin, 2010; Pedersen and Pedersen, 2010). Related to that, a project is currently being carried out to assess the impacts of temporary storage places in forested by Askungen Vital and EkoBalans (Thelin, 2010).

### **6.4 Recommendations: Advantages and disadvantages**

The current situation requires establishment of incentives for ash recycling through binding measurements. Only then can the goal of sustainable development through implementing closed production loops according to the concept of ecological modernisation be fulfilled. It is the Government's responsibility to ensure that the renewable energies are produced in a sustainable manner. The given incentives for bioenergy generation increase the demand for cheap biomass, but it is not ensured that ash is recycled. Until ash recycling is established on the market, binding incentive schemes for ash recycling are needed. This can be connected to existing schemes which regulate bioenergy production or forestry or could be established independently. The connection to pre-established certifications or regulating schemes has the advantage that a whole policy need not be established, and is preferred.

An oft-mentioned and very obvious solution would be to make the non-binding SFA recommendations binding. However, SFA does not support this idea, arguing that it would not fit into the context of Swedish society to impose a binding measure. Furthermore the measure would target the forest owners, who have no stake in the ash, which would make it very complicated to fulfil the measure. This might increase the price for wood fuels, which would have negative consequences for Swedish wood fuels in the international context. Even though biomass supply in Sweden is mainly national, there is a share of forest biomass imported and exported. If the costs for ash recycling are included in the Swedish wood fuel price an increased import of biomass might be the consequence. Currently Sweden is already one of the main importing countries from Canadian forest fuels due to higher prices for biomass in Europe (Magelli et al., 2008). This cannot be supported while aiming at sustainable natural resource management all around the world. It is recommended to refrain from including the costs for ash recycling in the wood fuel price.

A different perspective is that wood fuel could be regarded as nutrient and energy carrier and that forest owners only sell the contained energy, but keep the rights on the nutrients contained in the ash. Then forest owners should become active in demanding the ash back to their forest. This was proposed to the SFA, who acknowledged that this would contribute to increase ash recycling, but it was questioned if forest owners take such an active role and if single forest owners would have sufficient influence on bioenergy plants. Instead forest-owner associations like Södra should, on behalf of forest owners, help to address the issue towards the bioenergy plants (Andersson, 2010). This suggestion would ease the ownership issues concerning the ash, but still not solve how the ash is recycled back to the forest. Furthermore recycling ash could be seen as a compensation method for decreasing the ecosystems services like mineralisation of forest residues in the forest and the providing of nutrients. But it is outside the scope of this thesis to make suggestions how this approach could be operationalised.

Another way to connect ash recycling from the forestry side could be to include ash recycling as a criteria to be FSC certified. The disadvantage of the connection to the FSC certificate is that it cannot be ensured that all areas where forest residues are extracted are FSC certificated, as it is a voluntary scheme.

Currently the bioenergy plants own the ash, so the bioenergy plants should take responsibility to increase the share of ash recycling and to ensure the long-term sustainability of bioenergy. One theoretical option would be to connect ash recycling as a sustainability criterion to the electricity-certification scheme. This idea was proposed to the SEA, but it was then reported that this was discussed by the SEA during the development and introduction of the electricity-certificate. In the end it was decided that this additional criteria would make the implementation of the electricity-certificate too complicated to be effective (Lundberg, 2010). Now as the scheme is already established it should be tested whether the connection of ash recycling to the electricity-scheme is possible. Another combination from the energy industry's side could be to include ash recycling as a condition for the distribution of the certificate 'Bra miljöval' which is distributed by the Swedish Nature Protection Organisation (Naturskyddsföreningen). This bears the same disadvantage as the connection to FSC, because bioenergy plants are not obligated to have this certification and thus not all bioenergy plants are reached.

It becomes clear that there are several options for connecting ash recycling as sustainability criteria to both the energy and forest industry. It is a challenge regarding establishing

incentives through any kind of mechanism is a juridical issue related to ownership (Lundberg, 2010). The bioenergy plants own the ash but in most cases no forest, and the forest owners do not own the ash, but only forest. Any incentive scheme needs to be enforced on both forest owners and bioenergy plants, at least if the situation regarding the ownership of ash does not change as discussed above. This is seen as realistic and therefore the SFA and SEA need to establish a legislative tool in cooperation.

In the following, recommendations are made about which aspects a legislative measure should cover. It would be reasonable to structure the measurement in two parts, part one connected to the production of ash and part two connected to the use and recycling of ash. Part one would be mainly enforced by the SEA, establishing binding regulations which would prohibit the combustion of suitable wood fuels with other unsuitable biomass. This would increase the amount of suitable ash and could ease the shortage in supply of suitable ash. Not only the combustion would need to be regulated but the ash needs to be stored separated. The classification of suitable and non-suitable fuels would need to be established based on experience from recycling companies, then codified in the measurement but subject to steady examination. Quality control of ash still needs to be executed, because this gives a much-appreciated feeling of security, as reported by executing companies, bioenergy plants and forest owners. A standard for quality control, based on the recommendations of the SFA, should be connected to the measurement. The bioenergy plants then need to be obligated to recycle the suitable ash. This would increase the demand for companies which recycle ash. Therefore the measurement needs to include standards on how to recycle; these again could be based on the SFA's recommendations, and regional differences need to be considered and included. At the same time it needs to be considered that infrastructure to implement this measurement is in place and well-prepared.

Other uses for ash should not be prohibited, but fines established if suitable ash is used for other purposes than ash recycling. At the same time the establishment of infrastructure for ash recycling should be financially supported, including education for companies who would undertake ash recycling in the future and other possible measures.

The independent connection to Bra miljöval and FSC has advantages in financing, as only bioenergy plants which stand up for costs will try to get the certificates.

The legislative measurement needs to make an exception for very small plants with insufficient amounts of ash. Here local and unique solutions for each plant should be found in close cooperation with the municipality.

## **6.5 The contribution of ash recycling to the sustainability of bioenergy**

The discussed incentive scheme would improve the sustainability of bioenergy production from forest biomass, but would inherently only affect the pressure of the system (see Fig. 18, (3)). In the long-term, ash recycling should be the cheapest alternative of ash uses, because ash recycling is the only use that closes the loop between forestry and bioenergy production, and thus the only use which contributes to long-term sustainability of bioenergy and sustainable development. The understanding of the complexity and implications of human actions on world ecosystems would need to be based in mind-sets to achieve a less resource-intensive life style in western societies. Then not economic benefit, but concern for forest health should drive ash recycling. Drivers (Fig. 18, (4)) would be addressed, as

the demand for cheap energy would have been changed to the demand for economical competitive and ecologically sound bioenergy.

It would need to be discussed how ash recycling can be transferred to other countries, EU and non-EU, to avoid the potential unsustainability of forest biomass extraction in other countries as well. This is especially interesting taking the case of Canada, which currently exports 80 000 ton wood pellets to EU countries, including Sweden (Magelli et al., 2008). However, the challenge of how to operationalise such criteria is outside the scope of the study.

The precautionary approach to recycle the ash from bioenergy production from forest biomass closes the loop of the energy production system and contributes to ensuring the long-term health and growth of Sweden's forest. This is especially important keeping in mind forest's role in regulating the earth's greenhouse gases. Deforestation contributes to climate change, and therefore the reforestation after final cuttings is fundamental. The extraction of logging residues and ash recycling simplifies reforestation methods (Stupak et al., 2007). There are studies showing that the albedo of deforested areas is lower in northern Europe and would thus contribute to cooling potential (Bonan, 2008). Nevertheless this would decrease Sweden's potential sources of bioenergy generation drastically; if alternative biomass generating crops are not cultivated. Considering Sweden's geographical location and soil conditions including thousands of stone boulders, it is questionable to replace the natural ecosystem with an alien crop with unknown impacts.

This would not be in line with the precautionary approach. In this respect, Sweden's continued use of nuclear energy, including the intergenerational burden of nuclear waste, is surprising as well. The government's concern about decreasing competitive capability has hindered the phase-out of nuclear energy so far (Gan et al., 2005). It is ironic that conversion loss from nuclear energy equals the share that bioenergy contributes at the moment to Sweden's total energy supply (both 124 TWh). Sustainable bioenergy development, including ash recycling, needs to be emphasised to replace both fossil and nuclear energy. The development of bioenergy is supported by the established short-term incentive schemes (Gan et al., 2005). However, the protection of natural resources is not consistent, because ash recycling as ecological compensation measures is not binding. Within the current paradigm of economic growth ash recycling needs to be supported through a legal measurement until it is embedded in the sustainable bioenergy generation.

## **6.6 Potential improvement of the study and possible further research**

The study was carried out in a set timeframe of 18 weeks, which posed several limitations. The stakeholder analysis could have included a deeper dialog with indirect stakeholders, as municipalities, Skogsforsk, FSC, Naturskyddsföreningen and Värmeforsk. However, the position of these stakeholders was considered and assessed through scrutiny of internet presentations. To improve the information's credibility more than one person for one stakeholder role could be interviewed. This was done for forest owners and bioenergy plants, because they were seen as key stakeholders. Approximately 15% of bioenergy plants said that they recycle the ash, which is a bit higher than 10% according to SFA in 2009. This fact can be a bias in answers, but one needs to consider that only one ash producing sector was included in the study and that the two others (pulp and paper industry and saw mill industry) are known to recycle less (Thelin, 2010).

The material flow analysis is connected to several uncertainties regarding the averages used for calculations. Depending on the forest's yield power the amounts of primary forest residues varies between 10 and 50 ton, corresponding to an energy amount between 20 and 200 MWh. Considering that the ash content of forest residues varies between 2 and 6% the amount of ashes varies between as much as 0.2 and 3 ton. Therefore the quantities of nutrients and base cations which can be recycled to the forest vary as well, especially if the circumstance that nutrient content in ash is dependent on fuel sources, and combustion type is taken into consideration as well. However, it is considered to be reasonable to calculate with the average because the forest in Götaland has forest yield power around 30 ton per ha (Forestry Research Institute of Sweden, 2010). Additionally a higher ash content than 2% is not supported by bioenergy plants for economical reasons and it was considered as reasonable to calculate with 2%, instead of the average (4%)

This study could be complemented with a detailed market analysis of alternative uses of ash to assess the competitive threat to ash recycling. This should include the question when landfills will be covered and how this will change the situation for ash recycling. A similar study incorporating the two other ash producing sectors, pulp and paper industry and saw-mill industry would show how ash recycling could be enhanced in these sectors. Here the potential of Ecofor, which is a mixture of green sludge with ash could be assessed and the issues if ash should be treated as waste could be deepened. To assess further ash recycling's contribution to the sustainability of bioenergy from forest biomass a study including ash recycling in a live cycle assessment of bioenergy would be relevant. This is especially important to ensure that even if ash recycling is carried out the mitigation effect of bioenergy is really ensured.

## 6.7 Conclusions

The aim of this study has been to analyse the barriers to ash recycling from bioenergy generation of forest biomass. Using a systems perspective and two in-depth approaches the analyses have shown that the mixed combustion of biomasses decreases the share of suitable ash. In combination with competitive use of ash for other purposes this leads to a higher demand for ash for ash recycling than can be supplied in Götaland. It was recommended to restrict the mixed combustion of biomass to ensure that the SFA's goal to spread ash on all areas where forest residues are extracted can be fulfilled. This is not restricted to forest residues, but needs to include all forest biomass, except tertiary residues, as the material flow analysis showed. The stakeholder analysis provided an insight into the imbalance of the power-interest distribution between stakeholders and resulted that the lack of a binding measurement for ash recycling is recognized by all parties. The missing obligation for ash recycling conflicts with the precautionary principle. Despite the concern for overall decreasing generation of bioenergy, it is now inevitable to develop a binding measurement for ash recycling to ensure the long-term sustainability of forestry and bioenergy. However, it is to emphasise that a complex problem with numerous stakeholders involved as ash recycling, requires a solution, which is characterised through collaboration of both forest industry and energy industry.

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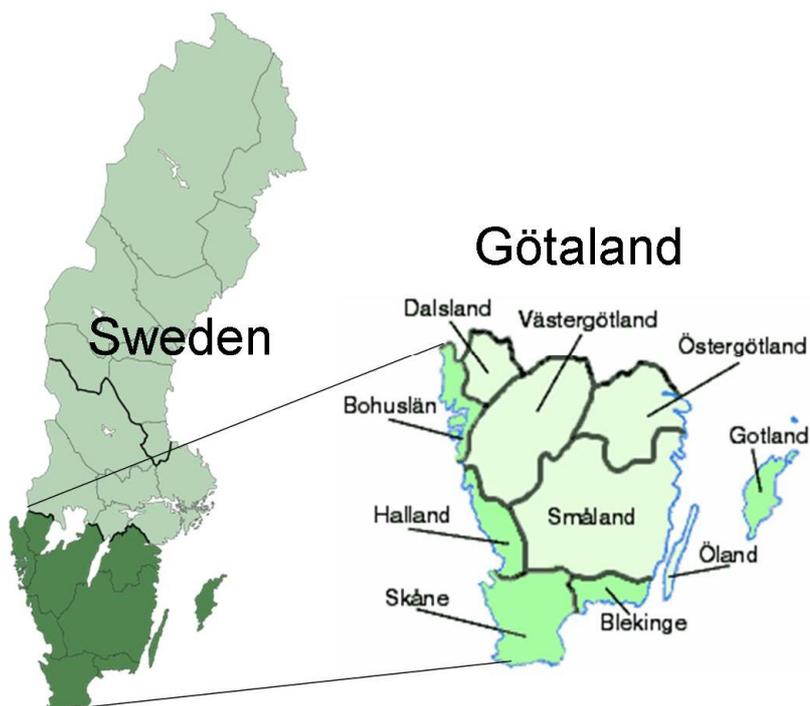
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## Appendix I – Map of Sweden with focus on Götaland



Overview map of Sweden (Sources: [http://en.wikipedia.org/wiki/File:Sverigekarta-Landsdelar\\_G%C3%B6taland.svg](http://en.wikipedia.org/wiki/File:Sverigekarta-Landsdelar_G%C3%B6taland.svg), Accessed 19 May 2010) and Götaland (Source: [http://en.wikipedia.org/wiki/File:Map\\_gotaland.png](http://en.wikipedia.org/wiki/File:Map_gotaland.png), Accessed 19 May 2010).

## Appendix II – Material flow analysis

**Materials and goods:** In material flow analysis ‘material’ is the generic term for both substances and goods. Substances are understood according to the chemical definition of a substance (a substance is any (chemical) element or compound composed of uniform units, e.g. nitrogen). Goods instead are a mixture of substances, for instance wood is composed of cellulose, lignin, air, water etc. and thus a good (Brunner and Rechberger, 2003). In this study all materials looked at are goods and therefore even the word material refers to the definition of goods hereafter.

### Initial values and conversion factors for material flow analysis:

- Extraction area in 2008: 85 000 ha (Kunskap Direkt III, 2009)
- Extraction of 80% of logging residues, excluding stumps (SFA I, 2008)
- Burning value of 4.9 MWh DM ton<sup>-1</sup> (Forest Research Institute of Sweden, 2010)
- Ash content of 2% of logging residues DM (SFA I, 2008)
- Average forest yield power of G24 (245 m<sup>3</sup> sk), with 31 ton DM logging residues. It was chosen to take values from a mixed forest with average yield power in Svealand (middle country part of Sweden) because this seemed to be most representative for whole Sweden. Data see below:

! hektar är 100 x 100 meter, eller 2 fotbollsplaner.

Bestånd

Svealand, blandskog på mellanbonitet

	ton torr.v./ha	MWh/ha
Stamdelar	121	593
GROT	31	152
Stubbe	29	142
Summa	181	887

Svealand, blandskog på mellanbonitet:

Ålder: 105 år  
 Volym: 245 m<sup>3</sup>sk  
 TGB: 451  
 Grundyta: 28 m<sup>2</sup>  
 Dgv: 25 cm  
 Stammar/ha: 650  
 Ståndortsindex: G24

Stäng

(Source: <http://www.skogforsk.se/sv/KunskapDirekt/skogsbransle/Energi-fran-skog/Hur-mycket-energi-finns-det-i-skogen/>, Accessed 18 May 2010).

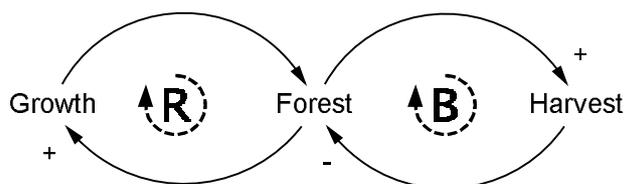
## Appendix III – Stakeholder analysis – Power-Interest-Matrix

**Stakeholder matrix:** according to Varvasovszky and Brugha, 2000

		Characteristics of each stakeholder in relation to the issue				
		Involvement in the issue	Interest in the issue	Influence/power	Position	Impact
Stakeholder group (n= number of stakeholders in one group)	Stakeholder 1	What the stakeholders task is in relation to the issue:	How much the stakeholder is and should be interested in the issue: low, medium, high	The stakeholders' influence or power to decide if the issue takes place: low, medium, high	How much the stakeholder supports the idea: supportive, passive, opposed	How much the process has an impact on the stakeholder: low, medium, high
	...					
	Stakeholder n-1					
	Stakeholder n					

## Appendix IV – Causal loop diagramming

Relationships are then valued using + and – notion. The + notion means that the relation is positive and the quantity of the variable is increasing, for example the more forest there is the more growth is happening and the more growth is happening the more forest there is (see left part of figure). This example was selected because it shows that CLDs tend to be strong simplifications and therefore the used variables and underlying assumptions need to be explained. It was assumed that there are no limiting factors to the growth of forest and it thus can spread.



Consequently as the quantity of forest increases so does the growth, and elements are thus reinforcing each other and the loop is called reinforcing (abbreviated with the letter R).

In reality there are of course a number of limiting factors (space, light, nutrients) which restrict and balance the forest to grow for ever. If an element decreases the quantity of the element it stands in relation with, the – notion is used. For example the factor harvest: the more harvest is done in the forest, the less (–) of the forest remains. Thus the loop is balanced (abbreviated with the letter B). If in this strongly simplified example the quantity of forest increases, decreases or remains stable depends on the proportions of growth and harvest. If the growth rate is higher than the harvest rate the forest quantity will increase, while if the growth rate is smaller than the harvest rate the forest quantity will decrease. If both rates are equal the forest quantity stays at the initial level. All CLDs are designed according to these principles, but of course can one loop consist of several factors and can be influenced by several loops and thus it is possible to conceptualise complex systems in a consistent and clear manner. Further information on how to develop causal loop diagrams and which rules should be followed can be found in chapter seven of ‘Modeling the Environment: An Introduction to System Dynamics Modeling’ by A. Ford (Ford, 1999).

## Appendix V – Stakeholder analysis: selection scheme for bioenergy plants & survey

- All bioenergy plants (heat and combined power, but not pulp and paper related bioenergy plants) from a map composed by Svebio (Svebio, 2009) were listed
- All bioenergy plants were then sorted according to their fuel use and bioenergy plants with use of forest biomass as fuels were selected
- These bioenergy plants were confirmed with a published list by SEA with all permitted bioenergy plants in Sweden 2009 (Source: <http://www.energimyndigheten.se/Global/F%C3%B6retag/Elcertifikat/Godk%C3%A4nda%20anl%C3%A4ggningar/Godkanda-anlaggningar-2010-05-01.xls>, Accessed 18 May 2010).

One survey was designed for the selected sample of bioenergy plants to study which technical factors like size, fuel combination etc., and advantage and disadvantage recycling of ash. The survey was constructed in two parts, part one is aiming for general information about the bioenergy plant (size, type of boiler, used fuel) and the second part collects information to the recycling of ash. See below:

Energy plants in Götaland, with similar size but different recycling status (heat GWh annually, electricity GWh annually): Eksjö, not recycling (16.2, -), Mark, recycling (25-149, 15), Tranås, partly recycling (25-149, 9). Eskilstuna’s bioenergy plant was chosen because it is bigger in size, uses 100% primary forest residues, but does not recycle and there was no bioenergy plant with these characteristics in Götaland available.

## Appendix VI – Stakeholder analysis: Survey for bioenergy plants

Part 1:

Biobränsle och askåterföring
[Exit this survey](#)

**1. Anläggningsdata och bränsleinformation**

**\* 1. Vänligen ange namnet på värme- eller kraftvärmeverket.**  
 Om det finns flera biobränslepannor och om de är eldade med olika slags biobränslen vore det mycket hjälpsamt om ni anger namnet på biobränslepannan och fyller i frågeformuläret för varje biobränslepanna (om det är flera pannor som eldas på samma sätt går det bra att sammanfatta).

**\* 2. Vilken slags panna används?**

Fluidiserad bäddpanna

Rostpanna

Pulvereldad panna

Annat eller synpunkt

**\* 3. Hur många GWh värme och hur många GWh el produceras av hela verket och av biobränslepannan?**

	el (hela verket)	värme (hela verket)	el (biobränslepanna)	värme (biobränslepanna)
0	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
1-24	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
25-149	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
150-299	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
>300	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

**\* 4. Vilken slags biobränsle används huvudsakligen?**

	0-10%	11-20%	21-30%	31-40%	41-50%	51-60%	61-70%	71-80%	81-90%	91-100%
Flis eller liknande av GROT	<input type="checkbox"/>									
Flis eller liknande av stubbar	<input type="checkbox"/>									
Flis eller liknande av bark	<input type="checkbox"/>									
Flis eller liknande av avverkningsrester	<input type="checkbox"/>									
Sågverks-biprodukter (spån m.m.)	<input type="checkbox"/>									
Nedklassad massaved	<input type="checkbox"/>									
Returträ	<input type="checkbox"/>									
Energiskog	<input type="checkbox"/>									
Pellets	<input type="checkbox"/>									
Briketter	<input type="checkbox"/>									
Trädpulver	<input type="checkbox"/>									
Torv	<input type="checkbox"/>									
Avfall	<input type="checkbox"/>									
Olja	<input type="checkbox"/>									

Survey Powered by:  
**SurveyMonkey**  
 "Surveys Made Simple."

## Part 2:

**Biobränsle och askåterföring** [Exit this survey](#)

## 2. Askhantering

**\* 1. Hur tas askan ut från pannan?**

Torrutmatas

Våtutmatas

Annat

**\* 2. Vad görs med askan?**

Hanteras som ren bioaska (bara aska av trädbänsle, trädet har alltså inte behandlats kemiskt)

Blandas med annan aska (t.ex. avfall, returträ, olja eller dylikt)

**\* 3. Hur används bottenaskan?**

	0-20%	21-40%	41-60%	61-80%	81-100%
Deponi	<input type="checkbox"/>				
Deponitäcke	<input type="checkbox"/>				
Konstruktion (t.ex. vägar)	<input type="checkbox"/>				
Återföring till skog	<input type="checkbox"/>				

Om återföring till skog, beskriv gärna lite hur och varför. Om inte, ange anledningen.

**\* 4. Hur används flygaskan?**

	0-20%	21-40%	41-60%	61-80%	81-100%
Deponi	<input type="checkbox"/>				
Deponitäcke	<input type="checkbox"/>				
Konstruktion (t.ex. vägar)	<input type="checkbox"/>				
Återföring till skog	<input type="checkbox"/>				

Om återföring till skog, beskriv gärna lite hur och varför. Om inte, ange anledningen.

**5. Tack så mycket! Om du har fler synpunkter, berätta gärna om dem här. Annars är det bara att trycka "Done". Tack.**

Survey Powered by:  
**SurveyMonkey**  
 "Surveys Made Simple."

An email with the link to the survey was sent out to the sample with bioenergy plants. After one week all bioenergy plants which did not respond were reminded. The survey was closed two weeks after this.

## Appendix VII – Stakeholder analysis: Interview themes

All participants were contacted by email first and then a face to face or a telephone interview was conducted. **Themes for semi-structured interviews/telephone interviews:**

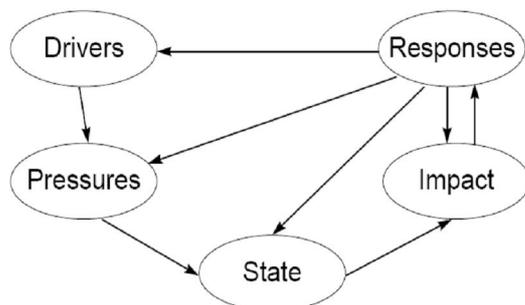
- General understanding of ash recycling, main reason to ash recycle
- Impact and effects of ash recycling
- Connection of ash recycling and system thinking, ‘closing the loop’
- Ash recycling and fuels use, which connection exists?
- Ash as product or waste. Ash as to replace ecosystem service in forests?
- Ash and biodiversity and other connected risks
- Barriers to ash recycling: Understanding and opportunities to overcome them
- Own role in relation to ash recycling
- Role of other stakeholders in relation to ash recycling
- Development of ash recycling in the past years
- Connection of ash recycling to legal measures, sustainability criteria
- Other comments concerning ash recycling

## Appendix VIII – Stakeholder analysis: Interviews forest owners

- 1) Har du hört talas om askåterföring? (Om nej vidare med 2), om ja vidare med 5)).
- 2) Har du försökt hitta information om någonting liknande? Skulle du vilja ha information om det?
- 3) Vad är din första synpunkt angående askåterföring?
- 4) Kunde du tänka dig att göra det i framtiden? (Slut)
- 5) Har du själv askåterfört på din mark? (Om nej vidare med 6), om ja vidare med 9)).
- 6) Vad är din syn på effekterna av askåterföring, t.ex. kompensation, för att öka tillväxt, motverka försurning, att sluta kretslopp eller bara för att minska mängden avfall?
- 7) Varför askåterför du inte?
- 8) Vad skulle ändras för att du skulle börja askåterföra? Synpunkter? (Slut)
- 9) Vad är din syn på effekterna av askåterföring, t.ex. kompensation, för att öka tillväxt, motverka försurning, att sluta kretslopp eller bara för att minska mängden avfall?
- 10) Vär för har du valt att askåterföra?
- 11) Fanns det ett problem eller skepticism i början?
- 12) Är du nöjd med hur det funkar nu?

Har du andra synpunkter angående det, hur kunde det fungera bättre?

## Appendix IX – Drivers Pressures State Impact Responses-scheme



Drivers are connected to human behaviour patterns, like consumption, that result in the environment-pressuring actions, like potentially unsustainable production industries. The state is the condition of the environment, which changes with increasing or decreasing pressures (Carr et al., 2007). Changing the state of the environment too much results in impacts on the human and ecosystem wellbeing (EEA, 1999). Responses try to re-establish the wellbeing of ecosystems including humans.

## Appendix X – Translation key words (English – Swedish)

county administrative board - länsstyrelsen

solid biofuel – biobränsle

forest biomass – trädbränsle

wood fuels - skogsbränsle

bioenergy – biokraft

bioenergy plants – biokraftanläggningar

forest residues – GROT (grenar och toppar)

district heating plant – värmeverk

cogeneration plant – kraftvärmeverk

ash recycling – askåterföring

sreturträ – recycled waste wood or recovered wood

## Appendix XI – Definitions

**Silviculture** is a site adaptive management concept which uses different measures to sustain the forest as well as possible depending on the different phases of lives of the forest, for instance regeneration, clearing, thinning and regeneration felling (SFA I, 2010).

**Effects of ash recycling** differ depending on soil types, soil status, species combination and other factors. For comprehensive information about chemical and plant-physiological effects of ash recycling see SEA (2006) and Röser et al. (2008). **Nitrogen** is an important macro nutrient and its abundance is determining for the effect of ash recycling. In forest with high nitrogen resources ash recycling increases the pH and the availability of nitrogen. This leads to potential forest growth. If too much nitrogen is available and nitrogen leakage might occur, extraction of forest residues in combination with ash recycling is beneficial. This removes nitrogen from the forest, but only reapplies the other nutrients. On nitrogen poor stands however ash recycling is beneficial in combination with nitrogen fertilisation because otherwise nitrogen is the limiting factor for growth.

